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A Basic Overview of Environment and Sustainable Development (Volume: 2)

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PREFACE

In today's world of global challenges, the connection between taking care of the environment, and achieving sustainable development has become a top priority for all of us. As we navigate towards an intricate and interconnected world, characterized by rapid technological advancements, population growth, and resource exploitation, the consequences of our actions on the environment have become increasingly evident.

Climate change, biodiversity loss, pollution, and resource depletion are a few factors of the environmental crisis that need our immediate attention and effective action. The impact of these challenges reaches far beyond borders, affecting nature, economies, and the well-being of both current and future generations. In this context, the concept of sustainable development has emerged as a symbiotic relationship between human prosperity and environmental health.

Sustainable development adopts a holistic approach that seeks to balance economic growth, social equity, and environmental conservation. The Sustainable Development Goals (SDGs), established by the international community, provide a framework for collective action to address poverty, inequality, and environmental degradation, fostering a vision of a more sustainable and inclusive future. Sustainable development is like taking care of our communities, making lives better, and ensuring we don't harm the planet. It's not just a good idea; it's something we absolutely must do to secure a healthy future for everyone. Considering all this, it is clear that we have to deeply understand how the environment and sustainable development work together.

This book, "Environment and Sustainable Development (VOL-2)," offers a comprehensive and accessible resource for the relationship between our environment and the quest for sustainable development. We intend to provide essential information to practitioners, educators, students, and all stakeholders who are involved in developing a sustainable future for our planet. The contents of this book are the result of collaborative efforts, bringing together the expertise and dedication of contributors who are committed to disseminating their knowledge in this crucial area. We extend our gratitude to these individuals and organizations for their invaluable contributions. Our goal is not to cover every aspect of environmental science and sustainable development. Instead, we aim to cultivate a sense of responsibility and informed decision-making among individuals so that they can recognize the need to balance human progress with environmental preservation.

The front cover of the book showcases a captivating image featuring a Royal Bengal Tiger in the Sundarbans Biosphere Reserve, West Bengal, India and a parakeet from Hooghly, West Bengal, India. This photograph symbolizes the delicate balance of nature and calls upon our minds to take the initiative for sustainable development. This photograph, captured by renowned professional photographer and Nikon wildlife expert Ramesh Karmakar, who was a student of Dr. Tanmay Sanyal, holds the exclusive copyright. Its use as our book cover is made possible through his permission.

***Dr.* Shubhadeep Roychoudhury**
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Dr. Koushik Sen
Mrs. Sudipa Mukherjee Sanyal

	Chapters and Authors	Pages
Chapter -1	Root Causes of Biodiversity Loss with Special Reference to India Sourav Bar, Soumik Dhara, Nithar Ranjan Madhu	1-34
Chapter -2	Migratory Birds in Peril: Unravelling the Impact of Climate Change Goutam Biswas, Sarthak Ranjan Sarkar, Bonhishikha Roy, Arkaprabha Pal, Somvit Nandi, Souvik Banerjee, Swapnendu Roy	35-48
Chapter -3	From Fields to Atmosphere: Understanding the Dangers of Stubble Burning on Environment and Public Health Rajib Majumder	49-64
Chapter -4	Role of Nutrition in Combating Air Pollution for Sustainable Development Smita Sahu, Arnab Chatterjee, Amit Kumar Banerjee, Prithviraj Karak	65-78
Chapter -5	Current Landscape and Future Perspectives of Biomedical Waste Management in India Sumitaksha Banerjee, Harendra Kumar, Tanmay Sanyal, Pronoy Mukherjee, Dattatreya Mukherjee	79-93
Chapter -6	Ecotourism: A Sustainable Development Perspective in India Abhinaba Sinha	94-104
Chapter -7	Sustainable Urban Development and Its Profound Impact on Human Health Tuhar Mukherjee, Debarshi Mondal	105-121
Chapter -8	Balancing Population Pressure for Sustainable Development: Strategies for a Harmonious Future Amina Khatun, Somnath Das, Sudipa Mukherjee Sanyal, Himika Deb, Anupam Ghosh	122-137
Chapter -9	Arth Ganga: A Sustainable Model for Ganga River Rejuvenation Puja Pal	138-154
Chapter -10	A Concise Approach to Health and Sustainable Development Mitali Mondal, Somnath Das	155-165
Chapter -11	Sustainable Healthcare: Medicinal Plants and Environmental Balance in Ayurveda Sujit Maity	166-184
Chapter -12	Eco-Health Dynamics: Climate Change, Sustainable Development and the Emergence of Infectious Challenges Arnab Chatterjee, Sutapa Sanyal	185-203
Chapter -13	Cognitive Impairment Among the Elderly Population Krishnendu Sarkar	204-212
Chapter -14	Distribution, Burrowing Adaptations and Threats of Dune Crickets with Special Reference to Schizodactylus monstrosus (Dury) Suvabrata Khatua, Nithar Ranjan Madhu, Sudipta Kumar Ghorai, Susmita Moitra, Aloke Saha, Sudipa Mukherjee Sanyal	213-230

Chapter -15	Cytotoxic Effects of Silver Nanoparticles on Plants: A Potential Threat to the Environment and Its Management Alokemoy Basu	231-243
Chapter -16	The Invisible Threat: Understanding Effects of Micro and Nano-Plastics on Human Health and Environment Arindam Chakraborty, Rima Mondal, Saheli Ali, Koushik Sen, Suasanta Roy Karmakar, Shubhadeep Roychoudhury	244-260
Chapter -17	Impact of plastic pollution on faunal survival with probable sustainable solutions Srinjoy Das, Debashmita Mandal, Kaustav Chakraborty	261-273
Chapter -18	An Environmental Pollutant: Bisphenol A (BPA), Posing a Risk to Human Health Kaushik Sarkar	274-287
Chapter -19	Impacts of Microplastics on Zooplankton Somnath Das, Dipak Kumar Tamili, Nithar Ranjan Madhu	288-303
Chapter -20	Sustainable Management Practices for Fish Waste in Madanpur and Simurali Fish Markets Pronoy Mukherjee, Dipanwita Das, Bibhas Guha, Sudipa Mukherjee Sanyal, Tanmay Sanyal	304-312
Chapter -21	Insights into the Adverse Effects of Bisphenol A on the Environment and Human Health Krishnendu Adhikary, Riya Sarkar, Sriya Choudhury, Sankha Chakrabortty, Prithviraj Karak	313-336
Chapter -22	Impact of environmental pollution on reproduction of Tilapia: an indispensable perception for understanding SDGs Indrani Banerjee, Hiya Roy, Sumana Saha	337-346
Chapter -23	Scientific Mud Crab Culture Practices in Sundarbans Delta: A Step Towards the Betterment of Sundarbans People Biplab Bhowmik, Lisa Basu, Priya Roy	347-353
Chapter -24	'Sustainable Aquaculture' and 'Rural Women' Pratap Mukhopadhyay, Urna Banerjee	354-367
Chapter -25	Qualitative and Quantitative Assay of Coliform Bacteria in Different Water Samples & Their Role in Sustainable Development Shrijeet Kayal, Sagar Verma, Sreenu Appikonda, Gargi Dutta, Chiradeep Basu	368- 376
Chapter -26	Environmental DNA: an Emerging Sustainable Tool for Ecological Monitoring Piyali Chowdhury	377-389
Chapter -27	Revolutionizing Leather Industry Wastewater Treatment: A Game-Changing Approach for Sustainable Environmental Management Md. Abu Imran Mallick, Riya Malakar, Narayan Ghorai, Aloke Saha, Pronoy Mukherjee, Tanmay Sanyal	390-407
Chapter -28	Present status and future outlooks of renewable energy in India for sustainable development Puja Pal	408-433

Chapter -29	Unlocking the Potential: A Comprehensive Review of Environmentally Sustainable Applications for Agro-Based Spent Mushroom Substrate (SMS) Md. Abu Imran Mallick, Rishab Nath, Narayan Ghorai, Samprita Mishra, Aloke Saha, Sudipa Mukherjee Sanyal	434-477
Chapter -30	Securing Coral Reefs: Integrating Sustainable Development Goals in the Anthropocene Susmita Moitra, Aloke Saha, Sudipa Mukherjee Sanyal, Madhuban Datta	478-505
Chapter -31	Utilizing Climate Physics: Advancing SDG 13 with Integrated Low Carbon Energy from Diverse Sources – A Glimpse Ahead Soumya Chatterjee, Pronoy Mukherjee, Aloke Saha, Koushik Sen, Raju Das, Tanmay Sanyal	506-519
Chapter -32	How Plastics Affect the Marine Environment: Its Sources, Threats, and Consequences, Potential Countermeasures for a Healthy Ocean Environment Anirban Pandey, Aloke Saha, Biswajit (Bob) Ganguly, Roger I.C. Hansell, Tanmay Sanyal	520-540
Chapter -33	Campus Ecosystems: Nurturing Biodiversity and Sustainability for a Greener Future Goutam Biswas, Diptak Chakraborty, Bhanumati Sarkar, Rajatesh Chakraborty, Nithar Ranjan Madhu	541-562
Chapter -34	Light Pollution in Urban Life: Effects on Environment and Human Health Sujata Roy Moulik, Rupali Nayek	563-575

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Chapter- 1

Root Causes of Biodiversity Loss with Special Reference to India

Sourav Bar, Soumik Dhara, Nithar Ranjan Madhu*, Biplab Mandal, Bhanumati Sarkar, Sudipta Kumar Ghorai*

Keywords: Biodiversity, Conservation, Pollution, Climate change, Extinction

Abstract:

The study analyses Indian case studies and examples to determine the main causes of biodiversity loss. India's biological variety presents particular challenges to biodiversity loss, a global issue with major ecological, economic, and social impacts. It may explore habitat degradation and climate change of natural resources, pollution, and invasive species as causes of biodiversity loss in India. It may also illustrate how biodiversity loss disrupts ecosystems, threatens food security, and affects human well-being. There are several causes of biodiversity loss. Most are linked. To combat biodiversity loss more effectively, we must understand its causes. Pollution, climate change, habitat loss, overexploitation, invasive species, etc. cause biodiversity loss. India is one of 17 mega-diversity countries with high biological diversity. India is one of the world's most populous nations. Thus, India's biodiversity is dwindling as its population grows. Since humans started to use fire, they have constantly changed the environment. Industrialization, agriculture, and fast urbanization have raised extinction rates for decades. Loss of life variety can break ecosystems from local ecosystems to the global biosphere. The loss of biodiversity might create a niche that disrupts the ecosystem. For instance, the extinction of tree species can impact its relatives. We must protect our biodiversity because we are deeply connected to it. The manuscript briefly examines Indian biodiversity conservation policies, tactics, and efforts.

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Introduction:

The term biodiversity or biological diversity, describes the variety present in every field of biology. Our food, fuel, shelter, medicine, and more depend on biodiversity. It's tied to humans and all the lives that interact to preserve the ecosystem. Biodiversity is defined as the variability among living species from all sources, including terrestrial, marine, and other aquatic habitats and their environmental complexes, according to the Convention on Biological Diversity, which was established in 1992 at the time. This includes diversity within species, between species, and within ecosystems. Biodiversity and its decline are natural until extinction rates are controlled. Earth has experienced five catastrophic extinctions before humans due to large volcanic eruptions, long ice ages, meteorite impacts, and colliding continents.

The current extinction scenario is different. This is happening quickly due to human activity. The current pace of extinction is one hundred to one thousand times higher than the rate before humans (Verhulst et al., 2018). This major change in biodiversity may cause dangerous consequences like the loss of resilience of the ecosystem and we may go through another mass extinction event (Barnosky et al., 2011). At present, diversification is lower than extinction. Human survival depends on biodiversity because we are part of it. So, it's a significant worry today. Every habitable place on Earth has biodiversity. Identified some of it which is known to become susceptible daily and we've tackled its extinction causes. Thus, we must understand biodiversity's past and present to respond soon (Gaston, 2003; Sigwart et al., 2018; Kundu, 2022; Haldar & Haldar, 2022).

Human activities are responsible for the profound changes that are currently occurring on Earth. At this point, we cannot determine the extent to which diversity has been lost. If we continue to be unable to take precautions about biodiversity, the entire ecosystem will be destroyed. We are aware that the living things that make up an ecosystem communicate with one another to produce the interconnected network necessary to maintain biodiversity. Therefore, eliminating one component from it may disintegrate that network. Before we can take action to stop the loss of biodiversity, we need to have a solid understanding of the many factors that contribute to it.

Major types of Biodiversity:

The presence of several levels of variety at every stage of biodiversity is beneficial to the health of ecosystems, species, and the planet as a whole. When catastrophe hits, an increase in biodiversity can be necessary for survival and it can serve as a form of environmental insurance for the entire globe (Hans et al., 2017).

Genetic Diversity:

The concept of "genetic diversity" refers to the variation that exists within the gene pool of a species, as well as the variation that occurs at the DNA level. Even while it is possible to infer genetic diversity based on the appearance of an animal, direct investigations of the DNA of a species provide a more accurate assessment of the genetic diversity of that species

(Poommouang et al., 2021). A population's ability to adapt to change is improved when it is genetically diverse. The presence of high amounts of genetic variety, for example, raises the chance that some members of the community may be less impacted by a disease that plagues a population and causes widespread devastation. By preserving a portion of a population, genetic diversity reduces the likelihood that that population would become extinct (Banks et al., 2013).

Species Diversity:

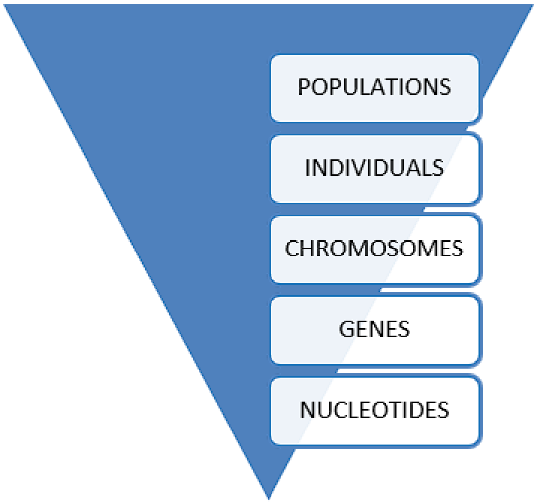
The concept of species diversity considers not just the total number of species found in a community, but also the relative abundance of each species and its function. For instance, there might be several distinct species in a group, yet only one predator might hunt a certain prey species. The prey's population numbers stay within what the community can sustain, while the predator's population levels are healthy (Heupel et al., 2014).

But suppose the predator suddenly becomes less common. In that case, the population of the prey species can rise in reaction, overeating its prey and creating a domino effect that would upend the entire community. On the other hand, a population with greater species diversity can have several predators pursuing the same prey. The community is thus shielded from any further destabilizing consequences if one predator population experiences a dramatic change (He et al., 2021).

Ecosystem Diversity:

The "ecosystem diversity" describes the variation in environments within a region. In contrast to species diversity and genetic diversity, ecosystem diversity takes into account both biological and non-biological sources of variety, such as sunlight and temperature. Regions with high ecological diversity form a geographic mosaic of communities that serve to shield a whole region from unfavorable developments (Alsterberg et al., 2017).

If, for instance, there is a diversity of less sensitive ecosystems surrounding a dry vegetation area that is prone to wildfire, the wildlife may not be able to spread to other dry vegetation areas in the same year, giving the species that make up the burned ecosystem an opportunity to relocate to an unaffected habitat while the burned land heals. Ecosystem diversity thus contributes to the preservation of species variety (Steel et al., 2021).



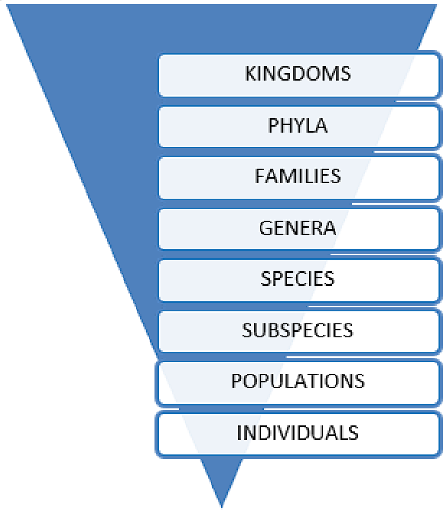


Figure 1.1: Species Diversity Figure 1.2: Genetic Diversity.

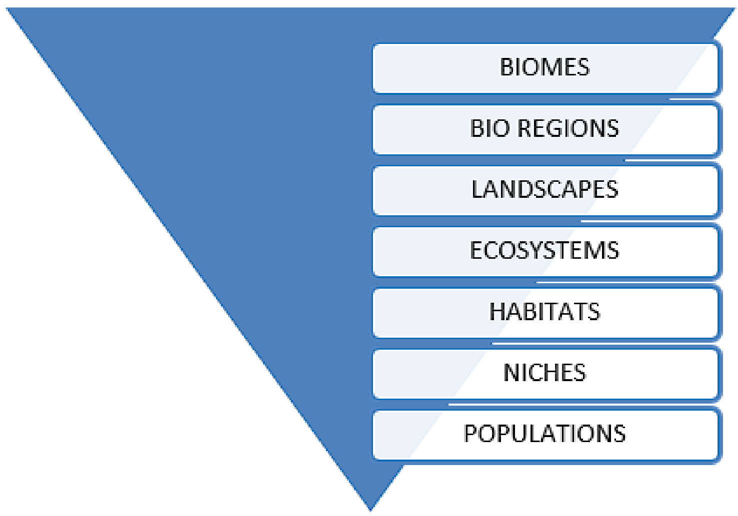


Figure 1.3: Ecosystem diversity.

Figure 1. 1, 1.2, 1.3 show the levels of biodiversity.

India as a megadiversity country:

The geographic coordinates of India are between latitudes 60 and 380 N and longitudes 690 and 970 E in South Asia. The Afro-tropical, Indo-Malayan, and Paleo-Arctic regions all converge in India. India has a great deal of diversity because of its distinct biogeographical location. The Bay of Bengal lies to the east, the Arabian Sea to the west, the Indian Ocean to the south, and the Himalayas to the north encircle India. India is home to four significant hotspots for biodiversity: Sunderland, Indo Burma, the Himalayas, and the Western Ghats (Stephen et al., 2015; Venkataraman et al., 2020).

However, India is losing biodiversity owing to a wide range of reasons. Endemism and species richness decrease as a result of rapid extinction. The IUCN lists the number of threatened animals that are endangered, vulnerable, and critically endangered below (Fig. 2.1). Figure 2.2 below lists the principal protected areas in India that support biodiversity conservation.

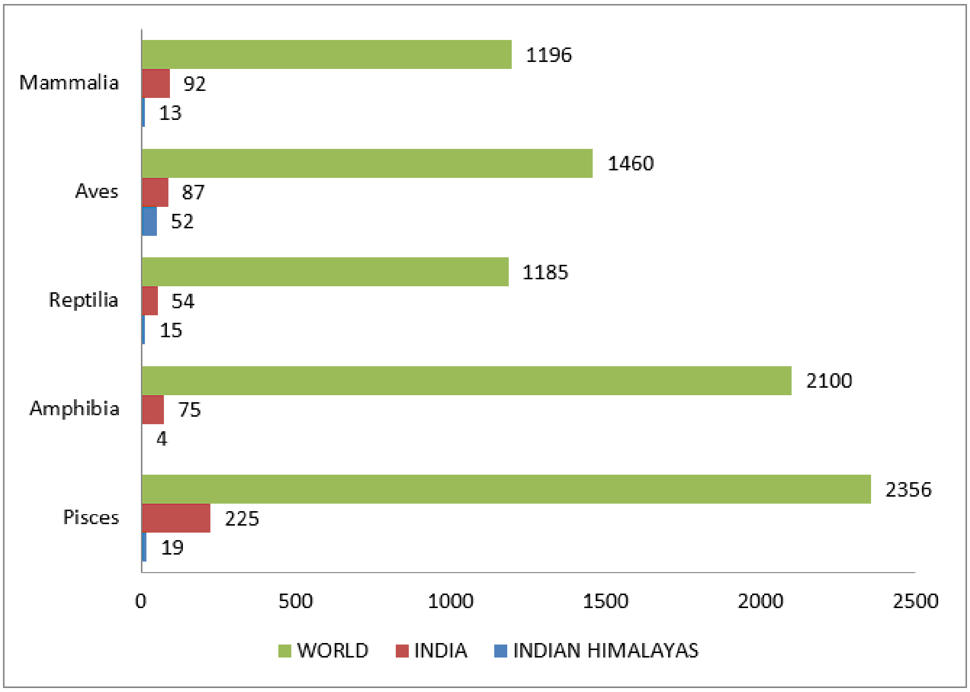


Figure 2.1: No of threatened vertebrates in the world, India and Indian Himalayas (IUCN- Red List 2017).

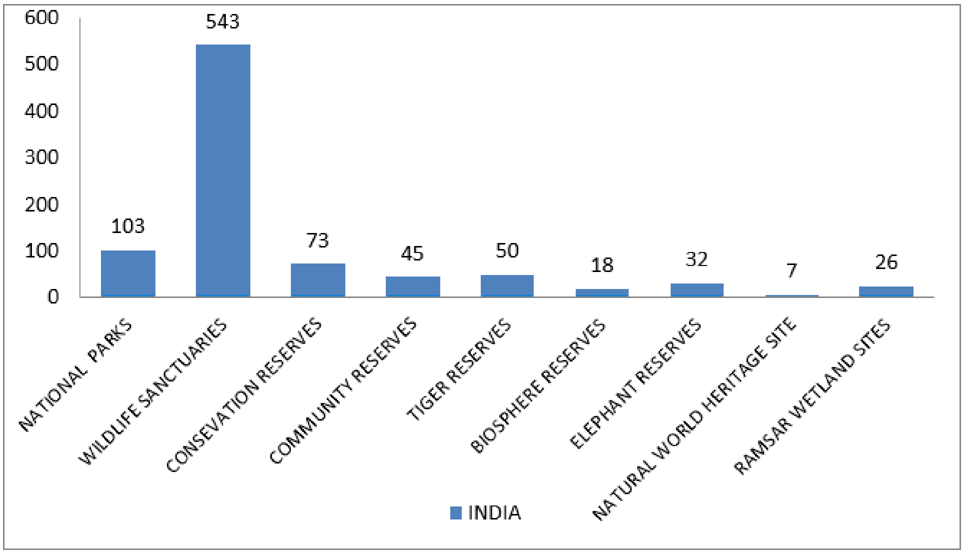


Figure 2.2: No of different protected areas notified from India (Source: Chandra et al., 2018).

Causes:

Various factors, including pollution, climate change, habitat loss, and overexploitation cause the loss of biodiversity. Due to human dominance over the past century, ecosystems have changed quickly, resulting in biodiversity loss worldwide. Most of the causes are related to the overuse that pertains to natural resources and the expanding human population. Here, we are concentrating on seven core causes of biodiversity loss (Fig. 3), which can trigger numerous other processes and initiate numerous induction cascades, leading to a sharp fall in biodiversity.

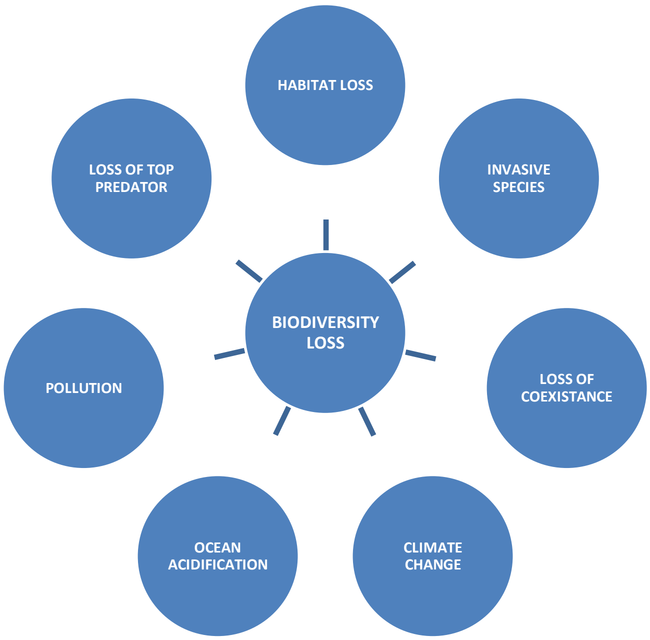


Figure 3: Major causes of Biodiversity loss.

Loss of habitat:

By the year 2100, it is predicted that changes in land use patterns, as well as changes in the atmosphere's CO_2 content, nitrogen deposition, and introduction of new species, will have had a global impact on biodiversity. Rapid rates of habitat loss are occurring (Verhulst et al., 2018). The destruction of habitat is ultimately the result of human action, such as clearing forests to make way for agriculture, filling marshes, building massive structures, etc.

To accommodate development and the insatiable needs of humans, the vast wilderness regions are connected into smaller land fragments. Genetic diversity is restricted by large biodiversity areas being divided and isolating plant and animal groups. There is a sharp fall in species diversity due to human overuse of natural resources, such as destructive fishing (Mukherjee et al., 2022; Sanyal et al., 2023).

The pace at which urbanization is occurring is accelerating the process of habitat destruction, and this trend is well-documented. The loss of many species that depend on these habitats is a result of habitat deterioration (Deb et al., 2022). The residence of native species is lost as a result of numerous other human activities and natural catastrophic catastrophes.

Natural causes like fire, flood, cyclone, etc are increased due to human activity. One of the most important factors for this is the formation of super cyclones like Amphan in West Bengal and Odisha coast. India is facing rapid population growth in the last decades. As a result of rapid population growth in India, the urbanization rate has been increasing daily. Fig.4.1 shows how fast the urbanization process has been in the last decade (from 2010 to 2020).

In recent years, several forest fires have been seen in India. The forest fire burned Shimlipal Biosphere Reserve, Odisha, in March 2021. A forest fire in Bandipur National Park happened in February 2019. Many other forest fire events have been seen in India, like the Uttarakhand Forest Fire, the Himachal Pradesh Forest Fire, etc. Fig. 4.2 shows how many forest fires have recently happened in India. Most of these forest fires are manmade and responsible for habitat loss, causing biodiversity loss.

According to the report of the Forest Survey of India (FSI), forest fires have increased from 8,654 in 2004 to 35,888 in 2017. A total number of 277,758 forest fire points are distributed in the following states - 20686 in Maharashtra, 24422 in Madhya Pradesh, 25995 in Chhattisgarh, 20862 in Assam, 32659 in Mizoram and 26719 in Odisha.

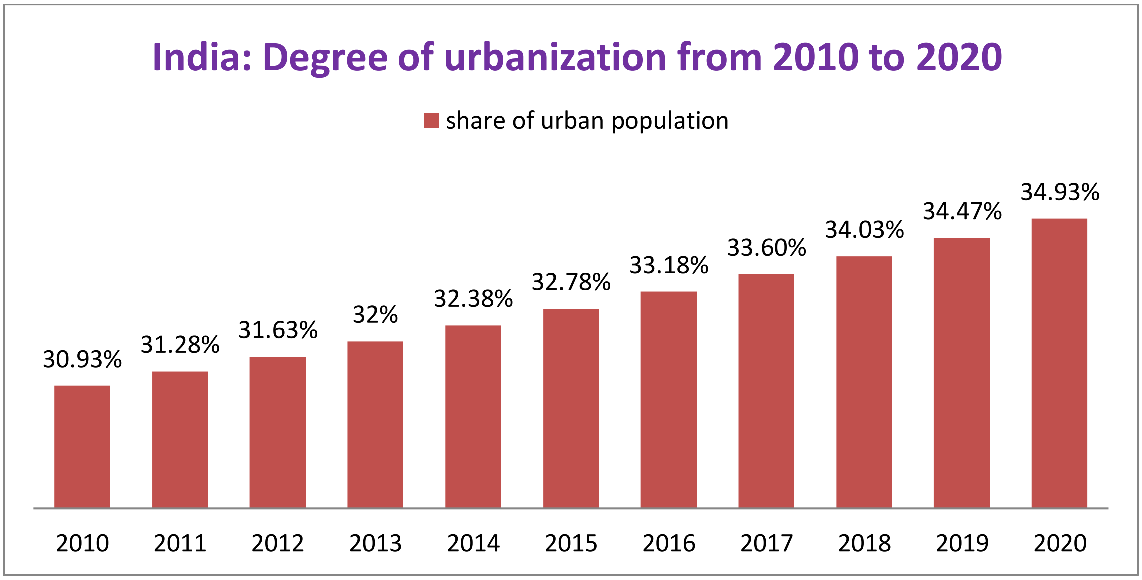


Figure 4.1: statistical representation of the rapid increase of urbanization in India.

Data source: ©Statista 2022 (https://www.statista.com/statistics/report-content/statistic/271312)

Invasive species:

An important factor that contributes to the loss of natural biodiversity is the introduction of species that are considered to be invasive. When the non-native alien species arrives in the new environment or is introduced there by humans, it begins to outcompete the native species and eventually becomes their dominant species. There is a small percentage of new species that are brought into an ecosystem that end up becoming invasive species and hurting the environment.

Figure 4.2: Forest fire at different places in India (Source: Forbes, India) https://www.forbesindia.com/article/take-one-big-story-of-the-day/can-wildfires-be-prevented-in-a-world-dealing-with-climate-change/68127/1

However, the majority of these new species do not become invasive (Vijeta et al., 2021). Through the modification of the habitat, the introduction of viruses, and the destruction of plants that are herbivorous in the native ecosystem, invasive species can manipulate the native ecosystem in several different ways. This ultimately results in a decrease in genetic diversity as a result of hybridization with native species. Competition for the usage of resources takes place between species that are native and species that are not native (Vijeta et al., 2021).

Ten species of invasive alien plants are regarded to be among the most dangerous in the world. *Lantana camara* is one of these species, and it is fast spreading throughout India. The physicochemical properties of the soil are changed as a result of this. Additionally, it is connected to the environmental and economic benefits and drawbacks that are related to the scenario of global climate change (Rai and Singh, 2019). More than 40% of the total range of Tiger's habitat in India is occupied by it and the southern Western Ghats, Shivalik hills and central India are the worst hit in India.

Parthenium sp. known as congress grass in India has spread over many tropical and subtropical countries. Although it is a native species of tropical America, it is found in almost all states in India and it is reported that its invasion causes loss of yield in several crops.

The introduction of species that are not native to the area is either accidental or intended. The introduction of noxious weeds, insect pests, and other undesirable organisms is done on

Figure 5.1: *Parthenium* sp. (Congress grass)

Figure 5.2: *Lantana camara.*

purpose. It was European ships that brought foxes, rabbits, and cats to Australia, and these animals have been responsible for the extinction of Australia's native biodiversity. In the instance of freshwater fish, the introduction of alien fish into rivers for a variety of reasons has resulted in the extinction of at least 18 species of native fish that were found in rivers in North America. The Nile perch was introduced into Lake Victoria, which resulted in a decrease in the fish biodiversity of the lake (Hens and Boon, 2005). The eucalyptus tree, which is native to Australia, has been brought to several tropical and subtropical regions around the world, including India, where it just acts as a nuisance (Hens and Boon, 2005).

When compared to natural prairie grasses, the perennial tussock grass known as Agropyroncristatum, which was introduced into the northern Great Plains of North America, has a relatively smaller root allocation. In comparison to the soil of natural prairies, the soil of *A. cristatum* contains lower levels of both accessible nitrogen and total carbon. Due to the presence of this species, the amount of carbon that was stored in the soil was reduced by 480 x 1012 grams. The quantitative content of organic matter and nutrients in the soil can be altered by soil invertebrates such as earthworms and termites. This, in turn, affects the composition of the flora and animals that are found above ground. However, even though they are very flammable, several grasses that are useful for cattle grazing have been introduced to the Hawaiian Islands. In the protected woodlands, these grasses spread quickly and caused the fire to spread farther and further. These grasses can rebound quite fast, in contrast to the many woody plants and endangered species that have been eradicated as a result of this fire.

Temperatures of the soil have a significant impact on the availability of nutrients and the level of productivity in late-successional boreal forests. When moss is present, it decreases the amount of heat that enters the soil, which in turn makes the permafrost, which is frozen earth, more stable. Because of this, the pace at which nutrients are cycled is slowed down after that.

The moss biomass decreases and the permafrost becomes less stable as a result of the increased fire frequency that occurs as a result of the climate change that occurs at high latitudes. As a consequence of this, the availability of nutrients increases, and the species composition of forests transforms.

According to the Zoological Survey of India, *Achatina fulica,* commonly known as the African Apple snail, is among India's most invasive exotic alien fauna. This molluscan species was first found in Andaman and Nicobar Island. It is harmful to many native species in India. *Paracoccus marginatus*, commonly known as Papaya Mealy Bug which is native to Mexico and America, has damaged huge papaya crops in West Bengal, Assam, and Tamil Nadu. *Phenacoccus solenopsis* commonly known as Cotton Mealy Bug, which is a native species of North America has severely destroyed the crops of cotton in Deccan. *Pterygoplichthys pardalis* commonly known as Amazon sucker mouth sailfin catfish, has destroyed the population of fish in many aquatic water bodies of Kolkata (Zoological Survey of India).

Figure 5.3: *Achatina fulica*.

Figure 5.4: *Pterygoplichthys* sp.

Biotic invasion has multiple effects on the ecosystem, directly or indirectly affecting biodiversity. As we have discussed, biotic invasion causes forest fires, ultimately leading to land use changes. Nutrient composition will be changed if the species' composition is changed. Less carbon sequestration is caused by biotic invasions that cause the climate change. Fig.5.5 shows various effects of biotic invasion that ultimately cause biodiversity loss.

Loss of coexistence:

The diversification of the ecosystem depends on some major mechanisms that help sustain so many species. Coexistence is one of those mechanisms. Coexistence demands the ability to use evolutionarily sustainable interspecific tradeoffs to deal with the factors limiting species' fitness and abundance. There are many limiting factors and trade-offs that exist in ecosystems. Species may coexist due to their interspecific trade-offs between their abilities to compete and their abilities to disperse, between their abilities to compete and their sensitivity to disease, herbivory, and predation, and between their abilities to survive with average conditions and their abilities to exploit resource (Tilman, 2000).

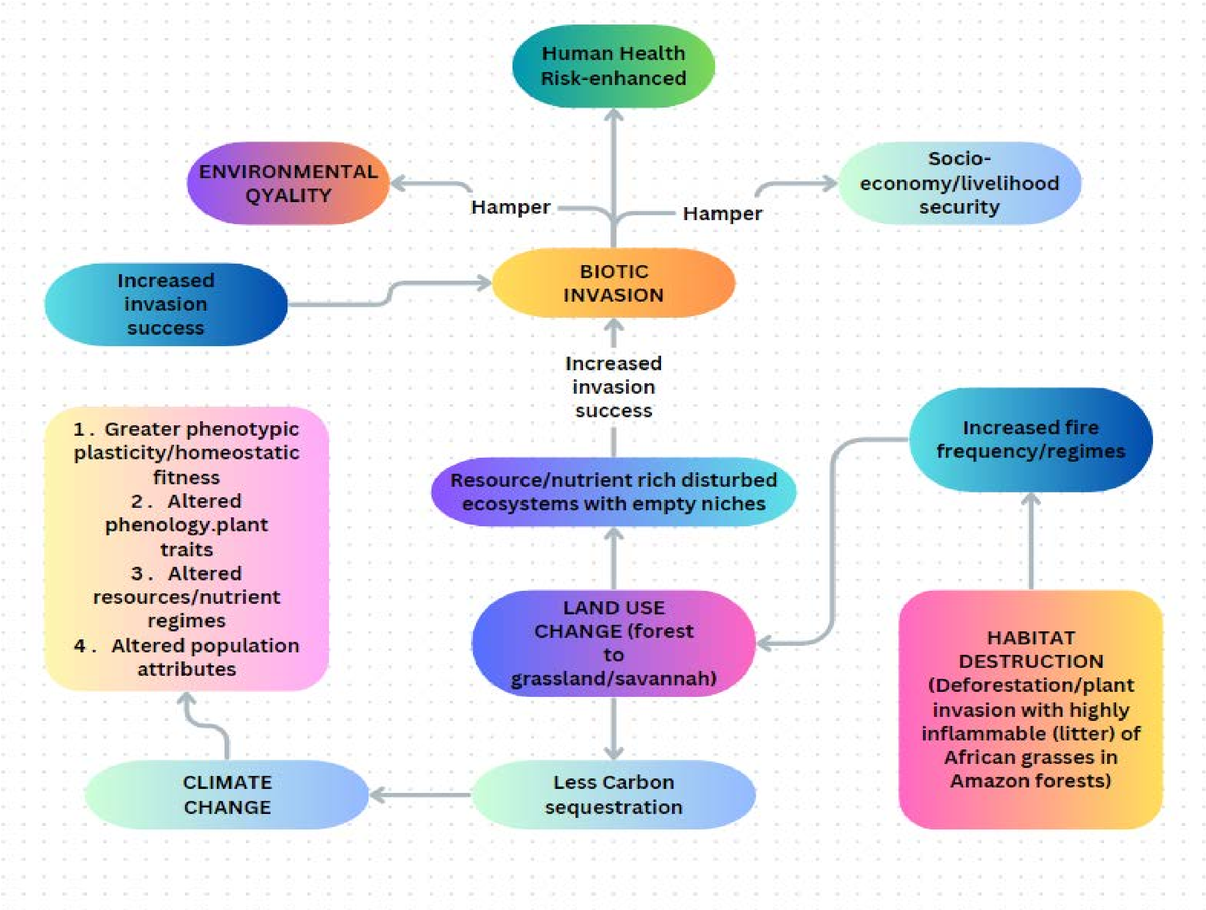


Figure 5.5: Impact of Biotic invasion.

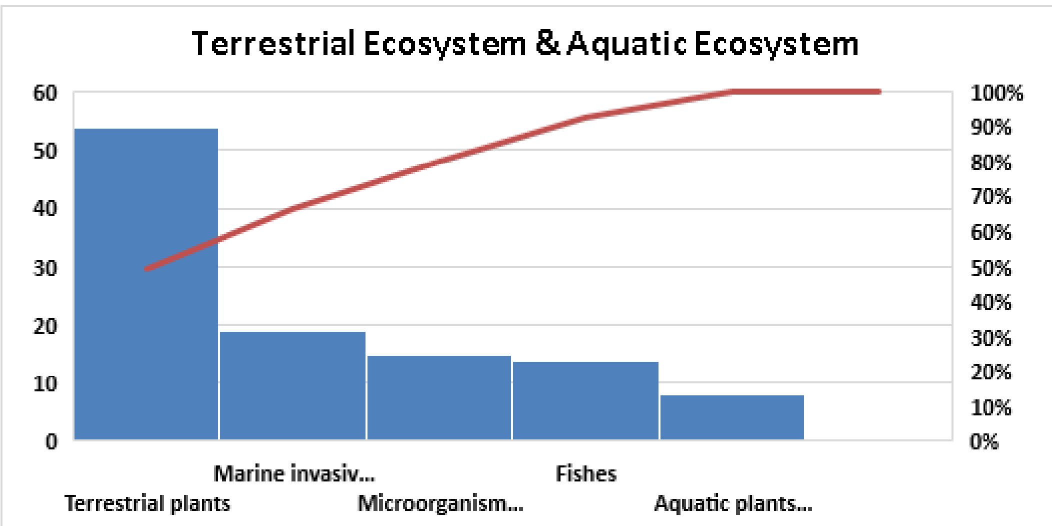


Figure 5.6 (a): Terrestrial Ecosystem & Aquatic Ecosystem.

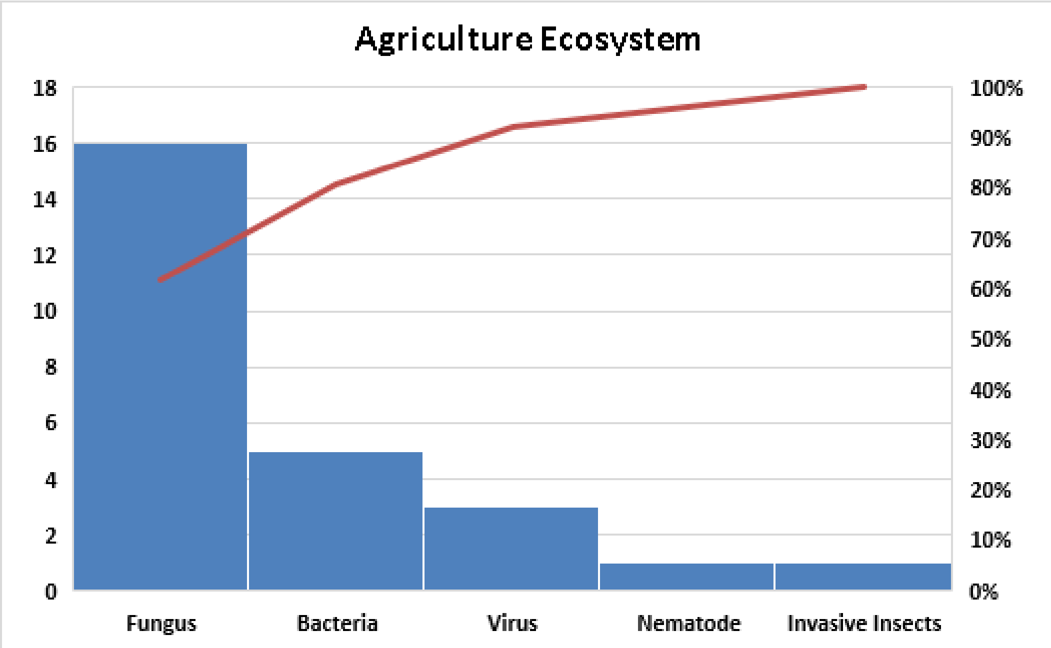


Figure 5.6 (b): Agriculture Ecosystem.

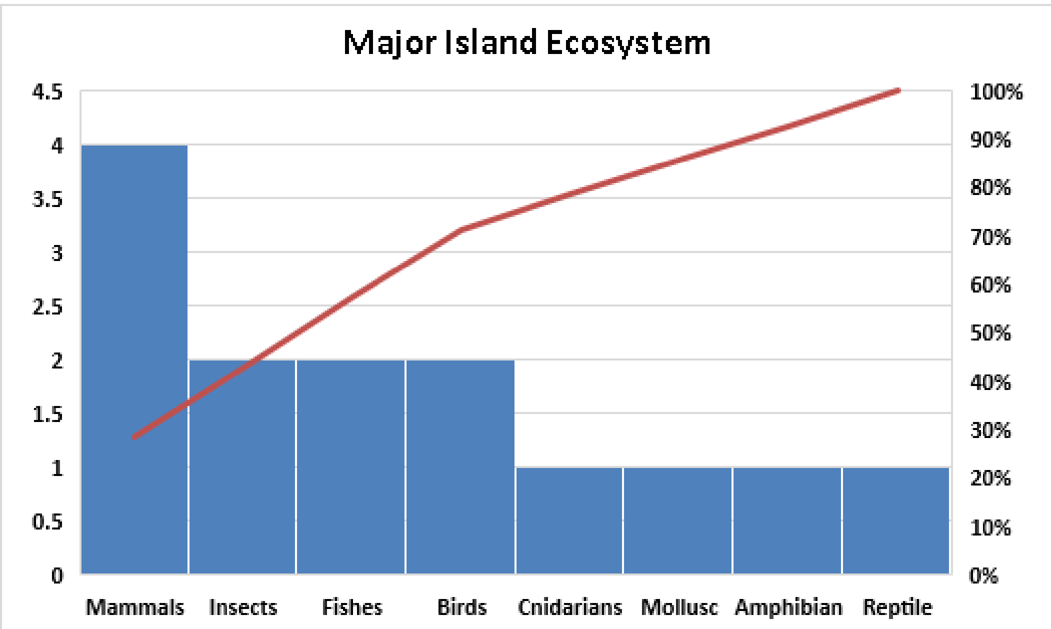


Figure 5.6 (c): Major Island Ecosystem

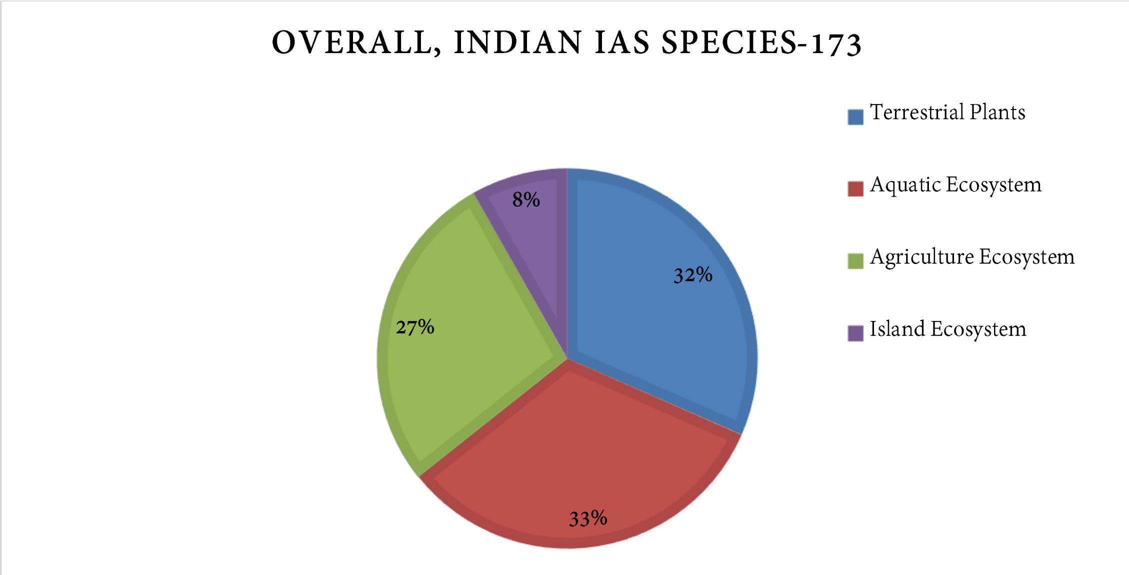


Figure 5.6 (d): Overall, Indian IAS Species-173

Figure 5.6: Information about alien species that have been reported in India [Data source: Invasive Alien Species of India Compiled by S. Sandilyan (National Biodiversity Authority, Ministry of Environment Forests and Climate Change Government of India)].

Species are coevolved with one another such as plants with their specific pollinators, medicinal plants, hosts with their specific parasites, etc. (Ghosh et al., 2022; Sarkar et al., 2021). Upon passing the final passenger pigeon (*Ectopistes migratorius*) passed away during the '90s, two of its parasites that are unavoidable and two lice species went extinct with the passenger pigeon. Moabi (*Baillonella toxisperma*) is an essential tree in West Africa, but it depends on elephants for its reproduction because only the elephants can swallow and disperse the Moabi seeds. So if elephants go extinct, probably Moabi will also extinct. These phenomena are known as the "Knock On" effect (Hens and Boon, 2005).

Darwin and Wallace proposed that a monoculture should be less productive than a diversified combination of plants because of the diversity of the plants. In addition, they proposed the underlying biological mechanism due to the ecological differences that exist between multiple species that cohabit. When a species goes extinct, it leaves behind a vacant niche space, which may affect the processes that occur within the ecosystem. A basic biological principle that predicts that communities that are intact and varied are generally more stable and function better than communities that have lost species is provided by Darwin and Wallace's hypothesis, assuming that it is valid (Purvis and Hector, 2000).

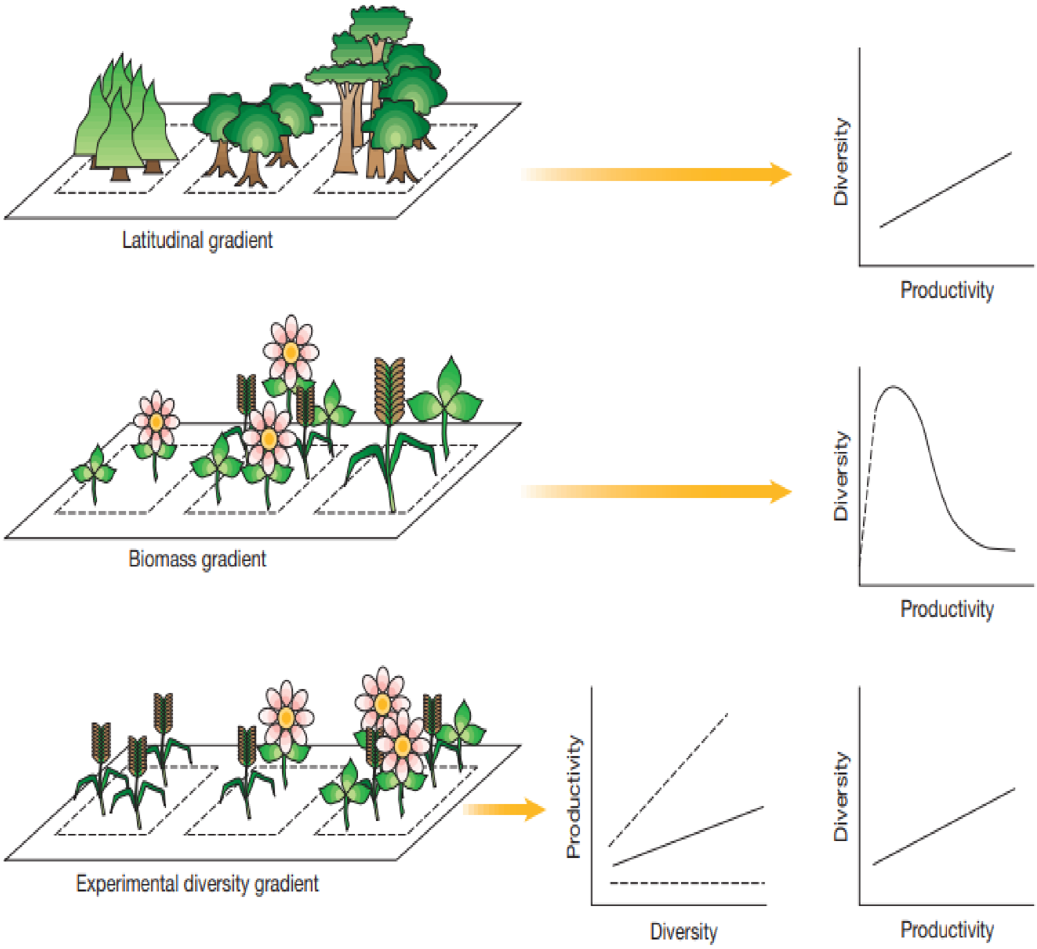


Figure 6: Relationship between diversity and productivity. According to the uppermost panel, it is observed that the presence of plant diversity in wide areas is positively associated with an increase in production, ranging from high latitudes to the tropics. The middle panel demonstrates that the diversity of plants that belong to small plots is inversely proportional to increased productivity and frequently results in a bigger unimodal distribution of diversity that is shaped like a hump. The number of species correlates with a variety of parameters, including as size, spatial heterogeneity, and competitive exclusion, and this correlation increases as productivity rises. In the lowermost panel, it is demonstrated that productivity has a tendency to grow with diversity, which in turn causes an increase in interactions between species that are either complimentary or positive. This indicates that there is a higher probability that varied communities contain a species that is extremely productive (Picture Source: Measure of biodiversity, Nature, Vol-405).

Climate change:

Biodiversity and climate change are strongly associated with each other. Climate has been changing from primitive Earth to the present Earth. So, climate change is quite a natural process through which species have evolved, but accelerated climate change disrupts ecological systems. Species cannot acclimate to the environment and hence, biodiversity loss is enhanced at an unnatural rate. Various human activities mainly induce climate change. As a result, the distribution of species is changed and many species become extinct, ultimately affecting the humans and global ecosystem.

Two key components of climate change have a direct and considerable impact on the biodiversity of India. These features are the variation in temperature and the rate of precipitation. According to Thuiller (2007), a temperature increases of one degree Celsius will cause a change of 160 meters vertically and 160 kilometers horizontally in the zone of occurrence of various species that are considered to be specialists. It has been noted by Sukumar (1995) that endemic mammals such as the Nilgiri Thar are in increased danger of going extinct (Soni and Ansari, 2017).

The impact of climate change on biodiversity is expected to increase due to the continued rise of CO_2 levels and temperature. As a result, the frequency and intensity of heat and storms will increase daily (IPCC, 2007). It has been analyzed that the rapid increase of greenhouse gases threatens global biodiversity. The prediction of IPCC, 2007 is that by the end of the 21st century global surface temperature may rise to 4^0C and also stated that an increase of 1.5^0C to 2.5^0C would threaten 20-30% of plant and animal species of the world, resulting in extinction. According to Bates et al. (2008), climate change may have a negative influence on over 5,000 plant species as a result of the loss of habitats that are suited for them. Additionally, the Intergovernmental Panel on Climate Change (IPCC) (2007) has noted that the primary function of increasing the levels of CO_2 in the global atmosphere is indicated by the increase in CO_2 concentration from 280 ppm in 1750 to 379 ppm in 2005. According to the assessments of the Intergovernmental Panel on Climate Change (IPCC), human activities have had a significant impact on the worldwide water cycle by altering the global carbon cycle (NASA, 2010). According to Goswami et al. (2006), more instances of heavy rainfall have been seen over India, whereas the number of instances of low and medium rainfall has dropped. Climate change has been shown to have widespread effects on several levels of biodiversity, including genes, species, communities, and ecosystems, according to research conducted (Parmesan, 2006; Bellard et al., 2012; Soni and Ansari, 2017).

Table 1: Physical change associated with climate change and its potential impact on biodiversity (Soni and Ansari, 2017).

Observed physical changes	Potential impacts on biodiversity
Rise in the temperature of the environs	Shifts in the range of species and populations, as well as changes in phenology, might eventually result in the modification or elimination of biotic interactions.
Modifications to the yearly and seasonal precipitation patterns	Modifications to the makeup of the community
Significantly increased occurrences of extreme	Deaths that occur as a consequence of flooding following storms or droughts; injuries or deaths that occur as a

events	consequence of extreme cold or heat waves
Modifications to the hydrologic regimes	Reduced stream flow has an impact on the permanence of the population and the makeup of the community
Modifications to the fire regimes	Modifications to the makeup of the community
Acidification of the oceans	The calcification rates of marine species are affected by changes in the water's chemical composition.
Rise in sea level	The loss of habitat and its fragmentation
An increase in the stratification of the ocean	The decreased productivity of ecosystems that are pelagic
Variations in the upwelling of the coast	Variations in the productivity of fisheries and ecosystems along the maritime coast.

The Olive Ridley turtle one of the smallest sea turtle present on Earth is facing the threat of extinction due to climate change. Rushikulya Beach of Odisha is one of the biggest nesting sites of this turtle. Due to intense floods and cyclones, the eggs of this turtle are affected. Turtles show temperature-dependent sex determination. Apart from the egg destruction, the rising temperature due to climate change causes a change in the gender ratio. The male turtle will be born if the egg hatches below 290C and if the temperature increases above 290C or 310C, the female will be born. As temperatures start to increase due to climate change, more females are produced. Thus, sex bias has been seen in Turtles (WION, 2023).

Ocean acidification:

The ocean covers almost 70% of the Earth's surface and any kind of abnormal condition in the ocean due to anthropogenic CO_2 emission can cause massive damage to the Earth's biodiversity. Ocean acidification is nothing but the lowering of the ocean's pH. Due to the increasing amount of CO_2, the ocean absorbs CO_2 much faster during the last few decades than previous thousands of years. The term "Ocean Acidification'' does not mean that the oceans have become acidic or will become acidic shortly rather it indicates a shift of ocean pH towards a less alkaline level. The present shift in ocean pH has already threatened the Coral reefs and calcifying organisms in the oceans. Oceans absorb two other acid-forming gases SO_x and NO_x. Globally, their impact is relatively minor but is expected to increase as the emission continues to increase (Abbasi and Abbasi, 2011).

One of the most important roles of the ocean is the exchange of carbon dioxide with the atmosphere, thereby maintaining the Earth's carbon cycle, which helps sustain the Earth's ecological balance and enables many life forms to survive. A complex web of interactions controls the exchange of CO_2 from the atmosphere to ocean water and vice versa. This exchange has continued since the last 800 thousand years, the average ocean pH would have remained at about 8.2. But from 1950 onward, CO2 emissions have risen sharply due to increased use of fossil fuels, cement production, agriculture, and various changes in land use.

One-third of the anthropogenic CO_2 that is absorbed by the ocean is responsible for the shift of ocean chemistry and causes more H+ to be released than before. It means that the ocean becomes less alkaline (Abbasi and Abbasi, 2011).

Figure 7.1: Olive Ridley Turtle at Rushikulya Beach (Source: WION, 2023).

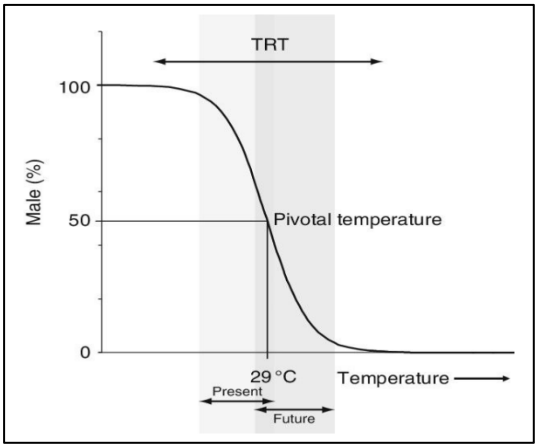


Figure 7.2: Temperature dependent sex bias in turtle (Source: Advances in Marine Biology).

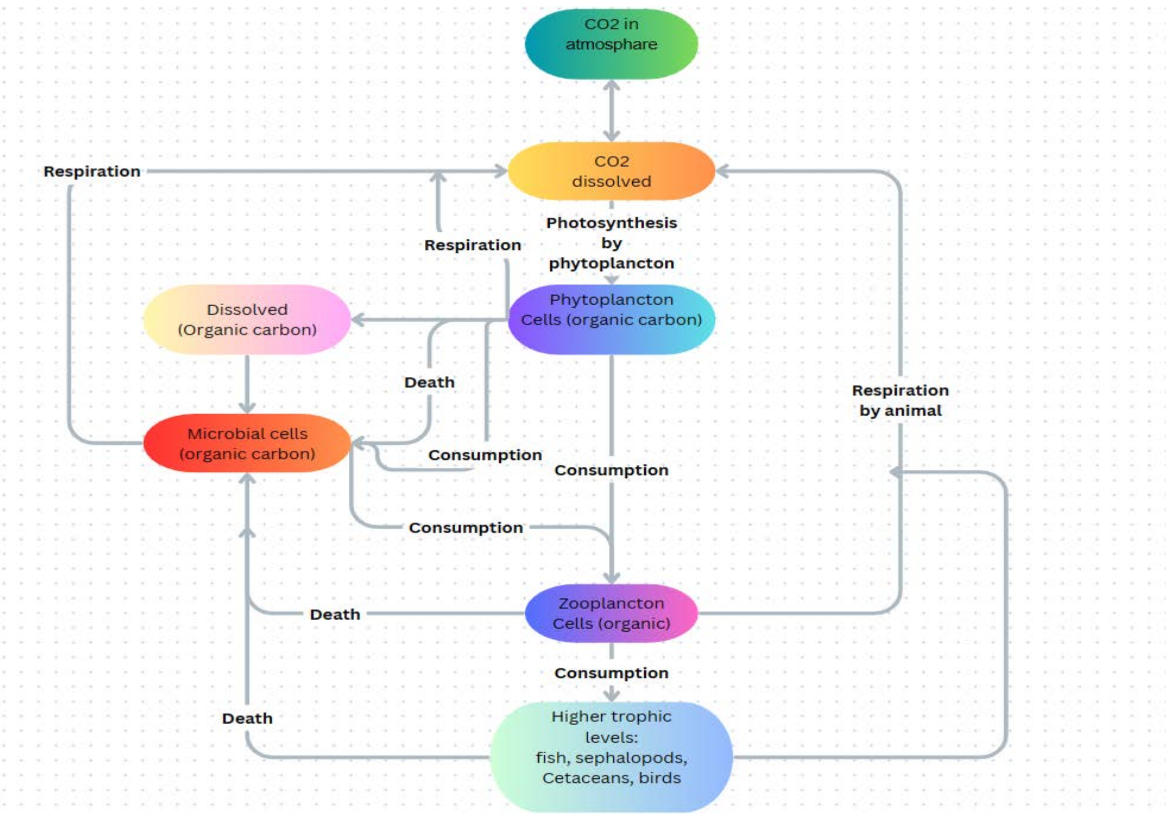


Figure 8.1: Interactions within the intricate web that are linked with the carbon dioxide cycle in the ocean.

Effect of ocean acidification on the biodiversity of Lakshadweep:

The coral reef ecosystem is popularly known as ‘The Rainforests of the Sea’ as it is the second most diverse ecosystem on Earth. It is one of the most beautiful ecosystems on our planet. Coral reef consists of the greatest number of species among all the marine ecosystems. A coral reef prevents coastal erosion by acting as a barrier against wave action along coastal areas, thus providing ideal conditions for the seagrasses to establish and flourish along the seashore. Coral reefs are mostly associated with seagrass beds and mangroves with active physical, chemical, and biological interactions and mutual benefits.

The islands of Lakshadweep are the only atolls that may be found in the oceans of India. The Union Territory of Lakshadweep is an archipelago that is located in the Arabian Sea where it is situated between the latitudes of $08^{0}00'$ North and $12^{0}30'$ North and the longitudes of $71^{0}00'$ East and $74^{0}00'$ East. It is around 220 to 440 kilometers away from the western coast of India. Lakshadweep is the Union Territory of India that is the smallest in size. The islands are the most northern section of the Laccadive-Chagos Ridge. They are made up of eleven atolls, each of which contains approximately thirty-six islands, as well as several submerged coralline banks, which are coral atolls that have expansive lagoon areas. In addition to having sandy beaches and seagrass meadows in the lagoons, islands are distinguished by the presence of huge coral reefs that surround them.

Table 2: Number of coral species reported from 12 islands of Lakshadweep (Pillai and Jasmine, 1989).

Sl.No.	Islands	No. ofgenera	No. ofspecies
1.	Minicoy	28	73
2.	Sheila	7	11
3.	Kavarathi	18	38
4.	Kalpeni	11	23
5.	Androth	7	15
6.	Agathi	10	27
7.	Bangaram	5	8
8.	Amini	15	37
9.	Kadamath	21	45
10.	Kiltan	19	42
11.	Chethlath	23	57
12.	Bitra	6	15

The corals in these islands are mostly dominated by *Acropora* sp. and *Porites* sp. (Anon, 2000). Occasionally, young colonies of *Psammocora* sp., *Stylophora* sp., *Pocillopora* sp., and *Leptoria* sp. are found on the reef flats. *Acropora* sp. is found to be dominant in the reef areas of Kavarathi, Agathi, and Kadamath islands.

Foraminifera plays a major role in ocean calcification in Plankton and bottom-dwelling environments. During the calcification process, the pH of encapsulated seawater decreases, so the alkalinity automatically declines. To prevent this, foraminifera increases the pH and raises the carbonate ion (CO_3^{2-}) concentration. If the pH of ambient water decreases due to ocean acidification, this process needs more energy. This is the reason why the calcifying organism is adversely affected by decreasing pH. Allowing more energy to calcify to counteract the effect of decreasing pH could avail less energy for other crucial metabolic processes, which may reduce organisms' growth (Abbasi and Abbasi, 2011; Sharma et al., 2022).

The coral reefs in warmer water regions generally exist within a narrow range of temperature, light, and aragonite saturation states. Due to ocean acidification, these physicochemical parameters are altered. Ocean acidification causes the rapid loss of symbiotic Dinoflagellate and ultimately results in coral bleaching. Coral calcification is directly proportional to the aragonite saturation, which solely depends on carbonate ion concentration. Doubling atmospheric CO_2 could cause a 10%-30% reduction in the calcification rate (Abbasi and Abbasi, 2011).

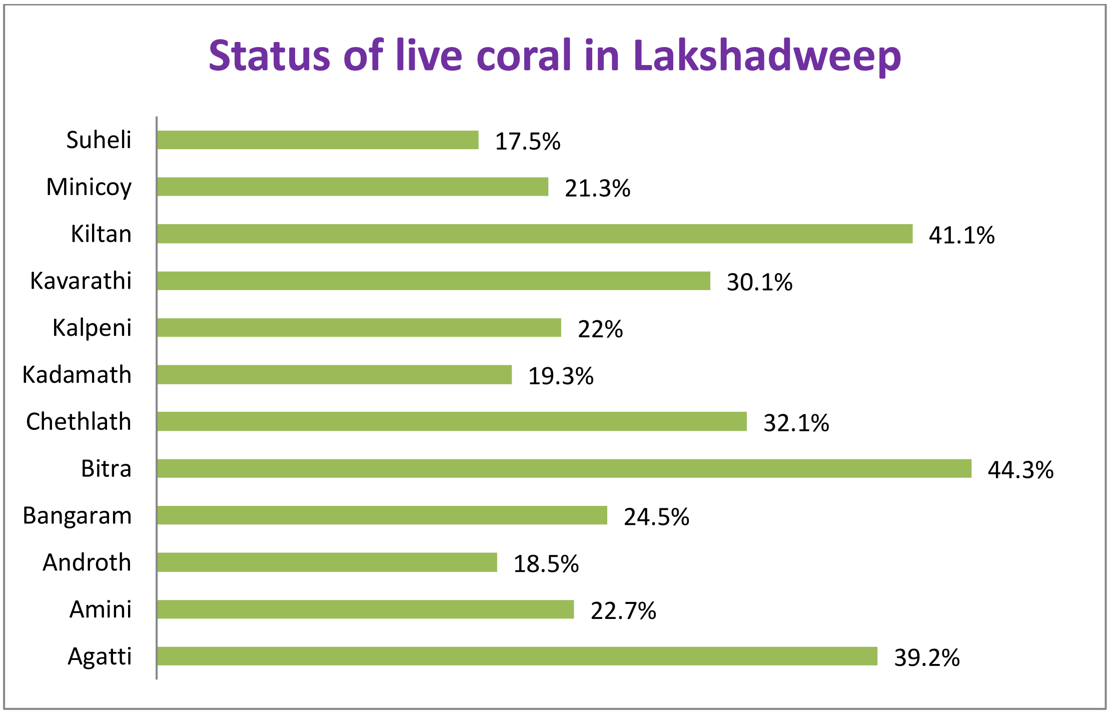


Figure 8.2: Status of live coral covers in 12 islands of Lakshadweep (2007) (Source: Ministry of Environment and Forest).

Pollution:

Pollution has many adverse effects on biodiversity and most of them are manmade. Basic abiotic components of an ecosystem, like soil, water, and air, are contaminated and the living components of an ecosystem are affected due to the unexpected change in physical parameters. Turtle fails to regurgitate due to the air pollution, causing internal injuries leading to death.

Microplastics in the environment also contaminate the air reduce the survival rate of larvae, diminish food consumption, and gradually weight loss in aquatic animals. The increasing concentrations of heavy metals in the soil are not easily broken down and accumulate by plants. Agricultural pollutants such as nitrogen from fertilizers alter the soil's pH and nutrient level (Maiti, 2010, 2013; Raha et al., 2023; Vijeta et al., 2021).

Light is also an essential factor for creatures' survival because it regulates the biological clock of every organism accordingly. The late-night street lights, lights from buildings, and headlights of vehicles have very harmful effects on the biological clocks of nocturnal animals like bats. The feeding habits of bats have decreased. The behavior of the Moth is altered due to light pollution and the prey-predator relationship of the moth gets affected. The moth is known as an efficient pollinator for many species but pollination is also affected due to behavior change (Vijeta et al., 2021).

Plastic pollution:

The marine ecosystem is globally affected by human-made waste products mostly made up of plastic. The marine debris, such as bottles, bags, balloons, rubber, medicinal wastes, etc., end up in the ocean and accumulate all along the coastline. UNEP/IOC has included the following items in the list of marine debris:

-Plastic (molded, soft, foam, nets, ropes, buoys, monofilament line)

-Fisheries related equipment,

-Smoking-related items such as cigarette butts or lighters,

-Metal (drink cans, bottle caps, pull tabs),

-Glass (buoys, light globes, fluorescent globes, bottles)

-Processed timber (including particle board),

-Paper, rubber, and cloth.

The sizes of debris can be broadly classified into the following categories, which are commonly acknowledged worldwide: The term "macro-debris" refers to waste with a diameter more than 20 millimeters, whereas "meso-debris" refers to debris with a diameter between 5 and 20 millimeters, and "micro-debris" refers to debris with a diameter of 100 millimeters (Barnes et al., 2009). Plastic is a major marine debris, so it affects marine animals and birds. At least 267 different marine species, like turtles, sea birds, seals, whales, fish, sea lions, etc. have been reported to be harmed by entanglement or ingestion of marine debris (Pawar et al., 2016).

As we already know, India is partly surrounded by oceans from East, West, and South, so the accumulation rate of marine debris along the seashore is very high. So, it is very hard to survive for those marine intertidal faunas with very restricted niches.

Figure 9.1: Collection and isolation of varieties of plastic marine debris from Baguran Jalpai beach, West Bengal.

According to estimates provided by the United Nations Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP), land-based sources are responsible for as much as 80 percent of marine debris, while activities that take place at sea are accountable for the remaining 20 percent (Pawar et al., 2016).

Table 3.1: Sources of marine debris (Data source: Plastic marine debris: Sources, distribution, and impacts on coastal and ocean biodiversity, 2016)

Sources of marine debris	
Land-based sources	**Ocean-based sources**
1. Storm water discharges 2. Combined sewer overflows 3. Littering 4. Solid waste disposal and landfills 5. Industrial activities	1. Commercial fishing 2. Recreational boaters 3. Merchant, military, and research vessels 4. Offshore oil and gas platforms and exploration

Due to the increasing demand for plastic, its production has increased decade after decade. Plastic production in the year 1950 was approximately 1.5 million tonnes; in 2011, it was approximately 280 million tonnes (Plastics Europe, 2012). Microplastic and Nanoplastic are very harmful to organisms that belong to lower trophic levels in the ocean. Industrial coastal areas have been identified as microplastic hotspot regions. The sediment of a populated coastal area can be contaminated by these micro and nano marine debris (Power et al., 2016; Dandapath et al., 2016). It isn't easy to eliminate plastic because it is non-biodegradable. It is only photodegradable into small pieces and may persist for centuries.

Table 3.2: some common types of plastic wastes [data source: Pawar et al. (2016)].

Acronym	Full name	Common example
PETE/PET	Polyethylene terephthalate	Soda bottles, Films
HDPE	High-density polyethylene	Milk jugs, Packaging, Shampoo bottles, Yogurt containers, Detergent bottles, Shopping Bags
PVC	Polyvinyl chloride	Clear food packaging, Candy wrappers, Some bottles, Water pipes, Curtains, Credit cards, Packaging films, Water films
LDPE	Low-density polyethylene	Plastic bags, Wire cloth, Squeezable bottles, Shopping bags
PP	Polypropylene	Caps, straws, Some bottles, Plastic bags and toys, Drinking straws
PS	Polystyrene	Takeout food containers, Disposable cups & plates, Fast food boxes, CD cases
PC PA Other	Polycarbonate Polyamide/Nylon Acrylonitrile butadiene styrene	Water jugs, DVDs, Sunglasses, Toothbrushes

Impact of plastic marine debris:

The environmental impact of plastic can be classified as physical, chemical, and biological. Marine debris travels throughout the ocean and can cause the degradation of physical habitats, the transportation of chemical contaminants, the endangerment of marine life, and the destruction of the aquatic ecosystem. Marine trash made of plastic has the greatest potential to effect changes in the ecosystem and to have an effect on the biota. Because it is suspended near the surface, it is carried by ocean currents to a great extent and remains in the environment for a considerable amount of time. If it is consumed, it is not easily digested. In light of this, the impact of plastic litter on marine environments is a more significant problem than other environmental problems.

Table 3.3: Environmental impact of plastic marine debris (Pawar et al., 2016).

Physical habitat impacts of plastic marine debris
1. Accumulation of debris (Modified habitat structure) 2. Habitat degradation 3. Damage and degradation of coral reef and soft sediment 4. Smother the benthos (reduce light penetration and oxygen exchange) 5. Decline benthic habitat-forming species. 6. Alien species invasions (free flow of marine debris)
Chemical impacts of plastic marine debris
1. Accumulation and transport of persistent organic pollutants (POPs) 2. Leaching of constituent contaminants from plastics A. Bisphenol A (BPA) B. Phthalates
Biological impacts of plastic marine debris
1. Ingestion by Marine turtles, Pelagic seabirds, Cetaceans, fish 2. Bioaccumulation 3. Mimicry of phytoplankton 4. Add toxic substances to the aquatic food chain 5. Entanglement

Pesticide:

Pesticides are one of the major causes of biodiversity loss nowadays. They affect the ecosystem directly by damaging biotic components and indirectly by contaminating abiotic components. Pesticides can be inserted into the food chain and damage the whole ecosystem. Only a decade after the 'green revolution' it became obvious that large-scale spraying of pesticides was causing serious damage to the environment. Many pesticides are toxic for insects, birds, mammals, amphibians, fishes, and other creatures that play beneficial roles in the environment. Wildlife poisoning depends on the quantity of the pesticide and its nature, including toxicity and other properties. Insecticides, rodenticides, fungicides, and more toxic herbicides threaten exposed wildlife (Bagchi, 2020; Das et al., 2022; Deb et al., 2020). Pesticides accumulate in the food chain, causing serious endocrine abnormalities and other physiological changes. Broad-spectrum use of insecticides and herbicides reduces the food supply for birds and mammals resulting extinction of rare species (Isenring, 2010).

Pesticides enter aquatic bodies like ponds, rivers, lakes, etc., and change the physicochemical parameters, affecting aquatic life forms. It reduces the dissolved oxygen in water bodies and causes behavioral and physiological changes in fishes. The eutrophication rate is also increased due to agricultural run-offs' contamination of water bodies. Killing aquatic plants by herbicides can decrease the amount of oxygen in water bodies, reducing fish productivity. Herbicide glyphosate is known to cause high mortality of tadpoles and juvenile frogs. Pesticides can enter into the body of aquatic organisms via Dermal absorption (Direct absorption via skin), Breathing (Uptake via gills during breathing), and oral uptake (entry via drinking contaminated water effects of pesticides on the environment) (Arya et al., 2021).

The population of beneficial insects like bees and beetles can decline by the broad spectrum use of insecticides like carbamates, organophosphates, and pyrethroids. Pesticide accumulation in the tissue of insectivorous birds leads to the death of many rare species of birds. The bald eagle population in the USA declined primarily because of overexposure to DDT and its metabolites. Pesticides can kill beneficial microorganisms present in the soil, reducing soil fertility (Arya et al., 2021).

Thermal Power Plant:

Kolaghat thermal power plant in West Bengal releases enormous amounts of fly ash containing Silica, Zinc, Copper, Calcium oxide, Aluminium, etc. that contaminate groundwater and aquatic bodies. These contaminants may harm aquatic biodiversity near Kolaghat thermal power station (Mondal et al., 2016).

Loss of top predator:

Top predators affect biodiversity positively due to their key functional roles in regulating trophic cascades. They can be dominant or keystone species as they strongly affect the ecosystem. Their loss can be a major contributing factor to the biodiversity loss in aquatic and terrestrial ecosystems. Loss of top predators can induce the decline of plant biomass as the herbivores start to dominate (Rajak, 2017; Sarkar, 2017). Without top predators, other mesopredators begin to invade the ecosystem and disrupt the whole balance of the ecosystem (Letnic et al., 2012; DeLa et al., 2012).

Sundarbans is one of the largest reserves for the Bengal tiger (*Panthera tigris tigris* L.), the top predator. The tiger population helps regulate the number and distribution of prey and maintains the forest structure, composition, and regeneration. The tiger-human conflict reveals that if the tiger does not exist, the biodiversity of the Sundarbans will be affected by various human activities like poaching, hunting, overexploitation, etc. The rapid decline of prey populations, such as spotted deer, wild boar, barking deer, rhesus macaque, etc., by cyclones led to the extinction of the tiger population. Loss of tiger gives free access to overexploitation. Therefore, decreased mangrove populations can cause huge biodiversity loss. So, the whole ecosystem of Sundarbans depends on the tiger population (Saha & Sarkar, 2022). Due to a lack of proper understanding and awareness of the value of these ecosystems and wildlife, people living around the Sundarbans ecosystem are careless about the integrity of these ecosystems and their valuable flora and fauna. These people deeply believe that tigers are their enemy When the tiger comes out, the villagers unite and put their maximum effort into killing the tiger. So, the common scenario is that the stray tiger is often killed by Poisoning, shooting, or snaring. The tiger-human conflict is so intense because the poor people of Sundarbans enter the tiger territory for fishing, honey collection, and Golpata collection. Suitable honey-producing trees in the Sundarbans, such as Kholsi, Baen, Kankra, Goran, Gewa, etc. exist in the forest's interior part, which is considered a tiger risk zone (Haque et al., 2015).

It has been reported that habitats occupied by top predators are more diverse than habitats without top predators (Sergio et al., 2005). Top-down control is regulated by the top predators. Therefore, the abundance of upper trophic level dwellers can affect the abundance of lower trophic level dwellers. Top-down control means that predation by higher trophic levels affects biomass accumulation at lower trophic levels. The higher trophic level always maintains its stability by competition and the next lower trophic level is maintained by predation. For the level system, predators and producers are regulated by competition. In the four-level system, top predators and herbivores are limited by competition, while predators and producers are limited by predation and consumption, respectively (Lawrence, 1991). Now, we can predict how important it is to maintain the existence of top predators to prevent biodiversity loss.

Policies adopted by the Indian government:

India, as a megadiversity nation, has adopted many policies and laws. The major goal of these laws and policies is to educate people about nature and its conservation. It is very important to give the message to the local people about how important role the of biodiversity is playing in our lives (Gogoi et al., 2023). Various countries have taken various strategies to protect biodiversity and India is one of them. Here, we are mainly focusing on the steps taken by India's government. The major steps are-

- The government of India enacted the Wildlife Protection Act in 1972. This act creates protected areas for wild fauna and punishments for hunting wild fauna specified in schedules I to IV thereof.
- Wetland Conservation and Management Rules, 2010 have been applied to protect wetlands in the states.
- The National Plan for Conservation of Aquatic Eco-System scheme has been started to manage wetlands in the states, including Ramsar sites in India.
- The Wildlife Crime Control Bureau has been established to control illegal wildlife trade, including endangered species.
- The Wildlife Institute of India, Bombay Natural History Society, and Salim Ali Centre for Ornithology and Natural History are some research institutes that have researched the conservation of wildlife.
- The Govt. of India banned the veterinary use of diclofenac drug which caused the rapid decline of the Gyps vulture population across India. The Bombay Natural History Society has started a conservation breeding program to conserve these vulture species at Pinjore (Haryana), Buxa (West Bengal), and Rani, Guwahati (Assam).
- An additional component known as "Recovery of Endangered Species" has been

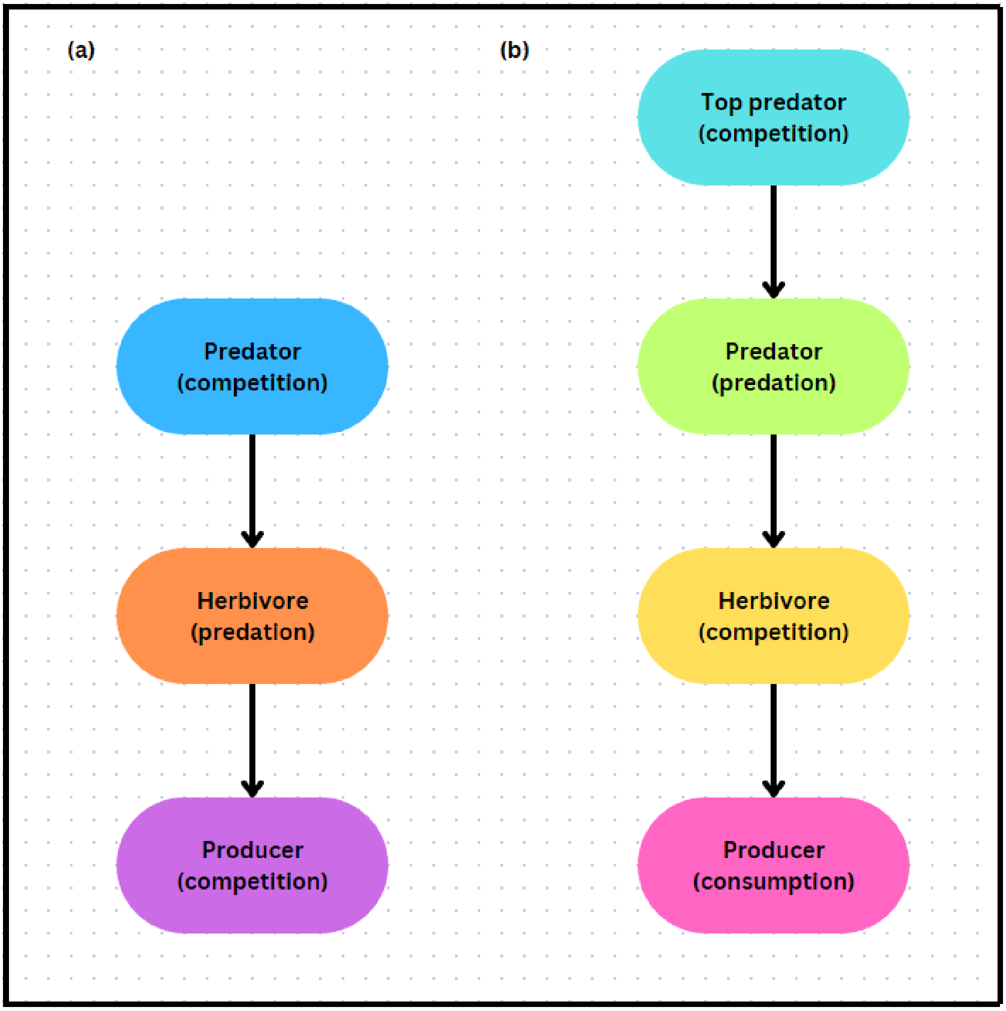


Figure 10: (a) Shows that predators and producers are limited by competition while herbivores are limited by predation. (b) Shows that top predators and herbivores are limited by competition while predators and producers are limited by predation and consumption respectively (Picture courtesy: Encyclopedia of Ecology, 2008).

- incorporated into the plan known as "Integrated Development of Wildlife Habitats," which has been amended. The recovery of sixteen different species has been identified, including the Snow Leopard, the Bustard (including Floricans), the Dolphin, the Hangul, the Nilgiri Tahr, the Marine Turtles, the Dugong, the Edible Nest Swiftlet, the Asian Wild Buffalo, the Nicobar Megapode, the Manipur Brow-antlered Deer, the Vultures, the Malabar Civet, the Indian Rhinoceros, the Swamp Deer, and the Jerdon's Courser.
- Under this 'Recovery of Endangered Species' government has spent lakhs of rupees on Hangul in Jammu and Kashmir, Snow Leopard in Jammu and Kashmir, Himachal Pradesh, Uttarakhand and Arunachal Pradesh, Vulture in Punjab, Haryana and

Gujarat, Swiftlet in Andaman and Nicobar Islands, Nilgiri Tahr in Tamil Nadu, Sangai Deer in Manipur.
- As per Wildlife Protection Act in 1972 protected areas like national parks, sanctuaries, conservation reserves, and community reserves have been created to protect important habitats of threatened species.
- The central government initiated ‘Integrated Development of Wildlife Habitats’, ‘Project Tiger’, and ‘Project Elephant’ with states' financial and technical assistance.
- The Central Bureau of Investigation (CBI) has been incorporated under the Wildlife Protection Act, 1972 to apprehend and prosecute wildlife offenders.

Important Acts to protect biodiversity in India:
- Fisheries Act, 1897
- Indian Forests Act, 1927
- Mining and Mineral Development Regulation Act, 1957
- Prevention of cruelty to animals, 1960
- Wildlife Protection Act, 1972
- Water (Prevention and Control of Pollution) Act, 1974
- Forest Conservation Act, 1980
- Air (prevention and control of pollution) Act, 1981
- Environment Protection Act, 1986
- Biological Diversity Act, 2002
- Scheduled Tribes and other traditional forest dwellers (recognition of rights) act 2006

Important policies to protect biodiversity in India:
- National Forest Policy
- National Conservation Strategy and Policy Statement on Environment and Development
- National Policy and macro-level Action Strategy on Biodiversity
- National Biodiversity Action Plan (2009)
- National Agriculture Policy
- National Water Policy
- National Environment Policy (2006)

Other schemes by Govt. of India (George, 1972; Views and Patel, 2021):
- Nagar Van Udyan scheme
- Swachh Bharat Abhiyan in 2014
- Project Tiger in 1973
- Green Skill Development programme in 2017
- National River Conservation Programme

- Green India Mission
- National Coastal Management Programme
- National Afforestation Programme
- National Mission on Himalayan Studies Under Climate Change Programme

Private initiatives:

There are so many companies all over the world that have adopted eco-friendly strategies to develop their companies. The motivation for eco-friendly initiatives is to remain relevant in the future business environment. These companies' production, servicing, and manufacturing can resolve many environmental concerns. Therefore, companies are trying innovative ways to promote a green environment (Saha, 2023). The rapid depletion of natural resources forces companies to go green with sustainable use of natural resources (De et al., 2018; 2019). Here, we will discuss some major reputed companies that have already taken eco-friendly initiatives (Matthews, 2020; Lawson, 2021).

- Coca-Cola and Pepsi (maintenance of water system on which their products depend. Coca-Cola has been working with WWF to conserve key watersheds and improve the efficiency of its use of water in a sustainable way.)
- McDonald’s (company uses energy-efficient appliances, sets up green parking lots, and uses considerate means to obtain their animal products.)
- Dell (promote safe disposal of its products and then recycling.)
- Google (use renewable energy sources, construct the world’s most energy-efficient data center, and support green energy projects.)
- Bank of America (promote a sustainable environment by recycling 30000 tons of paper per year.)
- Tesla Motors (manufactures eco-friendly cars.)
- Wal-Mart (applied a strict policy to cut off suppliers whose manufacturing, processing, and distribution methods contributed to vast carbon emissions and retail stores utilize 100% renewable energy sources.)
- United Airlines (since the year 2000, the airline has managed to reduce Nitrogen Oxide emissions by 75% and spent more than 16 billion US dollars to replace all their airplanes with more fuel-efficient airplanes.)
- Tesco (uses biodiesel trucks for deliveries and estimates its carbon footprint on each item sold.)
- Brooks (introduce a completely biodegradable running shoe.)
- S.C Johnson (reduce 1.8 million pounds of volatile organic compounds from its Windex artifacts and another 1.4 million pounds of polyvinylidene chloride from Saran Wrap.)
- Starbucks (bean-to-coffee approach and use of recycled coffee grounds in making their tables.)

- Toyota (reduced the overall carbon footprint and manufactured the world's first mass-market hybrid vehicle.)
- Pratt & Whitney (managed to lower the number of wasted ingots and reduce factory emissions.)
- HP (open various operational e-waste recycling plants and products are 100% recyclable.)
- Target (introduce eco-clothing line.)
- Ford Motor Company (owns the world's largest green roof and adopted a ten-part environmental policy.)
- Fisher Investments (preservation of Redwood and climate change initiative through cutting down on emissions and gases that threaten their existence.)
- Nike (uses sustainable and eco-friendly materials like recycled polyester and highlights green initiatives through advertisement.)
- Apple (focuses on three main areas – reducing its impact on climate change, preserving precious resources, and using safer product materials.)
- Disney (uses zero net direct greenhouse gas emission policies in all of its facilities and has adopted environmental policies like
- Zero waste (nothing in landfills)
- Net positive environmental impact
- Patagonia (gives 1% of all sales to ecological grants and organizations, involved in regenerative organic agriculture, water conservation, and sustainable material usage.)

Conclusion:

We are an integrated part of biodiversity; as an individual species, we have a key role in the ecosystem. Every species utilizes its niche according to its needs. We are also utilizing the environmental resources according to our needs. Extinction is always associated with evolution. There should be a balance between extinction and diversification. Now the extinction rate is faster than the diversification rate due to anthropogenic activities. If evolution's key is 'survival of the fittest', then we are modifying our environment so that we will probably not be fit to survive against upcoming environmental changes. Five mass extinction events happened during the pre-human era due to volcanic eruption, meteorite impact, long ice age, etc. Scientists predict that we are going through a sixth mass extinction event due to anthropogenic activities. So, this era is better known as the 'Anthropocene'. We must protect biodiversity from anthropogenic activities to sustain the whole ecosystem on Earth. Otherwise, the sixth mass extinction will probably destroy many life forms including us.

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Chapter- 2

Migratory Birds in Peril: Unravelling the Impact of Climate Change

Goutam Biswas*, Sarthak Ranjan Sarkar, Bonhishikha Roy, Arkaprabha Pal, Somvit Nandi, Souvik Banerjee, Swapnendu Roy

Keywords: Bird migration, temperature, habitat loss, altered route.

Abstract:

Avian migration, a phenomenon crucial for the survival and reproductive success of numerous bird species, is increasingly affected by the unprecedented changes in climate. Multifaceted impacts of climate change, encompassing alterations in temperature, and precipitation patterns directly impact the timing, duration, and routes of bird migration. Such changes disrupt food sources, breeding grounds, and crucial stopover sites, challenging the migratory journeys of numerous bird species. Rising sea levels and habitat loss further threaten the survival of these migratory birds. Understanding and addressing these climate-induced shifts in migration patterns are imperative for conservation efforts. The book chapter delves into observed and projected shifts in migratory behaviors, exploring specific case studies and examples that highlight the adaptive responses of avian species to changing environmental conditions.

Introduction:

Climate change is a natural process that has occurred throughout Earth's history for millions of years. However, anthropogenic activities including burning fossil fuels, deforestation, and

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industrial processes, release greenhouse gases like carbon dioxide and methane into the atmosphere, accelerating natural climate changes and causing global warming and weather patterns (Bhattacharya, 2015; Garcia et al., 2014; Saha & Sarkar, 2022). These actions have interconnected effects, intensifying and often permanently altering ecosystems and biodiversity. Widespread effects result from such changes, including unpredictable weather patterns, habitat degradation and the extinction of many species (Ambiya et al., 2016; Paul et al., 2017). Numerous studies have documented the consequences of global warming on various organisms particularly on the distribution and reproduction of species (Deb et al., 2020; Das et al., 2022). There have been reports of certain species adapting to mitigate the negative impacts of climate change. These adaptations include changing the time of their reproductive cycles or relocating from their current breeding zone to one that is more suited to the environment (Karl & Trenberth, 2003).

Avian migration is a remarkable natural phenomenon involving birds' seasonal movements across vast distances, responding to environmental cues like temperature, resource availability, and photoperiod, demonstrating evolutionary adaptations for survival (Rappole, 2013). Climate change significantly influences bird migration patterns, primarily due to alterations in temperature, weather patterns, and habitat availability. The rising global temperatures directly impact avian migration's timing, duration, and routes. Changing climatic conditions affect the availability of food sources and suitable breeding grounds, prompting shifts in migration timing and destinations for many bird species. Extreme weather events disrupt migratory routes and essential stopover sites crucial for resting and refueling during long journeys, further challenging bird migration. Additionally, rising sea levels and habitat loss threaten the nesting and foraging areas of numerous migratory bird species, impacting their survival (Carey, 2009). Understanding these climate change-driven alterations in migratory patterns is crucial for conservation efforts, necessitating adaptive strategies to safeguard critical habitats, ensure food availability, and mitigate the adverse effects on avian populations globally. Addressing the implications of climate change on bird migration requires urgent global initiatives to mitigate its effects and preserve the resilience of these migratory species in the face of ongoing environmental shifts (Bateman et al., 2020; Gogoi et al., 2023).

Climate change effects on bird migration:

Global temperatures have risen by approximately 1.5 degrees Celsius since the late 19th century due to human-induced factors like greenhouse gas emissions. These temperature changes vary across regions and seasons, leading to uneven global warming patterns. Extreme temperature events, such as heatwaves and cold spells, have become more frequent and severe (Fang et al., 2011). Rising temperatures resulting from climate change profoundly influence the intricate phenomenon of bird migration. These temperature shifts trigger adjustments in the timing and routes of migration as birds respond to altered environmental cues. For instance, warmer temperatures may prompt birds to initiate their journeys earlier or later than usual, aligning with changes in resource availability or breeding conditions along their migratory paths (Cox et al., 2010). Moreover, temperature changes directly impact the availability of food sources and suitable habitats, prompting birds to modify their traditional routes in search of optimal conditions. Some species may expand their territories to newly hospitable areas, while others may face constraints or habitat loss due to less favorable temperatures, potentially leading to shifts or contractions in their migration ranges. Beyond these spatial and temporal adjustments, temperature variations during migration can influence birds' behaviors, affecting their foraging strategies, reproductive patterns, and social interactions. Such alterations in migration dynamics can reverberate throughout ecosystems, affecting not just bird populations but also influencing the relationships among various species and impacting biodiversity on a larger scale (Koleček et al., 2020).

Extreme weather events, intensified by climate change, pose significant challenges to bird migration. Severe storms, strong winds, or unseasonal conditions along migration routes can force birds to adjust their flight paths or delay their journeys. Damage to critical stopover sites where birds rest and refuel during migration can disrupt their ability to complete the journey successfully (Cohen et al., 2020). Such disruptions can also impact the synchronization between bird arrival and optimal breeding or feeding conditions at their destination, affecting reproductive success. Moreover, extreme weather events can lead to mortality, injury, or stress among migrating birds (Newton, 2007). Birds caught in adverse weather conditions might face difficulties finding food, causing nutritional stress and potential population decline. These events may trigger behavioral changes, altering feeding patterns or energy expenditure, impacting the birds' overall migration strategy. Precipitation also plays a crucial role in bird migration. It affects food availability by influencing insect populations, impacting the timing and routes birds take during migration. Precipitation can disrupt habitats along migration routes, affecting nesting sites and food sources. Rainy conditions increase the energy birds need for flight due to wet feathers, potentially impacting their ability to cover long distances. Some bird species adapt their behavior in response to precipitation, altering foraging strategies or migration routes to navigate unfavorable weather conditions (Studds et al., 2011).

Sea level rise, a consequence of climate change, profoundly affects bird migration in coastal and wetland areas. It leads to habitat loss, altered ecosystems, and changes in nesting and feeding patterns crucial for migratory birds. Birds face challenges in finding suitable resting areas, altering migration routes, and adapting breeding behaviors. The altered migration patterns of birds, influenced by various factors including climate change, have far-reaching ecological consequences. Changes in migration routes and timing can disrupt species interactions, affecting biodiversity and ecosystem dynamics (Galbraith et al., 2002). These alterations impact ecosystem services such as pollination and pest control, influencing agricultural productivity. Mismatched timing between bird arrivals and flowering plants can disrupt vital mutualistic relationships, affecting plant reproduction. Habitat alterations due to changed migration can impact the health and stability of ecosystems along these birds' routes.

These shifts also influence global connectivity between distant ecosystems, potentially affecting nutrient flow and genetic diversity exchange. Conservation efforts must address these consequences by preserving habitats, maintaining migratory corridors, and understanding the drivers behind altered migration patterns to safeguard ecosystem health and resilience (Iwamura et al., 2014).

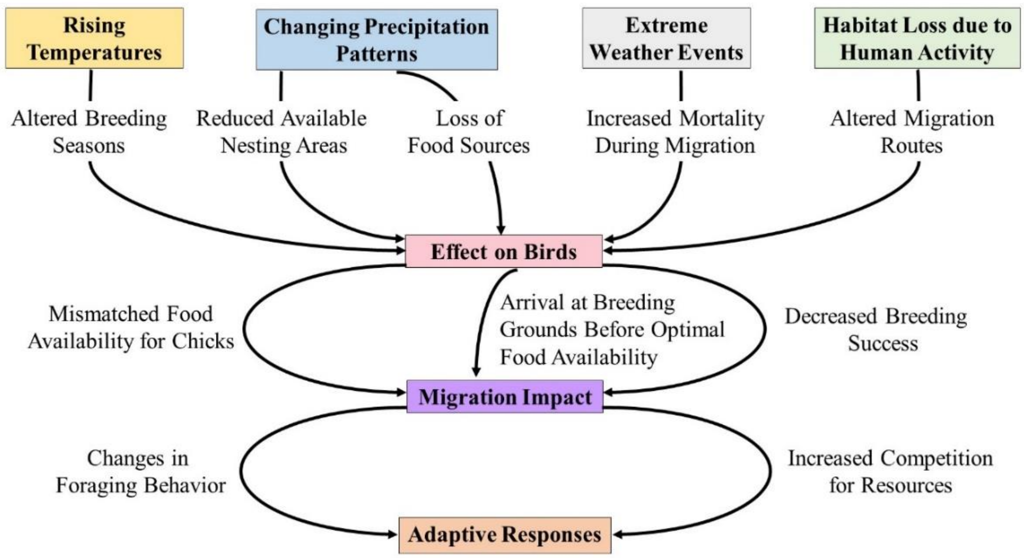

Figure 1. Diagram showing how climate change affects bird migration.

Case Studies:

There are several migratory bird species whose populations, behaviors, or habitats have been affected by climate change. The following tables showcase the intricate ways in which climate change disrupts migratory bird species, affecting their habitats, food sources, and migration patterns, ultimately impacting their survival and reproductive success.

Table 1: List of some non-Indian Migratory bird species impacted by climate change.

Bird Species	Scientific Name	Vulnerability	Migration Route	Reasons for Vulnerability
Red Knots	*Calidris canutus*	Moderate	Arctic to South America	Early snowmelt in the Arctic affected insect emergence, causing a mismatch in food availability for chicks (Meltofte, 2007).
Bar-tailed Godwits	*Limosa lapponica*	High	Alaska to New Zealand	Climate-induced changes in wind patterns make migration more difficult and energetically costly,

				especially for young birds (Batbayar, 2013).
Common Swifts	*Apus apus*	Moderate	Europe to Africa	Impact of climate change on insect populations, affecting food availability, and prompting changes in migration patterns and nesting sites (Gordo & Sanz, 2006).
Snow Geese	*Anser caerulescens*	Moderate	Arctic to warmer regions	Climate-induced earlier snowmelt leads to overcrowding in nesting areas, affecting breeding success and altering population dynamics (Hupp et al., 2018).
Barn Swallows	*Hirundo rustica*	High	Europe to Africa	Climate changes and pesticide use lead to declines in insect populations, forcing adjustments in migration routes and timing (Cheke et al., 2007)
Purple Martins	*Progne subis*	Moderate	South America to North America	Climate-induced changes in precipitation affect insect availability, impacting breeding success and population health (Greenlee et al., 2012).
Northern Wheatears	*Oenanthe oenanthe*	High	Sub-Saharan Africa to the Arctic	Changes in climate conditions along migration routes cause alterations in stopover sites, reducing access to crucial resources (Lehikoinen et al., 2010).
Blackpoll Warblers	*Setophaga striata*	High	North America to	Climate-induced habitat loss affects nesting sites

			South America	and changes in weather patterns impact migration timing (Rodenhouse et al., 2008).
Rufous Hummingbirds	*Selasphorus rufus*	Moderate	North America to Central America	Climate-induced changes in temperature and precipitation alter flower blooming patterns, affecting nectar availability.
Whimbrels	*Numenius phaeopus*	High	Arctic to the Southern Hemisphere	Climate-induced rising sea levels threaten coastal habitats, reducing crucial stopover sites essential for migration (Pearce-Higgins et al., 2017).
Arctic Terns	*Sterna paradisaea*	High	Arctic to Antarctic	Climate-related alterations impacting the availability of prey species are crucial for breeding success and overall population health (Bentley et al., 2020).
Sandhill Cranes	*Antigone canadensis*	Moderate	North America to South America	Climate-induced changes in weather patterns and human interference lead to disruptions in migration routes and stopover areas.
European Swallows	*Hirundo rustica*	High	Europe to Africa	Climate-related alterations in weather patterns and agricultural practices lead to declines in insect availability (Balbontín et al., 2008)
Sooty Shearwaters	*Ardenna griseus*	Moderate	Southern Hemisphere to Northern Hemisphere	Climate-induced changes in oceanic conditions impact the availability of food resources critical for

				survival during migration (McKechnie et al., 2020).
Eastern Curlews	*Numenius madagascariensis*	High	Siberia to Australia	Coastal habitat destruction and changing climate conditions cause loss of feeding grounds and affect breeding success (Pearce-Higgins et al., 2017).
Gray Catbirds	*Dumetella carolinensis*	Moderate	North America to Central America	Climate changes affect food availability and nesting habitats, impacting breeding success and overall population stability Mancuso et al., 2021).

Migratory birds flock to India during the summer and winter months, seeking refuge in its diverse landscapes. India's varied geography, spanning from mountains to wetlands, provides a welcoming environment for these avian species but the threat of climate change poses significant risks to Indian migratory birds (Chowdhury, 2023). These birds travel long distances across continents, relying on specific environmental cues, such as temperature, rainfall patterns, and food availability, to guide their migration. Climate change disrupts these cues, leading to various challenges:

Table 2: **Some Indian migratory bird species affected by climate change.**

Bird Species	Scientific Name	Vulnerability	Migration Route	Reasons for Vulnerability
Common Teal	*Anas crecca*	High	Palearctic to the Indian subcontinent and Southeast Asia	Loss of wetlands/marshes due to rising sea levels & human development (Chatterjee et al., 2017).
Bar-headed Goose	*Anser indicus*	High	Central Asia to the Indian subcontinent and Southeast Asia	Wetland depletion from rising seas & human development (Szabo and Mundkur, 2017).
Greenish Warbler	*Phylloscopus trochoid's*	High	Central Asia to the Indian subcontinent and Southeast Asia	Impact on wooded areas due to deforestation & climate (Katti, 1997).

Indian Pitta	*Pitta brachyura*	High	Indian subcontinent, Southeast Asia	Habitat fragmentation due to human activities (Dutta and Mohapatra, 2017).
Garganey	*Spatula querquedula*	High	Palearctic to the Indian subcontinent and Southeast Asia	Wetland loss, decreased suitable habitat & competition (Balachandran, 2007).
Rosy Starling	*Pastor roseus*	Moderate	Eastern Europe to the Indian subcontinent	Disease spread risks due to changing climate conditions
Northern Pintail	*Anas acuta*	Moderate	Palearctic to the Indian subcontinent and Southeast Asia	Temperature changes alter routes (Guillemain et al., 2013).
Black-tailed Godwit	*Limosa limosa*	Moderate	Arctic regions to Indian subcontinent and Southeast Asia	Weather shifts impacting routes & timing (Senner et al., 2019).
Blyth's Reed Warbler	*Acrocephalus dumetorum*	Moderate	Central Asia to the Indian subcontinent and Southeast Asia	Weather effects on routes & timing (Chernetsov et al., 2007).
Common Hawk-Cuckoo	*Hierococcyx various*	Moderate	Palearctic to the Indian subcontinent and Southeast Asia	Competition and overlap with resident species (Mukhopadhyay et al., 2017).
Common Sandpiper	*Actitis hypoleucos*	Moderate	Palearctic to the Indian subcontinent and Southeast Asia	Food source change, Altered aquatic invertebrate availability (Kannan et al., 2012).
Common Redshank	*Tringa totanus*	Moderate	Palearctic to the Indian subcontinent and Southeast Asia	Weather changes affecting routes & timing (Maclean et al., 2007)
Greater Flamingo	*Phoenicopterus roseus*	Low	Europe, Africa, Asia to the Indian subcontinent	Disrupted migration, Changes affecting routes & timing (Balachandran, 2012).

Eurasian Wigeon	*Mareca penelope*	Moderate	Palearctic to the Indian subcontinent and Southeast Asia	Temperature changes affect routes & timing (Chatterjee et al., 2023).
Yellow Wagtail	*Motacilla flava*	Low	Palearctic to the Indian subcontinent and Southeast Asia	Temperature impact on traditional routes (Aich and Mukhopadhyay, 2008).

Mitigation and future directions:

Mitigating the adverse effects of climate change on bird migration involves a multifaceted approach. Efforts focus on habitat restoration along migratory routes, aiming to restore vital features like wetlands and stopover sites. Creating and managing protected areas ensures these sites serve as safe havens for migratory birds. Key strategies involve identifying and conserving crucial stopover sites and securing vital resting and refueling spots during migration. Implementing climate-resilient land use practices and raising public awareness about the importance of migratory birds. Conducting continuous research and monitoring helps gather essential data on bird populations, migration patterns, and habitat changes, guiding conservation plans (Xu et al., 2020). Implementing adaptive management allows for flexible strategies that adjust to changing climate impacts. Adaptive management is crucial for bird species facing changing environments due to climate change. Its flexibility allows for real-time adjustments, aiding birds in adapting behaviors and habitats to dynamic conditions. Continuous monitoring and learning from feedback refine conservation strategies, reducing risks and tailoring approaches to different species' needs. This proactive approach ensures long-term sustainability, engages communities, and addresses uncertainties, making adaptive management indispensable in supporting bird species amid environmental changes (Faaborg et al., 2010).

Conclusion:

The phenomenon of avian migration encapsulates a complex interweaving of ecological, behavioral, and evolutionary mechanisms crucial for the persistence and resilience of bird species in the face of dynamic environmental challenges. To safeguard avian migration amidst climate change necessitates ongoing interdisciplinary efforts, including monitoring, predictive modeling, and diverse research. Prioritizing conservation, global collaboration, and public engagement is crucial, alongside policy focus on mitigation and resilient habitats. A holistic approach uniting research, adaptive management, and international cooperation is imperative to protect avian migration in the face of climate challenges.

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Chapter- 3

From Fields to Atmosphere: Understanding the Dangers of Stubble Burning on Environment and Public Health

Rajib Majumder

Keywords: Crop residue, agricultural fires, smog, air pollutants, soil fertility, health hazards

Abstract:

There has been a tremendous change in the agriculture sector, with a huge increase in production since the Green Revolution. Currently, agricultural activities occur throughout the year instead of being confined to a season. A marvelous success has been achieved in cereal crop production. Usually, right after paddy harvesting in the post-monsoon period (October-November), a short time gap becomes available to the farmers for the next crop to be sown. Combine harvesters or other forms of mechanical harvesters are used nowadays instead of traditional harvesting, which makes grain collection quite easier, quicker, and comparatively inexpensive but generates huge crop residues or stubble. Then, farmers rush for stubble burning to clear fields quickly for the next crop cycle. Such intentional burnings result in the formation of smog, the release of particulate matter, greenhouse gases, and other air pollutants, the raising of soil temperature, which kills soil microorganisms, and the loss of soil fertility. Additionally, stubble burning poses severe health hazards to the people residing there and causes eye irritation, and skin disease, and accelerates respiratory and cardiovascular diseases. Above all, stubble burning and all these ultimately affect economic activities, education, and tourism as well. So, proper crop residue management is a need of the present. Implementation of mechanized farming techniques, use of bio-decomposers, innovative approaches like the use of stubble for composting, mulching, biofuel production, fodder, etc.; crop diversification; mass campaigning; collaboration among stakeholders; financial assistance by the government to the farmers; and strict vigilance and enforcementagainst agricultural fires can reduce the incidents of stubble burning.

Introduction:

Population explosion is one of the most significant challenges facing the earth today (Van Bavel, 2013). By 2050, the world population is expected to reach 9.7 billion people (UN DESA, 2015). China and India continue to be the two largest nations in the world, accounting for 19% and 18% of the global population, respectively (UN DESA, 2015). Poverty, hunger, malnutrition, inequality, and pollution are among the worst causes of human suffering (Ray, 2019; Siddiqui et al., 2020). A common roadmap for peace and prosperity for people and the planet today and in the future is provided by the 2030 Agenda for Sustainable Development, which was endorsed by all United Nations Member States in 2015. Its core tenets are the 17 Sustainable Development Goals (SDGs), representing an urgent appeal for developed and developing nations alike to take immediate action as part of a global alliance to end hunger,

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establish food security, enhance nutrition and move forward with sustainable agriculture (United Nations, 2015; Sarkar et al., 2016; Banerjee et al., 2021; Mukherjee et al., 2022). There has been a tremendous change in the agriculture sector, with significant production since the Green Revolution to meet global food demand. Improvements in agricultural equipment, well irrigation systems, chemical fertilizers, pesticides, and high-yielding seeds as gifts of the Green Revolution ensure massive crop production (Nelson et al., 2019; Keil et al., 2021; Dawn et al., 2022; Dawn et al., 2023). Currently, agricultural activities are not limited to a single season but take place all year. Cereal crop production has been a tremendous accomplishment. Two planting cycles have a shorter time interval between them. In modern agriculture, grain collection is now easier and faster because of the advent and widespread use of combined harvesters (Gupta et al., 2004). A harvester may quickly finish reaping, threshing, and winnowing in one operation. However, a combine harvester leaves a significant amount of loose straw in the field, which is difficult to dispose of or utilize in a short period, forcing farmers to burn the leftover straw or stubble (Gupta et al., 2004; Abdurrahman et al., 2020). Stubble refers to the cut stalks and leftover straws from cereal crops that are left in the field after the grains are harvested (Wilkinson et al., 2021). Farmers use stubble or crop residue burning (CRB) to clear fields to reduce the spread of foliar and root diseases, manage pests, and remove weed seed banks from fields when the fallow period is too short to be employed again (Singhal et al., 2022). It is quicker, cost-effective, efficient, and requires minimum manpower (Chandel and Upadhyay, 2019).

Air pollution is one of the most serious environmental threats to human health (Majumder, 2021; WHO, 2022). Biomass burning, such as emissions from industries, motor vehicles, and thermal power plants, is a significant source of air pollution with global implications for public health, air quality, and climate change (Singh et al., 2023; Prasad et al., 2023). Crop residue or stubble burning is the fourth-largest source of biomass-burning emissions (Deshpande et al., 2023). Burning agricultural leftovers necessitates special attention because it emits significant amounts of greenhouse gases and hydrocarbons, as well as other gaseous pollutants and smoke particles containing carcinogenic compounds (Chawala and Sandhu, 2020; Deshpande et al., 2023). Soil is precious in our lives since it provides 95% of our food, either directly or indirectly. Plants take up essential nutrients, water, oxygen, and root support from the soil to grow and flourish. Thus, soil health is essential for obtaining both the quality and quantity of food required by humans and other animals (FAO, 2015). Burning crop stubble is a concern for agriculture because it depletes nutrients, kills microorganisms, and reduces soil fertility (Kaur et al., 2022). Therefore, this chapter highlights the adverse effects of stubble burning on the environment and public health and probable mitigation measures through which incidents of intentional crop residue burning could be minimized as well.

Current status of stubble burning:

Tropical regions account for 80% of all biomass burned globally (Shaik et al., 2019). China (25%), India (18%), Indonesia (13%), and Myanmar (8%) are among the Asian countries with high rates of biomass burning (Shaik et al., 2019). Stubble burning accounts for approximately 25% of all biomasses burning globally (Abdurrahman et al., 2020; Chanana et al., 2023). Wheat, rice, maize, cotton, and sugarcane are among the crops whose stubbles are burned the most (Pinakana et al., 2023). It is a common practice in Asia, Latin America, Africa, the United States, Canada, Europe, Australia, and New Zealand (Pinakana et al., 2023; Hindustan Times, 2023). Stubble accounts for around 34% of the biomass burned in Asia (Abdurrahman et al., 2020). China contributes about 44% of stubble burning, while Indian farms supply about 33% (Streets et al., 2003). The Indo-Gangetic Plain (IGP) in Asia, one of the most fertile agricultural beds in the world, spans 1/6th of the total land of South Asia, covering parts of Pakistan, India, Bangladesh, and Nepal (Abdurrahman et al., 2020; Chanana et al., 2023). The rotational rice-wheat cropping method is widely used in South and East Asia (Kaur et al., 2022). In India, about 20% of the total land area falls within the fertile IGP (Gupta et al., 2004; Abdurrahman et al., 2020). In India, the rice-wheat farming technique is used on an estimated 9.6 million hectares of land per year. Around 41% of yearly food production in India, largely comprising grains, comes from this region. India produces 620 million tonnes of crop residue each year, with 16% being burned in the field (Jain et al., 2014). Paddy straw contributes the most to stubble burning (43%), followed by wheat straw (21%), and sugarcane (19%) (Kant et al., 2022). The states where the majority of stubble-burning incidents happen in India are Punjab, Haryana, and Uttar Pradesh (Jain et al., 2014). Paddy is cultivated between June and October, while wheat is planted in November and March (Gupta et al., 2004). Due to the shortage of time between paddy harvest and wheat planting, the majority of farmers harvest their crops using combined harvesters, which produce a sizable amount of stubble (Chandel and Upadhyay, 2019). Due to the short time between crops, farmers burn the stubble in their fields to clear the land. Each season, the burning happens right after harvest. South Asian countries experience harsh haze throughout the winter season as a result of stubble burning (Palta and Kaur, 2023). CRB-related air pollution impacts developing countries such as India, Nepal, China, Thailand, and Egypt regularly (Lopes et al., 2020). As colder winter temperatures bring on an atmospheric inversion that allows pollutants to spend more time in the atmosphere, resulting in poorer dispersion and a slower rate of smoke diffusion. As a result, the smoke produced builds up in the atmosphere, causing more harm to the environment and humans (Abdurrahman et al., 2020; Keil et al., 2021). The overall effects of stubble burning have been summarized in Figure 1.

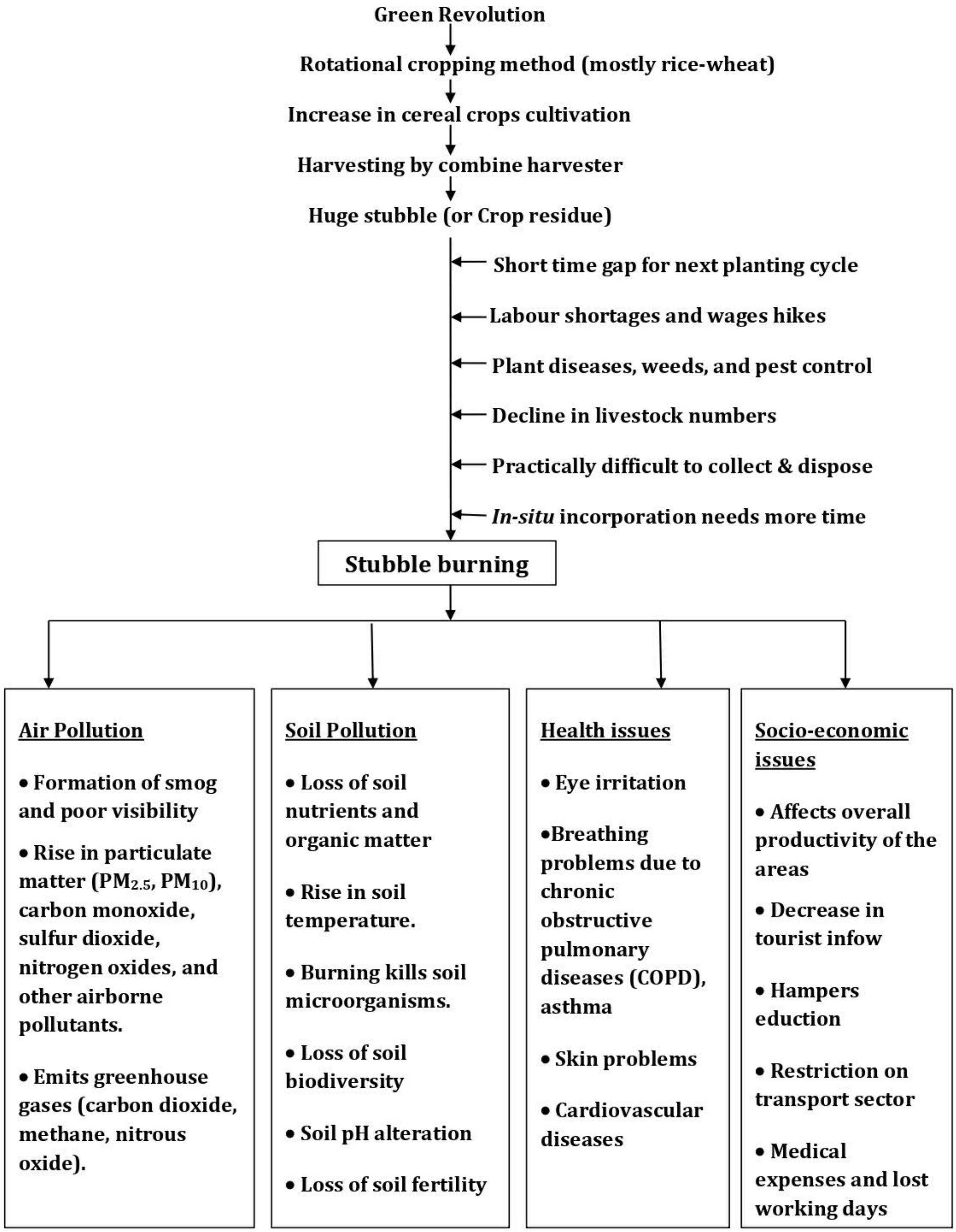

Figure 1. Adverse effects of stubble burning.

Effects on environment:

Effects on air:

Open burning of crop residue in agricultural fields generates enormous heat and releases smoke locally at first, which is then dispersed to surrounding areas by wind. It releases toxic gases into the environment, adding to air pollution. These include particulate matter ($PM_{2.5}$ and PM_{10}); greenhouse gases: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O); and other air pollutants, namely carbon monoxide (CO), sulfur dioxide (SO_2), ammonia (NH_3), nitrogen dioxide (NO_2), nitrogen oxides (NO_x), and various volatile organic compounds (VOCs), hydrocarbons, etc (Jain et al., 2014). It accelerates ozone pollution and aerosol load (Kaur et al., 2022). When one tonne of rice straw is burned, it emits 3 kg of particulate matter, 60 kg of carbon monoxide (CO), 1460 kg of carbon dioxide (CO_2), 199 kg of ash, and 2 kg of sulfur dioxide (SO_2) (Gupta et al., 2004; Abdurrahman et al., 2020). Air pollution is a common issue in the countries of East Asia, Southeast Asia, and South Asia (IQAir, 2021). In terms of average annual $PM_{2.5}$ concentration (µg/L), India ranked as the fifth most polluted country. In 2021, 11 of the 15 most polluted cities in Central and South Asia were located in India. New Delhi has been named the most polluted capital city in the world (IQAir, 2021). During the transition from monsoon to winter (October-November) every year, winds carry smoke and soot from stubble-burning areas of northwestern India, namely Punjab, Haryana, and Rajasthan, into the Delhi-NCR (National Capital Region), causing a pungent haze or "smog" with rising levels of particulate matter ($PM_{2.5}$, PM_{10}), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxide (NO_x), and other airborne pollutants (Chawala and Sandhu, 2020; Das et al., 2023). The current state of air quality is reflected in the Air Quality Index (AQI), which could range from 0 to 500. Depending on the health implications for humans, an AQI of 0-50 is deemed 'good,' 51-100 as ‘satisfactory’, 101-200 as ‘moderate’, 201-300 as ‘poor’, 301-400 as ‘very poor’, and 401-500 as ‘severe’. The AQI data of Delhi collected from the daily AQI bulletin of the Central Pollution Control Board (CPCB), Government of India, during the paddy harvesting period (mid-September to November) in the subsequent 3 years (2021, 2022, and 2023) showed an overall deterioration of AQI. The highest AQI recorded was 471 (severe) on November 12, 2021; 450 (severe) on November 03, 2022; and 468 (severe) on November 03, 2023 (Figure 2). AQI ranged in the poor to severe category during late October-November in each of the three years. AQI reached its peak in November. Prolonged exposure to unhealthy air may lead to breathing difficulties or many other complicated respiratory or cardiovascular diseases (Das et al., 2023).

Effects on soil:

Stubble burning immediately raises soil temperature, which affects both the physicochemical and biological properties of soil, primarily in the top soil layers (Kaur et al., 2022). The heat generated during stubble burning can reach soil depths of 1 cm and raise soil temperatures by 33.8°C-42.2°C (Gupta et al., 2004). It causes structural breakdown of soil and raises the chances of soil erosion. Long-term crop residue burning may result in nutrient loss, including essential nutrients (nitrogen, phosphorous, and potassium), as well as the organic carbon content of the soil. All soil parameters are negatively affected, including pore size, water retention capacity, moisture content, pH, specific gravity, electrical conductivity, chloride ion, magnesium ion, calcium ion, and humous content (Tripathi et al., 2015). Crop residue can act as a nutrient source for plants, making it crucial for agricultural productivity. One ton of paddy straw contains around 5.5 kg of nitrogen (N), 2.3 kg of phosphorous (P_2O_5), 25 kg of potassium (K_2O), 1.2 kg of sulfur (S), 50–70% of the micronutrients consumed by rice, and 400 kg of carbon, all of which are lost when paddy straw is burned (Government of India, 2022).

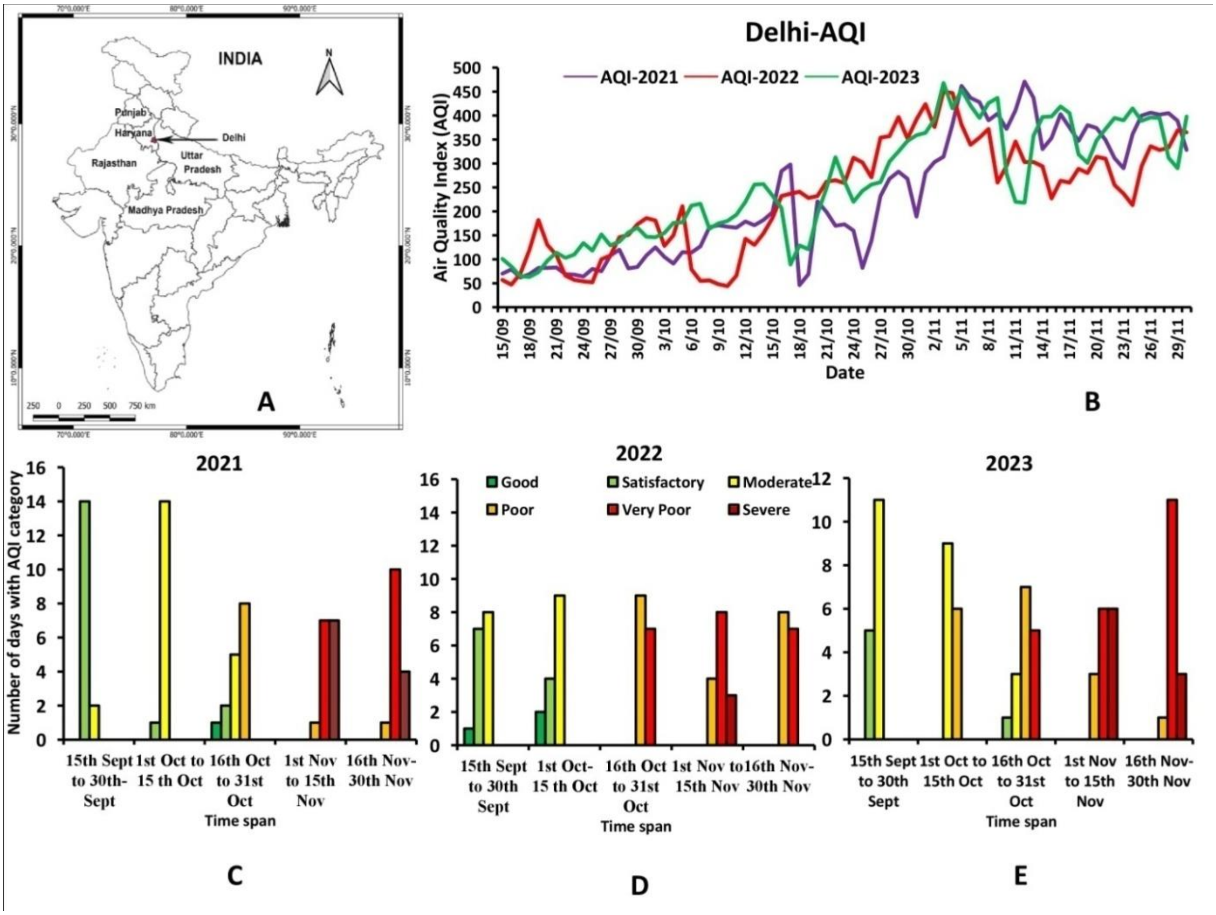

Figure 2(A-E). Air quality index (AQI) and their categorization depending on their possible health impacts in Delhi, India, during the paddy harvesting period (October-November) in the subsequent 3 years (2021, 2022, and 2023) (Data source: Central Pollution Control Board, Ministry of Environment, Forest and Climate Change, Government of India. https://cpcb.nic.in/AQI_Bulletin.php).

However, ash produced during the burning of crop leftovers is added to the soil profile (Palta and Kaur, 2023). Furthermore, the direct burning of crop residue in the fields causes a sudden fall in soil microbes and soil biodiversity (Dooley and Treseder, 2012). The high temperature generated destroys considerable bacterial and fungal populations in the top 2.5 cm of soil

(Bhuvaneshwari et al., 2019). Repeated firing incidents may reduce more than half of the soil bacterial population, although fungi can recover themselves and affect soil respiration (Gupta et al., 2004). Paddy straw burning reduced the populations of bacteria, fungi, actinomycetes, phosphate-solubilizing microorganisms, potassium-solubilizing microorganisms, cellulose, and microbial enzymes (Kumar et al., 2019). Nutrient recycling in ecosystems is also affected to a large extent by changes in microbial populations (Certini, 2005; Arunrat et al., 2022; Arunrat et al., 2023). All these, ultimately, permanently exhaust soil fertility. As a result, stubble burning is a threat to agriculture.

Stubble-burning effects on human well-being:

Effects on public health:

This burning stubble contributes to a general deterioration in air quality that exacerbates skin irritation and dryness of the eye, allergies, coughing, and chest congestion in the surrounding community (Raza et al., 2022). Fine particulate matter ($PM_{2.5}$)directly penetrates the lungs and deposits on the alveolar inner lining. Short-term exposure to $PM_{2.5}$ can impair lung function and aggravate asthma and cardiovascular disease (Chanana et al., 2023), whereas long-term exposure has been linked to an increased risk of chronic bronchitis, impaired lung function, and an increased risk of lung and heart disease-related death (Kumar et al., 2014). Furthermore, respiratory and cardiovascular diseases might be made worse by fine particles. These gaseous emissions can endanger one's health by exacerbating asthma, chronic bronchitis, and impairing lung function. TERI (2021) studied 3644 participants aged 10 to 60 years in the Patiala district of Punjab, India, when the ambient air $PM_{2.5}$ concentration ranged between 193-270 $\mu g/m^3$ to determine whether or not air quality from crop residue burning close to residential areas affects respiratory health. The study found that there is an increase in respiratory complaint cases, including wheezing, breathlessness on exertion, coughing in the morning and at night, skin rashes, runny noses, and itchy eyes, among all age groups, though older people are more affected than others. Additionally, lung function in females is reduced by 15–18%, while that of males is reduced by 10–14% for every 100 units ($\mu g/m^3$) increase in $PM_{2.5}$ concentration.

Socioeconomic implications:

Stubble burning and consequent smog buildup in the air, particularly during the months of October-November, hurt the social, economic, and cultural lives of the affected areas (Chawala and Sandhu, 2020; Abdurrahman et al., 2020). At that moment, the governments of the worst-affected states, like Delhi, the national capital of India, have no choice but to schedule an early winter break or close schools due to inclement weather (Government of National Capital Territory of Delhi, 2023). The government also imposes on the transport sector many restrictions, such as the 'odd-even scheme,' in which all means of transport slow down to reduce air pollution, restrictions on construction, and advice for working from home where possible (Saxena and Sonwani, 2019; Guttikunda et al., 2023; Das et al., 2023). The monetary value of lost workdays and medical expenses for illnesses caused by smoke pollution places an economic burden on the inhabitants and the overall productivity of the affected areas (Remoundou and Koundouri, 2009). Additionally, tourist inflow has been affected to some extent due to air pollution and associated health hazards (Abdurrahman et al., 2020).

Alternatives to stubble burning:

The escalating negative repercussions of unsustainable stubble burning have necessitated the adoption of sustainable and environmentally friendly alternatives for crop residue management practices to protect the environment and people's health (Shaik et al., 2019; Abdurrahman et al., 2020; Palta and Kaur, 2023). Figure 3 summarises various in-situ and ex-situ options for crop residue management practices as alternatives to intentional stubble burning in the open field (Abdurrahman et al., 2020; MoEF and CC, 2017; 2021).

In-situ management practices mostly involve either the incorporation of crop residues in the field (Porichha et al., 2021) or the adoption of mechanized farming techniques. Incorporating agricultural stubble into the soil is one of the simplest ways to manage it. It preserves the organic materials in the soil and promotes its fertility. The soil becomes more productive as nitrogen, biomass, and other nutrients are recovered from the decomposition of rice straw. Farmers should be encouraged to employ conservation tillage technologies: Happy Seeder, Paddy Straw Chopper, Mulcher, Rotavator, Super Seeder, Baler, and Crop Reapers. The super straw management system (SMS) needs to be provided in adequate quantities to avoid residue burning for the farmers (Government of India, 2022). It has been found that employing mechanized equipment, such as happy seeders, to mix straw into the soil works well, especially during tilling operations. These machines can do tillage and straw mulching without disturbing the topsoil. Happy Seeder can directly sow wheat into huge amounts of crop residue (Keil et al. 2021). One of the biggest barriers to farmers accepting alternatives to stubble burning is their poor economy, which keeps them away from purchasing such machinery and allied dependent machinery. Subsidies are required to provide farmers with funds to purchase agricultural no-burn technologies. Furthermore, changes in farming practices like crop rotation, crop diversification, intercropping, and staggering harvesting schedule may become effective in managing crop residue (Government of India, 2022). The 'Pusa bio-decomposer' capsule (a mix of microorganisms) used in agricultural fields in India to break down crop residue into organic manure is an eco-friendly and promising option (Biswas and Das, 2023).

Several ex-situ options are available as alternatives to stubble burning. Most farmers use crop residues as cattle feed. This is one of their common practices. Crop residues are frequently used in rural areas for roof thatching, bedding material for livestock, and packaging materials (Kumar et al., 2015). Straws of rice and wheat are commonly used as mulching materials for the production of fruits and vegetables. When straw decomposes, it enriches the soil with nutrients (Raja et al., 2022). Biochar produced from crop residues through pyrolysis can be used as a soil amendment (Abdurrahman et al., 2020). Compost made from agricultural stubble is nutrient-rich, increasing soil productivity (Porichha et al., 2021). One of the promising alternatives is to produce biofuel in liquid form from crop residues. Cellulose-based ethanol is the most common form available now. Certain Canadian companies use biomass, including crop residues, to manufacture bio-oil (Porichha et al., 2021). Straw may be subjected to combustion either directly (direct firing) or in a mixture with other fuels (co-firing) for power generation. Alternatively, by gasification, straw can be used to produce a mixture of fuel gases containing nitrogen (N_2), hydrogen (H_2), carbon monoxide (CO), and carbon dioxide (CO_2), and through combustion of such mixtures of fuel gas, electricity can be generated (Kumar et al., 2015; Porichha et al., 2021). Electricity can also be generated from biogas methane (CH_4) through anaerobic digestion of crop residues. In India, a 10-MW biomass-based first power plant situated at Jalkheri, Fatehgarh Sahib District of Punjab, generates bioenergy from biomass and offers an eco-friendly alternative to crop residues. However, bioenergy generation from crop residues is not at all profitable on a large scale due to its efficiency and economic costs. Paddy straw is used in many tropical and subtropical countries of Asia for the cultivation of mushrooms: *Agaricus bisporus*, *Volvariella volvacea*,and *Pleurotus* spp (Parihar et al., 2023). Paddy straw can be used to manufacture paper and pulp board as a raw material. Paddy straw in a proportion of 40:60 with wheat straw can be used to produce papers (Kumar et al., 2015). The major challenges for the adoption of ex-situ options as an alternative to stubble burning can be attributed to several factors, including logistical costs, a lack of an intricate agricultural residue supply network, transportation issues, a lack of knowledge and training in modern technologies, and a lack of financial capacity (Porichha et al., 2021; Raja et al., 2022).

Concerns about how to reduce agricultural fires are becoming more widespread among experts, citizens, and government policymakers (Keil et al., 2021). A large grass-roots awareness effort may be beneficial at some point in making farmers aware of acceptable alternatives to stubble burning. The number of stubble-burning incidences can also be reduced by thorough enforcement of laws prohibiting agricultural fires and maintaining vigilant surveillance. Research on alternate technologies for managing straw is ongoing, and crop- and area-specific applications must be developed. All stakeholders must be involved in comprehending and realizing the full potential of using crop leftovers with conservation agriculture for Indian agriculture to be sustainable and resilient (Parihar et al., 2023).

Conclusion:

Although quite an easy and quick way of clearing agricultural fields for the next crop to be sown, the negative effects of stubble burning on the environment and mankind far exceed its positive effects. It raises concerns about climate change, air pollution, and soil health deterioration. The root of the compulsion to go towards stubble burning is deeper into our social structure. Agriculture today has become expensive. The price rise of agrochemicals is a matter of concern today. In this situation, the firing of crop residues has become a suitable choice for the farmers. On the other hand, the revival of soil fertility, monetary costs for curing medical ailments, workday losses, disturbances in the principal economic activity and

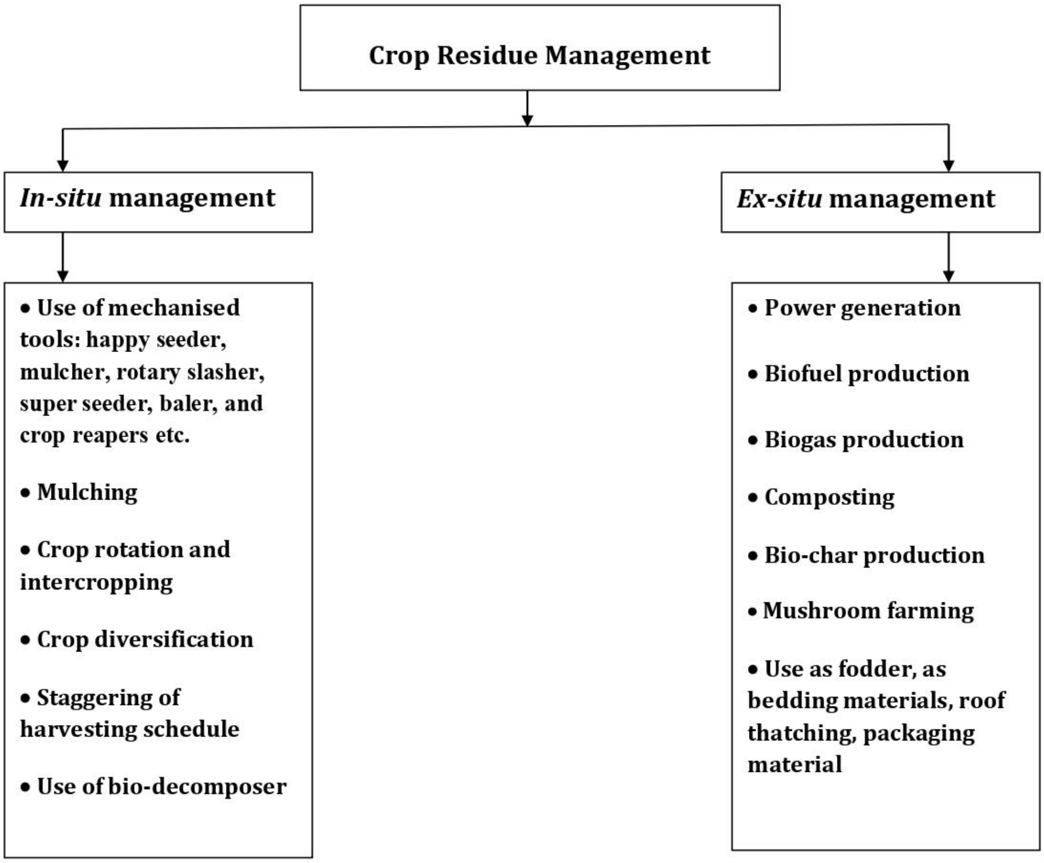

Figure 3. Alternative crop residue management practices.

productivity, and above all, pollution control add an economic burden to the citizens. Today, tackling stubble burning has become a social issue.Stubble burning, in the long run, can diminish soil fertility. Therefore, emphasis should be given to sustainable and eco-friendly crop residue management practices. A regular awareness program for the farmers should be conducted to make them aware of alternative options for stubble burning, which may be fruitful in minimizing firing incidents. The role of government, registered cooperatives, banks, and non-government organizations' initiatives in this regard is crucial in providing financial assistance or sharing conservation tillage technologies or super straw management systems (SMS) with the farmers. People's representatives, lawmakers, researchers, farmers, media, and people from all corners of society should come forward to fight shoulder to shoulder to stop stubble burning. Crop residue can be considered a valuable resource if adequate alternative management practices are implemented.

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Chapter- 4

Role of Nutrition in Combating Air Pollution for Sustainable Development

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Keywords: Nutrition, undernutrition, air pollution, Anthropocene.

Abstract:

The end of all forms of malnutrition by 2030 is one of the major targets of the United Nations' Sustainable Development Goals. As malnutrition is multifactorial and multifaceted, combating this insurmountable problem requires multiple strategies to achieve the United Nations' target. In this world, one out of nine children under five years of age are still hungry and undernourished. India is considered one of the major contributors to the global burden of malnutrition. Thus, policies to reduce malnutrition in India will impact the global arena. Nevertheless, the Global Nutrition Reports suggested that the country's target to reduce the prevalence of various indices of undernutrition like stunting, wasting, underweight, and anemia is sluggish. However, India will be the youngest nation in the world by 2030. To get the maximum demographic dividend, the nutritional status of the youth has to be optimal. However, due to poor nutritional status, the disability-adjusted life years are increasing, which harms the country's economic growth. On the contrary, India is also the world's fifth-largest economy. Thus, in this country, the impact of the industrial and agricultural revolution is havoc and even the reason for the increasing pollution level. Air pollution is the primary cause of health hazards in the country. Even air pollutants are responsible for causing undernutrition at an early stage of life. Thus, it is important to understand the missing link between undernutrition and air pollution in the age of the Anthropocene.

Introduction:

The United Nations' sustainable development goals aim to end all forms of malnutrition by 2030 (Grosso et al., 2020). Several policy measures have been taken globally and regionally to address the situation. Nutrition-sensitive and specific intervention strategies have been developed to tackle the global crisis (Ruel & Alderman, 2013). Despite several efforts, as per the Global Nutrition Report 2022, nearly one out of every nine children is severely undernourished. The prevalence of stunting, wasting, and anaemia among under-five children is

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195 million, 7.3%, and 60%, respectively (Chen et al., 2021). Although malnutrition is a global crisis, the major burden comes from low-middle-income countries (LMICs) like India (Khatun et al., 2016; Mistri, 2016; Mukhopadhyay, 2023). However, the causes of malnutrition in India and other LMICs are multifactorial, including political economy, health and healthcare, education, society and culture, agriculture and food systems, and water sanitation and the environment (Indra &Khoirunurrofik, 2022). Careful observation has revealed that globally and in LMICs, environmental measures of major nutrition-sensitive and specific intervention programs remain neglected. At the same time, every individual is exposed to environmental pollutants through ingestion, inhalation, and dermal absorption (Cohen et al., 2017a).

It has been noted that the impact of environmental contaminants undeniably hinders immune functions, resulting in heightened metabolic demands, loss of appetite, diminished food intake, increased breakdown of substances, and modified processing of nutrients linked to defensive mechanisms such as retinol and iron. Persistent exposure to pollutants also influences intestinal barrier function and initiates prolonged immune activation, both locally and systemically, along with inflammation and resistance to growth hormone (Yang et al., 2020). This sequence of occurrences stimulates inflammatory cytokines that centrally govern growth by inhibiting insulin-like growth factor 1, subsequently affecting the impact of growth hormone on longitudinal bone growth. Therefore, if intervention strategies are not planned to regulate environmental pollution, it can cause a chronic intergenerational cycle of undernutrition, i.e., stunting. Surprisingly, undernutrition causes 35% of disability-adjusted life years (DALYs) and deaths in children below five years of age worldwide (Bora, 2021; Upadhyay et al., 2018).

Global environmental pollution is on the rise (Das et al., 2016; Prasad et al., 2023). The fundamental mechanisms entail heightened cellular oxidative stress and subsequent inflammatory reactions. For instance, coplanar polychlorinated biphenyls (PCBs), a category of organic pollutants, exacerbate downstream inflammatory responses by binding to the aryl hydrocarbon receptor (AhR), which can enhance the transcription of cytochrome P450 (Cyp1a1) (Wang et al., 2023). Elevated Cyp1a1 triggers xenobiotic detoxification and generates reactive oxygen species (ROS) through an uncoupling mechanism. This ROS production leads to an escalation in oxidative stress, causing an imbalance in cellular redox status. This pro-oxidative cellular condition contributes to chronic inflammation, a characteristic feature of various diseases, such as malnutrition, atherosclerosis, diabetes, and other metabolic disorders (deSouza et al., 2022). Air pollution in India is considered the primary cause of health hazards. The impact of air pollution on nutritional well-being has not yet been explored. Meanwhile, the evidence suggests that undernutrition exacerbates the consequences of air pollution. Thus, this chapter attempts to understand the role of nutrition in dealing with the growing concerns of air pollution in India.

Air pollution in India:

A spatially and temporally varied, complex mixture of gases and particles causes air pollution. The two major indicators for quantifying air pollution are population-weighted annual mean concentrations of particle mass with an aerodynamic diameter less than 2·5 µm ($PM_{2.5}$) and tropospheric ozone, respectively (Pandey et al., 2021a). In mortality studies, $PM_{2.5}$ is the most consistent and robust predictor of long-term exposure. However, in the atmospheric reactions of precursor emissions, ozone, a gas produced, is associated with respiratory disease independent of $PM_{2.5}$ exposure (Cohen et al., 2017b). India has witnessed a constant rise in fine particulate matter ($PM_{2.5}$) in the air, jeopardizing its air quality. The World Health Organization (WHO) conducted a study that covered 100 countries between 2011 and 2016, revealing that 14 of the 15 notable cities in terms of $PM_{2.5}$ pollution were located in India (Pandey et al., 2021a). Alarmingly, as per the Global Burden of Diseases, 2019, 1.67 million deaths (17.8% of total deaths), out of which 10.4% were caused by ambient $PM_{2.5}$ pollution. Recent research indicates a growing surge in the generation of tropospheric or surface-level ozone in India. Ozone, a secondary contaminant, emerges as a result of chemical processes triggered by the interaction of nitrogen oxides (NOx) and volatile organic compounds (VOCs) with sunlight. A comprehensive investigation spanning from 2005 to 2020, carried out by IIT-Kharagpur, highlighted that tropospheric ozone ranks as the third most significant greenhouse gas, following carbon dioxide and methane (Martínez-Dalmau et al., 2021). This increased tropospheric ozone level, warming the climate from 0.2℃ to 0.5℃. Higher concentrations can result in respiratory issues, premature mortality among individuals, and harm to the growth of plants. Consequently, the primary sources of air pollution are acknowledged to be industrial and vehicular discharges, construction particulate matter, reliance on thermal energy for power generation, incineration of waste, and the utilization of wood and dung for cooking and heating in low-income and rural households. Numerous investigations have indicated that economic setbacks are closely linked to premature deaths and illness caused by air pollution (Das & Basu, 2021). This economic impact equated to 1.36% of India's Gross Domestic Product (GDP), signifying that the detrimental health effects of air pollution have the potential to impede India's long-term economic objectives. The exploration of various possibilities for alternative energy sources needs to be undertaken. Simultaneously, there is a need to intensify effective policy measures and proper investment to address India's air pollution crisis (Chakraborty & Basu, 2021).

Air pollution and malnutrition:

India is one of the major contributors to the global burden of malnutrition. The growing economic prosperity among the affluent increases the chances of non-communicable diseases. However, in this country, a still larger population remains below the poverty level, thus inducing a higher chance of a chronic intergenerational cycle of undernutrition. Previously, we have discussed the severity of the air pollution crisis in India. Understanding the chicken-egg paradigm, i.e., air pollution and malnutrition, is crucial. Although the spectrum of malnutrition is huge here, we are focusing on undernutrition. The impact of undernutrition is deeply associated with the early phase of life, i.e., childhood (Das & Basu, 2021).

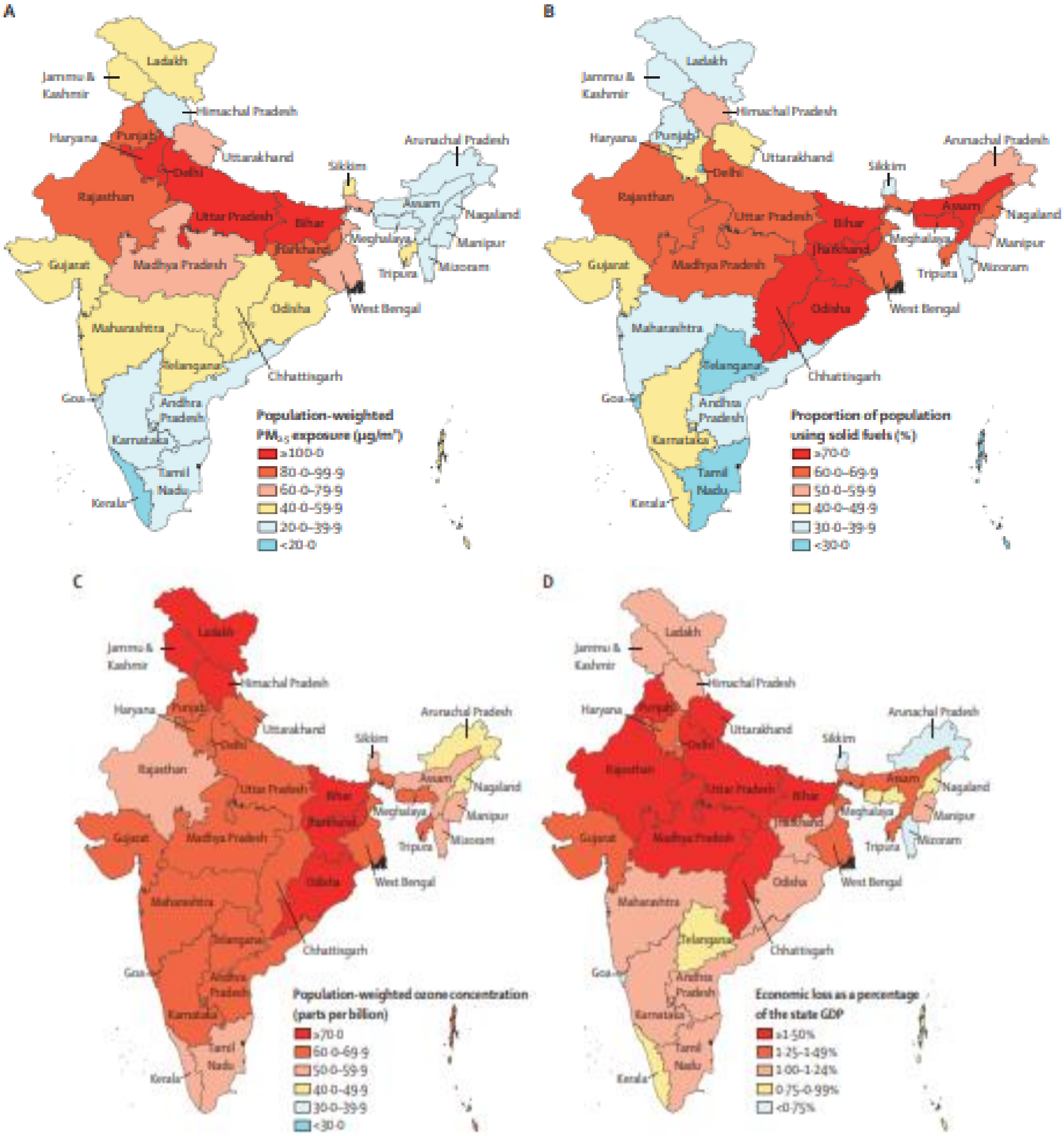

Figure 1: Exposure to atmospheric contamination and financial detriment arising from untimely fatalities and illness linked to atmospheric contamination in the Indian states, 2019 (A) Mean atmospheric concentration of $PM_{2.5}$, weighted by population. (B) Percentage of the populace utilizing solid combustibles. (C) The population-weighted concentration of ozone in parts per billion. (D) Economic decline due to untimely fatalities and illness resulting from atmospheric contamination is a portion of the state's gross domestic product (GDP). GDP denotes the gross domestic product. $PM_{2.5}$ stands for fine particulate matter featuring an aerodynamic diameter of 2·5 µm or less (Pandey et al., 2021b).

Given the multifaceted nature of malnutrition, India grapples with a substantial number of undernourished children alongside alarmingly high levels of air pollution. Hence, it is imperative to explore the potential correlation between these two factors. The subsequent four key elements warrant consideration when evaluating the influence of air pollution on child undernutrition: (i) stunting, characterized by height-for-age falling below 2 standard deviations (SDs) of the median in the WHO 2006 standard curve; (ii) wasting, denoted as weight for height below 2 SDs of the median in the WHO 2006 standard curve; (iii) underweight, indicated by weight-for-age below 2 SDs of the median in the WHO standard curve; and (iv) anemia, identified as a hemoglobin (Hb) level below 11g/dL (Spears et al., 2019).

Stunting is a major form of the intergenerational cycle of malnutrition and is associated with poor child development, lower productivity and earnings in adulthood, and an increased risk of chronic diseases later in life. Several studies have reported that air pollution has the potential to cause stunting. A study conducted in India by Spears et al., 2019, stated that with a decrease of 0.05 height-for-age standard deviations, an average 5-year-old girl would have a deficit of 0.24 cm in height if she were exposed to ambient air $PM_{2.5}$ of 100 µg/m3 in the month of birth. The same study reveals that the children's usual exposure to $PM_{2.5}$ concentration is 55 µg/m3. However, this lesser concentrated impure air can also reduce the height of a 5-year-old girl by 0.13 cm. Therefore, prenatal and postnatal exposure to air pollution is directly associated with childhood stunting (Sinharoy et al., 2020).

Several studies have reported that air pollution is associated with intrauterine growth restriction and preterm deliveries. Thus, the children born with these adversities are often found to be underweight or wasted. Surprisingly, some epidemiological studies highlighted that an annual mean $PM_{2.5}$ pollution was significantly associated with a greater risk of anaemia prevalence and decreased average Hb levels in children below five years of age. Hence, air pollution has remained neglected but has emerged as a prominent determinant of child undernutrition irrespective of the country's economic strata, but due to obvious reasons, the vulnerabilities are more common in all low- and middle-income countries (LMICs). Numerous studies show that apart from the growing concern about undernutrition, the chances of diabetes, cardiovascular diseases, and even obesity can be aggravated by ambient air pollution, especially in LMICs like India (Cohen et al., 2017a).

Role of nutrients in combat air pollution:

Various studies have expressed concern that air pollution greatly impacts human health (Sinharoy et al., 2020). A few distinctive mechanisms have been identified by which air pollution jeopardizes the health of human beings-

a) Oxidative stress and systemic inflammation
   - Mitochondrial dysfunction
   - Reduced telomere length
   - Reduced DNA methylation

Table 1: Measures of $PM_{2.5}$ levels, household cooking fuel use, and the prevalence of anemia, stunting, wasting, and underweight among under-five children in India, categorized by states and union territories (UTs).

State/ union territory	Annual population-weighted mean $PM_{2.5}$ levels ($\mu g/m^3$)	Percentage of households using solid cooking fuels	Anemia prevalence (per 100)	Stunting prevalence (per 100)	Wasting prevalence (per 100)	Underweight prevalence (per 100)
Andhra Pradesh	39	30.7	59.5	35.1	17.6	27.2
Arunachal Pradesh	27.1	55.4	56.7	32.3	16.9	25.7
Assam	40.2	73.4	36.3	38.1	13.5	26.9
Bihar	169.4	81.5	65.3	48.3	14.5	39.1
Chhattisgarh	52.5	74.8	45.7	38.6	15.8	33.4
Delhi	209	1.9	70.3	32.3	13.8	25.3
UTs other than Delhi	47.8	14.9	56.6	29.3	13.5	22.0
Goa	24.5	10.5	46.9	21.3	15.2	18.8
Gujarat	49.4	43.4	61.7	39.6	19.3	33.5
Haryana	125.7	45.7	74.0	35.2	12.5	27.9
Himachal Pradesh	38.6	58.1	52.9	32.1	10.6	20.8
Jammu & Kashmir†	57	41.8	53.2	30.2	8.1	17.6
Jharkhand	86.8	79.1	72.1	45.7	19.0	42.2
Karnataka	32.2	42.8	59.7	34.9	17.5	31.7
Kerala	17.3	35.5	38.0	21.6	15.4	19.3
Madhya Pradesh	77.9	69.8	67.9	40.9	18.8	37.1
Maharashtra	55.7	37.7	52.4	33.1	18.7	30.3
Manipur	42.9	58.3	29.7	32.2	7.7	16.5
Meghalaya	36.6	73.6	47.0	45.0	12.9	31.2
Mizoram	32.8	34.2	21.1	29.7	13.0	17.2
Nagaland	40.3	64.1	29.5	31.4	11.6	20.6
Odisha	49.2	76.7	45.3	35.9	17.3	31.9

Punjab	79.6	31.9	57.4	30.2	10.6	22.7
Rajasthan	93.4	68	59.5	37.3	17.5	33.2
Sikkim	50.3	34.8	51.8	28.5	6.3	16.8
Tamil Nadu	32.1	21	48.0	25.7	18.4	24.6
Telangana	47.2	28.1	62.6	31.7	19.1	28.3
Tripura	46.4	61	50.2	30.4	16.5	29.0
Uttar Pradesh	174.7	66.9	66.7	49.0	13.0	36.4
Uttarakhand	73.4	46	62.2	32.4	11.1	24.0
West Bengal	81.4	66.4	55.7	32.0	13.7	30.2

[*Source*: India State Level Disease Burden Initiative Air Pollution Collaborators 2019(Pandey et al., 2021b); India State Level Disease Burden Initiative Malnutrition Collaborators 2019(Swaminathan et al., 2019)].

b) Impaired immune development and function
- Defects in innate and adaptive immune function

c) Clinical and subclinical infection
- Repeated febrile respiratory infection
- Impaired lung structure and function
- Chronic immune activation
- Systemic inflammation

d) Nutrition: dietary intake and metabolism
- Anorexia
- Altered metabolism
- Increased nutrient requirements
- Inadequate diet

e) Bone metabolism
- Local and systemic regulation by proinflammatory cytokines
- Vitamin D deficiency

Most of the above-mentioned concerns associated with air pollution and health can be prevented, or at least the propensity of the impact can be reduced through lifestyle modification. Dietary adjustments and physical exercise are two major factors that could induce epigenetic changes in the human body. Thus, careful modifications will have a profound impact. Therefore, the diet must be enriched in antioxidant-rich nutrients to address chronic lower-grade inflammation. A few of the antioxidant nutrients are discussed below-

Vitamin-C:

Vitamin C, a water-soluble vitamin, is a potential antioxidant substance and is broadly distributed throughout the body. Ascorbate is deemed an outstanding reducing agent and neutralizes free radicals and oxidants. Numerous studies have indicated that vitamin C functions as a chemical-reducing agent both intracellularly and extracellularly. Intracellular vitamin C aids in preventing protein oxidation, while also regulating gene expression and mRNA translation. On the other hand, extracellular vitamin C protects against oxidants and damage caused by oxidants (Romieu et al., 2008). It contributes to antioxidant activity by scavenging a range of free radicals and oxidants in vitro, such as superoxide radical (O^{2-}), peroxyl radicals, hydrogen peroxide, hypochlorous acid, singlet oxygen, oxidant air pollutants, and oxidants released from activated neutrophils and macrophages. Consequently, owing to its scavenging properties, Vitamin C enhances immune function (Mustacich& Powis, 2000).

Vitamin E:

Vitamin E, a fat-soluble vitamin, inhibits oxidative damage to human tissue by interrupting the chain reaction of lipid peroxidation. The peroxyl radical scavenging properties of Vitamin E protect polyunsaturated fatty acids (PUFAs) present in phospholipids of the biological membrane and plasma lipoproteins. Prolonged exposure to O_3 can elevate the production of prostaglandin E2, a byproduct of arachidonic acid resulting from the lipid peroxidation of lung cells. It has been noted that vitamin E aids in decreasing prostaglandin E2, which seems to play a vital role as a fundamental component of alveolar surfactants. The quantity and composition of these surfactants are crucial for the normal functioning of the lung (Burton & Ingold, 1981).

β-carotene:

β-Carotene, a forerunner to vitamin A and various carotenoids, amasses in tissue membranes. It scavenges O^{2-} and directly interacts with peroxyl free radicals generated through exposure to O_3. Consequently, the antioxidative characteristics of β-Carotene are pivotal in regulating inflammation and the immune response (Siems et al., 2005).

Selenium:

Selenium, a vital trace element facilitating the neutralization of peroxides and free radicals, plays a pivotal role in averting inflammation. Intriguingly, selenium engages with each nutrient influencing the cellular pro-oxidant/antioxidant equilibrium, serving as an integral component of glutathione peroxidases and thioredoxin reductase. Moreover, it aids in enhancing the efficacy of vitamin E in overseeing lipid oxidation (Sies, 1997).

Flavonoids:

Alternative antioxidants, like flavonoids, act as eliminators of superoxide anions and peroxyl radicals. Besides their antioxidant functions, flavonoids can regulate cellular signalling pathways (Holguín et al., 2003; Saha et al., 2022a; Saha et al., 2022b).

Omega-3 fatty acids:

Elevated intake of omega-3 polyunsaturated fatty acids (n-3 PUFA) has the potential to mitigate the inflammatory response through various mechanisms. Despite the inflammatory impact on diverse body compartments, two prevalent characteristics persist, namely the unbridled generation of inflammatory mediators, encompassing i) eicosanoids, and ii) cytokines. While n-3 PUFA impedes the synthesis of eicosanoid mediators derived from arachidonic acid, many of which assume pro-inflammatory roles, it concurrently augments the production of anti-inflammatory eicosanoids from EPA. Additionally, it attenuates the chemotactic responses of leukocytes and suppresses pro-inflammatory cytokines and other proteins elicited through the NF-κB system, respectively. Numerous studies conducted on cell cultures underscore their capability to diminish the expression of adhesion molecules on both leukocytes and endothelial cells, thereby reducing intercellular adhesive interactions. Hence, the judicious consumption of n-3 PUFA emerges as pivotal in addressing inflammation induced by air pollution (Calder, 2010).

Synbiotic:

Synbiotics constitute an ideal amalgamation of favourable intestinal microorganism strains, termed probiotics, and prebiotics. They possess bifidogenic and lactogenic attributes, exemplified by substances such as fructo-oligosaccharide (FOS), galacto-oligosaccharide (GOS), and short-chain FOS (scFOS). In addition to these, polyphenols, omega-3 fatty acids, and human milk oligosaccharides (HMO), including 30Sialyllactose (30SL) or 60Sialyllactose (60SL), exhibit certain prebiotic characteristics. The application of synbiotics has the potential to mitigate the dysbiosis induced by air pollution, reinstating a eubiotic equilibrium in the gut by elevating *Bifidobacterium* and *Lactobacilli* levels while concurrently reducing the presence of pathogenic bacteria. Consequently, the synergistic utilization of prebiotic and postbiotic agents has proven efficacious in counteracting the health ramifications brought about by air pollution (Singh et al., 2022). Nevertheless, in addition to the aforementioned specific nutrients, achieving a well-rounded dietary approach is imperative to combat the health hazards induced by air pollution.

Table 2:The recommended dose of nutrients for combating air pollution.

Nutrient	Dose	Duration	Target group	Reference
Vitamin C	650mg/d 250mg/d	12 weeks 12 weeks	Adult	(Grievink et al., 1998); (Romieu et al., 2002)
Vitamin E	75mg/d 50mg/d	12 weeks 12 weeks	Adult	(Grievink et al., 1998); (Romieu et al., 2002)
β-Carotene	15mg/d	12 weeks	Adult	(Grievink et al., 1998),
Omega-3 fatty acids	3-4g/d EPA 2g/d EPA	12 weeks 3 weeks	Adult	(Marchioli et al., 2002; Mickleborough et al., 2003)

Conclusion:

Air pollution-induced malnutrition or malnutrition intensifies the impacts of air pollution; this interdependence requires an in-depth discussion. The section aimed to encapsulate both facets, delving into the mechanism of air pollution-induced undernourishment. Conversely, the significance of certain nutrients was extensively explored to comprehend their protective function in mitigating the severity of air pollution in everyday life. With India projected to become the world's youngest nation by 2030, the primary emphasis was on the life outcomes of children affected by air pollution. A notable observation is the lack of data on interventions specifically targeting nutrition in the context of child undernourishment and air pollution. As the United Nations advocates for diverse policies to eradicate all forms of malnutrition in the Anthropocene era, the role of pollution, particularly air pollution, warrants a reevaluation for genuine success.

Conflicts of interest:

The authors declare that they have no financial relationships or affiliations with any organization or institution that could have a financial conflict or financial interest in the topics or materials included in the work.

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Chapter- 5

Current Landscape and Future Perspectives of Biomedical Waste Management in India

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Keywords: Biomedical Waste Management, Nosocomial infection, BMWM in India, CBWTF, SWOT analysis.

Abstract:

Biomedical waste management (BMWM) is a crucial aspect of healthcare operations, encompassing the entire process from waste generation to its treatment and disposal. This paper provides an in-depth analysis of the present state of BMWM in different states of India, highlighting variations in Common Biomedical Waste Treatment Facility (CBWTF) utilization. The discussion includes the key initiatives undertaken by the Indian government, emphasizing the Biomedical Waste Management Rules of 2016, which expanded the regulatory framework and responsibilities. Furthermore, it explores various technologies for medical waste management, categorizing them into thermochemical, biochemical, and chemical methods. Thermochemical technologies such as incineration, gasification, pyrolysis, plasma-based methods, carbonization, hydrogenation, and liquefaction are discussed in detail, along with their operational conditions and potential products. The analysis underscores the need for collaborative efforts, technological advancements, and stringent regulations for addressing the challenges in BMWM. Special emphasis has been given to the importance of informed decision-making, SWOT analysis, and tailored waste-to-energy solutions for effective medical waste management in diverse healthcare settings.

Introduction:

Biomedical waste, abbreviated as BMW, is any waste generated as a result of operations such as diagnosing, treating, or immunizing humans or animals, as well as performing research

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and creating or testing biological compounds. From start to finish, the process requires a complete strategy that involves evaluating, measuring, separating, storing, transporting, and treating. The 3Rs philosophy is at the heart of successful BMW management (BMWM). Prioritizing waste avoidance and recovery above simply disposing of trash is a critical component of achieving successful BMWM. BMW disposal strategies are ordered hierarchically, with prevention being the ideal method, followed by reduction, reuse, recycling, recovery, treatment, and disposal. This emphasizes the need to address waste from its source rather than relying on a reactive "end-of-pipe" technique. A BMW treatment and disposal facility is a particular location where the complicated operations involved in BMW (biomedical waste) treatment, disposal, or management take place (Chartier et al., 2014). A key issue to note is that just a tiny fraction of BMW (biomedical waste) is classified as hazardous. This offers several threats to both the general public and healthcare personnel engaged in waste disposal, including physical, chemical, and microbial hazards. The vast majority, 75%–95%, is categorized as non-hazardous (Li, 1993). A key World Health Organization (WHO) meeting held in Geneva in June 2007 agreed on essential principles to support the secure and long-term management of healthcare waste. The urgent necessity for prudent resource allocation and an unwavering commitment to limiting the negative impacts of healthcare waste on both people and the environment were emphasized. Stakeholders involved in financing and supporting healthcare operations have a moral and legal obligation to pay for the costs associated with effective BMW management. Manufacturers must build environmentally friendly medical devices that can be safely disposed of. The WHO emphasized the need for governments to contribute a portion of their resources to the development, support, and maintenance of effective healthcare waste management systems that embrace modern methods and technology to reduce waste bulk and toxicity. Non-governmental organizations are strongly encouraged to undertake projects and activities that contribute to this overarching goal (Salkin et al., 2004). A previous study estimated that around half of the world's population is at risk from inadequate biomedical waste management (BMWM), jeopardizing either their work environment or public health. The ubiquitous occurrence of public health risks caused by inaccurate BMWM has been thoroughly established (Harhay et al., 2009). Instances such as the hepatitis B virus (HBV) pandemic in Gujarat, India, in 2009, with 240 documented infections, and the occurrence of infectious injuries among scavengers as a result of Afghanistan's massive immunization campaign (1.6 million) are particularly noteworthy (Chartier et al., 2014). The International Clinical Epidemiology Network conducted a major statewide review of 25 districts in 20 states, highlighting the inadequacies of BMWM systems across India. Only two major cities, Chennai and Mumbai, demonstrated much greater BMWM practices. The main issues were related to inadequate biological waste processing at the source and ineffective terminal disposal methods. According to the survey, approximately 82% of primary, 60% of secondary, and 54% of tertiary care health institutions were rated as "red," indicating either a lack of a credible BMWM system or an urgent need for significant improvement (Gadicherla et al., 2016).

Further supporting these findings, World Health Organization (WHO) surveys in 22 developing countries revealed that the proportion of healthcare facilities (HCF) without appropriate waste disposal systems ranged from 18% to 64% (Kumari et al., 2013). In India alone, around 0.33 million tons of biomedical waste are generated each year, with rates ranging from 0.5 to 2.0 kg per bed per day (Mathur et al., 2011). According to a recent study (David, 2016), bad practices in BMWM are caused by a lack of information and training.

Current Situation of BMWM in Different States of India:

Analyzing the provided data on Biomedical Waste (BMW) management in various Indian states reveals a noteworthy spectrum of circumstances (Costa et al., 2023). There exists a pronounced variability in the utilization of Common Biomedical Waste Treatment Facility (CBWTF) capacities, with percentages ranging from 17% to 86%. This discrepancy underscores disparities in the efficacy of BMW management systems and the facilities' ability to handle the generated waste. Some states, including Arunachal Pradesh, Goa, Mizoram, and Nagaland, lack CBWTFs or possess insufficient capacity, necessitating infrastructure enhancements. Notably, states like Chhattisgarh, Haryana, Maharashtra, and Punjab face challenges with CBWTF capacity utilization below 60%, pointing to potential issues in fully leveraging authorized capacity. Conversely, states like Assam, Jammu Kashmir, Kerala, and Tamil Nadu showcase efficient CBWTF capacity utilization, offering valuable insights for other regions. Although the total authorized CBWTF capacity exceeds the actual BMW generation, certain states may require additional capacity or infrastructure improvements (Figure 1). Addressing these challenges and fostering collaboration between states to share expertise and resources is crucial for cultivating a more cohesive and effective nationwide waste management system.

Initiatives of The Indian Government:

India, a country that has been at the forefront of addressing environmental issues, implemented Biomedical Waste Management (BMWM) laws in 1998. These laws, which came under the 1986 Environment Protection Act (EPA) and were later amended as drafts in 2003 and 2011, marked a significant advancement (Sharma et al., 1998). India ratified the legally binding Stockholm Convention in 2004 to decrease or eliminate persistent organic pollutants (POPs), in addition to its commitment to international environmental accords (Fiedler et al., 2007). By releasing the BMWM regulations in 2016, particularly on March 28, 2016, the Ministry of Framework, Forests, and Climate Change of the Government of India significantly contributed to the development of the regulatory framework. These regulations were deliberately created to fill in the legal gaps left by earlier legislation, using provisions from the EPA, 1986, and provide a comprehensive framework for the managed disposal of different kinds of biological waste (BMW) (Capoor, 2017). The Biomedical Waste Management Rules of 2016 significantly expanded the definition of biomedical waste beyond the traditional definition of healthcare facilities (HCF). This included a wide range of settings, including vacc-

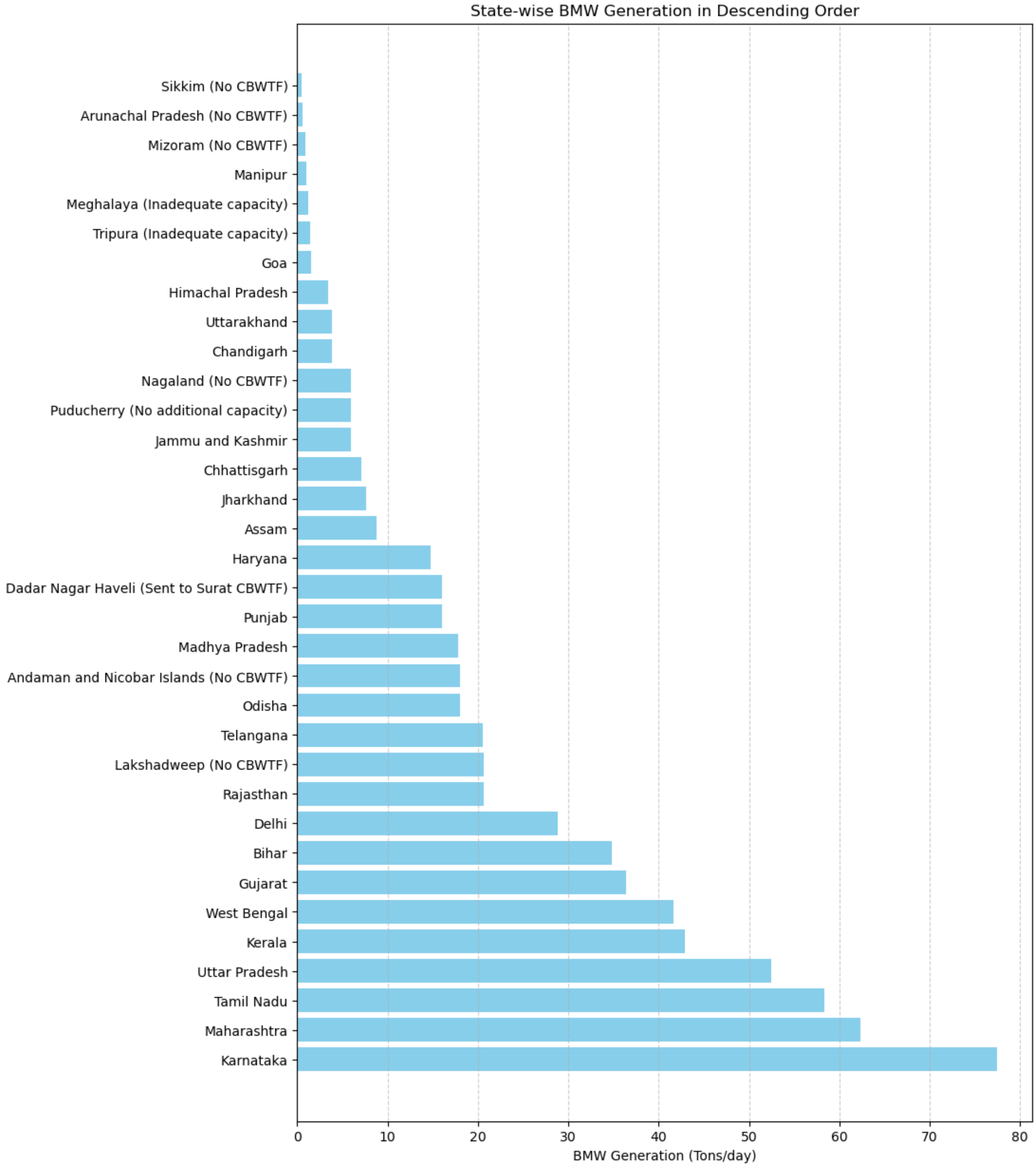

Figure 1: State-wise BMW generation in India.

-ination camps, blood donation camps, school first aid rooms, forensic labs, medical colleges, research laboratories, household biomedical wastes, and any other health-care activities related to various medical systems. To increase responsibility and clarity, the duties and responsibilities of the tenant, the Common Biomedical Waste (CBMW) management disposal facility, and the authorities were all spelled out. The occupier must guarantee the pretreatment of diverse biomedical waste streams, including blood samples, blood bags, microbiological waste, and laboratory garbage. This calls for following the regulations and doing on-site sterilization or disinfection. In addition to picking up trash, the occupier is in charge of offering health-care workers (HCWs) full support services, such as vaccinations, training, and workplace safety. By mandating that major incidents be reported to the relevant authorities and mentioned in the annual report, the guidelines emphasize responsibility and openness. Additionally, the occupier is expected to establish a strong framework for evaluating and overseeing BMWM operations via a dedicated committee. According to certain parts of the Act, both the occupier and the Common Biomedical Waste Treatment and Disposal Facility (CBMWTDF) acknowledge legal responsibility for any environmental or public harm resulting from negligent BMW management. The 2016 BMWM regulations contain criteria for waste disposal pits, effluent management, and other equipment-related standards in addition to these specific operating recommendations. To increase accountability and traceability, the regulations also include the use of barcoding and GPS technology. The company's focus on accident reporting, strict adherence to records, and establishment of a dedicated website connected to BMW is indicative of its dedication to openness and ongoing improvement. The regulations also place a strong emphasis on environmentally sustainable methods for final disposal technologies, promoting the use of green technologies, waste-to-energy solutions, newer technological approaches, plasma pyrolysis, and recycling that is made possible by licensed recyclers.

Technologies For Medical Waste Management:

There are broadly three types of classification for BMWM:

1. Thermochemical technologies
2. Biochemical technologies
3. Chemical technologies

Thermochemical technologies:

Incineration:

Incineration is the primary method for digesting and cleansing medical waste, to reduce both its volume and its risk. This approach produces a significant reduction, exceeding 80% in solid mass and 90% in volume (Shareefdeen et al., 2022). Incineration, which operates at temperatures ranging from 800 to 1450°C, allows for the complete annihilation of combustible components by oxidation processes aided by an abundance of air (Helsen, 2010; Kassim et al., 2022). Waste-to-energy conversion occurs when the heat generated during high-temperature incineration is converted into high-temperature steam, which then activates a turbine, which powers a steam turbine generator, generating electricity. Furthermore, considering its equal calorific values to gas and petrol, the incineration of polyolefin plastic waste is a potential possibility for providing a substitute for traditional fuels. This technique converts medical waste into high-value items, contributing to a circular economy (Costiuc et al., 2015). However, it is important to recognize that medical waste incinerators may be environmentally beneficial if they produce a certain amount of energy for recovery activities. Nonetheless, incineration may become a source of pollution if flue gases are not well managed, creating pollutants such as sulfur oxides, chlorines, carbon monoxide, or dibenzodioxins (Teymourian et al., 2021; Thind et al., 2021). Notably, Geyer et al. (Geyer et al., 2017) predict that by 2050, more than half of the world's plastic rubbish will be burned. As a result, there is an urgent need for in-depth research and development of clean flue gas systems to effectively control emissions during waste combustion.

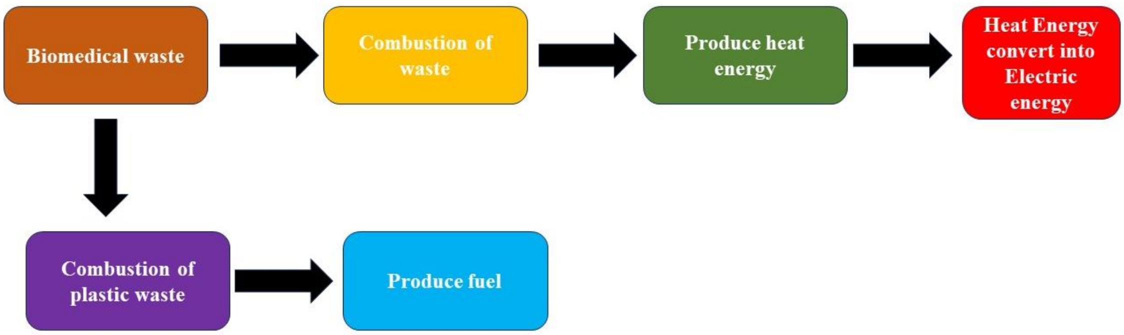

Figure 2: Brief mechanism of incineration for bio-medical waste management

Gasification:

Gasification is a thermal conversion technique used to treat medical waste, changing organic compounds into synthesis gases in a controlled oxygen atmosphere at high temperatures ranging from 800 to 1600°C (Awasthi et al., 2019; Zhang et al., 2021). The resultant syngas, predominantly comprised of carbon dioxide (CO_2), carbon monoxide (CO), hydrogen (H_2), methane (CH_4), and chain compounds consisting only of hydrogen and carbon, may be recycled into feedstock or synthetic fuel (Teymourian et al., 2021). The choice between air and steam gasification greatly affects the creation of value-added products. Air gasification, generated by a ratio of oxygen and nitrogen, is reasonably uncomplicated, although it creates gases with a poor calorific value. In contrast, steam gasification utilizes steam as the medium, giving gases with high hydrogen values throughout the endothermic process but with a large energy requirement. The purified syngas, devoid of contaminants such as acid gases causing equipment corrosion and tar creating obstructions, may be effectively employed in gas boilers, internal combustion engines, or gas turbines to recover power (Sun et al., 2021).

Pyrolysis:

Pyrolysis is a thermal breakdown process used in medical waste to break down large polymeric molecules into smaller ones, either in the presence of limited oxygen or in an oxygen-free environment. Plastic waste, for example, may be thermally destroyed in the absence of oxygen at temperatures ranging from 540 – 830° C (Wang et al., 2020). Pyrolysis may be classified as thermal or catalytic, with the former requiring an external energy source due to its endothermic nature and the latter requiring the use of a catalyst to accelerate chain breakages. Various feedstocks and operating conditions during pyrolysis result in end products of various states, including solids, liquids, and gases (Asim et al., 2021).

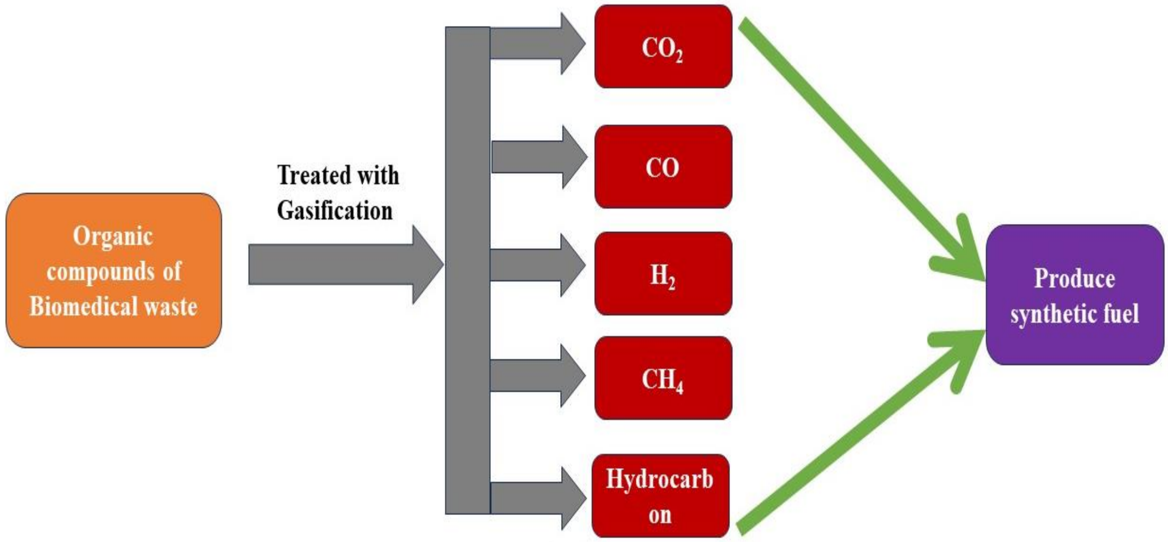

Figure 3: Through the application of gasification techniques, the organic compounds present in biomedical waste undergo conversion into syngas under elevated temperatures ranging from 800 to 1600^{0}C. These syngas can be utilized as a precursor for the production of synthetic fuels.

Plasma-Based Methods:

Plasma-based methods make use of the physical notion of plasma, which is the fourth state of matter and consists of radicals, charged ions, and free electrons (Shareefdeen et al., 2022). Depending on the energy sources and conditions during plasma generation, plasma technologies may be classified as hot or cold plasma. Thermal plasma is made up of electrons and heavier particles that are in thermal equilibrium, while cold plasma is made up of ions and neutrons that are at lower temperatures than electrons. In medical waste treatment, plasma-based methods such as plasma gasification, pyrolysis, and compaction are used as effective sterilizers. While plasma may produce valuable products such as syngas, hydrogen, and electricity, the enormous energy, density, and temperature involved with plasma treatment activities need caution. However, the technology has drawbacks, such as large capital costs and nitrogen oxide emissions (Erdogan et al., 2021; Munir et al., 2019).

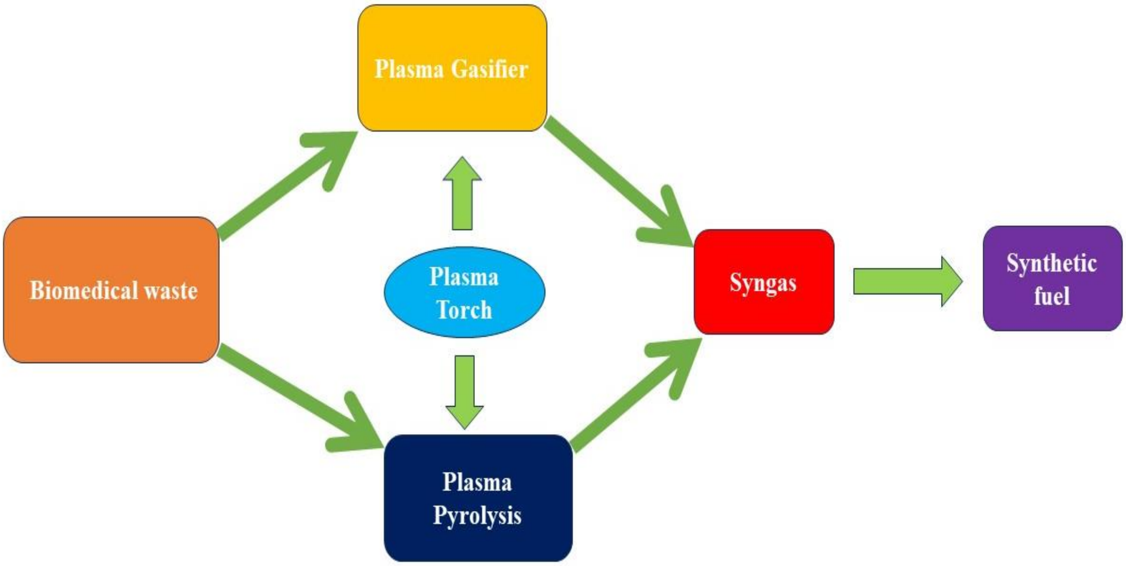

Figure 4: Biomedical waste can be effectively treated using either plasma gasification or plasma pyrolysis techniques. In both processes, the application of plasma enables the conversion of the waste materials into syngas, a valuable energy resource.

Carbonization:

Carbonization is a method of changing the carbon of polymer waste into homogenous carbonized goods, such as char or carbon-centric products incorporating carbon fibers and carbon nanostructures, by releasing volatile molecules (Asim et al., 2021). Carbonization may be categorized into dry and wet carbonization, with the former including torrefaction and the latter referred to as wet torrefaction. Dry carbonization, a simpler and more developed process, happens gradually under inert circumstances, whereas wet carbonization needs pressure and extreme temperatures (Zaini et al., 2017). Carbonization, particularly dry carbonization, is regarded as a possible option for medical waste transformation, but issues such as the creation of corrosive vapors from disposable face masks and the necessity for high-pressure reactors in wet carbonization must be solved (Joseph et al., 2021; Darmawan et al., 2017).

Hydrogenation:

Hydrogenation is a high-pressure process that degrades large hydrocarbon particles into small molecules by breaking C-C bonds in the presence of sufficient hydrogen and a catalyst. Through the reduction and saturation of organic components, this process converts plastic garbage into high-quality liquid fuels. However, the high cost of hydrogen, which is much more expensive than other fluidizing gases like nitrogen, as well as the need for hard equipment due to high pressure, make hydrogenation less prevalent than pyrolysis (Ragaert et al., 2017).

Liquefaction:

Liquefaction is a method of converting polymer waste into liquid value-added items like transportation fuel and chemical raw materials. This operation takes place at temperatures ranging from 300 to 450 °C and is pressurized with various solvents. In terms of hydrogen-

Table 1: Thermochemical Treatment Methods.

Thermochemical Treatment Methods	Description
Incineration	Mature technology for medical waste treatment. Minimizes waste volume at 90–95%. Requires flue gas cleaning system and integrated processes. Emits pollutants and needs strict emission control.
Gasification	The environmentally friendly method is more explored concerning coal treatment. Produces syngas for various applications. Requires further exploration in medical waste management. Needs stricter emission control compared to incineration.
Pyrolysis	High investment costs but profitable with an internal rate of return of up to 43%. Facilitates hydrogen production at high temperatures. Co-pyrolysis studies for enhanced oil production. Requires careful consideration due to the cost involved.
Dry Carbonization	Investigated for higher energy density products. Simpler process compared to wet carbonization. Value-added based on a relatively straightforward procedure. Continuous reaction limitation in wet carbonization.
Wet Carbonization	Moderate temperature, additional pressure. Suitable for wet medical waste. Continuous reaction limitation. Investigated for biochar and gas production.
Plasma-Based Methods	Utilizes plasma for waste management. High-energy, high-temperature processes for rapid heating and reactant transformation. Essential for achieving valorization of medical waste. Syngas, hydrogen, and electricity are valuable products. Requires careful consideration of energy costs.
Hydrogenation	Decomposes large hydrocarbon particles into small molecules with excess hydrogen and a catalyst. Transforms plastic waste into high-quality fuels. Higher transferring efficiencies of mass and heat. High-pressure requirements and expensive hydrogen stream compared to other gases.
Liquefaction	Turns polymers of waste into liquid value-added products. Processed at 300–450°C and pressurized with solvents. Applications include transportation fuel and chemical raw materials. Produces low-moisture, high-heating-value fuel. Needs further investigation for medical waste.

donating components and the depolymerization of plastic waste, liquefaction differs from thermal pyrolysis. Although liquefaction has advantages such as eliminating the requirement for feedstock drying and producing fuel with low moisture and oxygen concentrations, it still needs further research for medical waste applications (Ahmad et al., 2020).

Table 2: Thermochemical Treatment Operation Conditions.

Treatment Method	Temperature	Pressure	Reaction Agents	Oxygen Presence	Final Products
Incineration	High	Moderate	Oxygen	Oxygen required	Ash, flue gas, heat, electricity
Gasification	High	Additional	Oxygen/Steam	Varies	Syngas, ash
Pyrolysis	High	Moderate	Inert gas	Oxygen absent	Bio-oil, gas, char
Dry Carbonization	Moderate	Moderate	None	Oxygen absent	Char, gases
Wet Carbonization	Moderate	Additional	None	Oxygen absent	Biochar, gases
Plasma Methods	High	High	Plasma	Oxygen absent	Syngas, hydrogen, electricity
Hydrogenation	High	High	Hydrogen, Catalyst	Oxygen absent	High-quality fuels
Liquefaction	300–450°C	Pressurized	Solvents	Oxygen absent	Liquid value-added products

Biochemical Technologies:

Biological methods like biomethanation and fermentation, targeting biodegradable waste, convert organic compounds into valuable products. Biomethanation, or anaerobic digestion, produces methane-rich biogas and nutrient-rich digestate. Fermentation yields volatile fatty acids, alcohols, lactic acid, and hydrogen. These methods apply to wet agricultural and biogenic waste (Dudley et al., 2019).

Chemical Technologies:

Esterification, a chemical reaction between carboxylic acid and alcohol, creates esters and water. It is used for biodiesel and solvent production. Homogeneous and heterogeneous catalysts accelerate the reaction. For biodiesel, base-catalyzed transesterification is the preferred method (Khoshand et al., 2018).

Circular Economy & Biomedical Waste Management:

As of 2022, the country generates over 600 tons of biomedical waste daily, with an annual growth rate of 7-8%. Alarming statistics reveal that only about 20% of healthcare facilities comply with proper biomedical waste disposal regulations (Saxena et al., 2022). Currently, only a fraction of biomedical waste is treated through environmentally friendly methods, leading to severe environmental and public health concerns. By incorporating recycling and reusing strategies, the healthcare sector can substantially reduce its environmental footprint (Jacob et al., 2019). A circular economy is an economic system designed to maximize the sustainability of resources by reducing, reusing, recycling, and recovering materials and products. In contrast to the traditional linear economy, which follows a "take, make, dispose" model, a circular economy aims to minimize waste and keep products, materials, and resources in use for as long as possible. This approach promotes the continual use and regeneration of resources, contributing to environmental conservation and the reduction of negative impacts on ecosystems (Saha, 2023).

The integration of a circular economy is pivotal in addressing the challenges of biomedical waste management in India (Chew et al., 2023). Circular economy principles involve the reduction, reuse, and recycling of resources, minimizing waste and environmental impact. This approach aligns with Sustainable Development Goals (SDGs), particularly SDG 12 (Responsible Consumption and Production), fostering sustainable practices. In the context of biomedical waste, embracing a circular economy model ensures efficient utilization of resources and minimizes the hazardous impact on public health and the environment (Mahjoob et al., 2023). Despite India's progress in biomedical waste management, the circular economy is not fully realized, with gaps in infrastructure and awareness. Establishing a comprehensive circular economy framework is imperative to enhance the sustainability and effectiveness of biomedical waste management practices in the country.

Conclusion & Future Directions:

The development of thermochemical treatments for effective waste-to-energy conversion is the future route of medical waste management. While various ways have been proposed, some of them, such as hydrogenation, liquefaction, fermentation, and esterification, are still in the early stages of research and are not well known. Because of the complexities of medical waste and the need for disinfection before recycling, chemical, and thermal treatments are currently seen as more suitable for energy recovery while also aiding in effective disinfection. Notably, heat disinfection has been shown to effectively sterilize contaminated materials, including viruses such as COVID-19, in laboratory tests (Kaur et al., 2023). Incineration, gasification, pyrolysis, and carbonization are currently more feasible and economically viable thermochemical processes for medical waste-to-energy. While carbonization requires the least amount of heat, incineration, gasification, and pyrolysis need higher temperatures, resulting in varying degrees of medical waste degradation. The oxygen requirements and types of solid waste produced by incineration and gasification, in particular, differ. It is critical to understand the strengths, weaknesses, opportunities, and threats (SWOT analysis) of incineration, gasification, pyrolysis, and dry and wet carbonization before making informed decisions. Incineration is an established technique that may reduce waste volume, but it requires additional equipment for flue gas purification and integrated operations. Gasification, which is more environmentally friendly than incineration, needs further research. Despite high initial expenses, pyrolysis has the potential to be profitable, with an internal rate of return of up to 43%. Due to the limitations of continuous reactions in wet carbonization, dry carbonization should be investigated further for products with higher energy density products. Collaboration between politics and technology is essential, especially in light of increased medical waste. To promote proper waste disposal methods, clearer and stricter norms and regulations are essential, particularly in developing countries. Governments are being pushed to build a comprehensive infrastructure for waste collection, sorting, transportation, and valuing. The selection of waste-to-energy technologies should be based on the amount of medical waste, with mature technologies such as incineration suitable for regions with high waste volumes and environmentally friendly technologies such as pyrolysis and gasification encouraged in regions with low waste volumes. Sorting waste at the source, establishing handling capacities, and enforcing emission limitations via law all contribute to effective medical waste management and energy recovery.

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Chapter- 6

Ecotourism: A Sustainable Development Perspective in India

Abhinaba Sinha

Keywords: Ecotourism, Sustainable development, Biodiversity, Wildlife conservation.

Abstract:
Ecotourism has recently emerged as the favoured practice for addressing a range of environmental issues. It tackles various conservation problems, promotes environmental awareness, and generates revenue for the well-being of local communities. Thus, it provides a long-awaited solution for promoting sustainable development while ensuring the maintenance of environmental integrity. India, a nation blessed with a diverse array of landscapes, exceptionally rich flora and fauna, as well as cultural and tribal diversity, offers great prospects for the development and practice of ecotourism. Despite these positive attributes, India faces tremendous environmental crisis owing to its ever increasing population pressure and unemployment. Consequently, ecotourism emerges as the need of the hour, capable of generating revenues while simultaneously promoting sustainable development. It also serves as a solution to long-awaited conflicts between various environmental issues such as habitat destruction, fragmentation, and the utilization of human resources. Under this backdrop, the present chapter focuses on the various hallmarks of ecotourism, different types of ecotourism activities, the code of conduct for eco-tourists, and the merits and demerits of ecotourism. Furthermore, the chapter delves into the current scenario of the ecotourism industry in India. Thus, this chapter aims to briefly discuss the aforementioned aspects and raise awareness to fuel the popularity of this noble practice in this great nation.

Introduction:

Ecotourism emerged as a novel idea in the 1970s, and by the 1990s, it became a popular practice as it proved to be a potential solution to the prolonged conflict between tourism and threats to the environment (Ceballos-Lascurain, 1996). As one of the fastest-growing sectors of the global tourism industry, ecotourism has the potential to serve as an environmentally, socio-culturally, and economically feasible option for promoting sustainable development in noteworthy natural ecosystems and landscapes (Dandapath et al., 2016; Santarém et al., 2019). The term "ecotourism" refers to the development of tourism in natural environments with a primary focus on various conservation elements, creating environmental educational awareness, and generating revenues for local communities (Santarém et al., 2019). Thus, promoting tourism without compromising nature and natural processes and ensuring their sustenance for future generations to address their own needs (Fennell, 2020). The range of variable natural resources and landscapes in India is almost unparalleled in the world, ranging from immaculate forests, the

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humongous Himalayas, high-altitude grasslands, arid deserts, rivers with their tributaries, lakes, numerous wetlands, mangroves, beaches, volcanoes, and corals, exhibiting tremendous endemism (Raghav et al., 2013).

Ecotourism is a form of sustainable, non-invasive, and nature-based tourism that refers to responsible travel to natural areas, with the primary motive of conserving the environment and improving the well-being of its local inhabitants (Baloch et al., 2023). In addition to this, we possess a rich collection of mega-fauna, including Tigers, Lions, leopards, Elephants, rhinos, wild buffaloes, Indian bison (gaur), ungulates, Deers, and more than 1200 species of avifaunal diversity (Ministry of Tourism, 2022). Ecotourism requires a holistic approach across the three levels of the Government hierarchy, namely Central, State, and Local Government, and involves intense engagement with the private sector, local inhabitants, and Civil Society organizations. A comprehensive and effective strategy and a long-term shared vision involving all the stakeholders together to utilize the State's Ecotourism potential and use tourism for sustainable social and economic development, generating revenues, and creating job prospects for the present and future generations (Ministry of Tourism, 2022).

Hallmarks of Eco-Tourism:

According to wise scholars, the important attributes of ecotourism are as follows (Weaver, 2008; Fennell, 2020):

Involves travel to natural destinations:

These sites are generally uncommon, rather rare, and may be inhabited or not. They are often situated in environmentally protected areas of national, international, communal, or local interest.

Minimizes impact:

Tourism is always ecologically detrimental. Ecotourism provides the scope to reduce the adverse effects of hotels, trails, and other infrastructure by utilizing locally available resources, renewable energy sources, scientific waste disposal, promoting recycling, and preserving environmentally and culturally sensitive architectures and structures.

Builds environmental awareness:

One primary aim of ecotourism is to educate tourists and inhabitants of local communities. The role of operators and managers is crucial. Tour operators should make travellers aware by providing content that educates them about the country, environment, and local inhabitants. Furthermore, travellers should be informed about the code of conduct for both themselves and the tourism industry. The ecotourism itinerary should be designed and executed in a way that helps generate awareness in local communities, students, and the entire population of the host nation.

Provides direct financial benefits for conservation:

This form of tourism can generate revenues allocated for environmental protection, research, and academics through various means (e.g., park entrance fees, tour companies, accommodations, vehicle rentals, airlines, airport taxes, and voluntary contributions).

Provides financial benefits and empowerment for local people:

A fundamental rule for maintaining protected areas and sites for conservation is to develop a sound relationship with the local inhabitants in and around such areas. This practical aspect can be addressed by designing and developing ecotourism that involves the local community, enabling them to gain revenues and receive other residential benefits (such as potable water, roads, health clinics, etc.) from the conservation area and its tourist facilities.

Respect local culture:

Apart from being cleaner, greener, and better, ecotourism is also less invasive, and the degree of exploitation is comparatively lower than typical tourism. Conventional tourism frequently creates nuisances and induces adverse effects (e.g., prostitution, black markets, and drug issues). Ecotourism, in addition to being ecologically sustainable, is culturally enriching by giving value to the beliefs and cultures of the inhabitants.

Supports human rights and democratic movements:

Ecotourism plays a significant global role in bringing peace, prosperity, freedom, and harmony to all mankind. However, such attributes are not practiced in conventional tourism. Therefore, ecotourism practices also play a huge role in instilling international peace and harmony.

Thus, developing ecotourism is a substantial task, and concerned thinkers (planners, managers, and policymakers) need to prioritize and apply these dimensions if they genuinely want to achieve the basic goal of sustainable development in tourism (Santarém et al., 2019).

Types of Ecotourism:

Ecotourists can engage in responsible tourism through various forms. Below are different types of ecotourism identified by scholars (Belonozhko et al., 2022):

Scientific Tourism:

Scientific ecotours involve tourists volunteering for diverse nature studies and actively participating in field observations. This type of tourism entails exploration for scholars and includes fieldwork for students, with the primary objective being acquiring knowledge and wisdom. Examples of scientific ecotours include the behavioural field study of birds in nature or the documentation of individual counts in wild populations in the ocean (Deb et al., 2020; Das et al., 2022).

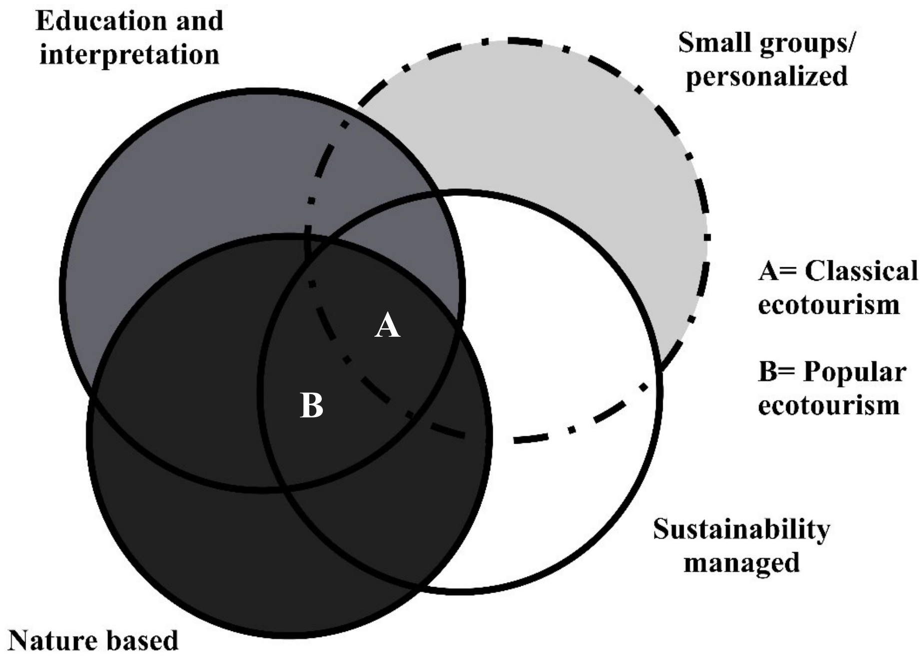

Figure 1. Dimensions of ecotourism (adapted from Fennell, 2020).

Nature History Tours:

This type of ecotourism focuses on acquiring knowledge about the environment and documenting information about local inhabitants and their culture. Nature history tours combine academic trips, popular scientific studies, and thematic excursions along specially designated ecological paths. These tours often include local excursions by academic institutions, during which mentors (teachers) raise awareness among students about nature, natural processes, and the benefits of sustainability. Such trips are widespread in Germany and have gained significant popularity.

Adventure Tourism:

Adventure tourism encompasses various tours primarily associated with different methods of movement and outdoor recreational activities. The main objective is to experience new sensations, and impressions, enhance physical endurance, and achieve novel goals. Also referred to as 'heavy ecotourism,' this type is characterized by tourists' motivation for adventure rather than a focus on the conservation of nature and its resources. Given its inclination towards sports tourism, classifying it as a type of ecological tourism introduces ambiguity. Activities include mountaineering, rock climbing, caving, trekking, and hiking.

Nature Reserves Travels:

This form of ecotourism involves touring to observe endemic and special natural objects and phenomena located in the vicinity of natural reserves. Typically, natural objects and phenomena are showcased, often accompanied by fictional representations of the lifestyle and events of native people. This type of tourism has the potential to become a popular and effective form of ecotourism. It is particularly common in Australia.

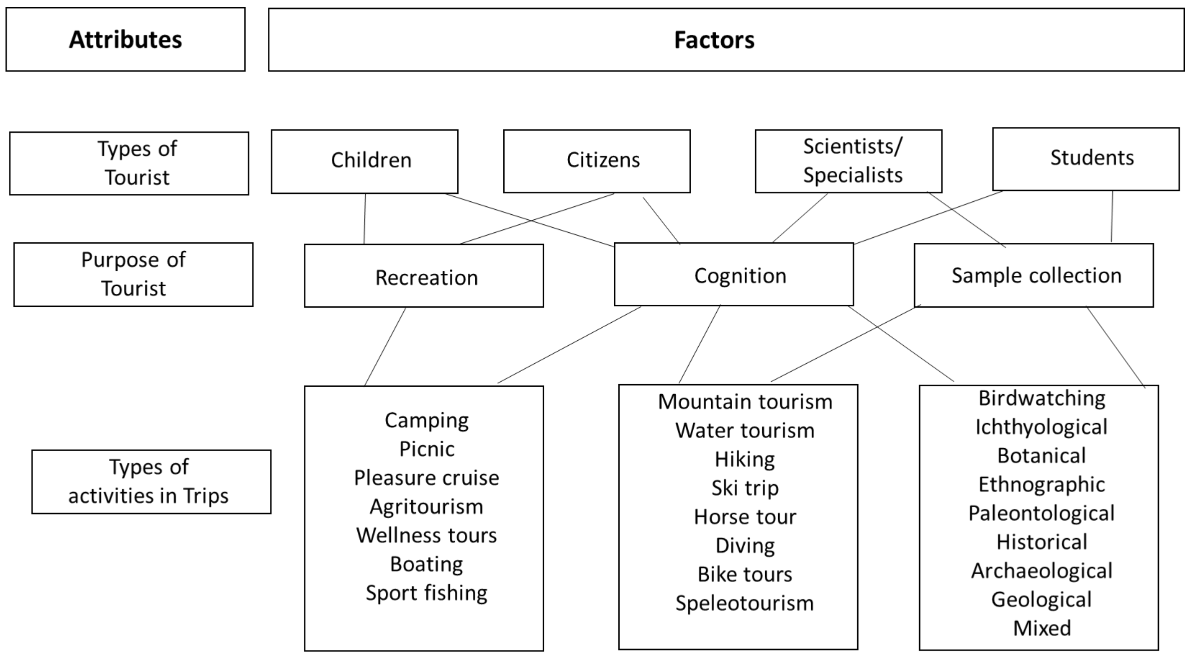

Figure 2. Different types and components of ecotourism (adapted from Belonozhko et al., 2022).

Guidelines for Ecotourists:

The Society for Responsible Tourism outlines the principles and guidelines of ecotourism, as stated by the Responsible Tourism Society of India (2020). It encourages travellers to mitigate their adverse impact before reaching sensitive destinations and cultures. Travelers should be prepared for each encounter with local cultures, as well as native flora and fauna. To minimize visitor impacts on the environment, strategies include providing literature, conducting briefings, leading by example, and implementing corrective measures.

Adequate leadership and the maintenance of small groups are essential to ensure minimal group impact on destinations. It is advised to avoid sites that are under-managed and over-visited. Managers, staff, and contract employees should be well-versed in and actively participate in all aspects of company policy to prevent negative impacts on the environment and local cultures. Access to programs that enhance communication and management skills in sensitive natural and cultural settings should be provided to these personnel. Contributing to the conservation of the visited region is emphasized. Additionally, the promotion of competitive, local employment across all aspects of business operations is encouraged. Accommodations should be site-sensitive, avoiding wasteful use of local resources and minimizing environmental impact. These accommodations should also provide opportunities for learning about the environment and fostering sensitive interchange with local communities. The focus of ecotourism is on personally experiencing natural areas in ways that lead to greater understanding and appreciation.

Importance of Ecotourism:

The unique attribute of ecotourism is that it demonstrates concern for the environment, being nature-based and with the aim of sustainable development. Ecotourism focuses on unadulterated, pristine natural environments through the protection of natural habitats, natives, and wildlife. It fosters cultural and environmental awareness by educating tourists about nature and natural systems. Another key aspect of ecotourism is that it promotes positive interaction and builds a strong bond between visitors and native hosts. Its primary concern is to minimize the adverse impact of tourism on nature and its inhabitants. Ecotourism boosts employment and provides revenue generation for local inhabitants by scientifically and sustainably utilizing natural resources. It encourages conservation by generating revenues and demonstrating the potential for long-term financial assistance for various conservation purposes (Jalani, 2012).

Ecotourism positively influences the circular economy in the food industry by fostering sustainable practices. Local communities often benefit from ecotourism, promoting regional food production and consumption. This approach reduces environmental impact, encourages the use of local resources, and creates a symbiotic relationship between tourism and the circular food economy, contributing to long-term ecological and economic sustainability (Saha, 2023).

Demerits of Ecotourism:

While ecotourism strives to promote environmental conservation and sustainable practices, it is not without its drawbacks. Numerous adverse effects on the environment arise from ecotourism activities, underscoring the importance of carefully managing and mitigating these impacts. One significant consequence is the crushing or clearance of vegetation. As eco-tourists explore natural habitats, the trampling and disturbance of plant life can lead to the degradation of ecosystems. This alteration of the landscape can have far-reaching implications for local flora and fauna, disrupting the delicate balance of the ecosystem. Moreover, the modification of physicochemical parameters of soil and water bodies represents another ecological challenge. The influx of tourists may introduce changes to the composition of soil and water, affecting the delicate equilibrium that sustains diverse ecosystems. Such alterations can have cascading effects, impacting the organism dependent on these environments. The introduction of weeds and pathogens is yet another concern associated with ecotourism. As visitors move between regions, they may inadvertently bring non-native species or harmful microorganisms, jeopardizing the health of indigenous flora and fauna. This poses a direct threat to biodiversity and the resilience of natural ecosystems. Water pollution emerges as a consequence of human waste generated by ecotourists. The improper disposal of waste, including sewage and other pollutants, can contaminate water sources, posing risks to aquatic life and compromising the quality of freshwater ecosystems. Simultaneously, air pollution becomes a pressing issue, driven by the emissions from generators, noise generated by machinery and vehicles, and the clamour of human voices. These pollutants have the potential to degrade air quality in pristine environments, impacting both wildlife and the overall visitor experience. Visual impacts, including the alteration of scenic landscapes, and disturbance to wildlife due to the factors mentioned above, amplify the ecological footprint of ecotourism. Additionally, the presence of food scraps and litter further contributes to the disruption of natural habitats and poses threats to wildlife through ingestion or entanglement. In conclusion, recognizing and addressing these demerits of ecotourism is crucial for ensuring the long-term sustainability of natural environments. Implementing responsible and ethical practices, along with robust conservation measures, can help strike a balance between the benefits of ecotourism and the preservation of our planet's biodiversity (John & Vijayan, 2018).

Ecotourism, despite its aim to promote environmentally responsible travel, can negatively impact elephant corridors. Increased human activity, noise, and infrastructure development associated with ecotourism can disrupt these vital pathways for elephants, leading to habitat fragmentation. This disturbance can hinder elephants' natural movement, migration, and access to essential resources, ultimately posing a threat to their survival and overall ecosystem health (Deb et al., 2022).

Ecotourism in India:

Ecotourism, as a concept, is quite interesting. Promoting ecotourism in India will lead to the conservation of wildlife and their natural habitat, which are under constant threat due to habitat degradation, fragmentation, overexploitation, and deforestation. The Indian forests are inhabited by different tribal communities, and ecotourism is an avenue to put these tribal inhabitants on the centre stage and generate funds for their well-being. It also provides ways for the development of remote areas surrounding the forests and tribal regions. Revenue generated using ecotourism practices might be a boon for the long-term economic benefit of our nation. Apart from aiding conservation initiatives, ecotourism can also shed light on many pertinent political and social issues in developing countries like India. Both locals and visitors become more aware of the adjacent nature and natural resources and can build a healthy relationship between natives and ecotourists. This mutual interaction not only enriches the ecotourists but also can lead to widespread benefits, as it can inculcate a positive mindset in the natives and boost the career development of their current and future generations (Pujar & Mishra, 2020). Ecotourism in the Sundarbans, a vast mangrove forest, has both positive and negative impacts on biodiversity. While it raises awareness and funds for conservation, improper management can lead to habitat disruption and stress on wildlife. Striking a balance is crucial to ensure sustainable ecotourism practices that protect the Sundarbans' unique and fragile ecosystem (Saha & Sarkar, 2022).

Potential of India as a hub for ecotourism sites:
• 70 percent of the Himalayas
• 7,000 km of coastline
• Among one of the three countries in the world with both hot and cold desserts
• Ranks 10th in total area under forest cover
• Ranks 6th in terms of the number of recognized UNESCO Natural Heritage sites. (National Strategy for Ecotourism, 2022)

Best ecotourism destinations in India:

Table 1: Popular ecotourism sites in India.

Serial no.	State	Name of the site
1	Andhra Pradesh	Tyda Maredumilli
2	Arunachal Pradesh	Namdhapa National Park
3	Assam	Kaziranga National Park Majuli
4	Goa	Galgibaga Beach
5	Karnataka	Coorg Nagarhole Nagarhole National Park Bandipur National Park
6	Kerala	Munnar Backwater waterways Thenmala Thodupuzha Eravikulam National Park Periyar National Park Kodaikanal
7	Ladakh	Tsomoriri Wetland Conservation Reserve
8	Madhya Pradesh	Kanha National Park
9	Meghalaya	Mawlynlong village
10	Nagaland	Jotsoma village
11	Odisha	Chilika
12	Sikkim	Khangchendzonga Biosphere Reserve
13	West Bengal	Sunderbans National Park

From the dramatic deserts of Rajasthan to the lush green forests of Cherrapunji, from the mighty Himalayas to the majestic deep blue beaches of the South, India has been a favourite ecotourism destination throughout the decade, hosting rich flora and fauna. The notable sites are (Das, 2014):

Ecotourism in India will take global and local eco-tourists to some of the cleanest villages in Asia, famous wildlife sanctuaries, and other renowned territories they have never visited before. Therefore, adopting a green approach and transitioning from being a tourist to an eco-tourism is the need of the hour.

Conclusion:

In conclusion, the exploration of ecotourism as a sustainable development perspective in India reveals a multifaceted approach to addressing environmental, social, and economic challenges. The rich biodiversity, diverse landscapes, and cultural tapestry of India create a unique canvas for the implementation and success of ecotourism. As highlighted in this review, the hallmarks of ecotourism, various types of ecotourism activities, guidelines for eco-tourists and the importance of ecotourism underscore its potential to be a transformative force. The discussion on the importance of ecotourism emphasizes its role in fostering environmental awareness, promoting positive interactions between tourists and local communities, and contributing to the conservation of natural resources. The demerits of ecotourism, though acknowledged, underscore the importance of responsible and ethical practices to mitigate adverse impacts. The focus on ecotourism in India underscores the country's potential as a hub for ecotourism sites. With its vast and varied landscapes, India stands poised to leverage ecotourism not only for wildlife conservation but also for the economic development of local communities. Identifying the best ecotourism destinations in India further substantiates the nation's allure for nature enthusiasts and advocates of sustainable tourism.

In the face of challenges such as population growth and unemployment, ecotourism emerges as a timely and promising solution. The review brings attention to the need for a comprehensive and collaborative approach involving government entities, private sectors, local communities, and civil society organizations to unlock the full potential of ecotourism in India. As we navigate the complexities of balancing tourism with environmental preservation, the principles and guidelines outlined for ecotourists become crucial. The responsible exploration of ecotourism requires a commitment to minimizing environmental impact, respecting local cultures, and actively contributing to the conservation efforts of visited regions. In essence, this review serves as a call to action, urging stakeholders and enthusiasts to recognize the transformative power of ecotourism in the Indian context. By embracing ecotourism as a sustainable development strategy, India has the opportunity to not only showcase its natural treasures but also to pave the way for a harmonious coexistence of nature, culture, and economic prosperity. Through responsible practices and strategic initiatives, ecotourism can become a driving force for a sustainable and vibrant future for India and its diverse ecosystems.

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Chapter- 7

Sustainable Urban Development and Its Profound Impact on Human Health

Tuhar Mukherjee, Debarshi Mondal

Keywords: Sustainable development, human health, green space, urban environment.

Abstract:

Urbanization, a pervasive global force, has shifted over half of the world's population to urban areas, altering habitation patterns significantly. While fostering economic growth and cultural exchange, this trend presents intricate challenges, particularly in public health. Sustainable urban development, grounded in environmental, social, and economic integration, emerges as a crucial response to the demands of rapid urbanization. This chapter explores the intricate relationship between sustainable urban development and human health within this transformative context. We aim to uncover the profound impacts of sustainable urban development on the well-being of urban populations, synthesizing existing literature and unveiling the interconnected nature of urban planning, environmental sustainability, and their collective influence on public health. Beyond analysis, our goal is to articulate how sustainable urban development can transcend conventional urban planning boundaries, acting as a catalyst for positive health outcomes. As urban environments evolve, scrutinizing the strategies and principles underpinning urban development becomes imperative. Through a multidisciplinary lens, we endeavour to unravel the complexities, challenges, and potential avenues for fostering healthier urban societies. Our ultimate aim is to ensure that cities not only thrive economically but also become sanctuaries for the optimal physical, mental, and social flourishing of their residents.

Introduction:

In the contemporary landscape of rapid urbanization, the intersection of urban development and human health emerges as a pivotal focus. This book chapter delves into the intricate relationship between sustainable urban development and its profound implications for human health. As cities burgeon and populations gravitate towards urban centers, the dynamic interplay between the built environment and public well-being becomes increasingly apparent (Kuddus et al., 2020). The chapter embarks on a comprehensive exploration of sustainable urban development strategies and their direct influence on various facets of human health. From air and water quality to the accessibility of green spaces and sustainable transportation, each aspect is scrutinized to unravel the intricate web of factors shaping the urban health paradigm.

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Furthermore, the chapter addresses the social dimensions of sustainable urbanism, considering equity, inclusivity, and community well-being as integral components of a healthy urban fabric. With a multidisciplinary approach, this chapter amalgamates insights from urban planning, public health, environmental science, and social sciences. By synthesizing current research and case studies, it aims to provide a nuanced understanding of how conscientious urban planning and development practices can be harnessed to foster healthier communities. Through this exploration, the chapter endeavours to contribute valuable knowledge to scholars, practitioners, and policymakers invested in steering urban development toward a sustainable and health-centric future.

Urban Planning and the Evolution of Health Infrastructure:

Urban planning, traditionally concerned with the design and organization of physical spaces within cities, has undergone a transformative evolution in recent decades. Beyond the aesthetics of skylines and the layout of streets, contemporary urban planning increasingly acknowledges its profound impact on public health. The nexus between urban planning and health infrastructure is a dynamic interplay that holds the potential to shape the well-being of entire communities (United Nations, 2018). Historically, urban planning was primarily driven by considerations of functionality, aesthetics, and economic development. However, as our understanding of the intricate relationship between the built environment and human health has deepened, urban planners are increasingly recognizing the role they play in creating environments that either foster or hinder health and well-being. A pivotal aspect of this evolution is the integration of health-oriented principles into the fabric of urban planning. The design of neighbourhoods, the layout of public spaces, and the accessibility of essential services all contribute to the health profile of a community. Walkable neighbourhoods, mixed-use developments, and the inclusion of green spaces within urban landscapes have become central tenets of health-conscious urban planning (Roy, 2016; Almusaed & Almssad, 2020).

Physical Activity and Walkable Neighbourhoods:

The design of urban spaces can significantly influence levels of physical activity, a crucial determinant of public health. Walkable neighbourhoods, characterized by pedestrian-friendly streets, sidewalks, and the proximity of essential services, encourage residents to engage in physical activities as part of their daily routines. Sidewalks lined with trees, benches, and public art not only enhance the aesthetic appeal of a neighbourhood but also create an inviting environment that encourages walking and social interactions (Baobeid et al., 2021). Studies have shown that individuals residing in walkable neighbourhoods are more likely to meet recommended physical activity levels, reducing the risk of chronic conditions such as obesity, diabetes, and cardiovascular diseases (Giles-Corti et al., 2016). Urban development can contribute to an increased risk of diabetes and cancer through factors such as sedentary lifestyles, pollution, and limited access to green spaces (Saha et al., 2022a; Saha et al., 2022b). Sustainable urban development requires prioritizing active transportation, green infrastructure, and public health initiatives to create environments that promote physical activity and reduce environmental hazards, thus mitigating the risk of chronic diseases like diabetes and cancer. As urban planners embrace the concept of walkability, they contribute to the creation of environments that support healthier lifestyles and, consequently, improved public health outcomes.

Green Spaces and Mental Well-being:

The inclusion of green spaces in urban planning represents another aspect of the evolving relationship between urban development and health infrastructure. Parks, community gardens, and recreational areas provide residents with spaces to relax, exercise, and connect with nature. Beyond their aesthetic appeal, these green spaces play a crucial role in supporting mental well-being. Access to green spaces has been associated with reduced stress levels, improved cognitive function, and enhanced overall mental health (Zingoni de Baro, 2022). Urban planners, aware of these benefits, are increasingly integrating green infrastructure into city plans. This shift not only beautifies urban landscapes but also contributes to the creation of resilient, mentally healthy communities.

Cycling Infrastructure and Active Transportation:

In addition to walkability, the provision of cycling infrastructure is gaining prominence in health-oriented urban planning. Designated bike lanes, bike-sharing programs, and secure bike storage facilities contribute to the promotion of active transportation. Cycling not only serves as an environmentally friendly mode of transit but also offers a means of incorporating physical activity into daily routines. Cities that invest in cycling infrastructure witness a surge in cycling as a mode of transportation. This shift not only reduces traffic congestion and air pollution but also fosters a culture of physical activity. The integration of cycling into urban planning strategies represents a proactive approach to improving cardiovascular health and reducing the prevalence of sedentary lifestyles (Gehl, 2010).

Challenges and Considerations:

Despite progress, health-oriented urban development faces obstacles. Low-density development and car dependence continue to threaten health-conscious urban planning. Planners encounter inadequate public transportation infrastructure, zoning laws that favour commercial spaces over residential ones, and economic inequities in health-promoting services. Retrofitting urban places for health can be logistically and financially challenging. Innovative policy frameworks, public-private partnerships, and social equity in urban development are needed to overcome these challenges (Bibri et al., 2020). The health-conscious paradigm shift in urban planning has transformed how we create cities. Walkability, green areas, and cycling infrastructure demonstrate a commitment to building urban environments that improve residents' health. The rise of health infrastructure in city planning offers optimism to urban planners facing growing urbanization. It envisions cities as dynamic ecosystems that prioritize residents' physical, mental, and social health. Urban planning may help build healthier, more resilient cities by encouraging physical exercise, mental health, and community engagement (Rydin et al., 2012).

Environmental Sustainability: A Crucial Determinant of Public Health:

In the intricate tapestry of urban development, the thread of environmental sustainability weaves a narrative that extends far beyond ecological concerns. It is a narrative that intimately intersects with public health, marking environmental sustainability as a crucial determinant in shaping the well-being of communities worldwide. As urbanization continues to accelerate, the impact of environmental sustainability on public health becomes increasingly paramount (VanWinkle, 2014).

Air Quality and Respiratory Health:

One of the primary dimensions where environmental sustainability directly influences public health is air quality. The combustion of fossil fuels, industrial emissions, and other anthropogenic activities contribute to air pollution, resulting in a myriad of health hazards. Particulate matter (PM), nitrogen dioxide (NO2), and ground-level ozone, among other pollutants, have been linked to respiratory and cardiovascular diseases (World Health Organization, 2016). Sustainable urban development actively addresses these challenges by advocating for low-emission transportation, promoting green building practices, and supporting the use of renewable energy sources (Mundorf et al., 2018). Cities that embrace these sustainable practices not only reduce their carbon footprint but also enhance air quality, mitigating the health risks associated with poor air quality.

Climate Change and Health Risks:

Environmental sustainability also intersects with public health through the lens of climate change. The alteration of climate patterns poses significant threats to health, including the spread of infectious diseases, extreme weather events, and food insecurity (Costello et al., 2009). Sustainable urban development, by reducing greenhouse gas emissions and promoting climate-resilient infrastructure, plays a pivotal role in adapting to and mitigating the health risks posed by climate change. Cities that prioritize environmental sustainability contribute to global efforts to curb climate change, safeguarding the health and well-being of their populations. The integration of green spaces, sustainable transportation, and energy-efficient buildings not only addresses immediate environmental concerns but also positions cities as pioneers in creating healthier, more resilient communities (Dubbeling et al., 2019).

Biodiversity and Ecosystem Services:

The preservation of biodiversity and ecosystem services is another facet of environmental sustainability with direct implications for public health. Urbanization often leads to habitat destruction and fragmentation, impacting the ecosystems that provide essential services, such as clean water, pollination of crops, and disease regulation (United Nations, 2018; Saha & Sarkar, 2022; Deb et al., 2022). Sustainable urban development seeks a harmonious coexistence between urban spaces and natural ecosystems, recognizing the vital role they play in supporting human health (Dandapath et al., 2016). Cities that prioritize environmental sustainability incorporate green infrastructure, protect natural habitats, and implement policies to safeguard biodiversity. This approach not only contributes to the conservation of ecosystems but also enhances the overall resilience of urban areas to environmental challenges, subsequently positively impacting public health (Hanna & Comín, 2021).

Challenges and Innovations in Environmental Sustainability:

Environmental sustainability improves public health, but obstacles remain. Cities must overcome urban expansion, industrial pollution, and poor waste management to achieve environmental sustainability. Sustainable technology, policy, and community engagement innovations are crucial to overcoming these difficulties. Cities that invest in renewable energy, effective waste management, and green infrastructure show dedication to environmental sustainability and public health. Sustainable policies, community education, and involvement form a holistic approach to urban development's many issues. Environmental sustainability is key to urban growth and public health (Banerjee et al., 2021; Das, 2022; Haldar & Haldar, 2022; Perkumienė et al., 2023). As cities struggle with increased urbanization, sustainable practices become an ecological imperative and a commitment to urban health and well-being (Kaur et al., 2023). Sustainable urban development transforms cities into environmentally conscious, public health-promoting environments by addressing air quality, climate change, biodiversity, and ecosystem services. Environmental sustainability is a key chapter in urban development, building a future where cities are resilient, vibrant, and organically aligned with residents' health and prosperity (Crane et al., 2021).

Social Equity and Its Impact on Access to Healthcare:

In the evolving landscape of urban development, the concept of social equity stands as a moral compass guiding the design and implementation of policies and infrastructure. Nowhere is this more crucial than in the realm of healthcare, where disparities in access to services can profoundly affect the well-being of individuals and communities. Social equity, as a fundamental principle of sustainable urban development, plays a pivotal role in shaping the accessibility and inclusivity of healthcare resources.

The Landscape of Healthcare Disparities:

Historically, urban areas have been hotspots for healthcare disparities, with certain populations facing barriers that hinder their access to essential services. Factors such as income, race, ethnicity, education, and geographic location contribute to these disparities, creating a complex web of inequities that challenge the fundamental right to health for all (Marmot et al., 2008). Sustainable urban development recognizes the urgency of addressing these disparities and actively integrates social equity principles into the planning and provision of healthcare services. The goal is to create a healthcare landscape that is not only accessible to all residents but also tailored to meet the diverse needs of different communities.

Inclusive Urban Planning for Healthcare:

One of the key mechanisms through which social equity influences access to healthcare is through inclusive urban planning. This involves strategic decisions about the distribution of healthcare facilities, the allocation of resources, and the integration of healthcare services with other essential community resources (Moirangleima, 2016; Chatterjee & Sarkar, 2022). Equitable urban planning seeks to ensure that healthcare facilities are distributed proportionally to the needs of the population, considering factors such as population density, demographics, and socio-economic status. This approach aims to minimize geographic disparities, making healthcare services more accessible to residents regardless of their location within the city.

Affordable Housing and Health Outcomes:

Social equity in healthcare is intricately linked to broader urban development policies, particularly those related to housing. Affordable and stable housing is a key determinant of health, influencing factors such as mental well-being, chronic disease management, and access to preventive care (Paraje & Vásquez, 2012). Cities that prioritize social equity in urban planning work towards creating affordable housing options in proximity to healthcare services. This not only reduces transportation barriers but also fosters a sense of community, contributing to improved health outcomes for residents. Affordable housing initiatives, coupled with healthcare accessibility, form a powerful strategy for mitigating health disparities (Kelly et al., 2022).

Community Engagement and Health Literacy:

Another dimension of social equity in healthcare involves community engagement and health literacy. Sustainable urban development recognizes the importance of involving communities in decision-making processes related to healthcare. Engaging residents ensures that healthcare services are culturally competent, linguistically accessible, and responsive to the unique needs of diverse populations (Chakraborty & Ghosh, 2019; Chatterjee & Sarkar, 2022). Moreover, promoting health literacy becomes a cornerstone in the pursuit of social equity. Communities with higher levels of health literacy are better equipped to navigate the complexities of the healthcare system, understand preventive measures, and actively participate in their own health management. Sustainable urban development initiatives emphasize education and community outreach as essential components of reducing health disparities.

Challenges and the Role of Policy:

Despite progress, socioeconomic justice in healthcare remains difficult. Systemic hurdles, economic inequities, and historical injustices continue to disproportionately affect specific populations. Sustainable urban development requires policies that address these core problems and promote resource and opportunity equality. Policy measures may lower income disparity, improve education, and combat healthcare discrimination. Cities can create more equal healthcare by tackling these structural concerns (Jackson, 2003). Social fairness drives healthcare access in sustainable urban development. Cities can reduce healthcare disparities by prioritizing inclusive urban planning, affordable housing, community participation, and legislative measures. The goal is to provide equal healthcare and a healthcare ecosystem that meets varied community requirements. Social fairness becomes a cornerstone of a healthy urban future where every person, regardless of background or condition, can achieve optimal health and well-being.

Case Studies: Realizing Sustainable Practices in Action:

The transformative potential of sustainable urban development becomes most evident when translated from theory to practice. Real-world case studies provide a tangible glimpse into how cities around the globe are implementing and reaping the benefits of sustainable practices. These examples serve as beacons of inspiration, demonstrating that the integration of environmental, social, and economic considerations is not only feasible but also conducive to fostering healthier, more resilient communities.

Copenhagen: Sustainable Transportation Revolution:

Copenhagen, Denmark, stands out as a paradigm of sustainable urban development, particularly in the realm of transportation. Faced with challenges of congestion and pollution, the city embraced a comprehensive strategy to prioritize sustainable modes of transportation. This included investing heavily in cycling infrastructure, pedestrian-friendly zones, and an efficient public transportation system (Gehl, 2010). The results are palpable. Cycling has become a way of life in Copenhagen, with dedicated bike lanes crisscrossing the city and a robust bike-sharing program. The embrace of sustainable transportation not only reduced air pollution and traffic congestion but also contributed to a more active and healthier population. Copenhagen's success serves as a testament to the transformative potential of sustainable practices in addressing both environmental and public health challenges.

Curitiba: Green Spaces Nurturing Well-being:

Curitiba, Brazil, offers an insightful case study showcasing the integration of green spaces into urban planning for the betterment of public health. The city prioritized the creation of accessible and well-maintained green areas, ranging from parks to community gardens (Zingoni de Baro, 2022). The intentional incorporation of green spaces was not merely an aesthetic choice but a strategic move to enhance the mental and physical well-being of residents. These green spaces serve as communal hubs, promoting physical activity, social interactions, and mental rejuvenation. Curitiba's commitment to green infrastructure aligns with the principles of sustainable urban development, emphasizing that a balance between urbanization and nature is essential for creating environments that actively contribute to public health.

Singapore: Vertical Green Living:

In the densely populated city-state of Singapore, innovative solutions to urban living and sustainability have taken the form of vertical greenery. Recognizing the constraints of limited land availability, Singapore has embraced the concept of vertical gardens and green roofs on skyscrapers and residential buildings. This not only enhances the city's aesthetics but also promotes energy efficiency, biodiversity, and improved air quality. Singapore's approach demonstrates that sustainable practices can be seamlessly integrated into the urban fabric, creating environments that are not only aesthetically pleasing but also contribute to the physical and mental well-being of residents (Tan et al., 2021). The city's commitment to vertical green living serves as an example of how sustainable practices can be customized to address the unique challenges of densely populated urban areas.

Portland: Sustainable Urban Planning and Social Equity:

Portland, Oregon, in the United States, showcases a commitment to sustainable urban planning that prioritizes social equity. The city has implemented policies that address housing affordability, public transportation accessibility, and the equitable distribution of resources (Cieszewska, 2000). By fostering a sense of inclusivity and actively involving the community in decision-making processes, Portland aims to create a city where the benefits of sustainable development are shared by all residents. The emphasis on social equity in Portland's sustainable urban planning extends to healthcare accessibility, education, and job opportunities. This comprehensive approach illustrates how a city can weave sustainability and social justice into the very fabric of its development, creating a model that prioritizes the well-being of all its inhabitants.

These case studies illuminate the multifaceted successes that cities can achieve by embracing sustainable practices. Copenhagen, Curitiba, Singapore, and Portland exemplify that sustainable urban development is not a one-size-fits-all approach; rather, it is a dynamic and adaptable framework that can be customized to suit the unique challenges and opportunities of each city. The lessons drawn from these cases go beyond the physical transformation of urban spaces. They underscore the interconnectedness of sustainable practices with public health, emphasizing that cities committed to environmental, social, and economic sustainability invariably nurture healthier and more resilient communities. While sustainable urban development holds immense promise for creating resilient, healthy cities, it is not without its share of challenges. Navigating the road ahead requires a keen understanding of the obstacles that cities face in the pursuit of sustainability and a commitment to innovative solutions. This section explores some of the persistent challenges and proposes future directions to overcome them, ensuring a sustainable and equitable urban future (Larbi et al., 2022).

Urban Sprawl and the Struggle for Density:

One of the foremost challenges in sustainable urban development is the persistent issue of urban sprawl. The expansion of cities into low-density, sprawling developments not only consumes valuable land but also contributes to increased energy consumption, traffic congestion, and reduced accessibility to essential services (Cieszewska, 2000). The struggle for density is a central dilemma; while high-density development can enhance sustainability, achieving it in a way that promotes social equity and preserves green spaces remains a complex task. Future directions involve rethinking urban planning policies to encourage compact, mixed-use developments that prioritize accessibility, public transportation, and green spaces. Incentivizing infill development and repurposing underutilized urban areas can be instrumental in combating the challenges posed by urban sprawl.

Resistance to Change and Stakeholder Engagement:

Resistance to change, whether from policymakers, developers, or the public, poses a significant hurdle on the path to sustainable urban development. Convincing stakeholders to embrace new, sustainable practices often requires overcoming entrenched interests, economic considerations, and cultural norms. The challenge lies in fostering a collective commitment to sustainable goals, recognizing that the benefits may not be immediate but are crucial for long-term urban well-being. Future directions necessitate a focus on stakeholder engagement and education. Promoting the economic advantages, health benefits, and social equity outcomes of sustainable practices can help garner support. Cities must invest in communication strategies that highlight success stories and demonstrate the positive impact of sustainable development on both the environment and the quality of life for residents (Ganeshu et al., 2023).

Inadequate Policy Implementation and Enforcement:

The formulation of sustainable policies is only the first step; their effective implementation and enforcement are equally critical. In many cases, the lack of political will, bureaucratic inefficiencies, or inadequate resources hinders the translation of policy intentions into tangible actions. The challenge lies not just in crafting ambitious policies but in ensuring their robust execution. Future directions call for a revaluation of governance structures, with an emphasis on streamlining processes and enhancing accountability. Cities should invest in capacity-building for municipal agencies, prioritize transparency, and establish mechanisms for ongoing evaluation and adjustment of policies. Collaborations between local governments, non-governmental organizations, and the private sector can also strengthen the enforcement of sustainable urban development initiatives (Howes et al., 2017).

Economic Disparities and Gentrification:

Sustainable urban development, if not executed carefully, can exacerbate economic disparities and contribute to gentrification. As cities invest in green infrastructure and sustainable amenities, there is a risk of displacing lower-income residents and perpetuating social inequities. The challenge is to strike a balance between revitalizing urban areas and ensuring that the benefits of sustainable development are shared inclusively. Future directions require the integration of social equity principles into every facet of sustainable urban development planning. Policies that prioritize affordable housing, protect vulnerable communities, and engage residents in decision-making processes can mitigate the negative consequences of gentrification. Additionally, adopting a holistic approach to economic development, one that fosters job creation and supports local businesses can contribute to more inclusive and equitable urban progress (Eakin et al., 2022).

Interdisciplinary Collaboration and Research Gaps:

Sustainable urban development requires coordination across urban planning, public health, environmental science, and social sciences. These disciplines working in silos make understanding and implementing sustainable practices difficult. Research gaps impede our understanding of urban development's complex effects on health. Future directions emphasize multidisciplinary research and collaboration. Academic, government and non-profit cooperation should be encouraged in cities to better understand sustainable urban development's complex difficulties and potential. Targeted studies that quantify sustainable practices' health, social, and environmental impacts are needed to fill research gaps and guide future efforts. The issues of sustainable urban development are complicated yet manageable. As cities go forward, they must manage urban sprawl, develop stakeholder participation, enforce policies, ensure social equity, and promote interdisciplinary collaboration. These recommendations attempt to make cities more sustainable and egalitarian, so all inhabitants benefit from development. Cities may achieve sustainability that benefits current and future generations by adopting new approaches, learning from mistakes, and adjusting to the changing urban terrain (Roslan et al., 2021).

A Holistic Vision for Future Urban Development:

In the dynamic tapestry of urbanization, the pursuit of sustainable and equitable futures demands a holistic vision that transcends traditional paradigms of development. As cities evolve into complex ecosystems, interwoven with the aspirations and well-being of diverse populations, it becomes imperative to forge a path that harmonizes environmental stewardship, social equity, and economic vitality. The concluding chapter of this narrative explores the principles, aspirations, and transformative potential encapsulated within a holistic vision for future urban development (Bibri & Krogstie, 2019).

Integrating Sustainability into the Urban Fabric:

A holistic vision for future urban development places sustainability at its core, acknowledging that cities are not isolated entities but integral components of the global ecosystem. This vision envisions cities as living organisms, where green spaces are not mere luxuries but essential components that breathe life into urban landscapes. The integration of sustainable practices into the very fabric of urban planning becomes a non-negotiable principle, from energy-efficient buildings to zero-emission transportation systems. Sustainability extends beyond environmental considerations to encompass social equity and economic resilience. The vision is not just about reducing carbon footprints but ensuring that the benefits of development are equitably distributed, creating cities where all residents can thrive. Green roofs, renewable energy sources, and sustainable water management become not just technological innovations but ethical imperatives in this holistic urban paradigm (Mrak et al., 2022).

Promoting Social Equity and Inclusivity:

A holistic vision for future urban development champions social equity as a foundational pillar. It envisions cities where every individual, regardless of socio-economic background, race, or ethnicity, has equal access to opportunities, amenities, and a high quality of life. Affordable housing, inclusive education, and accessible healthcare are not viewed as charitable endeavours but as fundamental rights woven into the urban fabric. The vision sees the city as a space for community building, where public spaces are designed to foster social interactions and cultural exchange. Inclusivity goes beyond eliminating physical barriers; it encompasses policies and initiatives that actively engage diverse communities in decision-making processes. By prioritizing social equity, future urban development envisions cities that are not just demographically diverse but socially inclusive, celebrating the richness of human experiences (Harris et al., 2023).

Fostering Innovation and Economic Resilience:

Holistic urban development embraces innovation as a catalyst for progress and economic resilience. The vision sees cities as incubators of creativity and entrepreneurship, where technological advancements are harnessed to address pressing challenges. Smart cities, driven by data and connectivity, become laboratories for testing innovative solutions to urban problems. Economic resilience in this vision is not solely measured by GDP growth but by the creation of sustainable jobs, the support of local businesses, and the cultivation of a robust urban ecosystem. Future cities are not just economic powerhouses but dynamic hubs that adapt to global changes while ensuring that the benefits of economic prosperity are shared inclusively (Vinod Kumar & Dahiya, 2017).

In the pursuit of holistic urban development, integrating the principles of a circular economy becomes paramount. Circular economies emphasize reducing waste, promoting sustainability, and fostering the continuous use of resources (Saha, 2023). By incorporating circular economy practices, cities can further enhance their economic resilience by creating closed-loop systems, where materials are recycled and repurposed. This approach aligns with the vision of future cities as dynamic hubs, ensuring long-term environmental sustainability and inclusive economic growth (Marchesi & Tweed, 2021).

Educating and Empowering Urban Citizens:

A holistic vision for future urban development places education and empowerment at its forefront. It envisions cities as learning environments where residents are informed, engaged, and actively participate in the shaping of their communities. Sustainability literacy becomes a cornerstone, empowering citizens to make informed choices about their lifestyles, consumption patterns, and civic responsibilities. Education extends beyond formal institutions to community-based initiatives, fostering a culture of continuous learning. Citizens are not passive recipients but active contributors to the ongoing narrative of urban development. In this vision, empowered citizens are essential partners in the co-creation of sustainable, resilient, and thriving cities (Shabalala, 2023).

Collaboration for Global Impact:

The holistic vision for future urban development recognizes that the challenges faced by cities are interconnected and global. It calls for unprecedented levels of collaboration, not only between different sectors within a city but also among cities worldwide. Knowledge exchange, best practice sharing, and collaborative problem-solving become the norm, transcending geographical boundaries. This vision sees cities as interconnected nodes in a global network, where lessons learned in one urban center inform policies and practices in another. The challenges of climate change, public health crises, and social inequities are met with a united front, as cities collectively strive for a sustainable and equitable world (Allam et al., 2022).

Forging a Sustainable and Inclusive Urban Tomorrow:

The holistic vision for future urban development is an inspirational compass that points towards a future where cities are vibrant, sustainable, and inclusive. It envisions a transformative paradigm shift, where the well-being of the environment, the empowerment of communities, and the prosperity of economies are not competing interests but harmonious components of urban development. As cities continue to evolve, this holistic vision serves as a guiding narrative, inspiring policymakers, urban planners, communities, and citizens to collaborate in shaping a future where cities are not just spaces of habitation but living expressions of our collective commitment to a better world. By embracing this holistic vision, we pave the way for cities that transcend the challenges of the present and become beacons of hope, resilience, and progress for generations to come (Bibri, 2021).

Conclusion:

In conclusion, this book chapter has delved into the intricate relationship between sustainable urban development and its profound impact on human health. Through a comprehensive exploration of various aspects, ranging from green infrastructure to equitable access to resources, it becomes evident that well-planned urban environments play a pivotal role in shaping the health and well-being of their inhabitants. As we navigate the challenges posed by rapid urbanization, the imperative to prioritize sustainable practices becomes increasingly apparent. By embracing eco-friendly urban planning, promoting active transportation, and fostering green spaces, cities can foster healthier communities. The interconnectedness of environmental sustainability and human health underscores the need for collaborative efforts from policymakers, urban planners, and the community at large. This chapter serves as a call to action, emphasizing the transformative potential of sustainable urban development in enhancing the quality of life and promoting a resilient and healthier future for all.

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Chapter- 8

Balancing Population Pressure for Sustainable Development: Strategies for a Harmonious Future

Amina Khatun, Somnath Das, Sudipa Mukherjee Sanyal, Himika Deb, Anupam Ghosh

Keywords: Population Pressure, Sustainable Development, Demographic Trends, Inclusive Policies, Technology Integration.

Abstract:

This chapter delves into the critical interplay between population pressure and sustainable development, offering insights and strategies for achieving a harmonious and balanced future. The escalating global population poses multifaceted challenges, impacting resource availability, environmental stability, and socio-economic structures. Recognizing the urgency of addressing these issues, the chapter explores innovative approaches to strike a balance between population growth and sustainable development. The discussion encompasses a comprehensive analysis of demographic trends, emphasizing the need for inclusive policies that prioritize social equity and environmental stewardship. The chapter also examines successful case studies and best practices from various regions, shedding light on effective strategies for managing population pressure while fostering sustainable development. Moreover, the importance of education and awareness campaigns are highlighted as integral components in empowering communities to make informed decisions about family planning and resource utilization. The chapter emphasizes the role of technology in enhancing resource efficiency and promoting sustainable practices. Ultimately, this chapter serves as a valuable resource for policymakers, researchers, and practitioners seeking a nuanced understanding of the intricate relationship between population dynamics and sustainable development. By providing actionable strategies and insights, it contributes to the ongoing discourse of forging a path towards a more harmonious and sustainable future.

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Introduction:

The 21st century is witnessing an unprecedented surge in global population growth, a demographic trajectory that significantly shapes the socio-economic and environmental landscapes. The global population is projected to reach 9.7 billion by 2050. According to the United Nations, the implications of this demographic expansion are profound and multifaceted (NATO Review - Population Growth, 2011). Against this backdrop of burgeoning population, the importance of addressing the associated pressure on resources, ecosystems, and economies becomes increasingly evident. Rapid urbanization, resource depletion, and environmental degradation are only a few facets of the complex challenges that emerge from the exponential rise in global population (Debrah et al., 2021). The strain on food production, energy consumption, and water resources underscores the urgency for a nuanced understanding of how population dynamics intertwine with the broader goals of sustainable development. At the heart of this exploration lies the recognition that addressing population pressure is not merely a demographic concern but a pivotal factor in steering the trajectory of global sustainability (Mani & Goniewicz, 2023; Erfani et al., 2023; Gupta et al., 2023). Balancing the equation between population growth and sustainable development is essential for mitigating the adverse impacts on ecosystems, ensuring social equity, and fostering economic resilience. The impending challenges necessitate a strategic and holistic approach that considers the diverse facets of this intricate relationship (Velenturf & Purnell, 2021; Saha, 2023).

As we delve into the nuanced dynamics of global population growth, the subsequent chapters will unfold the layers of demographic trends, environmental repercussions, and the progress made toward sustainable development goals. We will navigate through the landscapes of inclusive policies, technological innovations, and educational initiatives that hold the potential to reconcile the burgeoning population with the imperative for a sustainable and harmonious future (Das, 2007; Das, 2022). By addressing the intricacies of this interplay, we strive to contribute actionable insights to policymakers, researchers, and stakeholders alike, fostering a collective commitment to chart a course toward a balanced and sustainable global future. This chapter mainly embarks on a comprehensive exploration of the intricate relationship between population pressure and sustainable development, aiming to dissect the challenges and unveil strategies for cultivating a harmonious future.

Demographic Trends: A Global Perspective:

Demographic trends play a pivotal role in shaping the trajectory of global development, and understanding these trends is crucial for crafting effective strategies to balance population pressure with sustainable development goals (Basak & Sanyal, 2022; Basak et al., 2021). A comprehensive analysis of current global population trends reveals a complex landscape with significant implications for the socio-economic and environmental well-being of nations (Bongaarts, 2009). The world's population is currently experiencing unprecedented growth, with estimates suggesting that it has surpassed 7.9 billion people. This surge is not uniform across regions, leading to substantial regional variations and challenges (Population Boom, 2021). While some areas are grappling with rapid population growth, others face the challenges of aging populations and declining birth rates. Sub-Saharan Africa, for instance, is witnessing a population boom, presenting unique challenges for nations in the region (Chand & Tung, 2014). Conversely, many developed countries are dealing with demographic imbalances such as aging workforce and declining fertility rates. These regional variations contribute to a dynamic global demographic landscape, where different parts of the world are at various stages of the demographic transition. The implications of these trends are profound, touching on several aspects of sustainable development (Galor, 2012).

In regions experiencing rapid population growth, the strain on resources becomes more pronounced. This includes increased demands for food, water, energy, and healthcare services. The environmental impact is equally significant, with escalating emissions, deforestation, and habitat degradation associated with burgeoning populations (Mohammad Fakhrul Islam & Karim, 2020). Conversely, in regions facing declining populations, challenges such as a shrinking labour force, increased healthcare costs, and potential economic stagnation come to the forefront. The interplay between demographic trends and sustainable development is a critical consideration (Corlet Walker et al., 2021). The strain on resources and the environment in areas with high population growth rates poses challenges to achieving long-term sustainability goals. Conversely, regions with declining populations may struggle to maintain economic vitality and social support systems, which are essential components of sustainable development (Chu & Karr, 2017).

In addressing these challenges, a nuanced understanding of global demographic trends is vital. Policies aimed at balancing population pressure for sustainable development must be tailored to the unique circumstances of each region. Additionally, international cooperation and knowledge-sharing are essential to develop effective strategies that consider the interconnectedness of the global population (Hariram et al., 2023). The analysis of current global population trends underscores the need for a comprehensive and region-specific approach to balancing population pressure with sustainable development. As we navigate the complex demographic landscape, it is imperative to recognize the diverse challenges faced by different regions and work collaboratively to implement strategies that foster a harmonious and sustainable future for all.

Population Pressure and Environmental Impact:

The escalating global population has profound implications for the environment, exerting pressure on ecosystems and natural resources at an unprecedented scale. This chapter delves into the intricate relationship between population pressure and its environmental impact, shedding light on the critical challenges posed by the burgeoning human population worldwide. With the world's population surpassing 7.9 billion, the strain on the environment is becoming increasingly evident (Maja & Ayano, 2021). One of the primary concerns is the depletion of natural resources. As populations grow, the demand for essentials such as water, food, and energy skyrockets. According to the World Wildlife Fund, humanity's ecological footprint—the measure of how much land and water are required to produce the resources we consume and absorb our waste—has exceeded the Earth's biocapacity since the 1970s. This overconsumption exacerbates deforestation, water scarcity, and loss of biodiversity, contributing to a global environmental crisis (Ruz, 2011). Case studies from various regions underscore the global ecological challenges stemming from population pressure. The Amazon rainforest, often referred to as the lungs of the Earth, is facing unprecedented threats due to population-driven activities like logging and agriculture expansion. Deforestation not only diminishes the rainforest's ability to sequester carbon but also disrupts ecosystems, leading to the extinction of countless plant and animal species (Bakermans & Martín, 2021).

The interconnection between population growth and climate change is a critical aspect of this discussion. The Intergovernmental Panel on Climate Change (IPCC) highlights that population dynamics influence greenhouse gas emissions, with higher populations generally corresponding to increased emissions (Shukla et al., 2019). Rapid urbanization driven by population growth contributes to the expansion of carbon-intensive infrastructure and transportation systems. Moreover, the demand for energy and resources by a growing population intensifies the use of fossil fuels, exacerbating climate change (Chen et al., 2022). In the context of climate change, vulnerable communities worldwide face heightened risks. Small island nations are particularly susceptible to rising sea levels, a consequence of global warming. The displacement of populations due to environmental changes adds complexity to the global challenge of managing population growth sustainably (Mimura, 2023).

India, with its significant and rapidly growing population, provides a compelling case study. As one of the most populous countries globally, India faces immense pressure on its natural resources. The Ganges River, a lifeline for millions, is experiencing pollution and depletion due to population-driven urbanization and industrialization (Cohn, 2014). The need for arable land to sustain the growing population has led to extensive deforestation, impacting biodiversity and contributing to soil erosion. Efforts to address the environmental consequences of population pressure require a multifaceted approach. Sustainable land-use planning, conservation initiatives, and the promotion of eco-friendly technologies are essential components of a comprehensive strategy (Gomiero, 2016). Globally, the transition to renewable energy sources and the promotion of sustainable agricultural practices are critical steps toward mitigating the environmental impact of population growth. The environmental consequences of population pressure are profound and far-reaching. The challenges posed by overpopulation necessitate a global commitment to sustainable development practices (Kumar. J & Majid, 2020). By understanding the interconnectedness between population growth, resource consumption, and environmental degradation, policymakers and communities can work collaboratively to forge a path toward a harmonious future where the delicate balance between humanity and the planet is preserved.

Sustainable Development Goals (SDGs) and Population Dynamics:

The intersection of population dynamics and Sustainable Development Goals (SDGs) constitutes a crucial nexus in the pursuit of a globally sustainable future. As the international community grapples with the challenges posed by an ever-expanding global population, the United Nations has formulated a set of 17 SDGs to address a spectrum of interconnected issues, including poverty, hunger, health, education, gender equality, and environmental sustainability (Kroll et al., 2019; Mukherjee et al., 2022). Within the framework of the SDGs, specific targets directly address population-related concerns. Goal 3: 'Good Health and Well-being' includes targets related to maternal health and family planning, recognizing the intricate link between population dynamics and health outcomes (Guégan et al., 2018). Similarly Goal 5: 'Gender Equality' acknowledges the importance of reproductive rights and access to family planning services in achieving gender parity (Muttreja & Singh, 2018). Additionally, Goal 13: 'Climate Action' underscores the relationship between population growth and environmental impact, advocating for sustainable consumption and production patterns (Fallah Shayan et al., 2022).

A comprehensive assessment of progress towards population-related SDGs reveals both successes and challenges on a global scale. The United Nations Department of Economic and Social Affairs reports that the global population is projected to reach 9.7 billion by 2050, emphasizing the urgency of addressing population-related goals. While there have been notable achievements in improving maternal and child health, significant gaps persist in ensuring universal access to sexual and reproductive health services. Particularly, disparities in access to family planning services persist, with 214 million women in developing regions lacking reliable contraception (Starbird et al., 2016). Additionally, progress towards gender equality in decision-making processes and the elimination of harmful practices, such as child marriage and female genital mutilation, remains uneven. Furthermore, the impact of population growth on environmental sustainability is evident in the escalating demands for resources and the exacerbation of climate change challenges (Khosla et al., 2017). Despite advancements in renewable energy and conservation efforts, the strain on natural resources persists, necessitating a more concerted effort to align population dynamics with sustainable practices (Kabeyi & Olanrewaju, 2022).

India, with its burgeoning population and diverse socio-economic landscape, plays a pivotal role in shaping the global discourse on population dynamics and sustainable development. The country has taken significant strides in aligning its policies with the SDGs, recognizing the intricate relationship between population and development. India's National Family Health Survey (NFHS) indicates progress in improving maternal and child health, with an increase in institutional deliveries and a decline in maternal mortality rates. However, challenges persist in ensuring equitable access to family planning services across all demographic segments (Dubash et al., 2018). The government's commitment to family planning is evident in initiatives like the Family Planning 2020 campaign, which aims to expand contraceptive choices and promote reproductive rights. Despite these efforts, regional disparities and cultural factors continue to influence family planning practices, necessitating a nuanced and region-specific approach (Hardee & Jordan, 2021). The alignment of population-related goals with the SDGs is integral to achieving sustainable development on a global scale. While progress has been made, the complex interplay between population dynamics and sustainable development requires continued commitment, innovative strategies, and collaboration on an international scale. The Indian perspective adds a valuable dimension to this discourse, illustrating the challenges and opportunities inherent in balancing population pressure for a harmonious and sustainable future (Moallemi et al., 2020). As the international community advances toward the 2030 agenda, addressing population dynamics remains a cornerstone for realizing the vision of a more equitable and sustainable world (Herrera, 2019).

Inclusive Policies for Population Management:

Inclusive policies play a pivotal role in navigating the intricate landscape of population management within the broader context of sustainable development. Acknowledging the diverse socio-economic and cultural dimensions that influence population dynamics is essential for crafting effective and equitable strategies. Globally, countries have implemented inclusive policies that emphasize accessibility, education, and healthcare to address the challenges posed by population pressure (Summers & Smith, 2014). Several nations have successfully implemented policies that prioritize inclusivity in family planning and population management. For instance, the Nordic countries, known for their progressive social policies, have witnessed a decline in population growth rates due to comprehensive and inclusive measures. These encompass not only accessible and affordable healthcare but also robust support systems, including parental leave policies and childcare services. In doing so, these nations have demonstrated the efficacy of a holistic approach that considers the interconnectedness of population management with broader societal structures (Kruk et al., 2018).

India, with its vast and diverse population, has embarked on a multifaceted approach to inclusive family planning and population management. The National Population Policy of 2000 laid the groundwork by emphasizing the integration of reproductive health services with broader healthcare provisions (Mathai, 2008). Further, initiatives like the Janani Suraksha Yojana, a maternal health program, and the National Health Mission underscore India's commitment to inclusivity in reproductive healthcare. These programs aim not only to control population growth but also to improve maternal and child health outcomes by providing accessible healthcare services (Mishra et al., 2021). Inclusive policies extend beyond healthcare to encompass education and empowerment. India's focus on education for women, particularly in rural areas, has been instrumental in altering demographic trends. As women gain access to education and economic opportunities, fertility rates tend to decrease, contributing to a more sustainable population trajectory (Upadhyay et al., 2014). The implementation of inclusive policies requires a nuanced understanding of regional disparities and cultural sensitivities. Striking a balance between population management and inclusivity remains a global imperative. As nations navigate the challenges posed by population pressure, the adoption of policies that prioritize inclusivity emerges as a fundamental component of sustainable development in the 21st century.

Technology Integration for Resource Efficiency:

In the quest for sustainable development amid the challenges posed by population pressure, the integration of technology emerges as a pivotal force driving resource efficiency on both global and national scales. Technology, when strategically deployed, plays a transformative role in optimizing resource utilization and mitigating environmental impacts. Globally, numerous exemplars showcase the prowess of technology in fostering sustainability. Smart agriculture, employing precision farming techniques facilitated by sensors and data analytics, has significantly enhanced crop yields while minimizing resource inputs. Precision agriculture practices have reportedly increased global crop yields by 22% while reducing the use of water, fertilizers, and pesticides by 20%, 30%, and 50%, respectively (Dawn et al., 2023b; Singh et al., 2023). In the realm of renewable energy, technological innovations have propelled the transition toward cleaner sources. Solar and wind energy technologies have witnessed remarkable advancements, contributing to a 27% increase in global renewable energy capacity in 2020. The integration of smart grids and energy-efficient technologies further amplifies the impact, fostering a sustainable energy ecosystem (Hassan et al., 2023).

India, too, has fervently embraced technology to address the intricate balance between population growth and resource constraints. The government's ambitious "Digital India" initiative aims to harness the power of technology to bridge developmental gaps and enhance resource efficiency (Addo, 2022). In agriculture, the adoption of mobile-based advisory services has empowered farmers with real-time information on weather patterns, market prices, and crop management practices, leading to improved yields and reduced wastage (Javaid et al., 2022). Moreover, India's Smart Cities Mission leverages technology to enhance urban living while optimizing resource utilization. The integration of smart infrastructure, including intelligent transportation systems, waste management solutions, and energy-efficient buildings, reflects a commitment to sustainable urban development (Prajapati, 2023).

Population pressure can contribute to an increased prevalence of diabetes and cancer through lifestyle factors such as poor dietary habits, sedentary lifestyles, and limited access to healthcare resources. Sustainable healthcare technologies must prioritize affordability, accessibility, and scalability to effectively address the rising healthcare needs of growing populations while minimizing environmental impact (Saha et al., 2022a; Saha et al., 2022b). In the healthcare sector, technology has played a crucial role in improving access and delivery of services. Telemedicine services, especially pertinent in the context of the ongoing global health challenges, have emerged as a viable solution to bridge healthcare gaps, ensuring efficient and widespread medical support (Haleem et al., 2021). As the global community navigates the intricate intersection of population pressure and sustainable development, technological integration stands out as a potent ally. The judicious use of technology not only optimizes resource efficiency but also catalyses a harmonious trajectory toward a sustainable future.

Education and Awareness Campaigns:

Education and awareness campaigns play a pivotal role in addressing the complex relationship between population pressure and sustainable development (Mittal & Jora, 2023; Malhotra et al., 2023). Globally, the significance of education in population management is underscored by its potential to empower individuals, families, and communities with knowledge crucial for informed decision-making (Pauw et al., 2015). In a global context, countries with higher levels of education often exhibit lower fertility rates, emphasizing the correlation between education and family planning. According to the World Bank, nations with improved educational opportunities for women witness a decline in fertility rates. For instance, in Sub-Saharan Africa, where educational access has expanded, fertility rates have decreased from an average of 6.5 births per woman in 1990 to 4.7 in 2021 (Bongaarts, 2020; Chakraborty et al., 2023; Jafar et al., 2023).

In India, a nation grappling with significant population pressure, education emerges as a key instrument for promoting sustainable practices. The National Family Health Survey (NFHS) data indicates that states with higher literacy rates tend to record lower fertility rates. Kerala, a state in India with a robust education system, exemplifies this trend, boasting one of the lowest fertility rates among Indian states (Rangarajan & Satia, 2022). Awareness campaigns further amplify the impact of education by disseminating crucial information on family planning and sustainable practices. On a global scale, initiatives like the United Nations' "World Population Day" and various NGOs' efforts strive to raise awareness about the consequences of unchecked population growth (Misra, 2020). In India, programs like the "Jansankhya Sthirata Kosh" (National Population Stabilization Fund) aim to educate communities about the benefits of smaller family sizes and responsible reproductive choices (Dubbudu, 2015). The impact of education and awareness campaigns extends beyond family planning, influencing broader sustainable practices. Educated individuals are more likely to adopt environmentally conscious behaviors, contributing to a holistic approach to sustainable development (Kioupi & Voulvoulis, 2019). As nations grapple with the challenges of population pressure, investing in education and fostering awareness emerges as an indispensable strategy for steering towards a harmonious and sustainable future.

Future Prospects and Challenges:

As the global population continues its upward trajectory, prospects for balancing population pressure with sustainable development present both formidable challenges and unprecedented opportunities. One of the primary challenges lies in the sheer scale of population growth, particularly in developing regions. According to recent projections, the global population is expected to reach 9.7 billion by 2050, with a significant portion of this increase concentrated in Africa and Asia. This demographic surge poses intricate challenges related to resource allocation, environmental strain, and socio-economic stability (World Population Prospects 2022, 2022). In the face of such challenges, however, lies a unique opportunity to leverage the demographic dividend, especially in regions with a youthful population structure. If harnessed effectively, the youth demographic can drive innovation, economic growth, and social progress. Countries such as India, with a large and youthful population, stand at the forefront of this potential (Ssewamala, 2015). Investing in education and skill development besides creating opportunities for gainful employment can transform the demographic surge into a powerful force for sustainable development.

Moreover, future sustainable development hinges on the integration of advanced technologies and the adoption of eco-friendly practices. Innovations in agriculture, energy, and healthcare can mitigate the environmental impact of population growth. For instance, precision farming technologies can enhance agricultural productivity, reducing the ecological footprint (Dawn et al., 2023a; Dawn et al., 2023b). Similarly, the transition to renewable energy sources is crucial for meeting the increasing energy demands sustainably (Yadav et al., 2023). Policymakers and stakeholders must navigate these prospects and challenges with a comprehensive and forward-thinking approach. Implementing inclusive policies that prioritize education, healthcare, and employment opportunities is imperative. Moreover, international collaboration is essential to address cross-border challenges and promote knowledge-sharing for effective solutions.

So, while managing population pressure presents intricate challenges, the future holds promising opportunities for sustainable development. Strategic planning, innovative solutions, and global cooperation ensure the navigation of demographic landscape towards a harmonious and sustainable future. Policymakers and stakeholders play a pivotal role in shaping this future, requiring a collective commitment to address the complexities and unlock the potential for positive change.

Conclusion:

In conclusion, the intricate relationship between population pressure and sustainable development demands a nuanced and multifaceted approach. As we reflect on the key points elucidated throughout this chapter, it becomes evident that the global population trajectory is at a pivotal juncture, necessitating immediate and concerted efforts to strike a delicate balance. The demographic trends outlined underscore the gravity of the situation, with the world's population reaching an unprecedented 7.9 billion. This surge has far-reaching implications, especially in regions grappling with resource scarcity and environmental degradation. The environmental impact of unchecked population growth is alarming, with statistics revealing that approximately 80% of biodiversity loss and 70% of greenhouse gas emissions are linked to human activities influenced by population pressure.

The alignment of population-related goals with the Sustainable Development Goals (SDGs) highlights the global commitment to addressing these challenges. However, the journey towards achieving these goals is fraught with complexities, with notable gaps and regional variations. In the Indian context, the convergence of population management strategies with SDGs remains a priority, given the nation's population of over 1.3 billion and its ambitious development agenda. Inclusive policies emerge as a cornerstone in mitigating population pressure, and successful case studies from around the globe affirm the positive impact of policies that prioritize social equity and family planning. Notably, India's initiatives in this regard have shown promising results, with comprehensive family planning programs contributing to a declining population growth rate.

Technology integration, exemplified by global advancements and India's strides in leveraging technology for resource efficiency, offers a ray of hope. Innovative solutions have the potential to alleviate the strain on finite resources, fostering sustainability in the face of population pressure.

With education emerging as a powerful tool in shaping attitudes and behaviours, the significance of widespread awareness campaigns cannot be overstated. Globally and in India, education has proven instrumental in empowering communities to make informed decisions about family planning and sustainable practices. In navigating the future, challenges loom large, yet opportunities for sustainable development persist. The key lies in embracing a harmonious approach, considering the delicate equilibrium between population dynamics and sustainable practices. Only through collective and informed efforts can we hope to forge a path forward, ensuring a harmonious and sustainable future for generations to come.

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Chapter- 9

Arth Ganga: A Sustainable Model for Ganga River Rejuvenation

Puja Pal

Keywords: Arth Ganga, Ganges River, River Restoration, Water Management, Sustainable Development.

Abstract:

Ensuring the sustainable growth of the Ganga River is an imperative undertaking that addresses environmental, social, and economic obstacles. The Ganga holds immense cultural and economic significance in India, but it is plagued by several problems, including pollution, excessive water extraction, and habitat deterioration. The Indian Central Government intends to transition from the Namami Ganga Project to the Arth Ganga Project. This shift aims to promote the sustainable development of the Ganga River and its surrounding territories by emphasizing the economic and developmental activities associated with the river. The Arth Ganga Project aims to establish an economic connection between the people of the country and the Ganga River. This study aims to thoroughly examine the Arth Ganga Project, including its idea, distinctive characteristics, objectives, and implementation strategies for the rejuvenation of the Ganga River.

Introduction:

The Ganga River, revered as the lifeline of India, has faced persistent ecological challenges due to pollution, over-extraction, and unsustainable practices (Jhariya & Kumar Tiwari, 2020; Mondal et al., 2022). In response to this critical issue, the concept of "Arth Ganga" emerges as a beacon of hope and a sustainable model for the rejuvenation of the Ganga River. The term "Arth Ganga" encapsulates a holistic approach that extends beyond the conventional understanding of river conservation, emphasizing the inseparable link between economic development and environmental sustainability (Express News Service, 2022). This book chapter delves into the multifaceted dimensions of the Arth Ganga initiative, examining its origins, objectives, and the transformative potential it holds for the Ganga basin. The introductory section provides an overview of the historical and cultural significance of the Ganga River, setting the stage for the urgent need for comprehensive rejuvenation efforts. It also highlights the environmental degradation and water quality concerns that have necessitated innovative and sustainable solutions.

Arth Ganga represents a pioneering and sustainable model for rejuvenating the Ganga River, playing a pivotal role in the circular economy. This initiative integrates environmental conservation with economic development, emphasizing the holistic management of water

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resources. Arth Ganga envisions a circular economy approach by promoting responsible consumption and production, waste reduction, and the efficient use of natural resources (Express News Service, 2022). By fostering eco-friendly practices, this model not only contributes to the Ganga's revitalization but also aligns with broader sustainable development goals. It exemplifies how environmental stewardship can coexist with economic prosperity, offering a blueprint for other regions grappling with river degradation (Saha, 2023).

As we embark on this exploration, it becomes evident that Arth Ganga is not merely an environmental conservation program but a visionary strategy that intertwines ecological well-being with socio-economic development. The chapter aims to unravel the intricate layers of Arth Ganga, elucidating how it integrates sustainable practices, community engagement, and economic growth to create a symbiotic relationship between human activities and the river ecosystem. Furthermore, the introduction addresses the collaborative nature of Arth Ganga, involving stakeholders at various levels, including government bodies, non-governmental organizations, and local communities. By fostering partnerships and aligning diverse interests, Arth Ganga represents a paradigm shift in river rejuvenation efforts, emphasizing the interdependence of environmental sustainability and economic prosperity (Kumar, 2022). In essence, this chapter sets the stage for a comprehensive exploration of Arth Ganga, inviting readers to delve into a transformative model that not only seeks to revitalize the Ganga River but also strives to achieve a harmonious balance between human development and ecological integrity.

Economic and Biodiversity Potential of a River:

The biodiversity potential of each riverine ecosystem contributes to the overall value of the ecosystem services it provides. The economic potential of the system refers to the maximum value that can be obtained from it before the ecological system's collapse (Saha & Sarkar, 2022). In most instances, the overall economic potential will surpass the biodiversity potential. However, to fully maximize the economic potential, it is necessary to achieve a harmonious ecological equilibrium. Hence, it is imperative to regulate the degree of economic value extraction following a sustainable development strategy. This framework provides us with a concrete and systematic instrument to direct all development operations (Hariram et al., 2023; Srinivas et al., 2020). The River Conservation and Biodiversity components of the Ganga River Basin, as well as all other river basins, should be the central focus of all developmental operations. The accompanying image portrays the developmental and conservation goals of the river Ganga system (Das & Tamminga, 2012). This is expected to serve as a paradigmatic example of development not just for other river systems in India but also for river systems worldwide.

Restoration of Ecosystem:

Ecosystem restoration involves helping deteriorated or destroyed ecosystems recover and preserving intact ecosystems (Saha & Sarkar, 2022). Richer biodiversity makes ecosystems more fruitful, generates more wood and fish, and stores more greenhouse gases (Shivanna, 2022). Actively planting or reducing pressures to let nature recover are strategies to restore. It's not always possible or desirable to restore an environment. Farmland and infrastructure are still needed on forest land, and ecosystems, like societies, must adapt to climate change (Gann et al., 2019). Restoration of 350 million hectares of damaged terrestrial and marine ecosystems might provide US$9 trillion in ecosystem services by 2030. The atmosphere might lose 13 to 26 gigatons of greenhouse gases via restoration (UNEP, 2019). Inaction is at least three times more expensive than ecosystem restoration, although such interventions have economic rewards nine times greater than investment (Alikhani et al., 2021). Rivers, forests, farmlands, cities, wetlands, and seas may be restored (Figure 1).

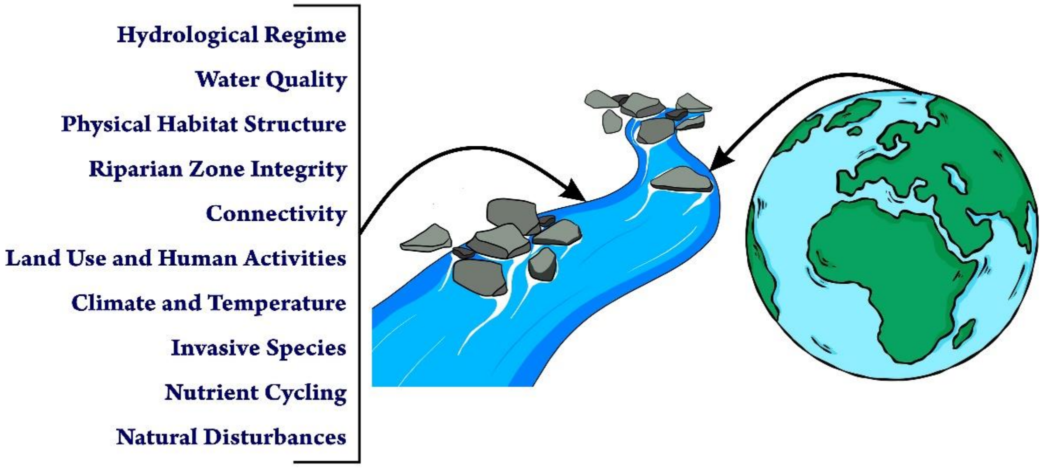

Figure 1. Riverine Biodiversity and its Influencers.

Over the past several decades, numerous significant aquatic species (fishes, dolphins, gharials, turtles, etc.) have perished from the Ganga (Saha & Sarkar, 2022). Now, a river ecosystem's inherent biodiversity is vital to the river basin's functional health and ecosystem services. To comprehend biodiversity changes in the National River Ganga and find ways to restore its ecological balance, one must study the River Ganga ecosystem's dynamics and analyse human and non-anthropogenic influences (Singh & Singh, 2020). Living species (plants, animals, and bacteria) interact with non-living environmental components in an ecosystem. Biological and abiotic components are connected via nutrient cycles and energy fluxes. Photosynthesis provides energy and carbon, while mineral nutrients are recycled. External variables (temperature, geological material, geography, and time) and internal factors (decomposition, periodic disturbances, species competition, and human activities) now regulate ecosystems. Since ecological processes are driven by species kinds, numbers, and relative abundances, species biodiversity is vital for ecosystem functioning (Chakraborty et al., 2023). Ecosystems can be assessed by their benefits to people or by their "ecosystem structure" (measurable qualities of a least damaged or reference state) (Sturbois et al., 2023). Ganga is a varied landscape-scale ecosystem. First, the river crosses three climatic-geographical zones: snow-clad and alpine Himalayas, tropical alluvial plains, and estuary zone and sea. River

Ganga's ecology depends on basin variety within each climate zone (Sharma et al., 2022). The river's ecosystem border may be the river banks, but its biotic and abiotic interactions with its riparian zones, flood plains, and drainage basin are frequently close. The saturated subsurface zone under the river bed forms a unique habitat (called a “hyporheic biotope”) for a diverse group of fauna, provides temporary refuge for aquatic organisms in times of trouble, and processes river nutrients and interacts with groundwater (Chandra & Zoological Survey of India, 2022). Many animals from far and near visit the National River Ganga and its tributaries, which are home to a diverse range of aquatic life from microscopic flora and fauna to larger invertebrates and vertebrates (De et al., 2023).

Potential challenges and threats to the biodiversity of River Ganga:

Human needs have led to the exploitation of riverine ecology. Ecological integrity is being affected and disturbed by significant threats to the Ganga basin and other river basins across the nation (Gupta, 2021).

Disintegration of River Habitats and Alterations to the Flow Regime:

The number of run-of-the-river (ROR) hydroelectric projects in the headstreams of the Ganga has altered the flow patterns. This has resulted in the fragmentation of habitats and changes in the flow regime. These hydroelectric projects have fragmented the river, making it impossible for some important fish, such as *Schizothorax sp.* and *Tor sp.*, to migrate. It is crucial to ensure that the Ganga River network is longitudinally connected and that there are sufficient water and silt flows (Vyas et al., 2023; Kala, 2011).

Alterations in river habitat:

The river's environment and form also change over time due to shifts in the flow regime. Erosion, channelization, and river realignment have resulted from changes in flow direction caused by large-scale gravel and sand mining, dumping of building wastes, and other solid wastes (Jaiswal et al., 2021). These changes alter the flora in floodplains and narrow the stream. Changes in habitat have a devastating effect on the ecosystem. Modifications to benthic flora and fauna, fish breeding grounds, and turtle nesting locations are all results of habitat modification (Jaiswal & Pandey, 2021).

Shrinkage in river habitat:

The ecosystem of river species is experiencing a decline as a result of significant human-induced water diversion from the Ganga River Network throughout the basin. The diversion of river movements is facilitated by several dams and barrages. During wet seasons, river water abstractions are moderate, while during dry flow seasons, they are substantial. Flows through the river channel are significantly diminished during the dry season but remain nearly constant at high levels during the rainy season (Sinha & Kannan, 2014). Over the past two centuries, urbanization and land-use changes in several regions may have increased the rate of peak discharge from the basin into the rivers, thereby elevating river flood peaks. Overall, the hydrological extremes of the river have intensified, thereby increasing the survival pressure on the biota (Amarasinghe et al., 2016).

Riverine Pollution:

The Ganga River downstream of Haridwar is significantly polluted by industrial and domestic pollutants. The pollution reaches a concerning level below Kannauj, specifically at the confluence of the Ramganga and Kali rivers and continues to the least of Varanasi. Extremely high concentrations of pollutants in a river are lethal to its biota (Bhattacharya et al., 2016; Sanyal et al., 2017; Singh et al., 2022).

Invasion of exotic species to river habitat:

Below Prayagraj, the Ganga is invaded by exotic fish such as common carp (*Cyprinus carpio*) and Tilapia (*Oreochromis niloticus*). These fish entered the Sangam through the Yamuna and have proliferated from Prayagraj to Bhagalpur and beyond. They surpass Indian Major Carps (IMC) due to their adaptability to fluctuating flows (Singh et al., 2010). Nine exotic fish species, including Nile tilapia, Thai magur, and grass carp, have been identified in the Ganga. However, the invasion is not limited to the middle and lower reaches. The sighting of another alien fish, the brown trout (*Salmo trutta fario*), downstream of Jhala indicates invasive species presence up to Bhagirathi (Das et al., 2022). Manmade river modifications, to which indigenous species are not acclimated, often give invasive species a competitive edge in river ecosystems. The invasion of exotic species into the Ganga River Network habitat is also a result of human activities. These invasions propagate new illnesses and parasitic organisms, disrupting river ecology. Therefore, it is crucial to control or eradicate the exotic species that have entered the river network (Choudhary et al., 2023; Mukherjee et al., 2022; Sanyal et al., 2023).

Riverine habitat infringement:

From ancient times, humans have utilized floodplains and riverbanks for various purposes. However, contemporary constructions on floodplains and farming on riverbeds during lean flow seasons have led to increased encroachments. The surge in construction on floodplains has modified runoff patterns into rivers, escalated pollution inflows with runoff, diminished groundwater recharge and base flows in rivers, and severed ecological linkages between rivers, floodplains, and floodplain wetlands (Serra-Llobet et al., 2022). Farming on riverbeds and the use of modern chemical pesticides like DDT and HCH have resulted in the contamination of the riverbed, causing harm to aquatic organisms, particularly hyporheic biota, and disrupting upper aquatic animal mating sites (Rad et al., 2022).

Anthropogenic nutrient shortage:

Anthropogenic nutrient shortages in the River Ganga ecosystem have received less attention than anthropogenic pollution. Anthropogenic influences on river nutrient concentrations are called nutrient enrichment, which increases nitrogen (N), phosphorus (P), and other nutrients found in agricultural, household, and industrial wastewaters. Conversely, nutritional deficiencies are commonly missed (Bowes et al., 2020).

Ecosystem Restoration Measures under Namami Gange:

Introduction to Arth Ganga: The Namami Gange campaign, led by the National Mission for Clean Ganga (NMCG), is dedicated to the conservation of the Ganga River and its tributaries. The primary objective of NMCG is to rejuvenate the river, ensuring a continuous and unpolluted flow (Aviral and Nirmal Dhara) while preserving its geo-hydrological and ecological integrity. The holistic approach and innovative features embedded in Namami Gange have positioned it as a pioneering river rejuvenation program, encompassing various aspects such as policy-making, project management, financial planning, investment sustainability, scientific research, knowledge management, institutional development, basin management, and planning (Koshy, 2023). Despite the ambitious goals of river rejuvenation, a significant challenge arises from the lack of scientific evidence, necessitating intensive research investigations. In response to this concern, NMCG has approved basin-based river rejuvenation research programs, as highlighted in the National Mission for Clean Ganga's 2020 report. These research initiatives cover a wide range of subjects, including history, culture, ecology, science, and technology. During a formal virtual presentation at World Water Week 2022 in Stockholm on August 24, 2022, Mr. G. Asok Kumar, Director General of NMCG, discussed the Arth Ganga project. The Arth Ganga initiative focuses on economic and developmental activities related to the Ganga, aiming to sustain the development of the river and its surrounding areas (PIB, 2022).

History and objective of Arth Ganga Project:

The Prime Minister of India announced the concept of Arth Ganga during the inaugural National Ganga Council meeting in Kanpur in 2019. He emphasized the need to shift from the Namami Ganga initiative to the Arth Ganga project model. The primary objective of the Arth Ganga project was to promote sustainable development of the river Ganga and its surrounding communities via targeted economic and developmental initiatives. The Arth Ganga Project tries to use economics to bridge the country’s people with the river Ganga. Arth Ganga is targeted to contribute at least 3% of the GDP (Gross Domestic Product) from the Ganges Basin itself, and the Arth Ganga project’s plans are aligned with India’s commitments toward the UN sustainable development goals (SDGs) (DD News, 2019).

Salient features of the Arth Ganga Project:

Six verticals have been proposed (Figure 2) to fulfil the objectives of the Arth Ganga Project, as outlined by PIB (2023):

Figure 2. Six Verticals of Arth Ganga Project.

- The initial component is Zero Budget Natural Farming, which entails the use of chemical-free or organic farming along a 10-kilometre stretch on both sides of the river Ganga. This initiative also aims to encourage the use of cow dung and organic waste as fertilizers through the GOBARdhan project.
- The second vertical focuses on the monetization and reuse of wastewater and sludge. This involves using treated wastewater for various purposes, such as industrial usage, irrigation, and generating revenue for Urban Local Bodies (ULBs).
- The Arth Ganga Project will include initiatives to generate livelihoods and job opportunities. This will be achieved by establishing habitats where local communities may engage in the sale of medicinal plants, products, and Ayurvedic goods.
- The fourth objective aims to enhance public engagement in the project by fostering collaboration among the stakeholders associated with the river Ganga.
- The Arth Ganga model aims to enhance and facilitate the preservation and promotion of the cultural heritage and tourism of the river Ganga and its surrounding areas. This will be achieved through activities such as boat riding, adventure sports, and the organization of yoga sessions along the riverbanks.
- The Arth Ganga model aims to enhance the institutional framework by empowering local government to effectively administer the water resources of the river Ganga.

The Unique Namami Gange Programme:

A conservation mission, the Namami Gange Programme aims to protect and revitalize the National River Ganga while simultaneously effectively controlling pollution. It was designated as the iconic "Flagship Programme" by the national government in June 2014. This falls under the purview of the Jal Shakti Ministry's Department of Water Resources, River Development, and Ganga Rejuvenation. State Programme Management Groups (SPMGs) are the federal equivalent of the National Mission for Clean Ganga (NMCG), which is implementing the Namami Ganga program. On behalf of the National Ganga Council, NMCG carries out its operational mandate (Figure 3). It comprises around 288 related projects, has a government-financed budget of Rs. 20,000 Cr, and is not a lapsable corpus. Afforestation, riverfront development, biodiversity, industrial effluent monitoring, river-surface cleaning, public awareness, and sewage treatment infrastructure are the primary goals of the Namami program (NMCG, 2020).

Figure 3. Five important pillars of Namami Gange.

The Initiatives of Arth Ganga:

Ministry of Jal Shakti, Govt. of India has proposed multiple new initiatives under the Arth Ganga Project. These are summarized below:

Jalaj Initiative:

Jalaj is being executed in collaboration with the Wildlife Institute of India. WII has established trained Ganga Prahari cadres from among the local populace to promote Ganga rejuvenation and biodiversity conservation (Mohan, 2022). The objective of Jalaj, an innovative mobile livelihood facility, is to synchronize skill development initiatives with the preservation of the Ganga. Jalaj serves as an exemplar for diversifying livelihoods by promoting locally produced goods and encouraging stakeholder engagement in ecological and economic domains to conserve rivers by the objectives of the "Arth-Ganga" initiative (WII, 2023).

Jalaj will achieve two goals: Firstly, to build 75 Jalaj for realizing Arth Ganga in the Ganga River Basin by integrating conservation and livelihoods, and secondly, to raise awareness of aquatic biodiversity conservation. The proposed initiative (Figure 4) would relate local livelihoods to Ganga River basin conservation aims to involve local populations. Local skill sets, raw materials, market, and demands will shape Jalaj's site-specific models, such as knowledge corners, livelihood training and sale points, ecotourism-based safari boats, nurseries, health and wellness centres, sewing and stitching centres, local produce-based food processing units and sale points, etc. The Jalaj model will include resources for aquatic biodiversity protection, livelihood training, and sales centres for trainees' goods (Mohan, 2022; WII, 2023).

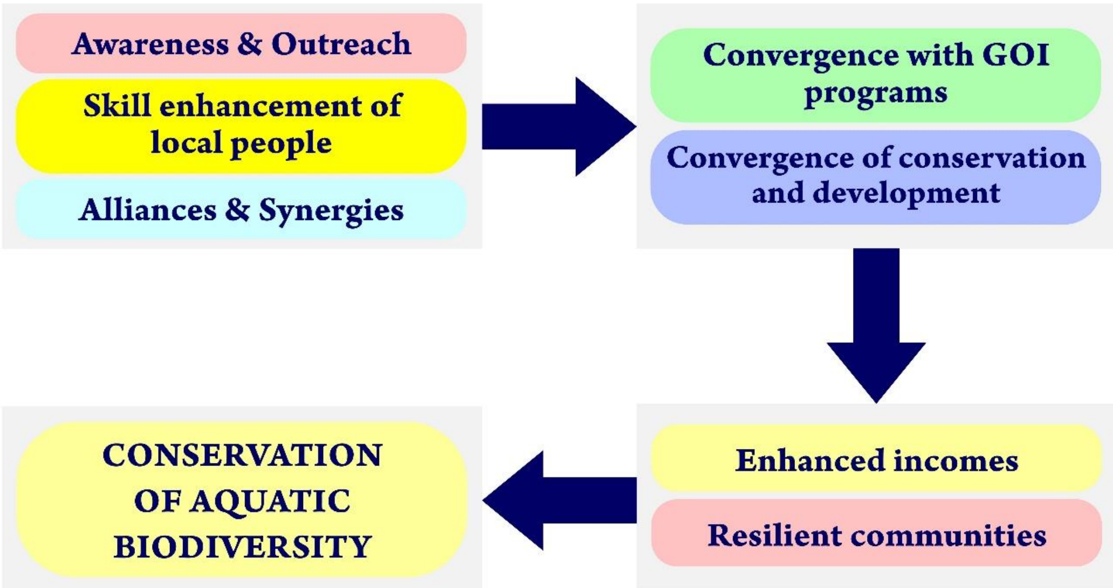

Figure 4. Steps involved in Arth Ganga implementation by WII.

Memorandum of Understanding between NMCG and Sahakar Bharati:

To accomplish sustainable and successful economic growth via public engagement, local cooperative establishment and strengthening, and Arth Ganga mission fulfillment. The MoU proposes naming 75 villages in five states on the main stem ‘Sahakar Ganga Grams,’ promoting natural farming among farmers, FPOs, and Cooperatives in Ganga-affected states to generate ‘More Net-Income Per Drop,’ facilitating the marketing of natural farming/organic produce under the brand Ganga through market linkages and promoting people-river connections through an economic bridge (Gupta, 2022).

Introduction of ImAvatar:

ImAvatar promotes the Arth Ganga program through tourism and the marketing of local agriculture and handicrafts. NMCG and ImAvatar would collaborate on religious and spiritual tourism and market links. The partnership includes digitizing NMCG and Namami Gange's touch points and assets. The launch of the Digital Dashboard for DGCs Performance Monitoring System by the Honourable Union Minister for Jal Shakti, Shri Gajendra Singh Shekhawat on April 6, 2022, was a step towards enhancing public participation, one of Arth Ganga's goals. District Ganga Committee Forum [DGC-4M (Monthly, Mandated, Monitored, and Minuted)] meetings were started to facilitate frequent district-level engagement on Ganga issues, including all stakeholders (Srivastava, 2022).

Initiation of a new course 'River Champ' on CLAP:

Indian river conservation awareness, activities, and discussions are raised online by the continuous learning and activity site (CLAP). Ganga Quest, an online quiz, educates kids and teens about the River Ganga. The Namami Gange Continuous Learning and Activity Portal hosted the Ganga Quest 2022 (APAC, 2022).

Ganga Bhog:

The program also aims to improve the well-being of local women who farm millet by making it easier to prepare healthy 'bhog' in temples. NMCG, in collaboration with the Himalayan Environmental Studies and Conservation Organization (HESCO), has developed a project in Rishikesh called 'Ganga Bhog - Gangotri Se Ganga Sagar Tak' to raise awareness among villagers about livelihood generation. The initiative, which was inaugurated on April 22 as part of Earth Day festivities, is yet another project within the Namami Gange program's 'Arth Ganga' idea. The campaign 'Ganga Bhog' is centered on the '5 Ms': maa (mother), mandir (temple), mitti (land), Mahila (women), and mota-and (millets) (Figure 5). Local women grow millet on the lush soil of the Ganga riverbed and present it as prasad to temples along the river. According to a government news release, the project also aims to improve the well-being of local women who produce millet and to make it easier to provide healthy bhog (a communal meal or offering) at temples. This was done with the United Nations General Assembly's declaration of 2023 as the 'International Year of Millets' in mind (Mishra, 2023).

Economic activity in the light of Arth Ganga:

"Arth-Ganga" will coordinate Ganga River business activities. Developing streams affect the ecosystem and riverbanks. Shri Mansukh Mandavia remarked that executing Narendra Modi's slogan of "Reform, Perform, and Transform" will quadruple Ganga cargo capacity with a concentration on interior waterways. Arth-Ganga will enhance farmers, small traders, and communities' economic growth and inclusion. Shri Mansukh Mandaviya, Shipping (Independent Charge), Chemicals, and Fertilisers Minister, said at the press conference that Inland Waterways is one of the most significant foundations of the "Arth-Ganga" project, which would lead to inclusive growth and huge job prospects in the National Waterways length. Shri Mandaviya observed, "Almost half of the Indian population lives around the Ganges River belt, in which about 1/5th of all India's freight originates and 1/3rd terminates in the states around the Ganges Belt." In recent years, the Ministry of Shipping has taken many measures that have increased Inland Cruises from 3 to 9, Cargo from 30,00,000 MT to 70,00,000 MT, and Vessel's flow from 300 to 700. The Ministry of Shipping has developed modest jetties for farmers, traders, and the public throughout the 1400 km National Waterway-1 from Banaras to Haldia. Farmers will obtain a higher return on their crops since shipping will be easier and cheaper. It will boost 'Ease of Living' and 'Doing Business.' The Inland Waterways Authority of India (IWAI) is using tiny floating jetties and ten Ro-Ro vessels to deliver commodities more efficiently and cheaply (Sagarmala, 2021). According to the report, the Ministry of Shipping is investing Rs. 200 crores in Varanasi (Uttar Pradesh) Freight Village and Sahibganj (Jharkhand) Industrial Cluster-cum Logistics Park to work with Inland Waterways. This will strengthen the local economy by creating massive direct and indirect jobs. National Waterway-1 would connect Varanasi to Nautanwa (280km), Kaughat to Raxaul (204km), and Sahibganj to Biratnagar (233km) in Nepal. Previously, Kolkata and Visakhapatnam Ports transported freight from Nepal. Under the Treaty for Transit of Cargo between India and Nepal, inland waterways, especially NW-1, would be authorized. It would reduce logistics costs and decongest Kolkata Port (Sagarmala, 2021).

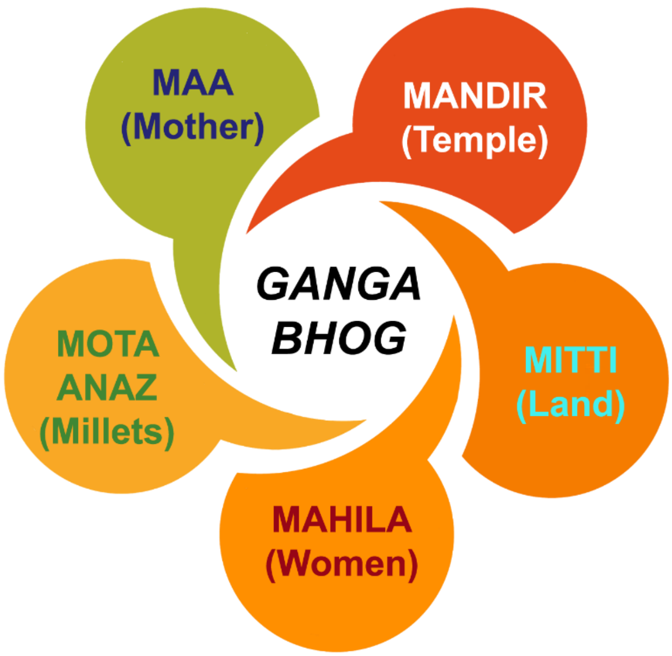

Figure 5. Ganga Bhog Concept under Arth Ganga Project.

Arth Ganga Campaign:

Clean Ganga Mission Encourages Farmers to Practice Zero-Budget Natural Farming. NMCG organized a field trip for approximately 30 farmers from the Ganga Basin (Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, and West Bengal) to Subhash Palekar Natural Farming (SPNF) to promote the adoption of natural farming practices as part of the Namami Gange initiative (Dwivedi, 2022). Subhash Palekar, a distinguished agriculturist recognized by the farming community as 'Krishi ka Rishi,' is well-known for his advocacy of the 'Zero Budget Natural Farming' approach, referred to as Subhash Palekar Farming in India. The workshop camp was held in August 2023. The objective of facilitating farmers for the workshop as part of the Namami Gange Programme is to effectively address the issue of polluted water from farms entering the River Ganga. Additionally, it aims to provide a viable and sustainable livelihood framework for farmers through the adoption of natural farming practices, aligning with the Arth Ganga initiative. NMCG also coordinated a training-cum-workshop event in Shirdi, Maharashtra, where farmers were encouraged to embrace zero-budget natural farming as a component of the ‘Arth Ganga Campaign’ (Bhagwat, 2019).

Conclusion:

In conclusion, the sustainable development of river ecosystems, such as the Ganga, demands a comprehensive and collaborative effort across various sectors. Balancing economic activities with environmental conservation is paramount to ensure the longevity of these vital waterways. The multifaceted approach of the Arth Ganga Project, as outlined in the present findings, encompasses water quality management, biodiversity conservation, water resource management, community engagement, preservation of cultural heritage, effective governance, and continuous research and innovation, providing a roadmap for achieving sustainability. The sustainable development of rivers is not merely an environmental imperative but also a prerequisite for the well-being of communities relying on these water bodies. By embracing the Arth Ganga strategies, we can strive to strike a harmonious balance between human activities and the preservation of the invaluable ecosystems that rivers represent. In doing so, we can secure a healthier, more resilient future for both rivers and the diverse life forms they support.

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Chapter- 10

A Concise Approach to Health and Sustainable Development

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Keywords: World Health Organization, SDG, UNESCO, Sustainable development, Universal Health Coverage.

Abstract:

The developmental pace of human civilization can be sustained through quality healthcare services, along with an accelerated rate of economic growth, by raising the perception of sustainability in society. The World Health Organization, in this context, defines the term 'health' as a 'particular state of human beings where three parameters of well-being, namely physical, psychological, and social function, are simultaneously provided without the existence of any diseases.' It is undeniable that the progress of human society can be nourished only through fulfilling the goal of ending poverty and inequality. As sustainable development contributes a major part to human development, priority should be given to environmental protection. However, the dismal fact is that in many third-world as well as second-world countries, humans are still victims of discriminating factors grounded in worldwide socio-economic settings. The injustice and inequalities against them for a long period produce a detrimental retrogression of their health. In this connection, the physical and mental well-being of humans demands a lot of attention for attaining sustainable development throughout the world according to SD-Goal-3.

Introduction:

The true meaning of sustainability is 'that can be maintained', and the meaning of development is 'the act or instance of growth'. 'Sustainable Development (SD)' was first introduced and developed by The World Commission on Environment and Development in a seminar report entitled "Our Common Future" in 1987. The main function of this report was to create mass awareness for sustaining the Earth's life support system with proper scientific management (Mensah, 2019). SD may be defined as meeting or fulfilling the needs of present generations without compromising the needs of the next generations. The concept elaborates on using planetary resources judiciously and immediately compensating for their uses. So, we can understand sustainable development as something that has to do with the long durability of resources, species of Earth, ecosystems, commodities, etc. This type of give-and-take policy will result in maintaining the Earth's balance between resource generation and resource

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consumption (Elsawy & Youssef, 2023). UNESCO's recent report shows the ultimate goal of SD is to construct a properly balanced Man and Biosphere relationship. The modern concept of SD has a focus on social development, economic development, and environmental protection for the future. Goals 1, 2, 3, 4, and 5 - all are relevant and interlocked, aiming to achieve good health for all on this planet (Elbakidze et al., 2013; Kaur et al., 2023).

Goals of SD:

The voice was raised around the world on educational improvement, poverty eradication, inequality elimination, and climate change. The environmental leaders of the world gathered on Sep. 25, 2015, at the UN in New York to adopt an agenda to be completed by 2030 for SD (Oluwasuji, 2023). In this agenda, 17 new Sustainable Development Goals were established. The original concept of SDGs was derived from the UN Conference on SD held at the Rio Conference in 1992, where Agenda-21 was also adopted. The main objectives of this conference were to create and establish a set of universally applicable goals that balance three main backbones of society, i.e., environmental, social, and economic perspectives (Shi et al., 2019). The 2030 agenda for SD adopted 17 Goals that form a collaborative and integrated approach among the countries of global partnerships to achieve the three corners of SD – economic growth, environmental sustainability, and social inclusion (Mishra et al., 2023).

Health and SD in Global Scenario:

Development that can satisfy the demands of present generations without posing an ultimatum to future generations is called sustainable development (Mukherjee et al., 2022). The term ‘ultimatum’ refers to the formation of environmental, social, and economic crises due to irrational decisions made for the benefit and profit of present generations only. Therefore, any developmental activity must be carried out through sustained use of available resources, enabling our descendants to meet their needs as well (Polasky et al., 2015; Ghosh et al. 2022; Erfani et al., 2023). Our future is already in danger due to the overuse of non-renewable natural resources that cannot be replenished. Hence, we must keep an adequate amount of fund resources for our future use. Thus, sustainable development can be achieved only through the use of renewable resources like hydroelectricity, geothermal energy, wind energy, solar energy, etc (Holden et al., 2014). Accordingly, sustainable development is nothing but the maintenance of a balance between the present and future generations' needs by employing several new inventions for the betterment of the environment, society, and economy internationally (Fallah Shayan et al., 2022).

Health and Sustainable Development in Indian Scenario:

Indian storyline depicts a progressive picture towards achieving Sustainable Development Goals. The United Nations General Assembly (UNGA) Summit in New York, in September 2015, put forth 17 goals and 169 of its targets to achieve a secure world by 2030. To acknowledge the Agenda 2030 for Sustainable Development (SD) 193 member states of the

United Nations came forth to raise voice for human rights (Unesco. et al., 2021). To reduce adverse effects on human health, mainly rural poverty should be alleviated, and access to necessary food procurement should be ensured. Among the 17 SDGs, the 1st Sustainable Development Goal (SDG-1) is 'No Poverty,' which is indirectly interlinked with human health and the intent to annihilate poverty from its root (Atukunda et al., 2021). To achieve success in this goal, the Indian government launched the Food for Work Programme (FWP) in 1977-78, which was later restructured as the National Food for Work Programme in 2001. Presently, the Food for Work Programme functions as a component of the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), which confirms at least 100 days of the "right to work" for the poor in rural areas for their livelihood security (Swapna, 2018). Besides this, Swaranjayanti Gram Swarozgar Yojana, Sampoorna Grameen Rozgar Yojana, Pradhan Mantri Gramodaya Yojana, and Rural Employment Generation Programme are the most important driving schemes to eradicate poverty and generate employment, which, in turn, lifts the purchasing power capacity of the rural poor. Thus, increased income normally assures good health (Gupta, 2016).

The second goal of Sustainable Development is Zero Hunger, which is directly related to promoting regenerative agriculture. Lowering CO_2 emissions through the use of environmentally friendly appliances by 38 million tons annually, as well as supplying clean cooking fuel (e.g., LPG) to 80 million poor households, clearly reveals India's credibility towards sustainable development by controlling health hazards. An accelerated rate of investment is required to combat poverty, which has a direct effect on human health. The National Institution for Transforming India (NITI Aayog) has the twin-concern authority to supervise the adoption and monitoring of the SDGs in the country and proactively realize the goals and targets (Voluntary National Review, 2020).

SDG-1(No Poverty) and SDG-2 (Zero Hunger):

Goal 1- Although poverty can manifest in many dimensions, its causes stem from unemployment, social exclusion, disasters, and diseases. That's why SDG 1 proposed 7 targets based on income poverty, including 1.1 and 1.2. Target 1.1 is focused on exterminating acute poverty; the second, bringing down poverty by at least 50%; the third, implementing a social protection system; the fourth, ensuring equal rights to ownership, basic services, technology, and economic resources. Target 1.5 aims to build resilience to environmental, economic, and social disasters (Küfeoğlu, 2022). The sixth target is to mobilize resources to implement policies to end poverty. The next one is to create pro-poor and gender-sensitive policy frameworks. Investment in all these poverty eradication actions is the need of the hour, as over 10% of the world's population still lives in extreme poverty, i.e., surviving on less than $1.90 per person per day (Tladi, 2022).

Goal 2- This goal is indirectly connected with health. The objective of this goal is to end starvation and malnourishment by 2030. The UN has formulated 8 targets for SDG-2, where food-related access, malnutrition, markers, production systems, agricultural practices, diverse genetic forms of seeds, cultivated plants, domesticated animals, research, and technology, etc., are to be noted. The paucity of connected or coordinated activity from food production to utilization at all levels hampers progress on SDG 2 (Saha, 2023; Haziqah Syafiqah Juhari, 2021; Katoch, 2024).

Sustainable Development Goal-3 (Good Health and Well-Being):

SDG-3 is concerned with "Good Health and Well-being", formulated by the United Nations in 2015. It is the third goal of the 17 Sustainable Development Goals, with the mission statement: Ensure healthy lives and promote well-being for all at all ages". It comprises reproductive, maternal, newborn, child, and adolescent health, including communicable and non-communicable diseases. In addition to these, Universal Health Coverage (UHC), which encompasses safe, effective, affordable, and quality medicines and vaccines, falls under the purview of this goal (Qu et al., 2023). SDG 3 aims to avert undesirable distress from avoidable diseases and untimely deaths by focusing on the objective of improving both the physical and mental health conditions of the country's overall population, as well as their well-being. Sustainable development is directly related to the good health and welfare of all age groups worldwide (Singh Thakur et al., 2021). The spread of the COVID-19 pandemic has resulted in severe human affliction associated with deaths, impeding the progress of the goal significantly (Kalal & Charola, 2021). Countries with a high concentration of diseases and marginalized groups of the population have become the priority areas of Goal 3, requiring significant investments in research, health issues, mortality reduction, and overall supervision (Khattak et al., 2023).

Relation between SDG-3 and SDG-5:

There exists a strong relationship between Sustainable Development Goal-5 and Sustainable Development Goal-3, as Gender Equality and the empowerment of all women and girls depend on Well-being and Good Health (Leal Filho et al., 2023). But how are these two goals interrelated? SDG-5 has nine targets to achieve gender equality. By 5.1, Ending all forms of discrimination against women and girls everywhere, and next, Eliminating all forms of violence and exploitation of women and girls; 5.3- Eradicate early forced marriage and female genital mutilation or harmful practices, and in the fourth corner, Value unpaid care and promote shared domestic responsibilities; 5.5- Ensure full participation in leadership and decision-making, and next also, Universal access to reproductive rights and health; 5.7- Equal rights to economic resources, property ownership, and financial services; 5.8, and it is to promote the empowerment of women through technology, and the last one, adopt and strengthen policies and enforceable legislation for gender equality (Karim et al., 2023). The targets of SDG 3 aim to ensure healthy lives and promote well-being for all at all ages, which includes Maternal mortality, Neonatal and child mortality, Infectious diseases, Non-communicable diseases, Substance abuse, Road traffic, Sexual and reproductive health, Universal health coverage, and Environmental Health (A. Durokifa, 2021; Saha et al., 2022a; Saha et al., 2022b; Saha &

Khatua, 2024; Saha et al., 2023). SDG 3 is directly and indirectly interconnected with several targets of SDG 5. It is undeniably true that good health and well-being are unachievable without boosting gender equality and women's empowerment globally (Kuhlmann et al., 2022).

Relation between Health Education and SDGs:

The main goal of SD is human resource development, and all aspects are related to different areas of education, such as health and environment, education for SD, peace education, vocational education, higher education, etc. EE and health education for SD focus on a particular field of specialization, specifically instructing us to protect natural resources and nature. The utilization of resources, the rate of production of resources and mental and physical fitness must be considered (Sarkar et al., 2022; Krishnamurthy & Sahay, 2023). The concerned organizations are fully responsible for maintaining the practice of the course and curriculum in our educational system to achieve the SDGs. With such diverse attention to achieving this goal, it is hoped that heartfelt efforts will bring a sound rate of environmental literacy and a positive attitude towards the environment and different burning environmental issues (*Educazione agli obiettivi per lo sviluppo sostenibile*, 2017). Education is the fundamental component for achieving SD worldwide. It acts as a positive catalyst in the proper management of resources through the incorporation of successful scientific techniques. Education instils knowledge, spirit, skills, intelligence, efficiency, and experience within students, which will help them become good leaders, decision-makers, and responsible environmentalist citizens in society (Pauw et al., 2015).

Universal Health Coverage (UHC):

People at all levels have access to a full scale of quality health services when and where they require them without monetary hardship. Presently, the global community has renewed its commitment to reach Universal Health Coverage worldwide. It is time for immediate and tangible action to make progress on the right track (National Academies of Sciences et al., 2018). Political leaders should enact policies that ensure equitable access to essential health services without economic hardship and that ensure good health and well-being is not an advantage for a few but a right for all. Countries must contribute to a resilient and fair health system with primary health care as the foundation and make universal health coverage a reality (Kruk et al., 2018). India foresees its path towards UHC, which is based on an assured range of extensive primary health care associated with vigorous secondary and tertiary protection, with rapid public investments crucial to this approach. Every 12th December is observed as UHC Day to call for strong and equal health protection that leaves no one behind (Kumar & Roy, 2016).

Some healthy steps for a healthy environment:

- Water conservation and management;
- Develop a rainwater harvesting system;

- Follow artificial groundwater recharge techniques;
- Enlarge watershed management techniques in semi-arid areas;
- Increase the area of ecologically unstable wasteland by implementing afforestation, reforestation, agro-forestation, social forestation, and joint forest management concepts;
- Use the rate of consumption of renewable energy;
- Resettle and rehabilitate refugees;
- Abide by environmental ethics;
- Express concerns regarding the terrible performance of global warming and drastic climate change;
- Adhere to the laws and legislations of the Environmental Protection Act (1986);
- Address issues involved in the enforcement of environmental legislation; etc.
- Green environment and green building for all.

Significance of quality health education & SD:

A quality health education provides strong support in acquiring a magnificent order of thinking and learning, thus creating healthy capabilities to analyze, synthesize, and evaluate complex facts in decision-making, planning, and problem-solving for achieving sustainable development (SD). Some initiatives were taken to fulfill the Millennium Development Goals (MDGs) in the year 2000, with the main focus on education in formal, non-formal, and informal forms as an essential mechanism to achieve SD (Hariram et al., 2023). It was believed that education would bring advanced changes in the teaching-learning process, fostering a thinking approach that stimulates learners to ask questions, analyze, engage in critical thinking, and make decisions that are less competitive more cooperative, and learner-centric (Sellars et al., 2018). Health education is essential for all in this aspect, contributing to creating a better and more secure world for subsequent generations. This will help live for people in a better and more secure world for subsequent generations. To measure improvements in education-based outcomes, there is an emphasis on holistic development (Kumar & Preetha, 2012).

Conclusion:

Despite numerous conservation efforts taken so far, our environment is becoming increasingly poorer than before. The prospect of drastic changes raises some basic questions about the present world, where we will bequeath nature and natural resources to future generations. Our present lifestyle must be reoriented and reshaped to rectify the damage done in the past by our ancestors. In terms of technological advancement, the present world is much better than in previous years, and it will be even better in the upcoming tomorrow than in the current condition. Universal Health Coverage (UHC), which is based on an assured range of extensive primary health care associated with vigorous secondary and tertiary protection through rapid public investments, is crucial to this approach. We need to foster environmentalism, environmental ethics, and eco-feminism attitudes within ourselves and others, which will contribute to a healthier future for our descendants. In the past two decades, considerable efforts from research fellows, environmentalists, environmental scientists, ecologists, social scientists, geologists, geographers, and demographers have taken initiatives to combat various burning environmental issues (e.g., population growth, biodiversity loss, habitat destruction, ozone layer depletion, environmental pollution, low mortality rate, global climate change, food and energy insecurity, etc.). This has been done with the help of both governmental and non-governmental organizations (NGOs) at primary, secondary, and tertiary levels. Although countries have taken initiatives to achieve zero population growth status, this situation is still unstable or absent. Nations' breakthrough works and efforts have succeeded in the dimension of renewable energy production, agro and social forestry creation, better advancement of pollution control technologies, increases in mass awareness, elimination of poverty and illiteracy, reduction of resource wastages, etc. These efforts will help make our planetary environment a much healthier place to live together in a harmonious rhythm. We all should recognize these efforts personally and collectively to protect our nature and natural resources, which, in turn, protect our health.

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Chapter- 11

Sustainable Healthcare: Medicinal Plants and Environmental Balance in Ayurveda

Sujit Maity

Keywords: Sustainable Healthcare, Medicinal Plants, Complementary and alternative medicine (CAM), Biomedicine, Biodiversity Conservation.

Abstract:

The intersection of traditional healing practices and sustainable healthcare is exemplified in the rich tapestry of Ayurveda, the ancient Indian system of medicine. At its core, Ayurveda relies on the therapeutic properties of medicinal plants, emphasizing a holistic approach to well-being that extends beyond individual health to encompass environmental harmony. The sustainable ethos of Ayurveda begins with the cultivation of medicinal plants. Practices such as regenerative agriculture, ethical harvesting, and biodiversity conservation ensure that the use of these plants is not only curative but also environmentally responsible. By integrating such practices, Ayurveda fosters a symbiotic relationship between human health and the well-being of the planet. Ayurveda's commitment to environmental balance extends to the principles of community engagement. Local communities are often involved in the cultivation and preservation of medicinal plants, instilling a sense of responsibility for environmental stewardship. This not only enhances the sustainability of healthcare practices but also strengthens the connection between individuals and their natural surroundings. The eco-friendly processing methods employed in Ayurveda contribute to the reduction of environmental impact. By minimizing waste and energy consumption in the production of medicinal formulations, Ayurveda aligns itself with the global call for sustainable and responsible healthcare practices. In essence, the philosophy of Ayurveda transcends the boundaries of individual health, recognizing the interdependence of human well-being and environmental vitality. Through the utilization of medicinal plants and adherence to sustainable principles, Ayurveda offers a timeless and holistic model for healthcare that not only heals the individual but also nurtures the planet.

Introduction:

In the quest for a healthcare paradigm that harmonizes with the principles of environmental sustainability, the ancient wisdom of Ayurveda emerges as a beacon of holistic healing. Grounded in the profound connection between nature and human well-being, Ayurveda places medicinal plants at the forefront of its therapeutic arsenal (Rastogi & Kaphle, 2011; Bhattacharjee, 2021; Kalal & Charola, 2021; Kar et al., 2022). This exploration delves into the intricate relationship between sustainable healthcare and the utilization of medicinal plants within the Ayurvedic framework. As the world grapples with the imperative of ecologically conscious healthcare, Ayurveda stands as a timeless testament to the symbiotic alliance between medicinal plants and environmental equilibrium (Kumar et al., 2017; Saha et al.,

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2022a). This journey unfolds the layers of sustainable cultivation, ethical harvesting, biodiversity conservation, and community engagement, encapsulating the essence of Ayurveda's contribution to the interwoven tapestry of human and environmental health.

Cultivation practices:

Cultivation practices play a pivotal role in the sustainability of Ayurveda, the ancient system of medicine rooted in nature's healing powers. At the heart of Ayurveda lies the utilization of medicinal plants, and the methods employed in their cultivation reflect a profound commitment to environmental well-being (Pandey et al., 2013; Saha & Khatua, 2024). This essay explores the sustainable cultivation practices embedded in Ayurveda, illustrating how they ensure a continuous and environmentally friendly supply of medicinal plants. Ayurvedic cultivation methods are deeply rooted in the principle of harmonizing with nature. This involves understanding the specific ecological requirements of each medicinal plant and tailoring cultivation practices to mimic its natural habitat. By doing so, Ayurveda not only ensures the health and potency of the plants but also maintains the delicate balance of the surrounding ecosystem (Jaiswal & Williams, 2017).

Ayurvedic cultivation leans heavily towards organic farming techniques, minimizing the use of synthetic fertilizers and pesticides. The emphasis is on enhancing soil fertility through natural means, promoting long-term sustainability, and preventing harm to the environment. This commitment to organic practices aligns with the growing global awareness of the importance of chemical-free agriculture (Tahat et al., 2020). To mitigate the risk of soil degradation and pest infestations, Ayurvedic cultivation often employs crop rotation and polyculture. This diversified approach not only fosters a healthier soil structure but also reduces the need for chemical interventions. It reflects a holistic understanding of the interconnectedness of various plant species and their reciprocal benefits in maintaining ecological balance (Shah et al., 2021).

Ayurveda places great importance on the use of native medicinal plants, recognizing their adaptability to local conditions. Cultivating and conserving these native species not only ensures a sustainable supply but also contributes to the preservation of biodiversity. Ayurvedic practitioners often actively engage in the conservation of endangered plant species, acknowledging their intrinsic value in maintaining the richness of natural ecosystems (Kumar et al., 2017; Saha et al., 2022b; Darro & Khan, 2023; Sarkar et al., 2023). Aware of the critical role water plays in cultivation, Ayurveda emphasizes efficient water management practices. This includes rainwater harvesting, drip irrigation, and other water-conserving techniques. By optimizing water usage, Ayurvedic cultivation minimizes its environmental footprint and addresses the increasing global concerns related to water scarcity.

Biodiversity Conservation:

Ayurveda, the ancient Indian system of medicine, stands out for its profound understanding of the interconnectedness between human health and the well-being of ecosystems. One of the distinctive features of Ayurvedic formulations is the extensive use of diverse plant species, a practice that addresses not only individual health concerns but also actively contributes to biodiversity conservation and the overall health of ecosystems (Pandey et al., 2013). Ayurvedic formulations are characterized by their reliance on a wide array of plant species, each chosen for its unique therapeutic properties (Katiyar et al., 2012). Traditional texts, such as the Charaka Samhita and Sushruta Samhita, provide detailed insights into the use of herbs, roots, leaves, and fruits from diverse plants (Saha et al., 2022a). This diversity ensures a comprehensive approach to healing, as different plants target various aspects of health and well-being (Sharma, 2016; Sarkar et al., 2016; Sarkar, 2017). Ayurveda, as a system of medicine, has preserved and transmitted indigenous knowledge about the uses and benefits of various plant species over centuries. This knowledge is not only a testament to the deep connection between communities and their environments but also serves as a reservoir of information for sustainable practices in herbal medicine (Chaudhary & Singh, 2012; Raha et al., 2022; Shriwas & Sharma, 2023).

The inclusion of a wide variety of plants in Ayurvedic formulations inherently encourages the conservation of rare and endangered species. As Ayurvedic practitioners recognize the value of each plant in maintaining balance, efforts are made to cultivate, rather than exploit, these species. This approach aligns with modern conservation principles and contributes to the protection of vulnerable plant populations (Nishteswar, 2014). The diversity of plant species used in Ayurvedic formulations reflects an understanding that ecosystems thrive when they are resilient and multifaceted. By incorporating various plants, Ayurveda acknowledges the role each species plays in supporting the overall health and resilience of ecosystems. This is particularly relevant in the face of environmental challenges, where diverse ecosystems exhibit greater adaptability (Sharma, 2012; Sarkar et al., 2021).

Ayurveda emphasizes sustainable harvesting practices, ensuring that the gathering of medicinal plants does not deplete natural populations. This approach involves ethical harvesting, encouraging the replanting of harvested species, and promoting cultivation over wild harvesting. These practices contribute to the longevity and sustainability of plant populations in their natural habitats (Maiti et al., 2010, 2013; Manohar, 2012; Banerjee et al., 2014). Modern scientific research increasingly supports the biodiversity-centric approach of Ayurvedic formulations. Studies on individual plant species and their synergistic effects within formulations have demonstrated not only their therapeutic benefits but also their potential role in ecological conservation. This scientific validation reinforces the relevance of Ayurveda in contemporary discussions on biodiversity and ecosystem health (Nedungadi et al., 2023).

Ethical Harvesting:

Ayurveda, the ancient system of medicine, not only harnesses the healing power of medicinal plants but also underscores the paramount importance of ethical harvesting practices. This commitment aims to prevent over-exploitation and depletion of natural resources, safeguarding the delicate balance of ecosystems. The significance of these practices resonates not only with the principles of Ayurveda but also finds validation in contemporary research and global conservation efforts (Jaiswal & Williams, 2017).

Ethical harvesting practices in Ayurveda prioritize the preservation of biodiversity. By ensuring that only a sustainable quantity of medicinal plants is gathered, Ayurveda contributes to the maintenance of diverse ecosystems. This aligns with global biodiversity conservation goals, acknowledging the interconnectedness of plant species in sustaining ecological health (Alves & Rosa, 2007). Ayurveda emphasizes sustainable resource management through ethical harvesting. This involves considerations such as selective harvesting, seasonal timing, and leaving adequate plant populations for natural regeneration. These practices ensure a continuous supply of medicinal plants without compromising the integrity of the ecosystems (Sheldon et al., 1997). Ethical harvesting not only benefits the environment but also has positive socio-economic implications. By ensuring responsible gathering practices, Ayurveda supports the livelihoods of local communities dependent on medicinal plant resources. This dual focus on ecological and human well-being exemplifies the holistic approach inherent in Ayurvedic principles (Chen et al., 2016).

Ethical harvesting practices in Ayurveda often involve efforts towards regeneration and reforestation. Ayurvedic practitioners and communities actively participate in planting medicinal plants, contributing to the restoration of habitats, and ensuring a sustainable supply for future generations. Ayurveda acknowledges the necessity of a legal framework to enforce ethical harvesting practices (Astutik et al., 2019). The World Health Organization (WHO) has provided guidelines on good agricultural and collection practices (GACP) for medicinal plants, emphasizing sustainable and ethical practices.

Regenerative Agriculture:

Ayurvedic principles seamlessly align with regenerative agricultural practices, placing significant emphasis on soil health. Ayurveda recognizes the soil as a living entity, and its well-being is considered fundamental to the vitality of medicinal plants. Regenerative practices advocated in Ayurveda include the use of organic fertilizers, crop rotation, and the incorporation of natural amendments (Newton et al., 2020). By prioritizing soil health, Ayurveda contributes to enhanced nutrient availability and resilience in the agricultural ecosystem. Ayurveda underscores the interconnectedness between soil health and the vitality of medicinal plants. Regenerative agricultural practices recommended in Ayurveda aim to enhance the overall well-being of plants, ensuring their robust growth and therapeutic potency (Srikanth et al., 2015). This emphasis on plant vitality aligns with the principles of regenerative agriculture, which seeks to create resilient agricultural systems capable of withstanding environmental challenges for long-term sustainability.

Ayurveda places great importance on the involvement of local communities in the cultivation and preservation of medicinal plants. Traditional knowledge is often passed down through generations within these communities, fostering a deep understanding of sustainable practices. Local communities actively engage in the cultivation process, utilizing their traditional wisdom to ensure the longevity of medicinal plant resources (Mn et al., 2018). Community engagement in Ayurvedic practices instils a sense of responsibility and connection to the environment. Local communities become stewards of their natural surroundings, actively participating in sustainable harvesting, cultivation, and preservation activities. This sense of ownership fosters a holistic approach to environmental stewardship, aligning with Ayurvedic principles of balance and interconnectedness (Uniyal et al., 2006). Engaging local communities in the cultivation and preservation of medicinal plants not only ensures environmental sustainability but also contributes to sustainable livelihoods. Ayurvedic principles advocate for a harmonious coexistence between communities and their natural environment, recognizing that the well-being of both is intricately linked (Chen et al., 2016).

Wildcrafting Guidelines:

Wildcrafting in Ayurveda involves the sustainable and ethical harvesting of plants from their natural habitats for medicinal and therapeutic purposes. Ayurveda, the ancient Indian system of medicine, emphasizes a holistic approach to health and wellness, and wildcrafting aligns with these principles when done responsibly (Kumar & Dua, 2016). Here are guidelines and principles for wildcrafting in Ayurveda:

Non-Invasive Harvesting: Gather plant parts in a way that doesn't harm the overall health of the plant. Avoid uprooting entire plants unless it's necessary for the medicine, and prefer harvesting leaves, flowers, or seeds. Minimize your impact on the ecosystem. Be discreet, avoid trampling other plants, and leave the environment as you find it (Mateo-Martín et al., 2023).

Seasonal Awareness: Choose the appropriate season for harvesting specific plants. Ayurveda recognizes the changing qualities of plants with the seasons, and harvesting at the right time enhances the medicinal properties of the herbs (Kala et al., 2006).

Knowledge and Identification: Thoroughly know the plants you intend to harvest to avoid mistakenly gathering toxic or endangered species. Consult with experienced practitioners or botanists if needed (Heywood, 2019).

Sustainable Practices: Take only what you need, ensuring that enough plants are left to support the population and maintain the ecological balance. Overharvesting can deplete plant populations and disrupt ecosystems. Consider cultivating medicinal plants in controlled environments to reduce pressure on wild populations. This also allows for consistent quality and availability (Heywood, 2019).

Ethical Considerations: Adhere to local and international laws regarding plant harvesting. Some plants may be protected or endangered, and harvesting them may be strictly regulated (Heywood, 2019).

Gratitude and Ritual: Before harvesting, practitioners often perform rituals or express gratitude to the plant's spirit. This reflects the belief in a deeper connection between humans and the plant kingdom (Heywood, 2019).

Community Involvement: If you are harvesting in an area inhabited by local communities, involve them in the process. Respect their knowledge and traditions, and consider contributing to community initiatives that promote sustainability (Kiper, 2013).

Continuous Learning: Adapt to New Information: Stay updated on scientific and traditional knowledge about the plants you are harvesting. Adapt your practices based on new insights to ensure the long-term health of both plants and ecosystems (Kiper, 2013).

Document and Share Knowledge: Record and Share Experiences: Keep detailed records of your wildcrafting experiences, including plant locations, harvesting methods, and observations. Share this information with the community to contribute to a collective understanding of sustainable wildcrafting (Kor et al., 2021).

Importance of Environmentally Friendly Processing in Ayurvedic Medicine Production

The production of Ayurvedic medicines involves various processing steps, and adopting environmentally friendly methods is crucial for minimizing the ecological footprint and promoting sustainability. Here are key reasons highlighting the importance of environmentally friendly processing methods in the production of Ayurvedic medicines:

Conservation of Medicinal Plants: Environmentally friendly processing methods often result in higher extraction efficiency, meaning that less raw material (medicinal plants) is needed to produce the same amount of medicine. This helps in conserving plant species and maintaining biodiversity (Asigbaase et al., 2023; De et al., 2023; Shriwas & Sharma, 2023).

Energy Efficiency: Sustainable processing methods prioritize energy efficiency, contributing to reduced overall energy consumption in the production chain. This not only lowers operational costs but also lessens the environmental impact associated with energy production (Ekins & Zenghelis, 2021).

Waste Reduction: Environmentally friendly processing focuses on minimizing waste generation. This includes optimizing extraction processes to extract maximum medicinal compounds, reducing the need for additional raw materials, and properly managing by-products to avoid environmental pollution (Abdel-Shafy & Mansour, 2018).

Water Conservation: Sustainable processing methods aim to minimize water usage through efficient extraction techniques and recycling practices. This helps conserve water resources and mitigates the impact of pharmaceutical production on local water systems (Strade et al., 2020).

Non-toxic Solvent Usage: Environmentally friendly processing often involves the use of non-toxic solvents or alternatives to traditional chemical solvents. This reduces the risk of environmental contamination and ensures the safety of ecosystems (Kaya et al., 2022).

Biodegradable Packaging: Sustainable practices extend beyond processing to include packaging. The use of biodegradable or recyclable packaging materials minimizes the environmental impact of waste generated by the packaging of Ayurvedic medicines (Ibrahim et al., 2022).

Carbon Footprint Reduction: Environmentally friendly processing methods contribute to a lower carbon footprint by minimizing energy consumption, waste generation, and reliance on resource-intensive processes. This aligns with global efforts to mitigate climate change (Yang et al., 2023; Saha, 2023).

Quality and Efficacy: Sustainable processing often involves gentler extraction methods that preserve the integrity and efficacy of medicinal compounds. This ensures that the final Ayurvedic medicines retain their therapeutic properties (Abubakar & Haque, 2020).

Consumer Trust and Responsibility: In an era where consumers are increasingly concerned about the environmental impact of products, adopting environmentally friendly processing methods aligns with ethical expectations. This can enhance consumer trust and brand reputation (Nguyen Tran Cam, 2023).

Regulatory Compliance: Adhering to environmentally friendly practices ensures compliance with environmental regulations and standards. This is not only a legal requirement but also contributes to the overall sustainability of the Ayurvedic medicine industry (Wang et al., 2021).

Climate Resilience:

Ayurveda, as an ancient system of medicine, demonstrates a deep understanding of the interconnectedness between the environment, medicinal plants, and human health. The selection of medicinal plants in Ayurveda is not arbitrary; it takes into account the resilience of these plants to climate variations (Kumar et al., 2017). This consideration contributes significantly to the adaptability of traditional healthcare practices in the following ways:

Climate-Specific Plant Selection: Ayurveda recognizes that different plants thrive in specific climates. Traditional Ayurvedic texts often provide guidelines on where certain medicinal plants are found abundantly. This climate-specific approach ensures that the plants chosen for medicinal purposes are well-suited to their natural habitat (Kumar et al., 2017).

Adaptation to Local Environments: Ayurvedic medicine draws extensively from local flora. By selecting plants that are native to a region, Ayurveda inherently incorporates an adaptation to the local climate. This adaptation enhances the resilience of these plants to specific environmental conditions, making them more robust and sustainable (Kumar et al., 2017).

Understanding Dosha Influences: Ayurveda is based on the concept of doshas (Vata, Pitta, Kapha), which represent different combinations of the five elements found in nature. Medicinal plants are selected based on their ability to balance or pacify specific doshas. This nuanced approach considers the impact of climate variations on the doshas and aims to restore balance (Kumar et al., 2017).

Seasonal Considerations: Ayurveda emphasizes the importance of seasonal variations in health and well-being. Medicinal plants are often recommended based on seasonal availability. The selection of plants that thrive in different seasons ensures that Ayurvedic remedies align with the changing health needs of individuals throughout the year (Kumar et al., 2017).

Resilience to Environmental Stressors: Medicinal plants chosen in Ayurveda are often resilient to environmental stressors, including variations in temperature, precipitation, and soil conditions. This resilience contributes to the reliability of these plants as sources of therapeutic compounds, even in the face of climate fluctuations (Kumar et al., 2017).

Biodiversity Preservation: The diversity of medicinal plants recommended in Ayurveda promotes biodiversity. By relying on a wide range of plant species, Ayurveda helps safeguard against the impact of climate change on individual plant populations. This approach supports overall ecosystem health (Kumar et al., 2017).

Local Ecological Knowledge: Traditional healers and Ayurvedic practitioners often possess deep ecological knowledge about the medicinal plants in their regions. This knowledge is passed down through generations, contributing to the adaptability of Ayurvedic practices as it incorporates insights into the resilience and behaviour of plants in response to climate variations (Kumar et al., 2017).

Consistency in Therapeutic Efficacy: The adaptability of medicinal plants to local climates ensures a consistent availability of therapeutic compounds. This reliability is crucial for the effectiveness of Ayurvedic treatments, providing practitioners with a stable source of medicinal materials regardless of climate variations (Kumar et al., 2017).

Cultural and Spiritual Significance: Many medicinal plants in Ayurveda hold cultural and spiritual significance. The selection of these plants is often deeply rooted in the local traditions and ecosystems, reinforcing the interconnectedness between human health, plants, and the environment (Kumar et al., 2017).

Promoting Sustainable Practices through Awareness Programs

Education and awareness programs play a pivotal role in promoting sustainable practices among Ayurvedic practitioners, contributing to the preservation of medicinal plant resources. These programs are essential for fostering a deep understanding of ecological principles, ethical wildcrafting, and responsible herbal medicine production. Here's how education and awareness initiatives are crucial in this context:

Educational programs can refer to ancient Ayurvedic texts that provide insights into sustainable practices. By understanding the historical context and teachings, practitioners can better appreciate the importance of preserving medicinal plants in their natural habitats.

Training programs can focus on developing the skills needed for accurate botanical identification (Rastogi, 2021). This helps practitioners recognize endangered or threatened plant species and encourages them to avoid using or harvesting such plants, contributing to conservation efforts. Education can highlight the interconnectedness of ecosystems and the impact of harvesting on the broader environment. Practitioners who understand these relationships are more likely to adopt sustainable practices to ensure the long-term health of medicinal plant populations (Heywood, 2019).

Awareness programs can disseminate guidelines for ethical wildcrafting, emphasizing practices that minimize harm to plants and ecosystems. This includes proper harvesting techniques, selective harvesting, and leaving enough plants to ensure natural regeneration. Education programs can encourage practitioners to cultivate medicinal plants in controlled environments or practice agroforestry (*Wildcrafting Basics*, 2017). This reduces the pressure on wild populations and ensures a sustainable supply of medicinal plants. Practitioners need to be aware of local and international regulations governing the trade and harvest of medicinal plants. Educational initiatives can provide information on compliance with these regulations, preventing illegal harvesting and trade (Ajazuddin & Saraf, 2012).

Education programs can stress the importance of collaboration with local communities. Involving communities in sustainable practices fosters a sense of shared responsibility for preserving medicinal plant resources. Encouraging practitioners to seek certifications for sustainable and ethical harvesting practices can be a part of education initiatives. Certifications validate their commitment to preserving medicinal plant resources. Beyond practitioners, awareness programs can target consumers. Educated consumers are more likely to support Ayurvedic products derived from sustainable practices, creating a demand for ethically sourced medicines (Chen et al., 2016). Education can inspire practitioners to engage in research focused on sustainable cultivation methods, innovative processing techniques, and the development of alternative plant sources. This promotes continuous improvement in sustainable practices. Educational programs can facilitate networking among Ayurvedic practitioners, researchers, and conservationists. This exchange of knowledge encourages the development and dissemination of sustainable practices within the community (Ronen & Kerret, 2020).

Policy Advocacy:

Supportive policies and regulations are crucial for promoting sustainable practices in Ayurveda, striking a balance between healthcare needs and environmental preservation. These policies play a significant role in guiding practitioners, manufacturers, and consumers toward practices that ensure the responsible use of medicinal plants and contribute to the overall well-being of ecosystems (Kumar et al., 2023). Here's an exploration of the need for such policies:

Conservation of Medicinal Plants: Regulating Harvesting Practices: Policies can establish guidelines for sustainable harvesting, emphasizing practices that minimize the impact on plant populations. This helps prevent overharvesting and ensures the conservation of valuable medicinal plants (Chen et al., 2016).

Biodiversity Protection: Policies can regulate and restrict the trade of endangered or threatened plant species. This helps protect biodiversity by preventing the exploitation of rare and vulnerable plants for commercial purposes (Lavorgna et al., 2018; Darro & Khan, 2023).

Cultivation and Agroforestry Incentives: Encouraging Sustainable Cultivation: Policies can provide incentives for practitioners and businesses to cultivate medicinal plants in controlled environments or practice agroforestry. This reduces the pressure on wild populations and supports sustainable sourcing (Ruba & Talucder, 2023).

Certification Programs: Recognizing Sustainable Practices: Policies can establish certification programs that recognize and reward practitioners and manufacturers adhering to sustainable practices. This creates a competitive advantage for those promoting environmental responsibility (Nygaard, 2023).

Research and Development Support: Funding for Sustainable Research: Policies can allocate funds for research and development focused on sustainable cultivation, harvesting, and processing methods. This support encourages innovation in sustainable practices within the Ayurvedic industry (Siebrecht, 2020).

Educational Requirements: Incorporating Sustainability in Training: Policies can mandate the inclusion of sustainability and ethical considerations in the education and training of Ayurvedic practitioners. This ensures that future professionals are well-versed in responsible practices (Patwardhan et al., 2023).

Public Awareness Campaigns: Government-Sponsored Awareness Initiatives: Policies can support public awareness campaigns to educate consumers about the importance of choosing Ayurvedic products derived from sustainable and ethically sourced medicinal plants (Katoch et al., 2017).

Regulation of Wild Crafting: Guidelines for Ethical Wild Crafting: Policies can establish clear guidelines for ethical wildcrafting, specifying permissible practices and emphasizing the importance of leaving enough plants for natural regeneration (Berry, 2015).

Local Community Engagement: Community-Based Conservation Programs: Policies can encourage the involvement of local communities in the conservation of medicinal plants. This may include community-based conservation programs that empower residents to actively participate in sustainable practices (Shukla & Gardner, 2006).

Integration with International Standards: Aligning with Global Sustainability Standards: Policies can align Ayurvedic practices with international sustainability standards, facilitating global cooperation and ensuring that Ayurveda contributes to broader environmental conservation efforts (Patwardhan et al., 2023).

Monitoring and Enforcement: Policies should include mechanisms for monitoring and enforcing sustainable practices. This can involve regular inspections, certifications, and penalties for non-compliance, creating a regulatory framework that ensures accountability (Pavlovskaia, 2014).

Research on Alternative Sources: Encouraging Exploration of Alternatives: Policies can support research into alternative sources for medicinal compounds, reducing reliance on a few species and promoting the sustainable use of a broader range of plants (Sofowora et al., 2013).

Sustainable Healthcare in Ayurveda:

In the contemporary discourse on healthcare, the intersection of traditional wisdom and environmental consciousness takes center stage. Ayurveda, the ancient Indian system of medicine, serves as a beacon in this discussion, offering a profound perspective on sustainable healthcare through its reliance on medicinal plants and the delicate equilibrium it seeks with the environment. Ayurveda's foundation lies in the belief that human health is intricately connected to the well-being of the natural world (Pandey et al., 2013; Jaiswal & Williams, 2017; Kar et al., 2022; De & Sharma, 2023). This philosophy is reflected in the selection and utilization of medicinal plants, where a deep understanding of plant resilience, seasonal variations, and ecosystem dynamics is paramount.

In the pursuit of sustainable healthcare, Ayurveda emphasizes several key principles:

- Ayurveda recognizes the intrinsic connection between human health and environmental balance. The emphasis on utilizing medicinal plants native to specific climates and seasons underscores the philosophy of living in harmony with nature.
- Ethical wildcrafting practices, guided by Ayurvedic principles, prioritize the well-being of plant populations. The emphasis is on non-invasive harvesting, leaving no ecological footprint, and fostering the natural regeneration of medicinal plants.
- Ayurveda acknowledges that human health is dynamic and influenced by seasonal changes. The system aligns healthcare practices with the seasons, ensuring that remedies are attuned to the varying needs of the body and the availability of medicinal plants.
- The vast array of medicinal plants recommended in Ayurveda contributes to biodiversity conservation. By promoting the use of diverse plant species, Ayurveda helps safeguard ecosystems and mitigates the risk associated with over-reliance on a limited number of plants.
- Ayurveda recognizes the importance of cultivating medicinal plants in controlled environments. This cultivation approach not only ensures a sustainable supply but also reduces pressure on wild populations, aligning with modern principles of agroecology.
- A crucial aspect of sustainable healthcare in Ayurveda is education and awareness. Practitioners, guided by a deep understanding of ecological principles, make informed choices that contribute to the preservation of medicinal plants and the overall environment.

- The integration of sustainable practices in Ayurveda is further fortified by supportive policies and regulations. These policies provide a framework for responsible harvesting, cultivation incentives, and adherence to ethical guidelines, creating a symbiotic relationship between healthcare and environmental preservation.
- Ayurveda's emphasis on sustainable healthcare transcends cultural boundaries. In an era of increasing environmental awareness, the principles embedded in Ayurveda offer a holistic model that resonates globally, fostering a deeper connection between healthcare and ecological responsibility.

In the evolving landscape of healthcare, Ayurveda stands as an inspiration of wisdom, advocating for a sustainable approach that not only addresses individual well-being but also ensures the preservation of the planet. The harmonious coexistence of medicinal plants and environmental balance in Ayurveda serves as an inspiration for redefining healthcare practices that are not just curative but also regenerative and harmonious with the world we inhabit (Chauhan et al., 2015).

Conclusion:

In conclusion, the exploration of "Sustainable Healthcare: Medicinal Plants and Environmental Balance in Ayurveda" unveils a holistic paradigm that harmonizes human well-being with environmental preservation. Ayurveda, deeply rooted in the ancient wisdom of natural healing, emerges as a beacon of sustainability in healthcare practices. The profound connection between medicinal plants and environmental balance underscores Ayurveda's commitment to ecological harmony. By incorporating principles of responsible wildcrafting, seasonal wellness, and biodiversity conservation, Ayurveda not only addresses individual health needs but also contributes to the overall health of our planet. The emphasis on cultivating medicinal plants in controlled environments aligns Ayurveda with contemporary agroecological principles, ensuring a sustainable supply of therapeutic resources. This cultivation-centric approach not only supports the longevity of Ayurvedic practices but also alleviates pressure on wild plant populations, fostering environmental resilience.

Education and awareness play pivotal roles in this sustainable healthcare narrative. The deep ecological knowledge passed down through generations, coupled with modern insights and policies, empowers Ayurvedic practitioners to make informed choices that safeguard medicinal plants and preserve ecosystems. As Ayurveda transcends cultural boundaries, its principles of sustainability gain global relevance. In an era where environmental consciousness is paramount, Ayurveda serves as an inspiration for a healthcare model that not only heals but also nurtures the delicate balance of our interconnected world. In a broader context, the sustainable healthcare ethos embedded in Ayurveda aligns seamlessly with global efforts towards holistic well-being. By embracing the wisdom of traditional healing practices and integrating them with modern environmental consciousness, we pave the way for a future where healthcare and ecological preservation coexist harmoniously, ensuring the health of generations to come.

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Chapter-12

Eco-Health Dynamics: Climate Change, Sustainable Development and the Emergence of Infectious Challenges

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Keywords: Climate change, sustainable development, vector-borne disease, environmental policies.

Abstract:

This comprehensive review explores the intricate relationships between climate change, sustainable development and emerging infectious diseases (EIDs). Changes in climate parameters, such as rising temperatures and altered precipitation patterns pose profound ecological, environmental and socio-economic threats. The review delves into emerging threats such as vector-borne diseases, the resurgence of dormant pathogens due to melting ice layers and the complex global health challenge of antimicrobial resistance. It emphasizes the importance of integrating EID risk into sustainable development planning through a multisectoral approach. The review underscores the pivotal role of Sustainable Development Goals (SDGs), particularly Goals 2 and 15, in mitigating EID risks, emphasizing the delicate balance required to simultaneously enhance agricultural productivity and conserve terrestrial ecosystems. Mitigation and adaptation tactics required for responding to climate change necessitate effective international policies, particularly in key sectors like agriculture, industry, forestry, transport and land use. Associations between climate change and infectious diseases suggest collaborative efforts among researchers, policymakers and nations to achieve a balanced and sustainable future. Effective mitigation, calibrated with the UN's 2030 Agenda for Sustainable Development, lowers the risks of new infectious diseases and ensures the well-being of both ecosystems and societies on a global scale.

Introduction:

Climate change is recognized as a multifaceted global challenge that affects various aspects of ecological, environmental, socio-political and socio-economic domains (Adger et al., 2005). It is generally characterized by elevated temperatures worldwide (Battisti and Naylor, 2009). However, the comprehensive, longstanding changes in temperature, pressure, humidity and precipitation patterns define the nature of climate change. Notable international and domestic effects of the changed climate include irregular weather patterns, the retreat of global ice sheets, and the corresponding rise in sea levels (Lipczynska-Kochany., 2018; Michel et al., 2021).

The 21st century is witnessing profound global transformations, such as rapid population growth, shifts in dietary patterns and an increase in energy demands (Tilman and Clark., 2014).

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These changes have sparked extensive debates and serious scientific inquiry. Concurrently, the United Nations' 2030 Agenda for Sustainable Development, designed to address environmental and social challenges, inadvertently introduces a heightened risk of infectious disease outbreaks (Di Marco et al., 2020; Mukherjee et al., 2022). The complex connection between observed and anticipated global climatic changes and the increasing prevalence of infectious diseases, such as the impactful case of COVID-19, must be explored with detailed scientific investigations (Basak et al., 2021; Basak & Sanyal., 2022; Sen et al., 2021; Kaur et al., 2023). The severity of this issue is further compounded by the enhancement of climate-related challenges through the consumption of fossil fuels. Determining the root causes of disease emergence demands a comprehensive approach harmonized with the Sustainable Development Goals (SDGs). The direct link between environmental change and the risk of emerging infectious diseases necessitates an action plan aimed at achieving various goals of Sustainable Development for healthy lives and promoting well-being (Di Marco et al., 2020; Saha et al., 2022a; Saha et al., 2022b). Goals 2 and 15 focus on agricultural productivity and the conservation of terrestrial ecosystems and have a direct influence on the risks of Emerging Infectious Diseases (EIDs) (Di Marco et al., 2020). Surprisingly, 70% of EIDs and nearly all recent pandemics find their origins in animals (Morse et al., 2012). This underscores the intricate interplay between wildlife, domestic animals, and humans shaped by diverse factors, including human population density, wildlife diversity, deforestation, agricultural expansion, livestock intensification and wildlife trade (Jones et al., 2008; Allen et al., 2017; Ghosh et al., 2023). Societal instability, particularly in conflict-affected regions, emerges as an additional driver amplifying EIDs (Stoett et al., 2016). Conflict influences human migration, and transmission risk and disrupts disease control efforts by affecting healthcare systems (Stoett et al., 2016). Goal 16 of the UN 2030 Agenda promotes effective institutions and the end of violence and acknowledges disease as a threat to societal security (Di Marco et al., 2020).

In light of the ongoing challenges outlined in the UN 2030 Agenda (Di Marco et al., 2020), this review underscores the profound impact of climate change on infectious diseases, emphasizing how climate patterns contribute to the emergence of pandemics. In this context, Sustainable Development Goals (SDGs), especially Goals 2 and 15, become very important. It is crucial to find the right balance between the progress of sustainable development and the emergence of new infectious diseases. Collective efforts to achieve the goals of the UN's 2030 Agenda (Di Marco et al., 2020) and to prevent the inception of new diseases are essential to ensure a safe and healthy future for human beings in the coming decades.

Unravelling Climate Change, Ecological Shifts and Disease Dynamics:

The close interrelationship between climate change and infectious diseases begins with profound ecological transformations induced by human activities; particularly noteworthy are deforestation and the alarming loss of biodiversity (Ryan et al., 2019; Bartlow et al., 2019). These activities affect the distribution, survival and transmission of pathogens, their animal reservoirs, and vectors (Mansour., 2013). Such environmental changes can potentially lead to higher rates of premature mortality (Di Marco et al., 2020). Various environmental modifications have profound implications for the prevalence and distribution of diseases by creating habitat conditions conducive to the transmission of specific illnesses (Ryan et al., 2019). The construction of canals, dams and irrigation pathways can give rise to diseases such as schistosomiasis, malaria, helminthiases and river blindness (Abbass et al., 2022). The alteration of landscapes through agro-strengthening practices like crop pesticides may intensify the incidence of malaria and Venezuelan hemorrhagic fever driven by increased rodent abundance and contact (Abbass et al., 2022). Suburbanization marked by deprived hygiene and water pollution in municipal areas can foster diseases like cholera and dengue, the latter finding breeding sites in water-gathering rubbish (Abbass et al., 2022). Deforestation and new tenancy contribute to the spread of malaria, Oropouche fever and visceral leishmaniasis through the creation of breeding sites, altered trajectories and the migration of vulnerable populations (Abbass et al., 2022). In agricultural settings, Lyme disease may proliferate due to the presence of tick hosts and heightened outdoor exposure (Abbass et al., 2022). Furthermore, ocean heating leads to red tide poisoning characterized by toxic algal blooms (Abbass et al., 2022). The 1998 Nipah virus outbreak in Malaysia resulted from increased pig farming near tropical forests where fruit bats, the virus reservoir, reside (Di Marco et al., 2020). Similarly, the origins of SARS and Ebola viruses are linked to bats either through hunting or greater human development (Di Marco et al., 2020). In each case, environmental modifications play a pivotal role in shaping the dynamics of disease transmission, highlighting the acquaintance between human activities and public health outcomes. To prevent such outbreaks, social and economic development aligning with a spectrum of societal issues outlined in the SDGs is crucial.

Rising Temperatures as Expanding Threats: Impact on Vector-Borne Diseases:

Before the industrial revolution, natural sources such as volcanoes, forest fires and seismic activities were considered the primary culprits for the emission of greenhouse gases (GHGs) (Murshed et al., 2020; Hussain et al., 2020; Murshed, 2022). However, contemporary anthropogenic activities linked to industrialization, urbanization and intensive agriculture are now recognized as the main drivers of climate change. Human actions, notably the substantial increase in the use of fossil fuels, widespread use of fuel-based mechanization, agricultural residue burning, deforestation and transportation activities (Huang et al., 2016), significantly influence global warming by releasing large quantities of heat-trapping GHGs (Balsalobre-Lorente et al., 2022; Mallick et al., 2022; Ishikawa-Ishiwata and Furuya, 2022). Additionally, industrial and agricultural processes release pollutants such as black carbon particles or soot, contributing to warming by absorbing incoming solar radiation (USGCRP, 2009). Moreover, human activities such as unsustainable land management and land use extend their impact on the climate of specific regions (IPCC, 2020). These types of illegal practices not only carry negative economic consequences but also amplify the climate crisis across various spatial scales. Alterations in land use, like the conversion of forests and peatlands into agricultural areas, release carbon stored in biomass and soil, contributing to 10 to 15 percent of total CO_2 emissions (FAO, 2011). This transformation and degradation affect roughly 39 to 50 percent of the world's land area, undergoing deterioration due to human activities (Vitousek et al., 1997).

Deforestation, elevated by factors such as agricultural expansion, infrastructure development, urbanization and industrialization, has notably increased atmospheric CO_2 levels (Adnan et al., 2011) and affects the exchange of water and energy (IPCC, 2020). The repercussions of changes in forest cover resonate globally and regionally, leading to unpredictable rainfall patterns, lengthy dry periods and the rise of wildfires, contributing to exacerbated pollution (Strasser et al., 2014; Saha & Sarkar, 2022; Deb et al., 2022). Frequent deforestation-induced droughts in vulnerable areas such as the Amazon and other tropical regions need special consideration (Gash et al., 1996). These alterations pose serious threats to plant species, wildlife and ecosystems with potential consequences for the spread of diseases.

Numerous studies illustrate the significant association between massive-scale species dynamics and various aforementioned climatic alterations (Abraham and Chain, 1988; Manes et al., 2021; Ghosh., 2022). The pace and magnitude of climate change alter compatible habitat ranges for entities and influence their ecosystems in diverse ways, including variations in species abundance, range shifts, alterations in activity timing and microhabitat use (Bates et al., 2014). In the face of climate change, local species must either accept, adapt, migrate, or confront the risk of extinction (Berg et al., 2010). Species that exhibit superior adaptive capacities have a higher likelihood of surviving in new ecosystems or a reduced ability to endure in their existing habitats (Bates et al., 2014).

Unlike traditionally confined to specific geographical regions, vector-borne diseases have undergone significant alterations in distribution patterns due to climate change. Diseases like Malaria, Leishmaniasis, Filariasis, Japanese Encephalitis and Dengue Fever have extended their ranges to higher altitudes once deemed inhospitable (Dhimal et al., 2015). Nepal, nestled in the Himalayan mountains, exemplifies this phenomenon with the emergence of major vector-borne diseases at high altitudes (Dhimal et al., 2015).

The proliferation of mosquito-borne diseases also occurs through mechanisms such as the invasion of vector species to new areas. For instance, the chikungunya virus, typically transmitted by *Aedes albopictus*, emerged in Europe with native European mosquito species like *Aedes geniculatus* potentially replacing *Aedes albopictus* in disease transmission (Ng et al., 2019; Prudhomme et al., 2019).

Tick habitats have extended to higher elevations and northern regions in Canada and Europe due to global warming, leading to the emergence of more than 11 bacterial tick-borne pathogens affecting humans (Tokarevich et al., 2011; Porretta et al., 2013). This expansion has resulted in the spread of tick-borne diseases like Anaplasmosis, Babesiosis, Powassan viruses, *Rickettsia helvetica*, *Neoehrlichia mikurensis* and *Borrelia miyamotoi* diseases (Kawahara et al., 2004; Jado et al., 2007; Bouchard et al., 2019). The northward expansion of *Ixodes ricinus* ticks, vectors of *Borrelia burgdorferi*, has been well-documented in Europe and Eurasia, reaching countries like the UK, Germany, Sweden and Russia (Jaenson et al., 2012; Cull et al., 2018). Ticks serve as vectors for numerous serious zoonotic viruses as well (El-Sayed &Kamel, 2020).

The spread of diseases is linked to the geographical expansion of ticks into new areas (Kazimírová et al., 2017). The viruses transmitted by ticks include Phlebovirus, Bourbon virus, Powassan virus, Tick-Borne Encephalitis viruses, Crimean-Congo Hemorrhagic Fever Virus (CCHFV), and Alkhurma Hemorrhagic Fever Virus (Mansfield et al., 2009). In Europe, the expansion of ticks is associated with the emergence of Tick-Borne Encephalitis (TBE) and Lyme disease (El-Sayed & Kamel, 2020). The prevalence of TBE and Lyme diseases has increased due to global warming and the northward migration of tick vectors (Lindgren, 2000; Randolph, 2004). Warmer winters since the mid-1980s in Scandinavia have led to a steady increase in TBE cases (El-Sayed & Kamel, 2020).

Factors contributing to the rise of tick-borne diseases include climatic changes (Andreassen et al., 2012; Lindgren & Gustafson, 2001). The Louping Ill virus, part of the TBE complex, has also been recently detected in Europe and the UK (Gilbert, 2016). Another emerging zoonotic tick-borne viral disease in Europe is Congo Haemorrhagic Fever (CCHF) (El-Sayed & Kamel, 2020). This virus poses a significant public health threat due to its high fatality rate in humans (Papa et al., 2015). The warmer climate allows ticks to invade new areas, contributing to the virus's endemicity in Africa, the Middle East, the Balkan Peninsula, Eastern and Southern Europe and Asia (Baylis, 2017). Ticks are also responsible for the emergence of Piroplasmorida, including *Babesia* spp. and *Theileria* spp. (El-Sayed & Kamel., 2020). Babesiosis, a major tick-borne protozoan disease in cattle, poses a global animal health problem with substantial economic losses (El-Sayed & Kamel., 2020). The increasing prevalence of babesiosis is exacerbated by the geographic expansion of ticks driven by global warming (Beugnet & Chalvet-Monfray., 2013).

Additionally, global warming not only influences the geographical distribution of vectors but also intermediate hosts, encompassing invertebrate hosts such as insects, rodents and migratory birds. For instance, the zoonotic bacterial pathogen *Chlamydia* sp. is transported by birds and annually infects 92 million people, as reported by the World Health Organization (WHO) (El-Sayed & Kamel., 2020). The transmission of this zoonotic pathogen is closely tied to bird movement and migration, which are in turn impacted by changes in climate and ecology (Geisler., 2012).

Furthermore, climate change, such as the global temperature rise, directly affects the transmission dynamics of diseases such as Malaria, African Trypanosomiasis, Yellow Fever, Plague and Dengue fever (Hickmann et al., 2015; Saha et al., 2023). Malaria is a prime example of the consequences of temperature changes. A modest global temperature rise of 2 to 3°C expands the proportion of the population at risk by 3 to 5% and exposes millions more individuals to the threat of infection (Shuman., 2010). Temperature shifts also influence the reproduction rates and extrinsic incubation periods of pathogens. For instance, the extrinsic incubation period for *Plasmodium falciparum*, the Malaria parasite, decreases from 26 days at 20°C to 13 days at 25°C, indicating the potential for a more rapid spread of the disease (Bunyavanich et al., 2003). *Plasmodium vivax* and *Plasmodium falciparum*, the parasites responsible for Malaria, are highly sensitive to environmental temperatures (El-Sayed & Kamel, 2020). Climate change directly influences the life cycle, survival and reproduction of pathogens, thereby affecting the ecology of diseases like the Japanese Encephalitis virus (JEV) (Tian et al., 2015; Mellor & Leake., 2020).

Unveiling Ancient Threats: Melting Ice Layers and the Resurgence of Dormant Pathogens:

The often underestimated threat of global warming lies in the melting of ice layers that have existed for thousands of years (El-Sayed & Kamel., 2020). The loss of land-based ice from glaciers and ice sheets through melting and thermal expansion of the ocean surface is expected to further elevate global mean sea levels (Gregory et al., 2001; Hansen et al., 2016). Rising sea levels will be responsible for ocean acidification, changes in rainfall patterns exacerbating droughts and worsening the overall impact of climate change (Allen et al., 2010). Rising sea levels not only pose threats to cities and river deltas but also reactivate frozen biological materials stored in the frozen soil (El-Sayed & Kamel., 2020). Melting ice reveals hidden biological materials beyond the potential discovery of ancient animal carcasses like mammoths. In 2012, for example, the Virola virus was detected in a 300-year-old frozen mummy in Siberia (Biagini et al., 2012).

The consequences of melting ice extend to the revival of ancient bacteria. In 2005, NASA scientists successfully revived bacteria that had been frozen in Alaska for 32,000 years, while 8-million-year-old bacteria were isolated from ice samples in Antarctica (Bidle et al., 2007). Viable bacteria have also been found in ice samples dating back 25,000 years and in Dominican amber, estimated to be 20-40 million years old (Katayama et al., 2007; Greenblatt et al., 1999).

The real-world impact of melting ice became noticeable in 2016 when a 12-year-old child died and 20 people were hospitalized in Siberia as a result of anthrax infections (El-Sayed & Kamel, 2020). The spores responsible for anthrax, caused by the bacterium *Bacillus anthracis*, were concealed for over 75 years under frozen soil until released as the ice melted (El-Sayed & Kamel, 2020). These spores, known for their resilience, can persist in a dormant form for a hundred years and can be transported by floods or insects such as tabanid fly (El-Sayed & Kamel, 2020). There is a conceivable risk that the smallpox virus could be stored frozen in human bodies buried in the frozen soil of Siberia where a significant smallpox epidemic occurred in 1890 (Antonenko et al., 2013; Walsh et al., 2018).

Antimicrobial Resistance: A Complex Global Health Challenge and Its Implications for Human Health and Economies:

Antimicrobial resistance (AMR) stands as a burgeoning and intricate global health challenge, generating substantial concern among health professionals worldwide (Garner et al., 2019). This phenomenon possesses the critical potential to undo much of the progress achieved in the field of health so far (Gosling & Arnell, 2016). The production of a vast quantity of antibiotics by numerous pharmaceutical industries globally is met with a gradual development of resistance among pathogenic microorganisms (UNEP, 2017).

Notably, AMR is not confined to a specific region or country; it is flourishing on every continent, propelling humanity toward a post-antibiotic era where currently susceptible pathogens may once again lead to endemics and pandemics after developing resistance (WHO, 2018). The escalating cases of drug resistance have made common illnesses such as pneumonia, post-surgical infections, HIV/AIDS, tuberculosis and malaria increasingly difficult and costly to treat effectively (WHO, 2018). The impact of climate change-induced global warming on the spread of antibiotic-resistant strains adds economic burden necessitating the development of new and costlier antibiotics (Abbass et al., 2022).

The exchange of antibiotic-resistance genes in wastewater, particularly in conventional urban treatment plants, serves as a hotspot for bacterial strains to share genetic material through horizontal gene transfer (Abbass et al., 2022). Although the extent of risks associated with antibiotic resistance in wastewater is complex, environmental scientists and engineers express particular concerns about the potential implications of resistance genes on human health (Ashbolt, 2015). In the worst-case scenario, antibiotic-resistant genes may find their way into the environment through irrigation water for crops and public water supplies, thus integrating into food chains and food webs (Pruden et al., 2013; Wu et al., 2019). This issue has been reported in various countries where wastewater is commonly used for irrigation, highlighting the multifaceted challenges posed by AMR (Hendriksen et al., 2019).

Furthermore, floods have the potential to facilitate the spread of antibiotic-resistant microorganisms into the environment (Carignan et al., 2019). This concern is particularly relevant due to the extensive use of antibiotics in agriculture and the presence of antibiotic-resistant microorganisms in both solid and liquid waste by-products (Wang et al., 2014). The risk lies in the possibility of these resistant microorganisms being dispersed during flooding, leading to the direct transfer of resistance genes to human pathogens.

Changes in precipitation patterns and the Escalation of Emerging Infectious Diseases (EIDs):

The Intergovernmental Panel on Climate Change (IPCC) projects a temperature increase of 1.5°C during this century (IPCC, 2018). Numerous studies suggest that this temperature rise could amplify hurricanes characterized by increased rainfall and stronger winds, leading to lasting consequences for sea temperatures and phenomena such as El Niño Southern

Oscillations (ENSO) in the Southern Pacific (Cann et al., 2013). Recent studies underscore the potential impact of climate change on the intensification and frequency of El Niño/La Niña events (Cai et al., 2014).

Historically, El Niño has brought heavy rainfall to the Horn of Africa, linked to Rift Valley Fever (RVF) outbreaks—a severe disease transmitted by mosquitoes affecting both cattle and humans (Linthicum et al., 1999). Extreme weather events contribute to the resurgence of waterborne diseases such as Cholera. Cholera, sensitive to temperature, becomes more virulent in warm conditions, spreading through contaminated water, swimming pools and shellfish consumption (Schets et al., 2006). The implications of global warming on Cholera and Vibrio-associated diseases extend to non-traditional regions, such as Northern Europe, posing a real and concerning prospect where increased disease prevalence has been observed (Andersson & Ekdahl, 2006; Semenza et al., 2012).

Climatic conditions, such as elevated humidity, temperature, and increased rainfall, can contribute to the proliferation of non-infectious diseases, favoring the growth of fungi and the dissemination of diseases associated with mycotoxins. During warm summers, multiple factors converge to increase the incidence of food poisoning. This includes heightened bacterial survival, prolonged outdoor activities where people consume food and beverages, and a rise in the population and activity of insects and rodents (El-Sayed et al., 2008; Milazzo et al., 2017; Park et al., 2018; Touchon et al., 2009).

Conclusion:

In conclusion, addressing the complex nexus of climate change, sustainable development, and emerging infectious diseases (EIDs) demands a robust and interconnected approach centered on effective mitigation strategies. The urgency of this matter is underscored by the far-reaching consequences of climate change, which not only impact ecological and environmental systems but also pose significant risks to global health.

Mitigating the risks of EIDs necessitates a careful balancing act, particularly in the pursuit of Sustainable Development Goals (SDGs), with a key focus on Goals 2 (Zero Hunger) and 15 (Life on Land). To meet growing food demand, the expansion of cropland must be approached sustainably to minimize the risk of emerging infectious diseases (EID). Environmental policies that advocate sustainable land-use planning, reduced deforestation, and heightened biodiversity protection not only contribute to SDGs but also act as crucial mitigators by minimizing wildlife contact and reducing the risk of disease transmission.

Societal disruptions and conflicts emerge as critical factors that amplify the risk of EIDs. Recognizing the detrimental impact of armed conflicts on healthcare infrastructure and stability is paramount. Mitigating EID risk and achieving SDGs are contingent on avoiding societal disruptions, especially armed conflicts. Conflict can severely damage infrastructure and stability, as seen during the West Africa Ebola epidemic. Violence against healthcare workers, treatment centers, and critical infrastructure decreases the effectiveness of containment measures. Local and international socio-economic and political instability is also liable for disease spread, even for infectious agents on the brink of eradication. For instance, the spread of wild poliovirus from Pakistan into Syria in 2013 and 2014 was linked to low vaccination levels due to years of conflict in both countries (Mbaeyi et al., 2017). Unmanageable epidemics can contribute to the breakdown of societal functions, exacerbating violence, sexual exploitation, educational disruption, food insecurity, and corruption. Therefore, mitigation efforts should aim to reduce local and international socio-economic and political instability, thereby preventing disease spread and contributing to overall societal well-being.

Unintended consequences, such as the elevated risk of disease transmission resulting from certain conservation measures or the rapid expansion of livestock production, must be carefully considered. For instance, expanding livestock production rapidly in developing countries can improve protein intake but poses a risk of spreading diseases due to increased contact between wildlife, livestock, and humans, leading to production losses. Prioritizing monogastric species over ruminants may reduce greenhouse gas emissions but raises the potential for the emergence of pandemic influenza. Implementing conservation measures, like establishing wildlife corridors, may heighten the risk of disease transmission among different populations. Unfortunately, the restoration of degraded natural habitats through reforestation in the northeastern United States has various benefits but contributes to an elevated risk of Lyme disease among people.

Effective international policies, particularly in key sectors like agriculture, industry, forestry, transport, and land use, are crucial for addressing the interconnected challenges of climate change and infectious diseases. The holistic approach advocated aligns efforts with the UN's 2030 Agenda for Sustainable Development, emphasizing the imperative of mitigating the impacts of climate change on disease emergence while fostering sustainable development for a healthier and resilient global future. Therefore, mitigation strategies should involve prioritizing monogastric species over ruminants, implementing conservation measures with caution, and recognizing the potential impacts on biodiversity, disease emergence, and societal well-being.

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Chapter- 13

Cognitive Impairment Among the Elderly Population

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Keywords: Dementia, Mild Cognitive Impairment, Population Ageing, Alzheimer's Disease, Exercise Training.

Abstract:

Our society is aging; the number of people over 60 years of age is increasing day by day. United Nations projected a 150 million population of people over 60 years in India by the year 2050. One of the many diseases associated with old age is Alzheimer's disease (AD). It is a burdensome disease which not only the patients but also the families, caregivers, communities, and society as a whole. AD is a neurodegenerative disease and it is only diagnosed at a very advanced stage of neuro-degeneration. To date, there are no pharmacological treatment or cure for the disease. It is estimated that the number of people affected with dementia will double every 20 years unless some effective prevention strategies or curative treatments are developed. Mild Cognitive Impairment (MCI) is a gentle form of dementia, and it is found to be a bridging state between normal cognitive changes with aging and the onset of AD. 12% and 20% of patients suffering from MCI advance to dementia within a year and three years respectively. This rate can reach up to 15% annually for patients with amnestic MCI. Therefore, the focus is to screen people with MCI and try to improve their cognitive functions to prevent or rather delay the onset of AD. The 2030 sustainable development goals also outline older people as key stakeholders for the sustainable development of society, in terms of their skills, experience, and knowledge. Therefore, research and development must be promoted both for the early diagnosis and treatment of cognitive decline among the elderly population.

Introduction:

Aging is the biological phenomenon by which a person grows older. With age, people become prone to diseases and disabilities, particularly non-communicable diseases (NCDs). These NCDs include cardiovascular diseases, hypertension, stroke, diabetes, chronic obstructive pulmonary disease, musculoskeletal disorders, dementia, depression, blindness, and visual impairments, etc. (World Health Organization, 1998). Globally NCDs are the leading cause of morbidity, disability, and mortality among those aged more than 60 years and also entail a significant number of resources for the treatment and care of affected individuals (World Health Organization, 2002).

There is no demarcated age after which a person is considered old. In India, usually, an age of 60 years and above is regarded as old age. The percentage of population of the older people is increasing every year. This is known as population aging, which is a phenomenon in which the median age of a society increases due to a rise in life expectancy or a decrease in birth rates.

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In the developed countries the population of elderly persons (aged more than 60 years) is estimated to rise from 274 million in 2011 to 418 million in 2050. As in the case of developing nations, the population aged 60 years and above is estimated to rise from 510 million in 2011 to 1.6 billion in 2050 (United Nations, 2011). By 2025, the number of persons in India over 60 is projected to reach over 150 million (World Health Organization, 2002).

Since the percentage of older people is increasing every year the concept of "Active Ageing" was put forward by the World Health Organization in the Second United Nations World Assembly on Ageing held in Madrid, Spain in April 2002. Active aging policies and programs should aim to enable older people to continue to work according to their capacities and preferences. It should also aim to prevent or delay disabilities and chronic diseases that are costly to individuals, families, and the healthcare system (World Health Organization, 2002).

A measure of the economic burden of the aging population is the dependency ratio. It is the ratio of the dependent or nonworking population (persons below 20 years and persons above 65 years) and the working population (persons ages between 21 to 64 years). The total dependency ratio of India in 2010 was more than 80% (United Nations, 2013). A healthy and working elderly population will reduce the burden on the working population.

Dementia is a collective term for a range of symptoms that are caused by disorders affecting the brain and have impacts on memory, emotion, behavior, and thinking. The most common type of dementia, Alzheimer's disease (AD), represents around two-thirds of diagnoses (Brookmeyer et al., 2007; Duron & Hanon, 2008b, 2008a; Solfrizzi et al., 2006; World Health Organization, 2023; Haloi et al., 2023 Mukherjee et al., 2023). It is a burdensome disease which not only the patients but also the families, caregivers, communities, and society as a whole. AD is a neurodegenerative disease and it is only diagnosed at a very advanced stage of neuro-degeneration. This makes the treatment more difficult and the progress of the disease is also not checked. The existing medical management of AD is inadequate. Approved pharmacological drugs for AD therapies in the USA can only slow the progression of some symptoms but that too only for 6-12 months (Kidd, 2008). It is estimated that the number of people affected with dementia will double every 20 years unless some effective prevention strategies or curative treatments are developed. The estimated number of dementia-affected people globally by the year 2040 is 81.1 million (Ferri et al., 2005).

Mild Cognitive Impairment (MCI) is a milder form of dementia. Several studies have confirmed that MCI, if untreated advances to Alzheimer's disease (AD). MCI can be regarded as a bridging state between normal cognitive aging and the onset of AD (Amieva et al., 2004; Busse et al., 2006; Luck et al., 2010; Luis et al., 2004; Maioli et al., 2007; Petersen et al., 2001; Schuff & Zhu, 2007; Solfrizzi et al., 2006; Tarawneh & Holtzman, 2012; Yaffe et al., 2006). MCI is identified as the stage when a person starts to lose memory to a greater extent than what is accounted for the age. 12 % and 20% of patients suffering from MCI advance to dementia within one and three years respectively (Solfrizzi et al., 2006). This rate increases to around 15% yearly for patients with dominant memory impairment (amnestic MCI) (Petersen, 2003).

The annual conversion rate of MCI to dementia (5-10%) is higher than the incidence rate of dementia from normal adults (1-2%) (Wang et al., 2013).

Since there is no effective cure for AD, efforts can be made to prevent or delay the onset of AD. MCI has been identified as the early stage of dementia. It is evident from several studies that cognitive training can improve the cognitive performance of persons with MCI (Ball et al., 2002; Ball & Owsley, 2000; Baltes & Willis, 1982; Greenberg & Powers, 1987; Rebok & Balcerak, 1989; Willis, 1987; Willis & Schaie, 1986; Yesavage, 1985). So, persons with MCI can be screened and proper cognitive training can improve their cognitive functioning and enable them to lead a healthy life.

Prevalence of cognitive impairment:

Poor cognitive function was found to be correlated with ensuing cognitive decline (Yaffe et al,1999). In a prospective study on approximately 5800 community-dwelling elderly, it was found that women who had more than 5 symptoms of depression scored significantly lower on cognitive tests than those of had 3 to 5 symptoms and 0 to 2 symptoms ($p<0.001$).

In a population-based cohort study in Italy, the overall prevalence of MCI was reported as 7.7% (95% CI=6.1-9.7). Old age and lack of education had higher odds for the incidence of MCI. The rate of incidence of MCI was found to be higher (76.8% per 1000 person-years) than baseline after a 4-year follow-up study. The multivariate-adjusted risk model was analyzed. The risk for development of Dementia from MCI was 4.78 for any dementia, 5.92 for AD, and 1.61 for Vascular dementia. For subjects with no memory impairment, no association was found (Ravaglia et al., 2008). In another study, a prevalence rate of 15.4% for MCI was found and this had a significant positive correlation with the increase in old age. Positive associations were found for vascular diseases and depressive symptoms (Luck et al., 2007).

A prospective cohort study among the elderly showed increased cases of MCI after 3 and half years of follow-up (Panza et al., 2008). In another study, the incidence rate per 1000 persons-year for MCI was found to be 13.2 (95% CI 7.79-20.91), and for AD was found to be 14.8 (95% CI 9.04-22.94). The cognitive decline was significantly affected by Education and baseline Mini-Mental State Examination (Chaves et al., 2009). Nutritional deficit (Khater & Abouelezz, 2011) and smoking (Anstey et al., 2007; Mons et al., 2013) were found to be other risk factors for the development of MCI. Ever-smokers had a significantly lower cognitive assessment score than never-smokers. The association was more prominent among the current smokers than the ex-smokers. However, persons who have quit smoking for more than 30 years scored higher in cognitive assessment than the current smokers (Mons et al., 2013).

The Indian scenario for the prevalence of MCI and dementia is also similar. A study in Kolkata found an overall prevalence of MCI of 15%. Prevalence of the amnestic type and multiple domain types was 6% and 9% respectively. Men had mostly the amnestic type while multiple domain type was found to be common among women after adjusting for age and education (Das et al., 2007). In another study on 1000 people (65 years and older), last month's prevalence of depression was found to be around 13%. poor income, hunger, cardiac illnesses history, transient ischemic attack, previous head injury, and diabetes significantly increased the risk for geriatric depression (Rajkumar et al., 2009). In another study with 54,000 subjects (60 years and older), the crude prevalence rates of dementia were found to be 1.25%. Alzheimer’s disease was the commonest subtype (55%) followed by vascular dementia (36%) (Banerjee et al., 2008). Similar results were also obtained in Kerala in a study among 2500 community-living elderly. Odds for dementia (and AD) were found high with increasing age and 9 years or more education level decreased the odds (Mathuranath et al., 2010).

Training Intervention to improve cognitive impairment:

Training interventions such as exercise an effective non-pharmacological interventions for dementia or MCI. It has helped in improving the quality of life among people suffering from dementia. Studies have shown a positive relationship between high physical activity in teenagers and a lower chance of cognitive impairment in older people (Middleton et al., 2010). Improved cognitive functions were reported in a study of about 2800 persons (65-94 years of age) after the application of 3 cognitive training targeting memory, reasoning, and speed of processing. Each intervention improved the targeted cognitive ability compared with baseline (Ball et al., 2002; Singh et al., 2023).

Colcombe and Kramer performed a meta-analysis of intervention studies. It was found that the cognitive ability of sedentary healthy adults was improved by aerobic fitness training. It was found from this study that fitness training had strong but selective benefits for cognition, with the largest fitness-induced benefits occurring for executive-control processes. The length and type of the training intervention, the duration of training sessions, and the gender of the study participants affected the improvement of cognition (Colcombe & Kramer, 2003).

The effect of different types of exercise on patients with MCI or dementia was analyzed in another meta-analysis. The result showed that patients with dementia showed a delayed cognitive decline when trained with Resistance training, whereas Multicomponent Exercise has a positive effect on cognition in general and on executive functions for patients with MCI. However, this meta-analysis stressed that further Randomised controlled trials are needed to further strengthen these findings (Huang et al., 2022).

Conclusion:

Dementia takes a heavy toll both on the patient and the caregivers. As the incidence of dementia is set to rise progressively, proper diagnostic tests and intervention strategies must be developed. Both the Government and Non-Government entities should make it one of their priorities to invest in research on the elderly.

The 2030 Sustainable Development Goals outlined by the United Nations Development Programme (UNDP) (Dugarova, 2017) give particular focus to older persons. Elderly people can help in the sustainable development of society with their experience, knowledge, and skills. This makes it evident that people of this age group lead healthy independent lives.

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Chapter- 14

Distribution, Burrowing Adaptations and Threats of Dune Crickets with Special Reference to *Schizodactylus monstrosus* (Dury)

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Keywords: Adaptation, Threat, cricket, *Schizodactylus monstrosus*.

Abstract:

Schizodactylus monstrosus, sometimes known as Drury, is an Orthoptera species classified under the family Schizodactylidae. Only two genera of this insect may be found across the globe: the winged *Schizodactylus*, which is native to Eurasia, and the *Comicus*, which is native to Africa and does not have wings. The genus *Schizodactylus* is known from Burma to Turkey, including India. Seven species of this genus were discovered, namely S. *monstrosus* (Drury), *S. inexpectatus*, *S. burmanus*, *S. minor*, *S. tuberculatus*, *S. hesperus*, and *S. brevinotus*. Recently, Thailand discovered the eighth species *S. salweenensis*. It is a nocturnal, carnivorous, and also anabolic insect. *S. monstrosus* is strictly night active or nocturnal, which is supported by its coloration. The insect's color is creamy yellow and light green on the belly, and its wings are brown. Despite various works done previously on the burrowing behavior of *Schizodactylus monstrosus*, our investigation unfolds some new facts about their burrowing behavior as well as anthropogenic threats that cause a vigorous decline in population density.

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Introduction:

Dune cricket, Maize cricket and Monster cricket, is an orthoptera that belongs to the family Schizodactylidae. Due to their long antennae, villagers of Rajasthan called it 'MOOCHHAR' because it looked like a mustache (Mahapatra et al., 2019). In the state of Bihar, the *Schizodactylus* are referred to as the 'Bherwa of Bihar' due to their big size, powerful build, fierce appearance, burrowing behavior, and nocturnal behavior. Burrows are constructed by this species in the sand, typically near rivers and streams. Unlike the fully formed insects, the immature ones do not have wings yet and are very interesting. One of the most striking characteristics is the appearance of the flying insect, which is characterized by its most menacing jaws (Maxwell-Lefory, 1906; Fletcher, 1914).

As nocturnal insects, they come out of their burrow to act as active predators. They feed on ground beetles, grasshoppers, other insects, and small frogs. Some insect populations are prevented from growing and becoming dominant in dune habitats by the presence of *Schizodactylus*, which plays an important function in the ecosystem (Shabbir, 2014). Some arthropods and vertebrates are night-prowlers that feed on these species, and they are themselves voracious carnivores with a tendency to predate (Roy et al., 2017; Ivanišová et al., 2022). Different species of *Schizodactylus*, in addition to their destructive actions, play an essential position in the local food chain, which helps prevent many insect populations from growing and becoming dominant in the field. In addition, this species functions as a source of nutrition for a variety of reptiles, including wall lizards and snakes, as well as birds, including Shaheen, Alectoris, and Chukars. Because of their unusual tarsi, these insects can sprint on sand and live inside burrows during the day. They are most active at night on the surface of sandy and arid settings. There is a possibility that the construction of easy tunneling is the reason why they select sand places for their living. In isolated burrows, both the adults and the nymphs create their nests. While constructing their burrow, they scrape and dislodge sand from the burrow with their mandibles and anterior legs. They then use their abdomen and rear tibia to push the sand out of the burrow behind them. They are equipped with several morphological adaptations that allow them to dig in sandy environments.

Schizodactylus exhibits several remarkable characteristics that set them apart. One notable feature is their exceptionally long hind wings, which, in fully mature forms, coil tightly into a compact spiral at right angles to the substrate when at rest. Additionally, their tarsal segments are extensively developed and possess broad expansions adorned with lateral lobe-like or finger-like structures, further enhancing their distinct appearance.

Distribution:

In India, *S. monstrosus* is the only representative of this family. Over the world, there are only two genera of this insect, the winged *Schizodactylus* from Eurasia and the wingless

Comicus from Africa. The genus *Schizodactylus* is known from Burma to Turkey, including India. Seven species of this genus, namely *S. monstrosus* (Drury), *S. inexpectatus* (Werner, 1901), *S. burmanus* (Uvarov, 1935), *S. minor* (Ander, 1938), *S. tuberculatus* (Ander, 1938), *S. hesperus* (Bei Bienko, 1967), *S. brevinotus* (Ingrisch, 2002) were discovered. Recently, Thailand discovered the eighth species *S. salweenensis* (Dawwrueng et al., 2018). In India, it is reported from Ajmeer (Khattar, 1972), Jammu and Kashmir (Mukharjee, 1988), West Bengal (Hazra et al., 1983), South India (Fletcher, 1914), Chhattisgarh (Chandra & Gupta, 2005).

As the name suggests dune crickets are generally found in dunes near the river bank. The sand bed consists of light brown, creamy-yellowish masonry sand or fine sand. *S. monstrosus* is a burrowing insect (Khatua et al., 2020). A borescope camera is used to observe them inside the burrow. The solution of Plaster of Paris and water in a 1:1 ratio can be used to determine the length and pattern of the burrows. They come out from the burrow after pouring solutions. So, it is easy to collect the specimen without any injury. When the structure hardens after 40 minutes, the burrow can be easily dug out for a more detailed understanding of its structure.

Brownish or greyish brown, the body is thick and brownish. It has a big head that is quite short and has powerful mandibles. Located below the eyes, the antennae, which are longer than the body, are inserted. In addition to having robust spines, the legs have a substantial build. The auditory tympana is absent from the anterior tibiae. Except for the Gryllidae, the tarsi have four segments. When at repose, advanced species' front wings (tegmina) are bent angularly downward along the sides of the body, just like in Gryllidae. However, the base of the wings is not changed to produce a stridulatory organ, as it typically is in Gryllidae. Little stridulatory teeth can be found at the base of the abdomen in both males and females and in older nymphs (which have larger stridulatory teeth than those found in adults). Compared to Gryllidae, the cerci are much stiffer, as they lack the basal club-shaped sense organs present in Gryllidae. Additionally, the cerci are relatively lengthy and do not have annulations. Compared to Gryllidae, the ninth abdominal sternum of the male bears minute styles. The ovipositor is rudimentary. In contrast to other Orthoptera, its chromosomes are few.

Life History:

Metamorphosis consists of discrete stages that are separated by a substantial transition between them. In arthropods, the animal undergoes a process known as molting, which involves the animal's exoskeleton. The new exoskeleton is expected to have formed beneath the previous skin. The newly formed skin is inflated and then hardens after the molting process. An insect will eventually attain its ultimate adult form following a series of molts. At this point, it will no longer undergo any further molts.

In the year 1890, Dyar was the first person to investigate the various stages of the Lepidoptera butterflies. He suggested that the head capsule of these larvae can expand in geometrical succession, which would increase width at each ecdysis. However, this does not apply to all other species, and the ratio may not be constant for the various body parts present in the same species. Riffat & Wagan (2010, 2012) stated that antennal segments, length of antennae, pronotum, and total body length of nymphal instars have significant importance in distinguishing the various stages of *Hieroglyphus* spp. Criddle (1926) reported that several antennal segments, the development of wing rudiments, and the modification of the pronotum are crucial for the study of the immature stages of Orthoptera. However, Riffat & Wagan noted that these factors are important for distinguishing between the various stages of *Hieroglyphus* species. Cowan (1929), on the other hand, suggested that the development of the ovipositor in females and the sub-genital plate in males is a basic characteristic that may be used to define the immature stages of *Anabrus simplex*. However, this characteristic is not very dependable in *Schizodactylus*.

To determine the various phases of *Schizodactylus*, the length of the body, the antennae, the hind femur, the development of the genitalia, the size of the pronotum, and the length of the wings rudiments, as well as their position, are particularly extremely essential variables.

Key to knowing extant species of *Schizodactylus:*

1. Wings to their fullest extent
2. This species, *S. inexspectatus*, has extremely short wings, reaching hardly more than half of the abdomen (Werner,1901).
3. Pronotum normal, larger than three millimeters in the middle
4. *S. brevinotus* has a pronotum that is quite short but has a medium length of 2.2 millimeters (Ingrisch, 2002).
5. The highest point of the male subgenital plate, which is projected
6. There is no projection on the apex of the male subgenital plate, and there is a triangle excision in the middle.
7. A subgenital plate that is longer than it is wide, with the protrusion corresponding to a pair of lobes
8. *S. burmanus* has a subgenital plate that is longer than its breadth and has a protrusion that is shaped like a rounded lobe with a flat top (Uvarov, 1935).
9. According to Dawwrueng (2018), the projection of *S. salweenensis* is spherical and protrudes forward in lateral view. Additionally, the first and second internal apical spurs are of a similar shape.
10. Compound eyes are typical, average in size, and the body length of a guy is greater than 27 millimeters.
11. Compound eyes are quite large, having a side length of half the length of the head, and their size is small. The body length of a male S. minor is between 23 and 25 millimeters (Ander, 1938).
12. Size enormous in body length, more than 42 millimeters in males and 47 millimeters in females; the first internal apical spur of the post tibia is acute apically; male titillators

are slender; female subgenital plate with hind edge rounded in the middle- *S. monstrosus* (Drury, 1770).

13. Size medium in body length, measuring 27 millimeters in males and 29 millimeters in females; the first internal apical spur of the post tibia is less acute apically; male titillators are robust; female subgenital plate has a hind edge that is straight in the middle (Bey-Bienko, 1967).
14. The tegmina and wings of *Schizodactylus* species, such as *S. minor* and *S. sindhensis*, are lengthy, tapering posteriorly and rolling into a spiral that rests over the cerci. These characteristics are characteristic of *Schizodactylus* species. It is not the case that *S. inexpectatus* has tegmina sides that abruptly turn down and cover the lateral side of the abdomen; however, this is the case in other species. Choudhuri & Bagh (1974) also discovered that the female of the *S. monstrosus* species laid her eggs at the very end of the burrow hole.
15. The eggs of the female *S. minor* are laid along the side walls of the burrow, whereas the eggs of the female *S. sindhensis* are laid in a pit at the bottom of the burrow. *S. minor*, *S. monstrosus*, and *S. sindhensis* were the species that produced the most eggs, according to the records. There are 18 eggs found in *S. minor*, 34 in *S. monstrosus*, and 43 in *S. sindhensis* throughout the study. On the other hand, the behavior of the *Schizodactylus* species regarding courtship is unknown.

The short-tailed cricket, which belongs to the genus *Anurogryllus* and is a member of the gryllid family, is an example of a species that exhibits more advanced maternal care and subsocial behavior. Female crickets construct brood chambers, which protect their eggs and early instar nymphs from potential predators or other members of the same species. Additionally, she takes fecal waste and places it in specialized burrow chambers. She then feeds the young material that she has collected or tropic eggs that have not been fertilized (West & Alexander, 1965; Weaver & Sommers, 1969; Walker, 1983). It has been determined that the genus *Schizodactylus* does not possess any indication of brood chambers or sophisticated maternal care.

Morphological description of nymphal instars of *Schizodactylus monstrosus:*

1st nymph

Minute tegmina and wing rudiments were found in little triangular lobes on the lateral margins of the meso and metathorax. These lobes were located above the mesothorax. At this stage, these lobes were not distinguishable.

2nd nymph

There was a small increase in the size of the triangular tegmina and wing rudiments, and they became different from the meso and meta thoracic segments by the formation of discrete ridges. A slight anteriority and a downward inclination characterize these lobes.

3rd nymph

Although there was a little increase in the size of the tegmina and wing rudiments, they continued to be triangular lateral flaps of the meso and meta thorax and were separated by distinct ridges.

4th nymph

Laterally downwards on the meso and meta thorax side, the tegmina and wing rudiments continue to grow in size, but they continue to remain so. Additionally, longitudinal striations manifested themselves during this stage, and indications of their presence could be seen on both rudiments.

5th nymph

The size of the tegmina and wing rudiments continues to grow, and they eventually transform into a colorful conical rudiment.

6th nymph

During this stage, the tegminal rudiments were angled slightly in the other direction, turning laterally downwards, and the wings were stretched out. As a direct result of this, the ridge has entirely separated the anal region, which is becoming increasingly distinct at this time.

7th nymph

The tegmina and wing pads were positioned in a reversed position. During this time, the tegmina extended to the boundary of the meta thoracic on the posterior side, while the wing pads reached the first abdominal segment respectively. On the other hand, the wing pads were overlapping the basal posterior side of the tegminal rudiments.

8th nymph

It was observed that the tegmina and wing pads were reflected over the back, and their size continued to rise. At this point, the tegmina had reached the first abdominal segment, and the wings had stretched to the second abdominal segment. During this stage as well, tracheation was more noticeable in both of the foundational stages.

9th nymph

Both the tegmina and the wing pads grew in size to the point where they almost completely covered the dorsal and lateral sides of the first fourth abdominal segments. As a result of the wing pads covering the fifth abdominal segment and the tegmina reaching the fourth abdominal segment, the color of both rudiments got darker.

Diagnostic Characters:

According to the current definition of the genus *Schizodactylus*, it includes all large and robust Schizodactylids that have wings that are developed and, except *S. inexpectatus*, which has wings that are reduced, extend beyond the apex of the abdomen, where they terminate in a prominent coil. The mouth parts of *Schizodactylus* species are significantly larger than those of other species, and they have a broad labrum in the shape of a diamond. Additionally, their pro- and mesothoracic legs are strongly compressed laterally. The genus can be easily distinguished from *Comicus*, the only other genus in the family. *Comicus* is distinguished by a body that is noticeably smaller and more graceful (often measuring less than 25 millimeters), long and slender legs, and wings that are completely reduced in size.

Schizodactylus minor Ander:

Description of Female:

The female adult is of medium size, measuring 29.31±0.68 mm in length, and is characterized by being thin, graceful, thick, and conspicuous in appearance. The shape of the head is broad and conical, the frons are long, the vertex is arched, and it slopes steeply between the compound eyes. The fastigium of the vertex is short and deeply wrinkled, and it is between the dorsal borders of the antennal scobae. For a length of around 7 centimeters, the filiform antennae consisted of more than 300 segments. The remaining portion of the antennae are pale and brown, while the scape is white and has black spots on its surface when viewed from above. The mandibles are white and cover the front side of the labrum, which is big and shaped like a diamond. Their sinuate incisor lobes are utilized for digging the burrow, and they cross each other when they are standing still. The transverse sulcus is located directly beyond the anterior edge, the lateral margins are sinuate, the anterior margin is concave, and the posterior margin is extensively concave and sinuate. The pronotum is shorter and rectangular. The dorsal surface of the pronotum is covered with patches that are dark greyish-brown in color. There is a transverse suture on the dorsal side, and a similar ridge on the ventral side appears to be a clip. Tegmen and wings that are significantly larger than the body are spirally curled up at the apex.

Spinules of between five and eight minutes are seen on the ventral internal margins of the fore femur, from eight to nine minutes on the ventral-external margin of the mid femur, and from fourteen to twenty minutes on both ventral margins of the hind femur. All of the knee lobes on the legs are obtuse, and the fore tibia has four long ventro-external spines and four long ventro-internal spines beside two apical spurs on each side. The internal spurs are longer than the exterior spurs, with the ventral-internal spur being the longest of the three. In the middle of the tibia are four long ventro-external spines and three to four short ventro-internal spines. Additionally, there are four long dorso-internal spines and one shorter dorso-external spine directly before the apical spurs. Additionally, there are two apical spurs on each side, with the internal spurs being longer than the external spurs, with the dorsal-internal spur. Each side of the hind tibia has three dorso-external spines and four dorso-internal spines of medium length. There are three apical spurs on each side, with the internal spurs being longer than the external ones. There is one external spur and two internal spurs out of these spurs. The ventro-apica margin of the hind tibia is distally widened, and it has four short spines just below the apical spurs and one spine that is longer at the internal angle. There are four segments on each of the legs, each with a pair of apical claws. The second and third segments are very short, each with a pair of enormous plantulae. The first segment of the hind tarsus has a pair of massive, compressed, triangular lateral projections.

When the epiproct is triangular, wrinkled in the center line, and obtuse at the apex, the last abdominal tergite is short, transverse, and sub-united with the epiproct. Cerci are compressed, particularly in the apical region, and the apex is obtuse. The basal region is conical, while the apical region is linear. The apex of the subgenital plate is broadly rounded and simple. With an abbreviated apex, the ovarian ovipositor was significantly shortened, although it still exceeded the apex of the subgenital plate. No segmentation is present in the cerci, which are elongated and plank-shaped.

A bright whitish or creamish-yellow hue can be found throughout the body, with dark brown or greyish spots on the dorsal cream and greenish patches on the ventral side. A light yellowish tint can be seen laterally on the head, and it has dark brown patches on its dorsal surface. The head is white and cream, and it has brown or green dots. In contrast to the remainder of the antennae, which are yellowish or pale brown, the base of the antennal segment is brown. Tegmina and wings are brownish on the dorsal side, while the lateral side is light brownish. The fore, mid, and hind femurs are off-white or light pinkish in hue, or light green in color, with muddy brownish patches on the outer lateral surfaces of the femur. The color of the hind tibiae is light pinkish, whereas the color of the fore and mid tibiae is considered to be light greenish. The claws on the legs are big, long, and curved. They have a brownish tint, and the tips of the claws are black. A light or off-white tint may be found on the tergites of the abdomen, and they have dark brownish spots on their mid-posterior edges. The abdominal region is visible from the ventral side, green, and somewhat protruding downward. There is a slight off-white hue to the cerci.

Description of Male:

At a length of 25.12±0.36 millimeters, the adult male is of a modest size. The appearance of the pronotum is typically characterized by a characteristic black pattern that includes a narrow longitudinal stripe in the middle. The pronotum's maximum width, which measures 5.17±2.07mm, is bigger than its median length, which measures 2.02±0.09mm. There are no transverse light stripes on the basal part of the tegmina, the apical section of the tegmina is rolled, and the wings and tegmina have reached their completely grown state. The armament and number of spines and spurs on all legs are the same as in females; however, the expended external spurs of the hind tibia vary in the following ways: the upper spur is less sharpened apically, the median spur is slightly incurved with a lower margin that is somewhat concave, the apex is short and asymmetrically sharpened, and the apex of the lower spur is more sharpened than the median spur. This transverse, sclerotized plate is only visible from behind or below and represents the tenth abdominal tergite. It is interrupted in the middle of the body. Under the plate is a pair of thick, elongated titillates measuring 0.7 millimeters in length. Their apex is mammiform and firmly up-curved, equipped with two pairs of dark, sharp teeth measuring 0.2 millimeters in length. The tip of the subgenital plate was removed in a triangular fashion. The cerci are elongated and somewhat curved dorsally, progressively narrowing in the basal two-thirds, and then slightly widening again in the apical third, with the apex being sharply pointed. There are minute spots on the ventral side of the abdomen, and the general colouration is comparable to that of their female counterpart.

Schizodactylus monstrous Drury:

Description of Female:

The general morphology is identical to that of males, with the short transverse subunit with epiproct at the end of the abdominal tergite. The latter is triangular, with a furrowed midline and an obtuse apex. Cerci are 8.36 ± 0.29 millimeters larger, particularly compressed in the apical region, in addition to having a conical basal and a digit-shaped apical region, and their apex is obtuse. It is moderately transverse or scarcely elongated, with a hind margin that is straight at the middle; a small and very characteristic tongue-like appendage that protrudes behind the sub-genital plate of a female; the upper surface of the appendage has a longitudinal furrow; the lateral margins before the apical part are parallel or slightly convex; the apex is rectangular or practically rounded, and it is just occasionally slightly sharpened. The ovarian ovipositor measures 1.5 millimeters in size and is significantly diminished, yet it still manages to repress the apex of the subgenital plate. No segmentation is present in the cerci, which are elongated and plank-shaped.

Description of Male:

The adult is huge, measuring between 43 and 54 millimeters in length, thick, robust, and noticeable in appearance. The antennae are filiform and approximately 10 centimeters in length. A dot of black, which is white, is located on the inner surface of the scape. The remaining antennae are a light brownish color. From the front, the mandible was covered by the labrum, a massive, diamond-shaped structure emarginated and white. The latter are elongated and sinuate; when they are at rest, they traverse each other. The palps of the maxillary and labial regions appear to be larger. Compared to the lateral edges of the pronotum, the anterior margin has a concave form on the anterior side. Both the posterior margin and the anterior margin are sinuate and widely concave. Just behind the anterior edge, which is tuberculate mid-dorsally and dorsolaterally, a transverse sulcus can be found. Tegmina and wings are both fully formed, with the apical region having a rolled shape. The wings are also fully developed. Neither the basal section of the tegmina nor the transverse bright stripes are present in this region. On the ventro-interior borders of the fore femur, spinules measure 12-15(18) minutes. There are 12–15 spinules on the ventro-external margin of the mid femur; the hind femur has minute spinules on both ventral margins; and the knee lobes of all legs are obtuse. Fore tibia has four long ventro-external spines and four long ventro-internal spines, with two apical spurs on each side, with the internal spurs being longer than the external spurs and the ventro-internal spur being the longest of the three. Mid tibia with four long ventro-external spines and three short ventro-internal spines, four long dorso-internal spines, and one shorter dorso-external spine right above the apical spurs; two apical spurs on each side, with the internal spurs being longer than the external spurs, with the dorsal-internal spur being the longest of the two. There are three dorso-external spines and four dorso-internal spines on the hind tibia, all of which are of medium length. Additionally, three apical spurs are on each side, with the internal spurs being longer than the exterior spurs. Out of these spurs, one is external and two are internal. There are four short spines located directly below the apical spurs on the ventro-apical border of the hind tibia, and one larger spine is positioned at an internal angle. It is a tarsus with four segments and a pair of apical claws on each leg. In addition to the fact that the second and third segments are quite brief and each includes a pair of enormous plantulae, the first segment of the hind tarsus is characterized by huge, compressed, triangular lateral extensions. Without transverse light stripes, the art of tegmina is presented.

The final abdominal tergite characterized by a broad and short median projection that is divided by a profound median longitudinal furrow. The upper surface of this projection is covered by a rather dense number of tiny spinulae. The subgenital plate is half as long as the preceding sternite, which is moderately elongated. The lateral borders are parallel in the basal half and convergent in the apical half. The apex has a severe angulate excision that reaches the center of the plate, and the lobes are triangular sub-acutely. A pair of thick elongate titillators that project from underneath the plate, with their apex being mammiform and strongly upcurved, equipped with black sharp teeth that are transverse, sub-united with epiproct, epiproct being triangular and wrinkled in the middle line, and their apex being obtuse. The cerci are compressed, particularly in the apical region, and they have a conical base and digit shape in the apical region, with an obtuse tip. The subgenital plate is straightforward, apex-shaped, and generally rounded.

In general, the body has a creamish-yellow hue, with black spots on the dorsal surface and a cream-green color on the ventral surface. From above, the head is characterized by three dark stripes running longitudinally and a long bow-shaped vertical stripe behind the eyes. There are brownish spots on the dorsal side of the head, which is pale with a greenish tinge in the front, light cream at the lateral, and a creamy head. Except for the scape, which is white with a somewhat dark dot on its inner surface, the antenna is a light brown color. Both the labrum and the pronotum are white, with the pronotum being pink with spots of yellow light and dark light brown dorsally. Dorsally, the tegmina is brown, and laterally, it is a lighter shade of brown. Cercus is characterized by its white hue and covered in a large number of sensory hairs. In the cephalic area, two huge compound eyes are kidney-shaped and dark brown. Additionally, there are brown antennae with yellow bases.

The previous records of the deepest holes were 35.25 ± 8.50 centimeters made by *S. minor* (Channa, 2013), 66.81 ± 7.73 centimeters made by *S. monstrosus* (Channa, 2011), and 160 centimeters made by *S. inexpectatus* (Ayadin, 2005). The deepest borrow, which was just measured, is 193 centimeters deep, and the burrow with the lowest depth is 52 centimeters. Most of the burrows are found within the 62 cm to 87 cm range. In most instances, the smaller burrows that are less than 75 centimeters in length have a little leftward turn. However, after 100–120 centimeters, the longer tunnel, which is more than 170 centimeters long, abruptly turns to the left. There were 76 to 94-centimeter burrows created in thirty minutes by fifty mature insects that were used in an experiment to determine the speed at which they made the tunnel. It is not possible to brunch or use the side tunnels. *S. monstrosus* burrows are said to remain closed after they have been completed, according to Khattar's 1972 research. Nevertheless, it has been noticed that the openings of the burrows only remain closed throughout the summer months. A further observation that has been made is that the angle of the tunnel shifts from one season to the next. During the dry season, the tunnel is constructed at 600 degrees, but during the wet season, it is constructed at 450 degrees. There are instances in which *S. inexpectatus* will construct burrows that contain a small chamber at the end of the tunnel (Ayadin, 2008). External burrowing adaptations can be broken down into three primary categories:

1. The mouth is supported by a big mandible that covers the labrum. This jaw is used to dig out the sand, and the forelegs, each with two large claws, are used to grab the sand.
2. The tibia, the dorsal spine, the apical spurs, the triangular plate, the euplantulae, and the nail comprise the huge, muscular, and bushy hind legs. The apical spurs, the triangular plate, and the euplantulae are some of the components that contribute significantly to the increase in surface area. Since this is the case, these insects are good hoppers but only moderate runners. After the mandible has dug up the sand, it is then pushed out of the tunnel by its hind legs, which have been modified in a certain way.
3. Only the ninth nymphal stage is capable of flight; this is the only stage. When an adult is present, the posterior portion of the tegmina will often create a rolling structure to facilitate a smooth passage down the tunnel. According to observations, insects that have reached adulthood cannot spread their wings.

As a result of increased anthropogenic activity over the past few decades, *S. monstrosus* has been confronted with a significant threat to its ability to survive. For centuries, people have held the concept that different portions of the body can treat a variety of illnesses. The inhabitants of the Muslim colony manufacture amulets out of various parts of their bodies. Head parts are used to improve intelligence, genital parts are used to alleviate infertility problems, and hind legs to cure axima in children. There are also other applications for these parts.

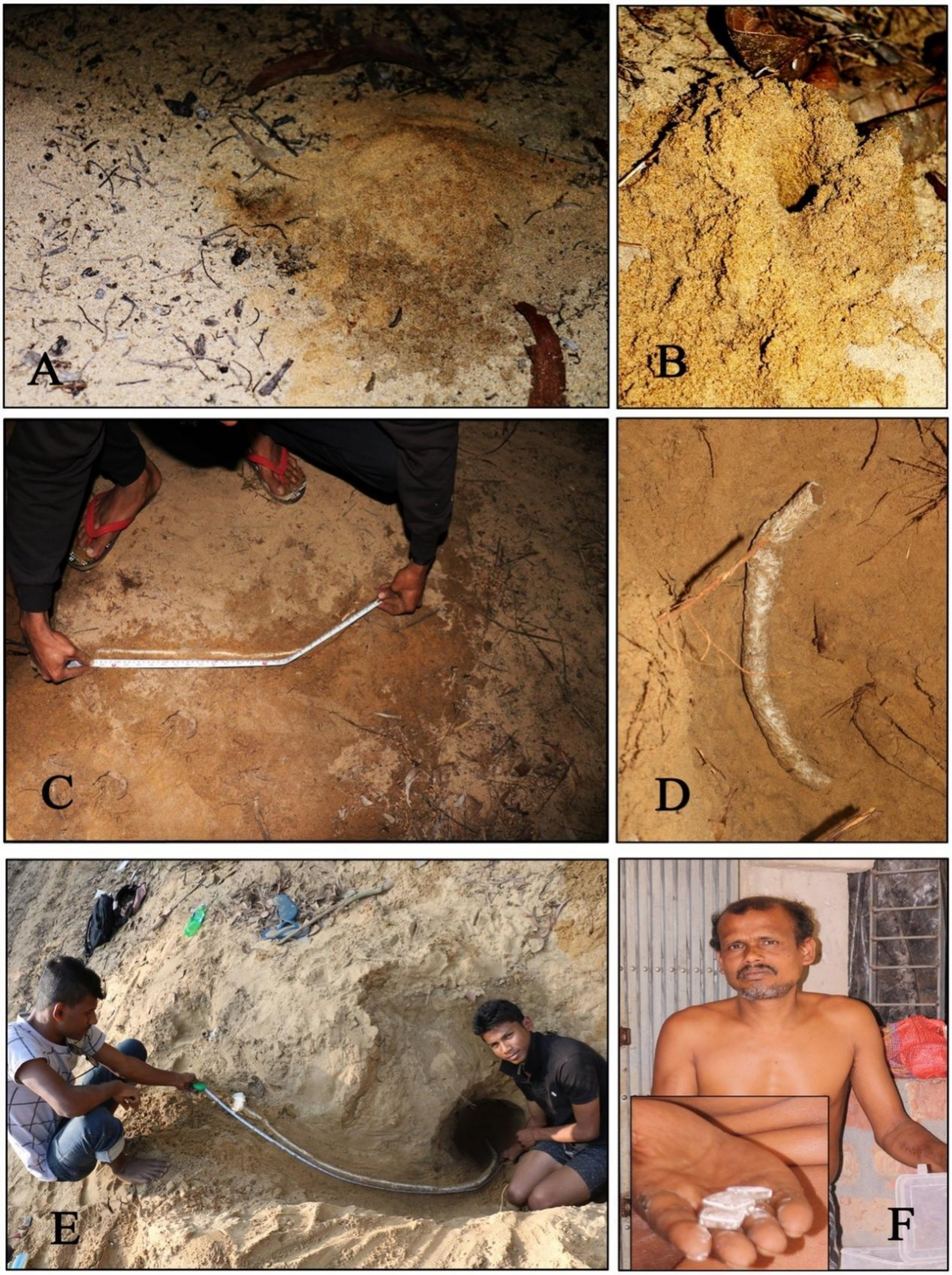

Figure 1. (A). Early Made Burrow, 1(B). Freshly made burrow, 1(C). Smallest Burrow, 1(D). Solidified Structure of Paris Solution Shows the actual shape of a tunnel, 1€. Longest Burrow, 1(F). Villagers made Amulet using *S. monstrosus* (Source: Corresponding Author's works with Khatua et al., 2020).

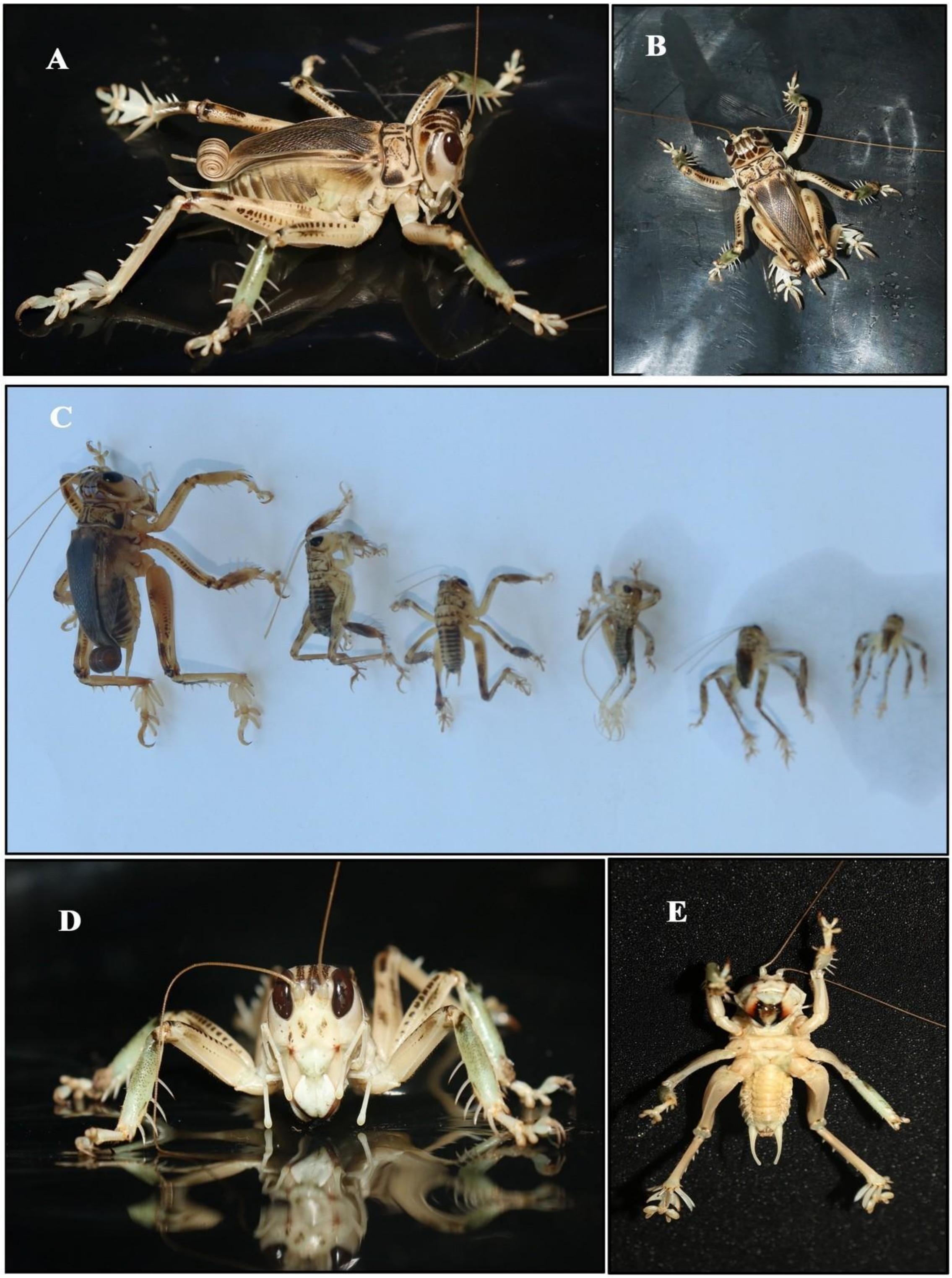

Figure 2(A). Adult S. *monstrosus* , 2(B). Dorsal view of Adult S. *monstrosus,* 2(C). Different nymphal stages of S. *monstrosus,* 2(D). Front view of S. *monstrosus,* 2€. Ventral view of S. *monstrosus* (Source: Corresponding Author's works with Khatua et al., 2020).

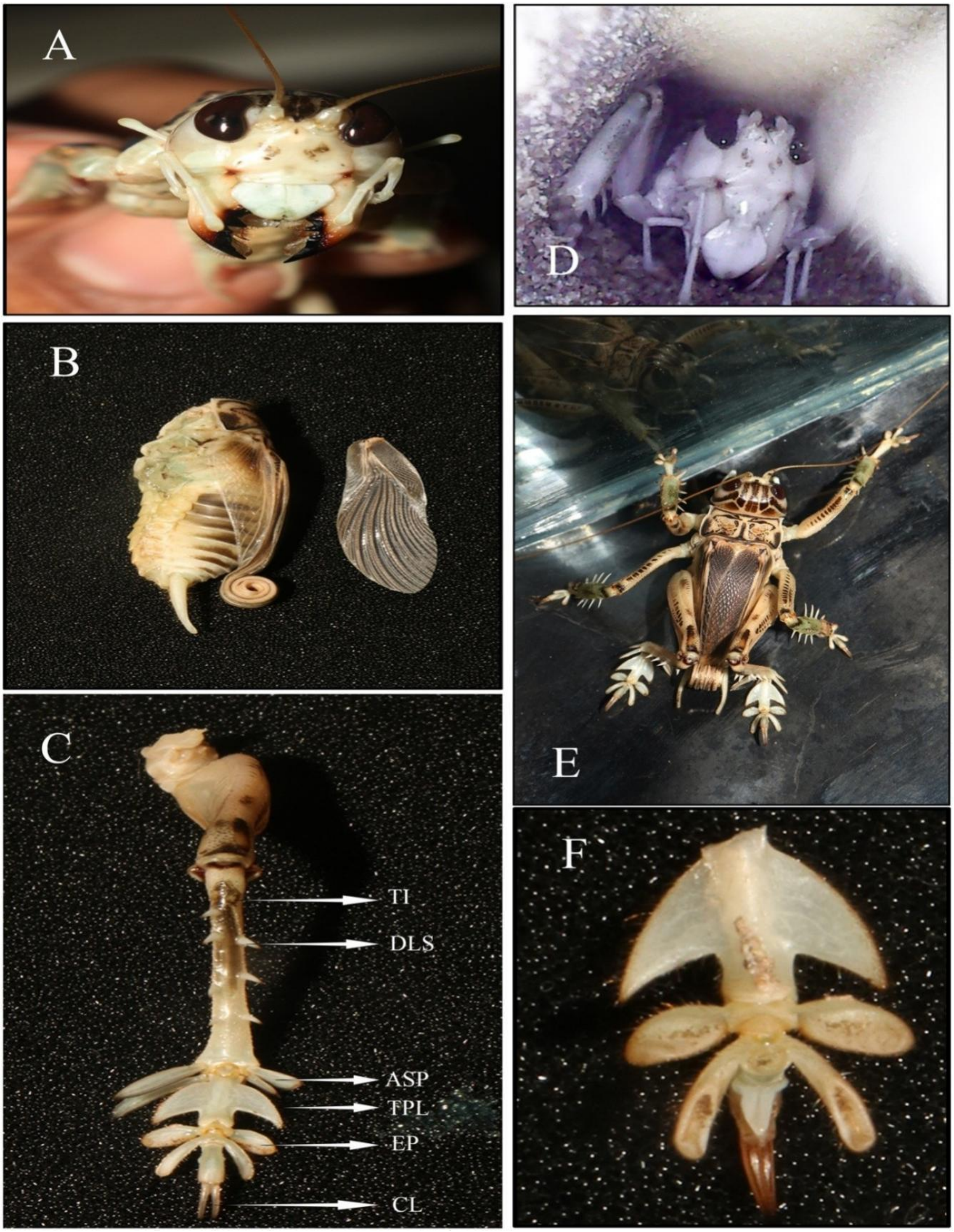

Figure 3(A). Mandible, 3(B). Wings of S. *monstrosus,* 3(C). Hind leg of *S. monstrosus* (dorsal view), 3(D). The specimen in a burrow, 3€. Full-grown specimen, 3(F). Special Structure of hind leg for burrowing (Abbreviation:TI: Tibia, DLS: Dorsolateral Spines, ASP: Apical Spurs, TPL: Triangular plate, EP: Euplntulae, CL: Claw) (Source: Corresponding Author's works with Khatua et al., 2020).

Around 100 to 150 amulets are sold by each household in the Muslim colony every month, with the price of an amulet ranging from Rs. 351 to Rs. 551. What this suggests is that a significant number of insects are captured daily. The transfer of sand is another danger the species must contend with. A significant number of insects are removed from their natural environment as a result of the transfer of sand from riverbanks to buildings. Because of this, their number is decreasing at a startlingly rapid rate.

According to Khattar (1972), *S. monstrosus* is known to burrow on soils with a high humidity level and dig deeper until they find the moisture and humidity level they are looking for, which is between 88.5 and 98.5 percent. In situations when they are dispersed away from riverbanks and the soil contains a lower humidity level, they are compelled to dig significantly larger burrows.

It is common practice for *S. monstrosus* to keep the tunnel's opening covered during the daytime hours to shield themselves from the influence of sunlight. During the summer, they dig tunnels at angles of 600 degrees to go deeper in their search for humidity. However, during the rainy season, they do not have to dig burrows at angles of 600 degrees since they do not need to go deeper. This species is a deep-rooted burrower, which contributes to the process of soil aeration. Because it is a carnivorous animal, it consumes a number of the agriculture pests that are commonly known and play an important part in the food chain.

In today's world, the *Schizodactylus* is in danger of going extinct due to increased human activities. Therefore, a substantial amount of research ought to be carried out on this subject to keep an eye on the species and reduce the risks.

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Chapter- 15

Cytotoxic Effects of Silver Nanoparticles on Plants: A Potential Threat to the Environment and Its Management

Alokemoy Basu

Keywords: Nanoparticles, nanomaterials, nano waste management.

Abstract:

Nanomaterials are nowadays very common in our daily used products. The most prevalent nanoparticles that we encounter are silver nanoparticles. Almost all electronic appliances, including mobile phones, contain a certain amount of silver nanoparticles. Due to the unmanaged and unforeseen disposal of products containing nanomaterials over the years, silver nanoparticles have become almost omnipresent in the environment in different forms and concentrations. Research has shown that silver nanoparticles, in their lower size range with higher concentration and longer exposure time, can cause severe toxic effects on the plant cell cycle, growth, and development. Therefore, to restrict the encroachment of nanoparticle-containing waste or nano-waste into the environment, there should be a specialized management system that can assess, categorize, and formulate suitable strategies for the safe disposal of those nanowastes.

Introduction:

Particles falling within the size range of 1 to 100 nm in at least one dimension maintain their individuality, despite their minuscule size, and are categorized as Nano Particles (Albrecht et al., 2006). The extremely small size of these particles leads to a change in the physical and chemical properties compared to the bulk samples of the original compound from which these Nano Particles are derived (Auffan et al., 2009). Recent advancements in technology have facilitated the design and engineering of nanoparticles for diverse applications in medicine, biology, material science, physics, and chemistry (Rastogi et al., 2017; Sadhu et al., 2022; Dianová et al., 2023). Unfortunately, the introduction of nanoparticles into human life and the environment on Earth has occurred without due consideration of associated risks (Roco, 2003). Notably, in recent years, the synthesis of nanoparticles has shifted towards utilizing biological materials, particularly plant-based materials in a process known as green synthesis (Mukherjee et al., 2001; Pasupuleti et al., 2013; Paul & Yadav, 2015).

Silver nanoparticles (AgNPs) hold significant importance, being recognized as a broad-spectrum biocide effective against a wide range of bacteria (Sengottaiyan et al., 2016), fungi (Lamsal et al., 2011; Tripathi et al., 2017) and exhibiting antiviral properties (Sun et al., 2005)

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along with anticancer potential (Rajeshkumar et al., 2016). The adoption of a green process for metal nanoparticle synthesis has resulted in a manifold increase in the application of silver nanoparticles across various domains, including biosensors (Nam et al., 2003), cell labeling (Wu et al., 2003), DNA detection (Taylor et al., 2000), oxidative catalysis (Shiraishi & Toshima, 2000), and antibiotics (Kreuter & Gelperina, 2008).

An alarming consequence of widespread Nano Particle use is the release of nanomaterials into the environment. With industries employing nanotechnology in diverse forms, the generation of waste containing residual nanomaterials and the introduction of nano-waste into the environment have become unavoidable. Interestingly, nanoparticles were present in the environment even before the advent of nanotechnology. Depending on their type, nanoparticles may be released into the atmosphere as aerosols, into the soil and surface water. Nanoparticles can be released as bare particles, functionalized particles, aggregates, or embedded in a matrix (Nowack & Bucheli, 2007). They can pose ecotoxicological hazards, undergo biodegradation, or bioaccumulate in the food chain (Scenihr, 2006; Rajalakshmi & Paari, 2023).

Common sources of natural nanoparticles in the environment include by-products generated from the combustion of fuels such as coal, petroleum, and wood burning, as well as automobile exhaust. Additionally, aerosols from atmospheric phytochemistry and volcanic activity contribute to the presence of natural nanoparticles. Given the rapid proliferation of nano products in the market, there is an urgent need for comprehensive research in the expansive fields of nanotoxicology and nanowaste management (Bystrzejewska-Piotrowska et al., 2009).

Cytotoxic effects of Silver Nanoparticles:

In their study, Babu et al. (2008) observed a decrease in the mitotic index (MI) of the *Allium cepa* root tip meristem when treated with silver nanoparticles (AgNPs). Notably, the decrease in MI was more pronounced with longer exposure times for each concentration of AgNPs. The data revealed a higher decrease in MI in a 20 PPM solution compared to 10 PPM, while 40 PPM and 50 PPM showed almost the same and higher MI than 20 PPM (Fig. 1). Additionally, an increase in the frequency of various chromosomal aberrations (CA) was noted with escalating concentrations of AgNPs and prolonged exposure times. Unlike MI, the change in CA frequency was found to be more significant with variations in AgNP concentration than exposure time (Fig. 2) (Babu et al., 2008).

Daphedar & Taranath (2017, 2018) investigated *Drimia indica* and *Drimia polyantha*, respectively, and found similar increasing trends in chromosomal aberrations, such as anaphase bridges, sticky chromosomes, laggards, diagonal chromosomes, C-metaphase, multipolar anaphase, and disturbed metaphase. The overall mitotic activity decreased with higher concentrations and longer exposure times to silver nanoparticles. *D. polyantha* root tips treated with 16 μg/ml of AgNPs for 24 hours exhibited dead cells (Fig. 3). The highest frequencies of chromosomal bridges and stickiness were observed after treatment with 12 μg/ml AgNPs for 24 hours. The mitotic index was highest in the control and lowest in the 16 µg/ml AgNPs solution at 24 hours of treatment (Fig. 4) (Daphedar & Taranath, 2017, 2018).

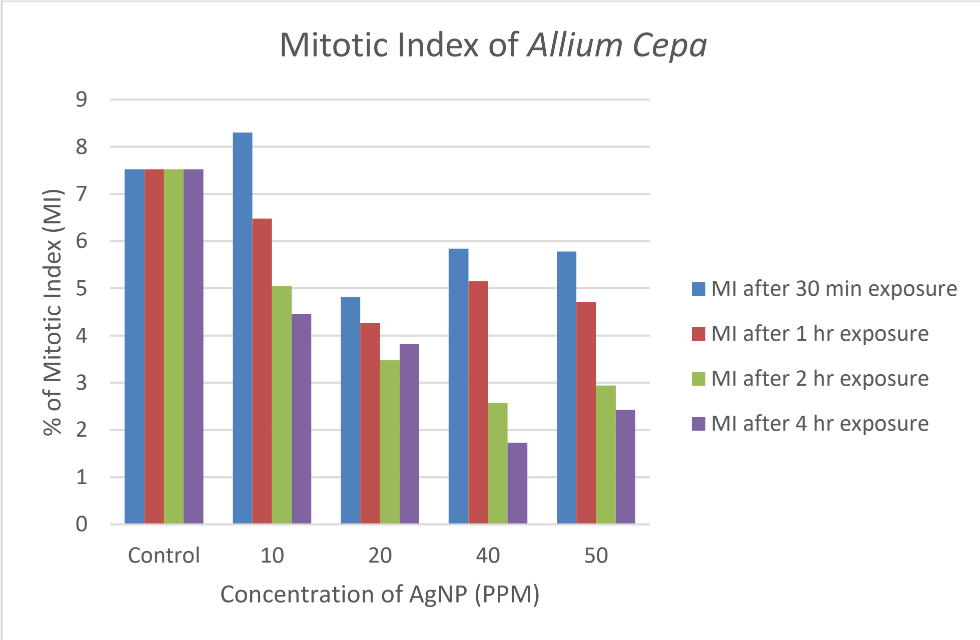

Figure 1. The graph has been developed from the secondary data obtained from Babu *et. al*. (2008) showing the decreasing trend of the Mitotic Index with increasing AgNP concentration and exposure time in *Allium Cepa*.

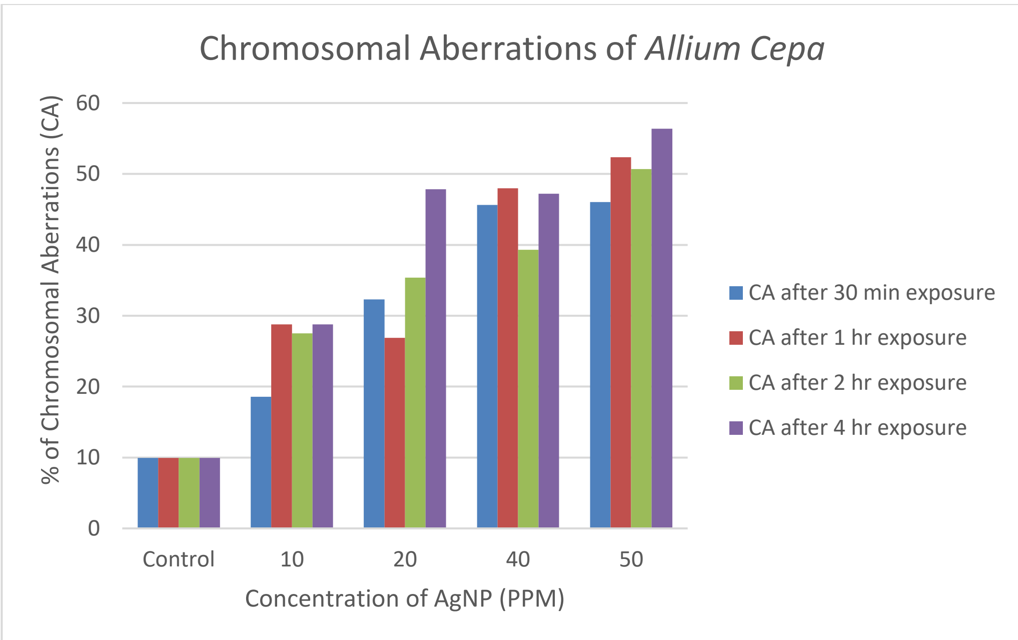

Figure 2. The graph has been developed from the secondary data obtained from Babu *et. al*. (2008) showing the increasing trend of the chromosomal aberrations with increasing AgNP concentration and exposure time to *Allium Cepa*.

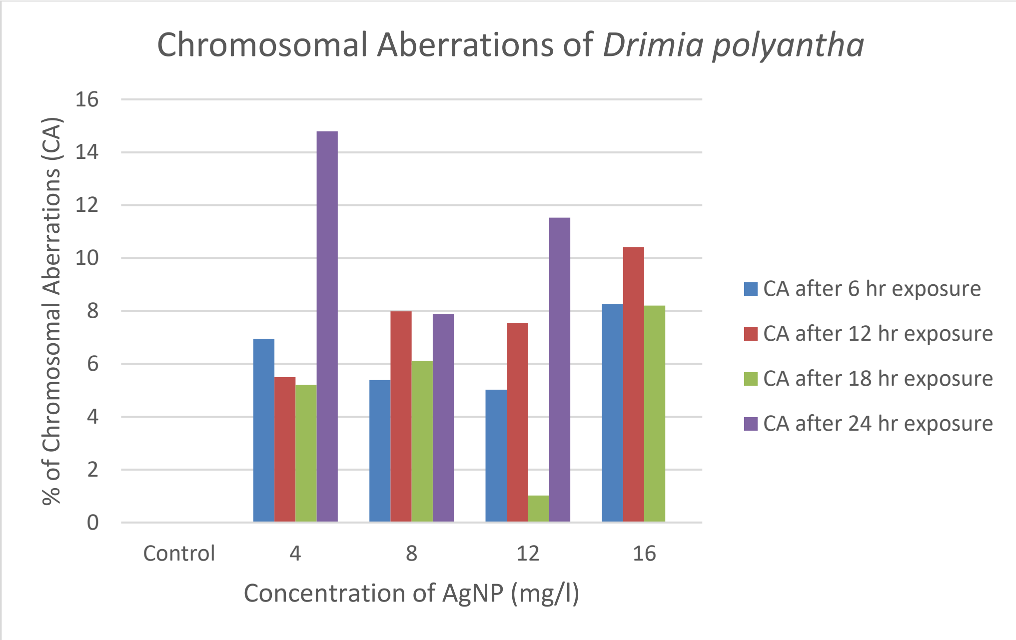

Figure 3. The graph has been developed from the secondary data obtained from Daphedar & Taranath (2018), showing the increasing trend of the chromosomal aberrations with increasing AgNP concentration and exposure time in *Drimia polyantha*.

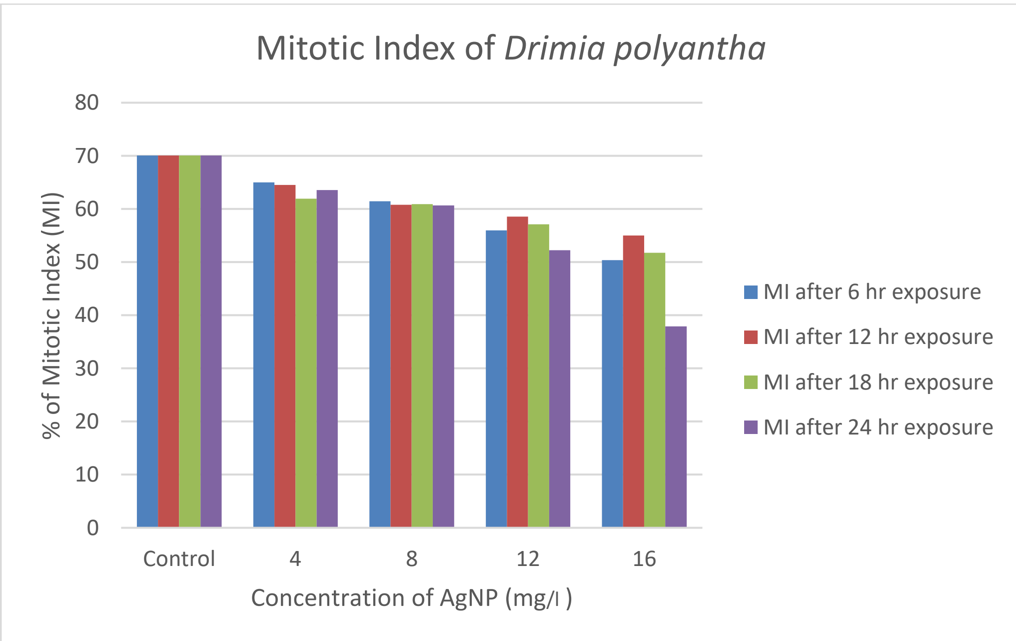

Figure 4. The graph has been developed from the secondary data obtained from Daphedar & Taranath (2018), showing the decreasing trend of the Mitotic Index with increasing AgNP concentration and exposure time in *Drimia polyantha*.

Abdel-Azeem & Elsayed (2013) demonstrated that different sizes of AgNPs can result in varying degrees of cytotoxicity in *Vicia faba* root tip meristem. They observed a decrease in the mitotic index when treated with smaller nanoparticles, and this decrease further intensified with longer treatment times (Fig. 5). The concentration of AgNPs for all treatments was fixed at 50 PPM. The frequencies of chromosomal aberrations significantly increased with decreasing NP size (65 nm to 20 nm) and increasing exposure time (6 to 24 hours). Treatment with 20 nm NPs for 12 hours resulted in 80.72% mitotic abnormalities, leading to cell death with prolonged exposure (Fig. 6). The inhibitory effect of AgNPs on DNA synthesis at S-phase and the interaction of AgNPs with tubulin SH group were proposed as potential causes for the observed effects (Abdel-Azeem & Elsayed, 2013; Sudhakar et al., 2001; Kuriyama & Sakai, 1974).

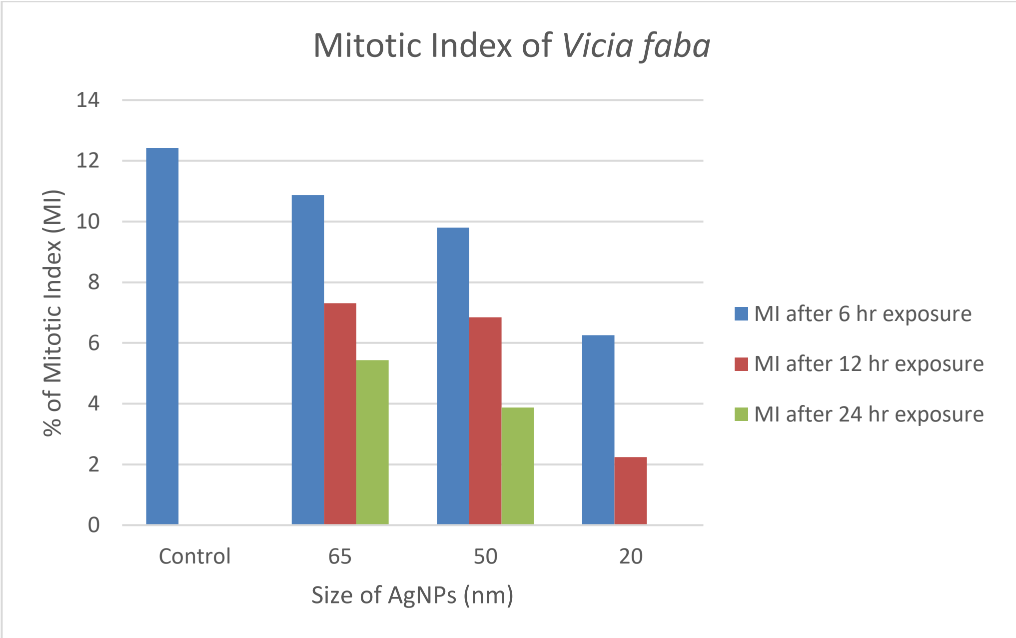

Figure 5. The graph has been developed from the secondary data obtained from Abdel-Azeem & Elsayed (2013), showing the decreasing trend of the Mitotic Index with increasing AgNP concentration and exposure time in *Vicia faba*.

Fouad & Hafez (2018) investigated the cdc2 gene expression along with cytological studies of the root tip meristem of *Allium cepa*. They observed a decreased mitotic index and increased frequencies of chromosomal abnormalities with the treatment of silver nanoparticles. The expression of the cdc2 gene was found to be reduced by 28-61.8% with increasing concentrations and exposure times of AgNPs. The decrease in CDK gene expression in response to stress leading to cell cycle arrest or delayed entry into mitosis was suggested as an explanation (Kitsios & Doonan, 2011). In contrast, Syu et al. (2014) recorded an increase in protein cell-division-cycle kinase 2 in Arabidopsis when treated with AgNPs, highlighting the differential characteristics of nanoparticles of the same compound (Remédios et al., 2012). The interaction between CDC2 kinase and spindle formation during mitosis was linked to various types of chromosome aberrations, and genotoxic effects of AgNPs appeared even in the absence of cytotoxic symptoms, suggesting a more genotoxic nature (Fouad & Hafez, 2018).

The eukaryotic cell cycle is regulated by various mechanisms, including the reversible phosphorylation of cyclins (CYC) by cyclin-dependent protein kinases (CDKs). CDKs, such as CDKA, play a crucial role in mitosis by interacting with chromosomes and localizing to mitotic structures. CDKA has important functions in both G1/S and G2/M transitions (John et al., 2001; Tank & Thaker, 2011; Francis, 2009; Hirayama et al., 1991; Stals et al., 1997; Boruc et al., 2010; Hemerly et al., 1995).

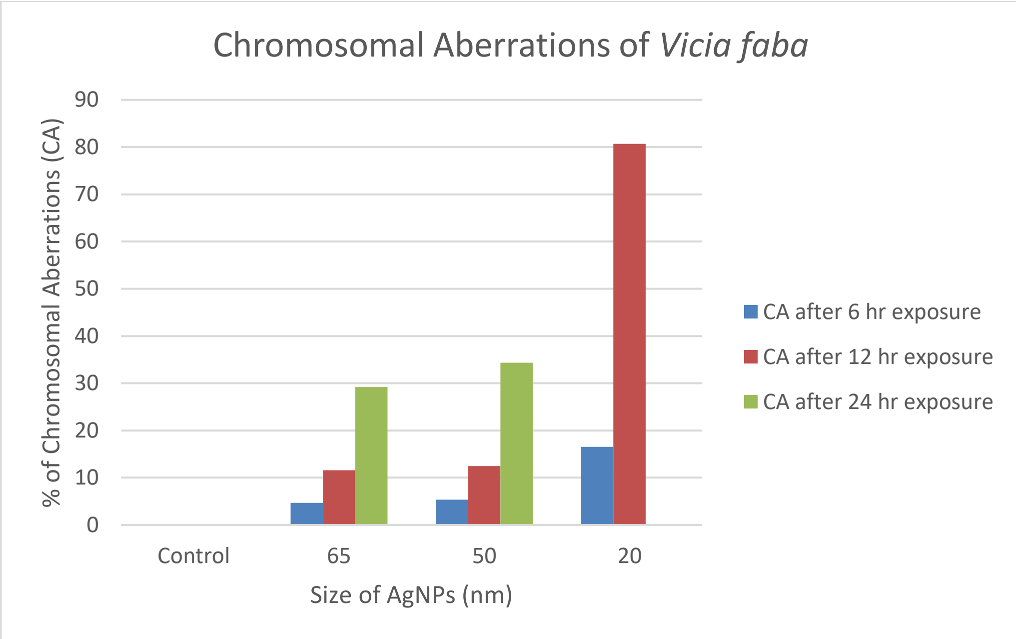

Figure 6. The graph has been developed from the secondary data obtained from Abdel-Azeem & Elsayed (2013), showing the increasing trend of the chromosomal aberrations with increasing AgNP concentration and exposure time in *Vicia faba*.

Some related toxic effects of silver nanoparticles:

Labeeb et al. (2020) investigated the impact of AgNPs on seed germination in *Pisum sativum*, along with the assessment of the mitotic index. Significant reductions in germinability and the occurrence of root deformities were observed upon treatment with AgNPs. Abdel-Azeem & Elsayed (2013) noted a significant decrease in germinability and root growth of *Vicia faba* seeds exposed to a fixed concentration (50 PPM) and duration (9 hours) of AgNPs, with a correlation to the smaller size of the nanoparticles.

In line with these findings, Lee et al. (2014) reported a reduction in the germination rate of *Arabidopsis thaliana* across three generations when subjected to AgNP treatment. Stampoulis et al. (2009) demonstrated the inhibitory effect of 40 nm AgNPs on the growth of *Cucurbita pepo*. Salama (2012) observed increased shoot and root elongation in *Phaseolus vulgaris* and *Zea mays* at AgNP concentrations of 20, 40, and 60 ppm, while concentrations of 80 and 100 ppm were found to inhibit shoot and root elongation.

Furthermore, Stampoulis et al. (2009) indicated that 100 nm AgNPs at concentrations of 100 and 500 mg/L led to significant decreases of 41% and 57% in biomass and respiration rates.

Gubbins et al. (2011) demonstrated the growth-inhibiting effects of AgNPs on *Lemna minor*. It is noteworthy that nanometer-sized particles exhibit special toxicity and are generally more toxic than their larger counterparts (Donaldson et al., 1999). Additionally, particles with a diameter of less than 50 nm have been identified as highly toxic (Oberdoster, 1996).

Sources of Silver nanoparticle wastes and their sustainable management:

Metallic nanoparticles, such as silver nanoparticles, may be released through leaching from structural components, including inner elements of appliances like fridges, vacuum cleaners, washing machines, air conditioning systems, and other electronic devices, as well as nanoparticle-coated wall paints. This release can occur when these items are casually and unsupervisedly disposed of in waste disposal sites or processed in waste treatment/recycling systems. Given the prevalence of silver nanoparticles as engineered nanomaterials (Rejeski & Lekas, 2008), questions arise regarding the use of AgNPs in domestic appliances. It has become evident that strategies for nanowaste management need to be developed before the disposal of nanoproducts begins. From a toxicological perspective, nanomaterials significantly differ from normal waste, making conventional tests and waste management systems such as incineration or basic landfills potentially unsuitable for them (Bystrzejewska-Piotrowska et al., 2009).

As per Leppard et al. (2003), conventional methods for wastewater treatment prove ineffective in the comprehensive removal of nanoparticles (NPs) from effluents (Westerhoff et al., 2008). Existing wastewater treatment systems demonstrate NP removal efficiencies ranging from 0% to 40%, underscoring a substantial likelihood of NP presence in drinking water, thereby creating a potential avenue for human exposure (Westerhoff et al., 2008). An investigation by Zhang et al. (2008) revealed that, despite rapid aggregation during potable water treatment processes, 20–60% of NPs persisted in settled water even after 24 hours. Consequently, NPs may endure for a relatively prolonged period, albeit in an aggregated state, within an aqueous environment characterized by low concentrations of electrolytes (Zhang et al., 2008). Nevertheless, traditional water treatment methods such as alum coagulation can eliminate 80% of NPs, and the incorporation of a 0.45 mm membrane filtration in the final stage enhances the removal efficiency to over 90% (Limbach et al., 2008).

The cytotoxic effects of certain nanoparticle types can be mitigated through the application of organic coatings (SCENIHR, 2006). These coatings serve to diminish the efficacy of nanoparticles, rendering them inert in the environment. However, this inert state is contingent upon the durability of the coating. Consequently, the future design and development of nanomaterials must prioritize the establishment of robust coatings to ensure sustained inactivity (Scenihr, 2006). Phytoremediation, a sustainable approach to environmental cleanup, has gained prominence in mitigating soil and water pollution. As silver nanoparticles become prevalent, understanding their impact is crucial for effective management strategies to ensure the long-term health of ecosystems and sustainable coexistence (Saha et al., 2022).

To address potential risks associated with synthetic nanomaterials, it is imperative to adopt a life cycle approach that encompasses production, utilization, and disposal (Bystrzejewska-Piotrowska et al., 2009). Implementing precautionary measures is essential, including:

1) Mandating companies engaged in engineered nanomaterial production to label products containing nanoparticles. Displaying basic information about the levels and nature of emitted nanomaterials facilitates easy separation and recovery (Powell et al., 2008). Additionally, it is crucial to specify the expected lifetime of products containing nanoparticles, such as refrigerators with nanosilver compartments.
2) Conducting thorough investigations into the water and moisture-mediated leaching of nanoparticles from waste into the environment. The disposal of nano-waste should be managed to prevent water interaction (Bystrzejewska-Piotrowska et al., 2009).
3) Undertaking comprehensive research on the potential toxicity of released nanoparticles (Handy et al., 2008).
4) Revising personal protection equipment and work routines for handling nano-waste to ensure safety (Bystrzejewska-Piotrowska et al., 2009).

Conclusion:

In conclusion, the widespread use of silver nanoparticles (AgNPs) in various products, coupled with the inadequate management of nanowaste, poses a significant threat to the environment, particularly in terms of its cytotoxic effects on plant life. The research reviewed herein underscores the intricate relationship between AgNPs and plant cell cycle dynamics, growth, and development. The evidence presented reveals that AgNPs, especially in smaller sizes and higher concentrations with prolonged exposure times, induce substantial cytotoxicity, leading to a range of chromosomal aberrations, decreased mitotic indices, and adverse effects on seed germination.

Moreover, the findings emphasize the need for a specialized nano-waste management system to address the unique challenges posed by nanoparticles in terms of their disposal and potential environmental impact. The current methods of wastewater treatment and traditional waste disposal may prove ineffective in comprehensively removing and neutralizing AgNPs, necessitating innovative approaches for sustainable waste management.

As we move forward, a life cycle approach encompassing the production, utilization, and disposal of nanomaterials becomes imperative. Precautionary measures, including labeling of products containing nanoparticles, understanding water-mediated leaching, comprehensive toxicity assessments, and revising safety protocols for nano-waste handling, are crucial steps toward minimizing the environmental risks associated with AgNPs.

The complex interplay between nanotechnology and the environment demands interdisciplinary research, collaboration between industries and regulatory bodies, and proactive measures to safeguard our ecosystems. Implementing these strategies is vital not only for curtailing the potential threats posed by silver nanoparticles but also for ensuring the responsible and sustainable integration of nanomaterials into our daily lives.

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Chapter- 16

The Invisible Threat: Understanding Effects of Micro- and Nano-Plastics on Human Health and Environment

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Keywords: Micro-plastics, Nano-plastics, Environmental exposure, Human exposure.

Abstract:

Micro- and nano-plastic (MNPs) pollution has now become a global environmental threat that has persisted for the past few decades. Although large-scale experimental research evidence is still lacking, it has been found from a few research works that micro- and nano-plastic (MNPs) pollution has a significant negative impact not only on the environment but also on human health and well-being. This review aims to understand three main routes of human exposure to MNPs: ingestion, inhalation, and dermal contact. It further demonstrates the potential routes through which these MNPs are translocated to different tissues such as the lungs, intestines, and skin, damaging these organ systems. This correlation is significant with the studies conducted on both *in vivo* animal models and *in vitro* human-derived cell culture methods. Long-term exposure to MNPs could cause respiratory, excretory, immunogenic, gastrointestinal, and endocrine disruption. Some available reports also suggest that prolonged exposure to MNPs in humans could lead to oxidative stress, cytotoxicity, reproductive problems, congenital deformities of embryos, and even some forms of cancers. Although direct evidence supporting all of these effects of MNPs on human health and wellness is very limited, extensive research works are still needed not only to support these claims quantitatively but also to assess the potential threats for the future that might endanger human health and civilization.

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Introduction:

Normally micro-plastics (MPs) are fragments with a diameter of ≤ 5 mm in size, while nano-plastics (NPs) have a particle size of ≤ 1 µm in size (Prata et al., 2020). Plastic pollution is found everywhere in this world, such as in oceans, rivers, soils, sediments, and the atmosphere, and also in animal biomass (Lau et al., 2020; Bandyopadhyay et al., 2023). The presence of micro-plastics (MPs) has also been reported in marine ecosystems, contaminating various edible items such as drinking water, marine fishes, and edible salts obtained from marine sources (Schymanski et al., 2018; Iniguez et al., 2017; Karthik et al.,2018). According to some research works, it has been found that different forms of micro-plastics (MPs) found in oceans, contaminating even zooplanktons and deep-sea organisms of this world (Taylor et al., 2016; Sun et al., 2018; Issac & Kandasubramanian, 2021; Lim, 2021). Several studies have indicated that microplastics (MPs) often enter the human body through the food web due to their very small and irregular size and shape disturbing the internal homeostasis of the human body (Murray & Cowie, 2011; Farrell & Nelson, 2013; Banerjee et al., 2021). Various cosmetic products and abrasives are produced from plastic pellets and plastic particles owing to the production of primary MPs in large quantities (GESAMP, 2015). Normally MPs are composed of polypropylene, polyethylene (PE), terephthalate, polymethyl methacrylate, and nylon. Among these, polyethylene (PE) alone is responsible for almost 93% of the MP production in the environment (Gouin et al., 2015; Das & Das, 2021). Generally, these are added directly into cosmetic products to enhance their cleansing and exfoliating activity. Apart from cosmetics, they have also been used in soaps and toothpaste for decades (Zitko & Hanlon, 1991). Other products used in daily life such as eyeliner, lip-gloss, deodorant, shampoo, etc may also contain MPs which may contribute to the global production of large amounts of MPs regularly (Leslie, 2014). On the other hand, nanoplastics (NPs) have been considered much more dangerous for living organisms than microplastics (MPs) because of their large quantity within the ecosystem and reactiveness and they potentially could reach more remote locations within the human body, damaging organ-system level completely (Sharma et al., 2022). Some of the studies show that in combination with solar light radiations, weathering processes, and natural enzymes can transform bulk amounts of plastics into microplastics and nanoplastics, contributing to a large amount of production of MNPs in the global ecosystem (Sorasan et al., 2022; Othman et al., 2021). Recent studies have revealed that MNPs can induce both particulate toxicity and chemical toxicity to the organisms (Koelmansetal., 2022; Ebrahimi et al., 2022). According to some reports, many other very small particulate matters, such as PM_{10} (aerodynamic equivalent < 10 µm), $PM_{2.5}$ (aerodynamic equivalent < 2.5 µm), and some genetically engineered nanoparticles have been found to show almost similar effects on humans like MNPs and a significant correlation has been found particularly between the exposure to $PM_{2.5}$ with lung damage and high mortality rate (Xing et al., 2016). Epidemiological studies revealed that lung damage and some forms of cardiovascular diseases are predominantly found due to prolonged exposure to genetically engineered nano-particles (Tang et al., 2015). However, there is a paucity regarding epidemiological studies on the potentially hazardous effects of MNPs on human health to date and there is an urgent need to fill the vacuum at an enormous pace not only to identify the potential hazards for the future but also to eliminate it at the earliest.

Different pathways of exposure of MNPs to humans:

Inhalation:

Inhalation of MNPs through air:

People can be exposed to MNPs whether they are inside or outside of their rooms. In both conditions, they are being exposed to MNPs unknowingly. It has been found that individuals spend almost 89% of their daily time in their rooms and the amount of MNPs present in their surrounding air affects their health conditions significantly (Zhang et al., 2020). The rate of deposition of MPs varies significantly in different indoor conditions with the highest surprising at home (up to 1.96×10^4 particles/m^2/day) and lowest in classrooms (up to 6.20×10^3 particles/m^2/day) (Yao et al., 2022). On the other hand, it has been found that the air in the dormitory (9.9×10^3 particles/m^2/day) contains 5.5 times more MPs than in the office (1.8×10^3 particles/m^2/day) (Zhang et al., 2020). Thus the amount of MPs present in the air varies from room to room significantly and this variation has been attributed to various factors affecting the quality of air within rooms, such as utility of the room, abundance of people, amount of MPs present just outside of the room etc (Zhang et al., 2020). Normally infants spend more time at home than adults (Cox et al., 2019). Thus there is a very high probability that they may inhale the indoor dusts that too contain MPs and affect their health badly (Feng et al., 2023).

However, the outdoor air is more extensive and mobile than indoors. Therefore the concentration of MNPs is generally much lower than indoors (Feng et al., 2023). Thus the potential impacts of MPs present in the outdoor air generally have a much lesser effect on human health than in the indoor air (Feng et al., 2023). However, more extensive outdoor studies are required especially on roadsides, building construction sites, or landfills not only to assess the air quality parameters in these sites properly but also to assess the potential health risks of MNP exposure for those people living or working at that place.

Ingestion:

MNPs exposure to humans can also occur through ingestion of foods which is considered to be a major route of exposure other than inhalation. Some commonly used foods are contaminated by MNPs and people are consuming these foods unknowingly, affecting their health conditions badly.

Human exposure through consumption of sea foods:

It has been reported that there are almost 690 marine animals including some species of fish, mollusks, and crustaceans consumed by humans regularly (James et al., 2020; Curren et al., 2020; Leung et al., 2021). It has also been reported that most of the MP contamination is found within the intestine of fish rather than its meat (Wootton et al., 2021). Fortunately, the intestines of fish generally are not consumed by people and are discarded during cleaning. On the other hand, the whole body of marine mollusks such as clams, mussels, and oysters are also consumed by humans quite regularly. Thus there is a high chance of MP exposure in humans who are consuming these mollusks regularly. Some crustaceans such as crabs and shrimps are also consumed by humans. Some researchers have reported that the amount of MPs present within the inedible part (such as gills, stomach, etc) (4.4 particles/animal) is much higher than the edible part (1.2 particles/animal) (Yin et al., 2022). Thus to reduce the MPs exposure, it is suggested that do not consume the inedible parts such as gills, stomach, intestine, etc of crustaceans and other fish species.

Human exposure through consumption of polluted drinking water and beverages:

Like other food sources drinking water has also been contaminated by MNPs and people are consuming these polluted waters regularly worsening their health conditions. Some research works have revealed that the abundance of MPs found in tap water varies significantly with bottled water (Feng et al., 2023). The particle size of MPs in bottled water normally ranges from 1 µm to 5 µm (Akhbarizadeh et al., 2020). Overall, the maximum amount of MPs found in the tap water (maximum up to 930 particles/lit) was much lower than the bottled water (up to 2649 ± 2857 particles/lit in single used PET bottles and 6292 ± 10,521 particles/lit in glass bottles) (Obmann et al., 2018; Kristein et al., 2021). Moreover, MNPs have also been detected in high amounts in some useful beverages like milk, tea, beer, and soft drinks (Li et al., 2022; Shruti et al., 2020; Da Costa Filho et al., 2021). Thus it can be stated that close monitoring regarding the presence of MNPs in drinking water and beverages is really necessary for establishing a proper food safety standard to improve the health conditions of people.

Human exposure through consumption of contaminated salt, sugar, and honey:

Edible salts can also be contaminated with MPs like that of other food products. It has been found that the amount of MPs present within the salt varies greatly from country to country across the globe. In the case of China, the total amount of micro-plastic material present in edible salts varies significantly, from 550-681 particles/kg in sea salts (Yang et al., 2015). The situation in India is also very similar to that of China. It has been reported from Gujarat which is one of the largest salt-producing states in India that total micro-plastic materials present in edible salt range from 46 to 115 particles/200 gms and in Tamilnadu, it is from 23 to 101 particles/200 gms (Vidyasakar et al., 2021). Almost similar reports have been found for edible sugar and honey. It has been reported from Germany, France, and Spain that the total amount of micro-plastic materials present in edible sugar and honey are 560 particles/kg and 540 particles/kg respectively (Liebezeit & Liebezeit, 2013). Therefore, other food items like cooking oils, soy sauce, tomato sauce, spices, etc should be properly examined before use to ensure food safety in humans. Moreover, present studies on micro-plastic contamination in crops and livestock are very few and it is really necessary to examine the impacts of MNPs exposure to humans through the food chain and assess any kind of biomagnification effect of MNPs.

Dermal contact:

Human skin is exposed directly to various cleansing products such as toothpaste, soaps, sun cream lotions; hair gel, face wash gel, etc, and all of them are contaminated with MPs (Lei et al., 2017; Feng et al., 2023). Some airborne MNPs along with some particulate matter can also settle down over the skin surface (Feng et al., 2023). Unfortunately, due to a lack of research evidence, it is really difficult to estimate the number of MNPs absorbed by the skin. So a large amount of research work is needed not only to quantify the amount of MNP absorbance through the skin but also to understand the probable pathways triggering the process.

Accumulation of MNPs within different human tissues and their translocation:

In recent years, various types of micro- and nano-plastics have been detected in various tissues or organ systems within the human body. This type of tissue accumulation indicates that MNPs can enter the circulatory system and can translocate through the plasma membrane of cells. MNPs also possess the capability of escaping from the immune cells of the body's immune system and can accumulate within different tissues of the human body.

Accumulation of MNPs within human lungs and its translocation:

It has been reported that inhalation is one of the most important biological processes through which MNPs can enter the human body (Zhang et al., 2020). The average size of these MNPs is known to be 1730 ± 150 μm (Baeza-Martinez et al., 2022). Although some amount of comparatively larger particles are being cleared out by the action of nasal hairs, mucus secretion within nasal passage, ciliary movements within the respiratory tract, the action of macrophage within respiratory pathways, or coughing and sneezing, unfortunately, smaller particles can translocate through the respiratory pathways and can enter into the circulatory system (Geiser, 2002). Particle size ranging from 0.5-5 μm can easily cross the mucus villi and tissue macrophage system of the lungs in comparison to larger particles ranging from 15-20 μm (Wright et al., 2017; Ruge et al., 2013). As a result, comparatively smaller plastic particles adhere to the wall of the lungs or with alveoli and are translocated easily to the blood circulation of humans. Then these smaller fragments go to other organs carried by the bloodstream, causing damage to these organs.

Accumulation of MNPs within the human intestine and its translocation:

Like the respiratory pathway, MNPs also can enter the human body through the gastrointestinal pathway. MNPs enter through the gastrointestinal pathway mainly with contaminated foods and water. After entering into the intestine, MNPs are translocated to the circulatory system mainly using 3 pathways: (i) endocytosis of epithelial cells, which is capable of transporting mainly nano-plastics (NPs), (ii) transcytosis transport of microfold (M) cells of Peyer's patches of ileum which is believed to be the main transport process of MNPs and it can translocate particles (with a diameter of < 10 µm) to the mucosal lymphoid tissue of Peyer's patch and (iii) perception process, in which shedding of cells from intestinal tips occurs and this process can generate poresand comparatively larger particles [eg. Polyvinyl chloride (PVC) particles with a diameter ranging from 5 µm to 110 µm] can pass through these pores (Feng et al., 2023). However, more intensive research works are still needed not only to understand the complete mechanism of transportation of MNPs through the gastrointestinal tract but also to determine the distribution of MNPs within the gastrointestinal system.

Accumulation of MNPs within the skin and its translocation:

It has already been known that the skin is the most important organ of the human body and not only does it serve as a barrier to prevent the penetration of different particulate matters into the human body but also prevents the entry of different microbes, serving a very important function of the innate immune system. Although, research works regarding the process of accumulation and translocation of MNPs through the skin are rare, very few of them have suggested that nano-plastics (NPs) have the potential to penetrate the skin barrier and enter into the circulatory system and can reach anywhere within the body (Filon et al., 2016). Presently, there are 3 known pathways through which NPs can travel from the outer skin layer to the innermost parts of the body. These are: (i) through cellular bypass: in this process, molecules with a diameter <1 nm to 4 nm can pass through the skin; (ii) through sweat gland and hair follicles: in this process, molecules with a diameter 4 nm to 20 nm can pass through the skin and (iii) through damaged skin or skin lesions: in this process, molecules with a diameter 21 nm to 45 nm can pass through the skin (Filon et al., 2016).

Accumulation of MNPs within other organ systems and its translocation:

MNPs enter the stomach through foods that reach to the intestine and pass to the bloodstream through the intestinal villi. It has been found that the diameter of the largest blood vessel (aorta) of humans is around 25000 µm and the diameter of the smallest blood capillary of humans is around 8 µm (Muller et al., 2008). Thus, due to the very small size of MNPs, they can be translocated through the bloodstream quite easily. Moreover, recently traces of MNPs have also been detected in the human liver, spleen, kidney, and placenta (Horvatits et al., 2022; Ragusa et al., 2021). However, more research evidence is required to assess the potential impacts of MNPs on other organs of the human body.

Effects of MNPs on different organs of the human body:

MNPs exposure could lead to the toxicity of different organ systems of humans producing various significant effects particularly on the digestive system, respiratory system, circulatory system, immune system, reproductive system, endocrine system, nervous system, excretory system, and even causing some forms of cancers. All these effects of MNPs are summarised by obtaining knowledge from both *in vivo* and *in vitro* studies (Figure 1).

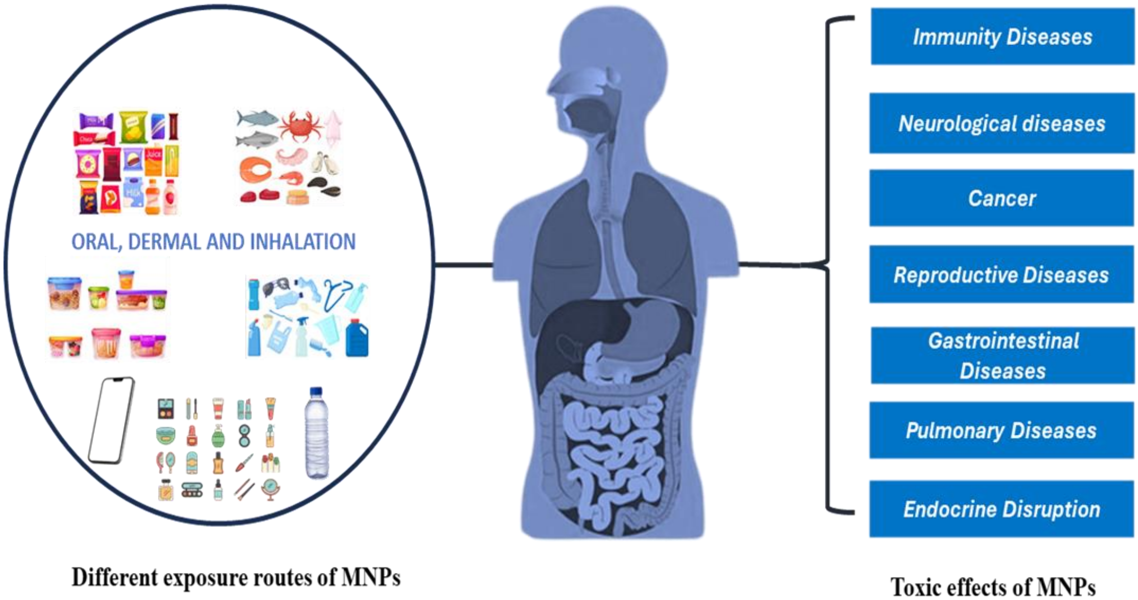

Figure 1. Different Modes of MNPs Induced Toxicity in Human.

Effects on digestive system:

The digestive system plays a very important role including the breakdown of solid food particles, their digestion and absorption particularly from the small intestine, and maintaining the internal homeostasis of humans. Exposure to MNPs showed an adverse effect, particularly on the intestinal wall, proteins, carbohydrates, and lipid digestion, and interfered with nutrient absorption, causing gastrointestinal disturbances (Tan et al., 2020). Moreover, MNPs exposure could lead to a reduction in the bio-accessibility of vitamin D3 for Ca^{+2}absorption through the gastrointestinal wall (Li et al., 2020). A stable gastrointestinal microbial status is essential for maintaining human health. Exposure to MNPs also hampers internal microbial status as reported in mice (Li et al., 2020). Thus, it can be stated that MNP exposure exerts a significant negative impact not only on the digestive system but also on the overall health status of humans.

Effects on respiratory system:

As stated above, apart from the digestive system, another major route of exposure is through the respiratory pathway by which numerous amounts of MNPs could reach to the internal body parts disrupting the internal homeostatic equilibrium of the body. It has been reported that MPs could reach not only the sputum through the nasal cavity (Jiang et al., 2022) but also the alveoli and lung tissue (Baeza-Martinez et al., 2022; Jenner et al., 2022). However, concrete evidence suggesting the direct link between MNP's exposure to lung diseases is still lacking and more extensive research works are needed to draw such a conclusion. However, few studies indicate that exposure to MNPs could alter the endogenous surfactants of human lungs, decreasing the activity of lung cells which makes them more susceptible to various pulmonary disorders, such as pulmonary fibrosis, asthma, pulmonary frosted glass nodules, etc (Feng et al., 2023).

Effects on circulatory system:

The circulatory system is very important in humans. It not only carries CO_2 and O_2 to and from the lungs respectively but also it carries various nutrients to different tissues for its survival. It also helps in the collection of different harmful metabolic waste products from tissues and transports these materials to kidneys for successful elimination. A recent hematological study conducted on 22 healthy individuals reveals the presence of MPs (>700 nm) in blood with an average concentration of 1.6 µg/ml MNPs (Leslie et al., 2022). Recent evidence suggests that exposure of MNPs to humans could show a harmful effect not only on RBCs but also on platelet formation and angiogenesis. Moreover, MNP exposure for a prolonged time could result in thrombosis in humans (Kim et al., 2022; Feng et al., 2023).

However, research on the effects of MNPs on the human circulatory system is limited to date and more extensive research evidence is required not only to understand the possible mechanism of action of MNPs on the circulatory system but also its impact on the overall health of human beings.

Effects on the immune system:

The immune system is one of the most important systems in humans which protect the body from foreign invaders, maintaining human health and wellness. The immune system is comprised of lymphoid tissues, immune-regulatory cells (both B cells and T cells and their subtypes), antibodies, tissue macrophages, NK cells, and different types of cytokines (such as IL1, IL2, IL 3, TNF α, TNF β, etc). These all help to eliminate foreign particles, bacteria, fungi, parasites, etc commonly known as antigens or more precisely, immunogens. Both *in vivo* and *in vitro* experiments, conducted on animals showed that exposure to MNPs could cause increased secretion of pro-inflammatory substances leading to the onset of different autoimmune diseases (Remmelts et al., 2021; Davidson et al., 2001). Autoimmune diseases are caused due to the formation of autoantibodies within the body due to some unknown reasons. Recent studies indicate that the onset of autoimmune disorders occurs due to genetic as well as environmental factors (Davidson et al., 2001).

The immune system is present in different organs of the human body including lymph nodes, bone marrow, spleen, tonsils, Peyer's patches, and many others. Although limited information is available regarding the impacts of MNPs on the immune system, so a detailed investigation is necessary to assess the potential impacts of MNPs exposure on these parts of the human body.

Effects on the reproductive system:

Nowadays, research is going on to observe the impacts of MNPs exposure on the reproductive system, especially after the discovery of MPs presence in the human placenta(Ragusa et al., 2021). Jin et al., 2021 and some others have reported that *in vivo*polystryreneMPs exposure could cause reproductive toxicity in mice which could affect the overall reproductive health of individuals and hamper the production of healthy offspring. MNPs exposure affects the reproductive health of both male and female rats or mice. In male mice, decreased sperm count, damage in the blood-testes-barrier, and inflammation in seminiferous tubules are seen upon MNPs exposure. On the other hand, inflammation of both ovaries and decreased oocyte quality have been observed upon MNPs exposure as reported in the case of female mice (Jin et al., 2021; Feng et al., 2023). However, extensive investigations are required to observe the presence of the same effects in the human reproductive system and its transmission from one generation to the next.

Effects on endocrine system:

The endocrine system which produces different hormones plays a vital role in regulating various physiological activities in humans. Although limited reports are available to date claiming direct effects of MNPs on the endocrine system, few of them are claiming that certain MNPs carry some endocrine disrupting chemicals (EDCs), such as phthalates, bisphenol A (BPA) or steroid hormones along with them, disrupting the endocrine system and causing hormonal imbalances in humans (Campanale et al., 2020; Guedes-Alonso et al., 2021). Evidence coming out from laboratory animals suggests that EDCs can interfere with the production of different hormones leading to a variety of health problems such as the onset of type II diabetes mellitus, hypo or hyperthyroidism, obesity, reduced sperm count or sperm motility, etc(Guedes-Alonso et al., 2021). Additionally, other endocrine-disrupting elements such as dioxins and polychlorinated biphenyls (PCBs), etc are present along with EDCs and are also present in the environment showing combined toxicity in humans (Feng et al., 2023).

Effects on the nervous system:

The nervous system is made up of a complex network of neurons and also plays an important role in regulating various physiological activities in humans. Once entering the blood circulation, some forms of MNPs can cross the blood-brain barrier, causing damage or dysfunction in neuronal systems. It has been reported that MP exposure could lead to learning and memory dysfunction in mice when exposed to 2 µm PS particles (0.016 mg/gm) continuously for 8 weeks. This occurs due to the transport of PS particles through blood circulation, crossing the blood-brain barrier entering the hippocampus region of the brain, and producing neuroinflammation. This fatal neuroinflammation in turn alters the gene expression and finally alters the conformation of proteins responsible for synaptic plasticity (Lee et al., 2022). Moreover, it has also been reported in mice that PS particles with a diameter of around 5 µm could also induce oxidative stress and lower the levels of acetylcholine, thereby, altering the signal transduction process in neurons. These effects ultimately augment memory loss and neuronal dysfunction processes in mice (Wang et al., 2022).

However, more research works are needed not only to understand the exact mechanism of action of MNPs on the human nervous system but also to assess properly its activity, especially on neurotransmitter production, memory, learning process, cognitive function, and behavioral process of humans.

Effects on the excretory system:

MNPs show a marked negative impact on the excretory system, particularly on both kidneys. PS particles cause inflammation, malfunctioning mitochondria and endoplasmic reticulum, and autophagy in kidney cells (Wang et al., 2021). Thus the overall functions of both kidneys become jeopardized, retaining metabolic waste materials within the body and hampering the activity of other organs within the human body.

Effects on locomotor system:

It has been reported that MNPs could inhibit the locomotor ability of fish, soil animals, and birds (Feng et al., 2023). Fortunately, its effect on human locomotor activity remains minimal (Feng et al., 2023). However, more studies are required to assess the magnitude of the impact of MNPs on the human locomotor system.

Relationship between Microplastic toxicity with Cancer progression:

It has been known that MNPs show a marked negative impact on the overall human body and organ systems. Many recent research works have suggested a strong correlation between chronic microplastic toxicity and cancer progression in different cells of the body. It has been reported that the fragmented Polypropyoline Microplastics (PPMPs) promote the cell cycle, proliferation, and secretion of the inflammatory cytokine IL-6 in human breast cancer cells, thereby, promoting metastatic processes, while PPMPs neither induce cytotoxicity nor enhance cellular motility (Park et al., 2023). However, more studies are required not only to assess the magnitude of the impact of MNPs on the cancer progression process in different organs but also to understand the mechanism of action through which MNPs are producing such effects in humans.

Prospects for research works:

Based on the above discussion, it can be stated that the ongoing research processes on the potential impacts of MNPs on the environment and human health and wellness are at a very early stage. Thus there remains a big gap in the mechanism of actions of MNPs especially in different organ systems of humans. Therefore, systematic and in-depth studies are required to understand the whole process. A few research prospects are as follows:

(i) First of all, a standardized protocol for the detection of MNPs in the surroundings is needed to assess the quality of air, food, or drinking water. The process should be simple in form and applicable worldwide for all countries irrespective of race or financial status.

(ii) For the assessment, an *in vitro* model organism should be chosen to conduct all the necessary experiments, to mimic human exposure. For a better understanding of translocation, cellular uptake, and the mechanism of actions of MNPs within different organ systems, all of the modern tools and techniques should be applied.

(iii) Finally, a massive campaign is needed from the government as well as from social activists to educate people about probable upcoming environmental and health hazards due to the extensive use of plastics.

Conflicts of interest:

Declared none

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Chapter- 17

Impact of plastic pollution on faunal survival with probable sustainable solutions

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Keywords: Plastic Pollution, Plastic Waste, Fauna, Ecosystem, Sustainable Solution.

Abstract:

Every day, millions of tons of plastic waste are produced by humans which causes severe impacts on our ecosystem and biodiversity. Nowadays plastic is the main anthropogenic waste material globally due to irrational production, inappropriate and unscientific disposal, and inadequate recycling management of plastic. As a result, the fauna of the terrestrial and aquatic ecosystems both are in danger of plastic pollution. Birds are an important part of our biodiversity and they are affected by plastic pollution. Nowadays, birds use plastic debris for different purposes which ultimately causes the death of birds. Plastic waste occupies the global landscape and has parallel impacts on different species of insects. Bees have started to use plastics as brood material. Marine and land mammals both are severely affected by plastic pollution. Plastic pollution is an emergency danger for coral reefs and all food webs do exist at coral reefs. Every day many fish lose their life by suffocation from entering plastic bags and eating or entangling plastic debris. Plastic pollution has many harmful effects on amphibians and reptiles such as habitat disruption, disease transmission, reproductive and physical health problems, etc. In this book chapter, we have discussed the effect of plastic pollution on different types of faunal survival as well as diversity and also probable sustainable solutions to save our mother earth and its fauna from plastic pollution.

Introduction:

Plastic pollution is also called “white pollution”, the most important threat to the global ecosystem. Less than a million tonnes of plastics were produced globally in 1950 which was significantly increased i.e., 368 million tonnes in 2019. Since 2019, the production of plastic products has surged by 5% annually. 51% of plastic is produced and consumed by Asia, while China produces 32% (Anand et al., 2023; Arpia et al., 2021).

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Nowadays, plastic is the main anthropogenic waste material globally due to irrational production, inappropriate and unscientific disposal, and inadequate recycling management of plastic. As a result, the terrestrial and aquatic ecosystems both are in danger of plastic pollution. Plastic waste is disclosed into the environment and it is a great evil for all life forms (Kumar et al., 2021).

Effects of plastics on Avifauna:

Every day, millions of tons of anthropogenic wastes are produced by humans which causes severe impacts on our ecosystem and biodiversity. Birds are an important part of our biodiversity and they are also affected by anthropogenic waste pollution such as plastic pollution (Deb et al., 2020; Das et al., 2022). Un-scientific urbanization and lack of proper disposal of anthropogenic waste by humans are responsible for the anthropogenic waste that birds use today. Birds use plastic debris for different purposes like 1) Nest building. 2) Sometimes building a nest with anthropogenic plastic debris is more useful for attracting a mating partner, increasing the chance of successful mating. 3) In many cases some plastic products give more strength to the nest (Jagiello et al., 2019).

The harmful effects of using these plastic materials for nest building are 1) the chances of increased nest predation because these materials can increase nest visibility (Borges and Marini, 2010). 2) Sometimes medical waste is also found in bird nests as nesting material. It is too dangerous because, through this, human diseases can spread very easily among different birds and animals and many healthy people. 3) Sometimes birds collect toxic anthropogenic materials like used liquid mosquito repellent wicks, which cause different toxic effects on birds, even cause of death. 4) Sometimes in birds, plastic may cause harm by entangling or ingesting when used for nesting (Blem et al., 2002; Townsend & Baker, 2014; Votier et al., 2011).

According to Jagiello et al. (2019), there was a study done on 36 bird’s nests and they reported that non-natural anthropogenic waste accounts for 92% of which 88.9% was plastic beings (Jagiello et al., 2019). In another study on 53 nests of black storks in Central Poland, the nests contained almost 26% of products made of plastics (Janic et al., 2023).

We have collected different species of bird’s nest photos and nests after birds permanently leave the nest or nest which are destroyed and fall on the ground by storm in South Kolkata. We found different anthropogenic wastes from different bird nests such as nylon threads, hard plastic, plastic bags, fishing line, iron nets, medical wastes, different color sewing threads, synthetic cotton, pieces of cloth, plastic bottle caps, electric wires, plastic straw, different types of rope, plastic strips, etc where most of the anthropogenic wastes in bird nest are plastically born.

Figure 1. A single plastic Chinese manjha thread causes the death of this bird.

Figure 2. Red-vented bulbul, use plastic sack, thread, and bag as nest material.

Impact of plastics on Arthropods:

Plastic waste occupies the global landscape and has parallel impacts on different species of insects. Two species of Megachilid bee use two different types of plastic polyurethane and polyethylene plastics in place of traditional nesting materials. It was reported that *Megachile rotundata* used polyethylene-based plastic bags in place of cut plant leaves which is their traditional nesting material. On the other hand, *Megachile campanulae* used polyurethane-based exterior building sealant in place of plant and tree resins for constructing brood (MacIvor & Moore, 2013). Plastic pollution is everywhere and it is present in aquatic ecosystems from surface water to benthic sediment. Nearly 70,000 species of Crustacea have a large distribution and different roles in the trophic webs. According to Pisani et al., 2022, it is suggested that Crustaceans are at high risk due to an overload of plastic pollution. Plastic is ingested by Crustaceans and through the food web; it is transferred to different trophic levels (Pisani et al., 2022).

Mammals and plastic pollution:

Marine and land mammals both are affected by plastic pollution. 56% of mammals living in marine environments do ingest plastic and 69% are affected by entangled plastics (Ayala et al., 2023). Microplastics are found in marine mammals (Zantis et al., 2021). Most of the Sperm whale's death is caused by plastics. Approximately 29 kg of plastic trash was found from a young whale that died on the coast of Spain in 2018. A few months later another sperm whale death body was found in Indonesia, and hundreds of plastic items were collected from whale stomachs. In the stomach of a young Cuvier's beaked whale, 40kg of plastic bags were reported in 2019 (Kruse et al., 2023). Plastics are also harmful to our domestic mammals and indirectly impact our economy. Dogs, goats, rodents, and cows eat almost everything. They sometimes collect their food from waste dumps where plastic garbage is and eat everything that smells like food and mistakenly entangle plastic waste. Consequently, they face gradually a slow painful death after some days (Muthu and Kamalanathan, 2021).

Coral reefs and their biodiversity collapse to plastic pollution:

Plastic pollution is an emergency danger for coral reefs and all food webs do exist at coral reefs. According to Pinheiro *et al*., 2023, a survey of 84 shallow and deep coral reef ecosystems in 25 different locations of the Pacific, Atlantic, and Indian Oceans was made. Anthropogenic waste was found in 77 out of 84 coral reefs. 88% was plastic debris within all anthropogenic waste (Pinheiro *et al*., 2023).

Fish fauna and plastic pollution:

Every day many fish lose their life by suffocation from entering plastic bags and eating or entangling plastic debris. But now plastic pollution has reached one step which is micro-plastic pollution. The mangrove ecosystem is affected by plastic pollution globally. A study in the Sundarbans mangrove forest on 13 fish species accounts for microplastics in their gastrointestinal tract (Bhattacharjee et al., 2023; Saha & Sarkar, 2022). According to Azevedo-Santos et al., 2021, fish are highly affected by plastic pollution among other fresh-water organisms that recorded plastic ingestion in natural or semi-natural fresh-water ecosystems of the world (Azevedo-Santos et al., 2021).

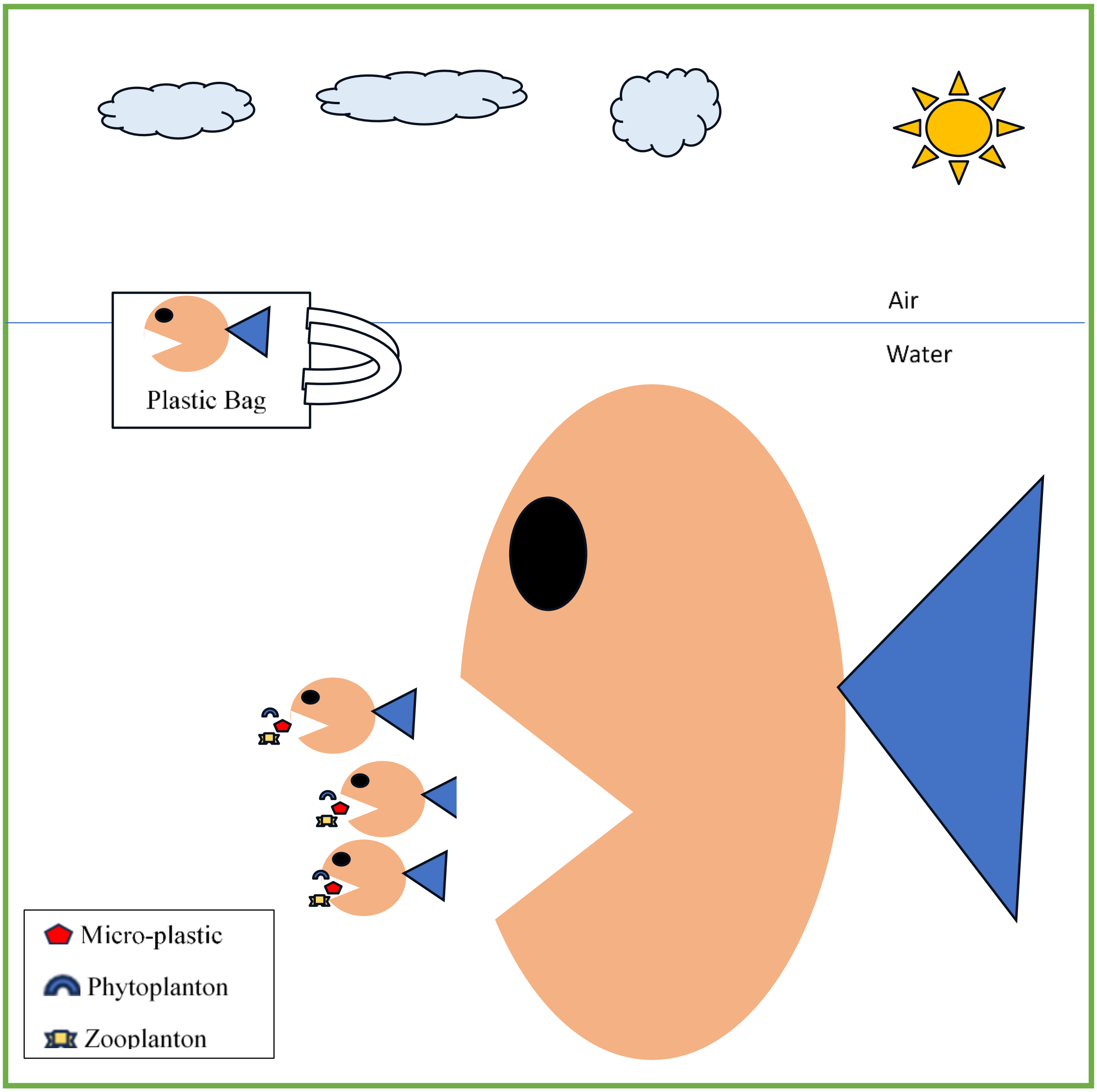

Figure 3. How plastic pollution affects fish fauna.

Amphibian and Reptile fauna's interaction with plastic pollution:

Plastic pollution has many harmful effects on amphibians and reptiles such as habitat disruption, disease transmission, reproductive and physical health problems, etc. According to Hou & Rao, 2022, microplastics are recorded in tadpoles, turtles, snakes, lizards, and crocodiles' bodies. However, it demands more research on the effects of microplastic on amphibians and reptiles (Hou & Rao, 2022).

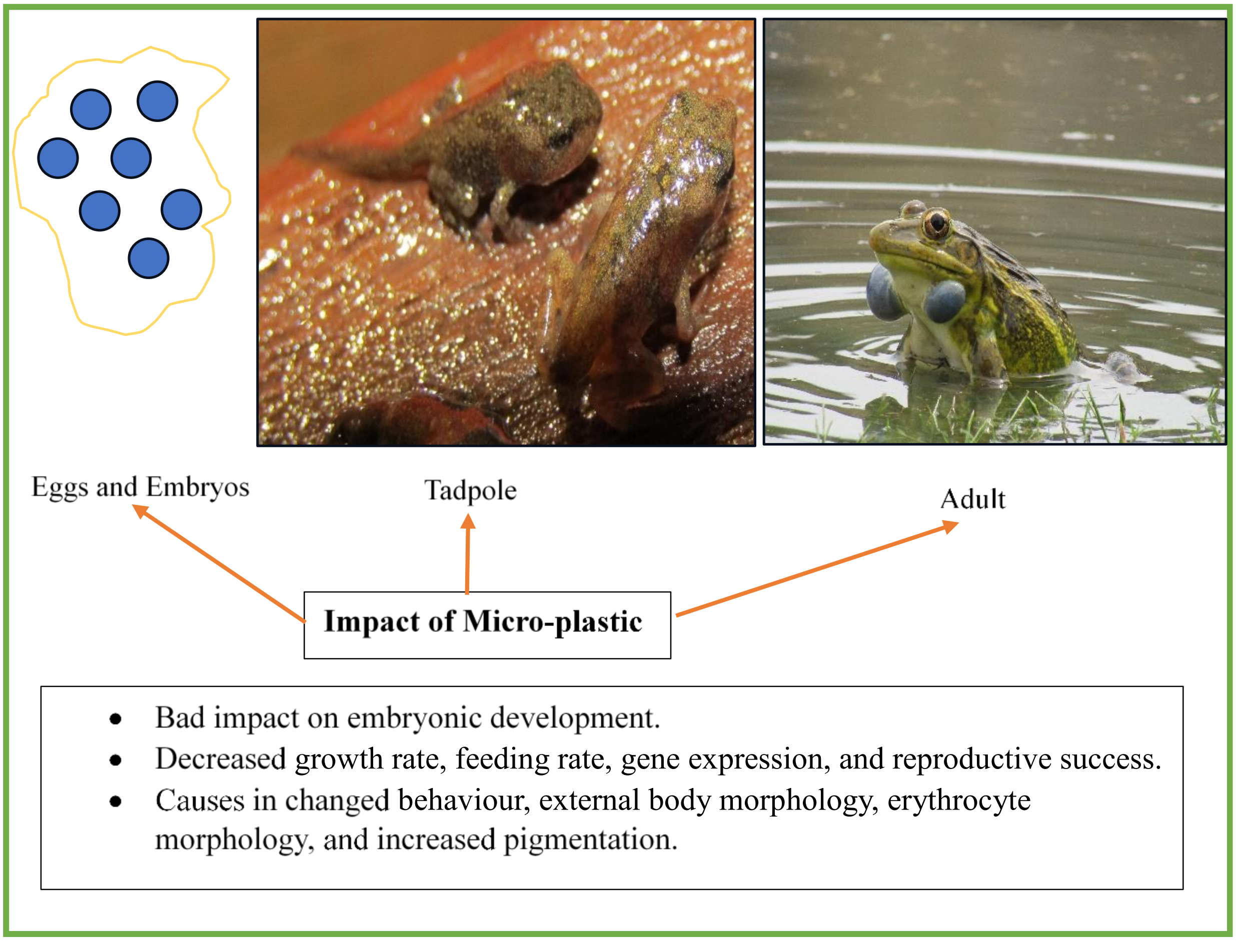

Figure 4. Impact of micro-plastics on different phases of the lifecycle of a frog.

How to protect the animal world from evil plastic pollution:

Controlling plastic pollution is a complex issue that requires a multifaceted approach. The use of plastics can be decreased at the production level by (a) using eco-friendly, biodegradable, or alternative materials (like glass); (b) enhancing product design to minimize plastic usage, increase product longevity, permit repair and reuse, and enhance recyclability by reducing the number of polymers, additives, and mixtures; and (c) outlawing specific single-use plastics (Walker & Xanthos, 2018; Browne et al., 2011). By creating lids that are inseparable from plastic bottles to promote proper disposal is an example of enhanced design. A long-term strategy to reduce the consumption of plastics, for example, is to raise consumer awareness of the environmental impacts of their choices through formal (i.e., in educational institutions) or informal (i.e., news, clean-up tasks) education (Chang et al., 2015; Ambrose et al., 2019).

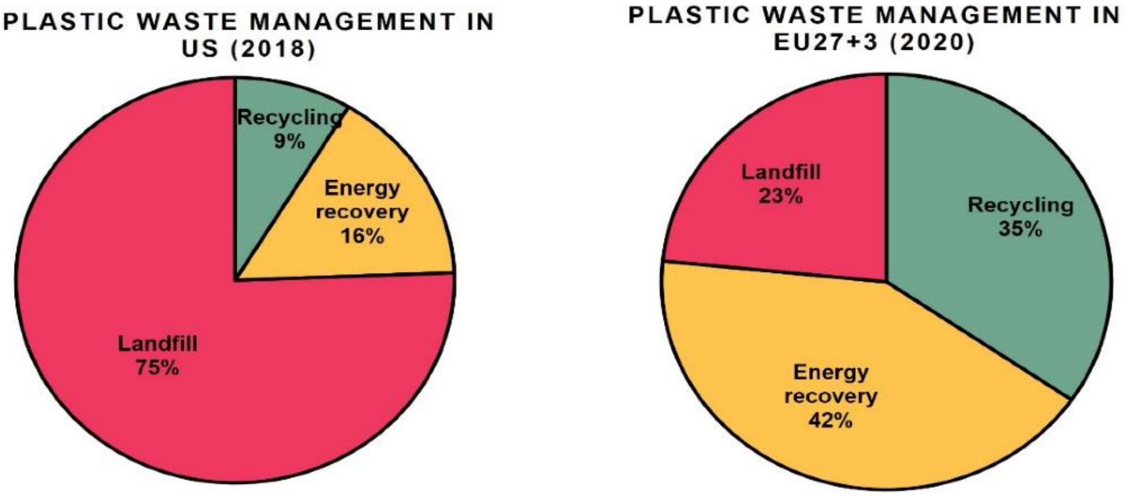

Figure 5. Post-consumer plastic waste management in the US (2018) and EU27+3 (2020). The figure is created according to the data from the US EPA and Plastics Europe (Lomwongsopon & Varrone, 2022).

Organic and Biodegradable Polymers as Substitutes for Traditional Plastics :

The quest for environmentally friendly materials has intensified due to the growing significance of environmental sustainability. The goal is to substitute renewable resources of petroleum and other fossil fuels and raise recycling goals and waste management effectiveness (Iriarte et al., 2009; Lambert & Wagner, 2017; Napper et al., 2020). Bio-based polymers, sometimes known as bioplastics, are made without regard to biodegradability, such as bio-polyethylene, and are alternatively produced from renewable feedstocks, or biomass. Regardless of the source of their feedstock, naturally occurring microorganisms (like bacteria, fungi, or algae) break down biodegradable polymers into carbon dioxide, and organic matter (mineralization). Furthermore, when subjected to particular plastic-degrading organisms (such as *Zalerion maritimum*), typical plastics may biodegrade, generating valuable biological products or organic matter and providing an alternative to contaminated or deteriorated plastics (Prata et al., 2019).

Recycling of plastic waste:

Current technologies frequently tend to lessen the characteristics of monomers created from plastic trash and speed up their end-of-lifetime, even while standard recycling procedures lower the amount of plastic that ends up in landfills. Consequently, recent research is beginning to highlight microbiological recycling techniques as an essential supplementary means of addressing the end-of-life of those difficult-to-recycle plastic waste streams. In reality, using biological depolymerization and bio-recycling to process plastic waste offers the chance to create higher-value products under environmentally friendly and sustainable conditions (lower energy and temperature requirements, no hazardous chemicals, etc.), all without any requirement to pre-sorting (Lomwongsopon & Varrone, 2022; Bandyopadhyay et al., 2023).

Degradation of plastic waste by Microorganisms:

One of the most promising methods for recycling plastic waste is the microbial and enzymatic breakdown of the polymers. This process can also be used to convert waste plastics into higher-value bioproducts, like biodegradable polymers through mineralization. Plastics undergo biodegradation by the release of extracellular enzymes by the microbe, the enzyme binds to the plastic's surface which initiates the hydrolysis of short polymer intermediates, which are then taken up by microbial cells and used as a carbon source to generate CO_2. Although these plastics are synthetic compounds, several microbes that can break down these polymers have been discovered recently.

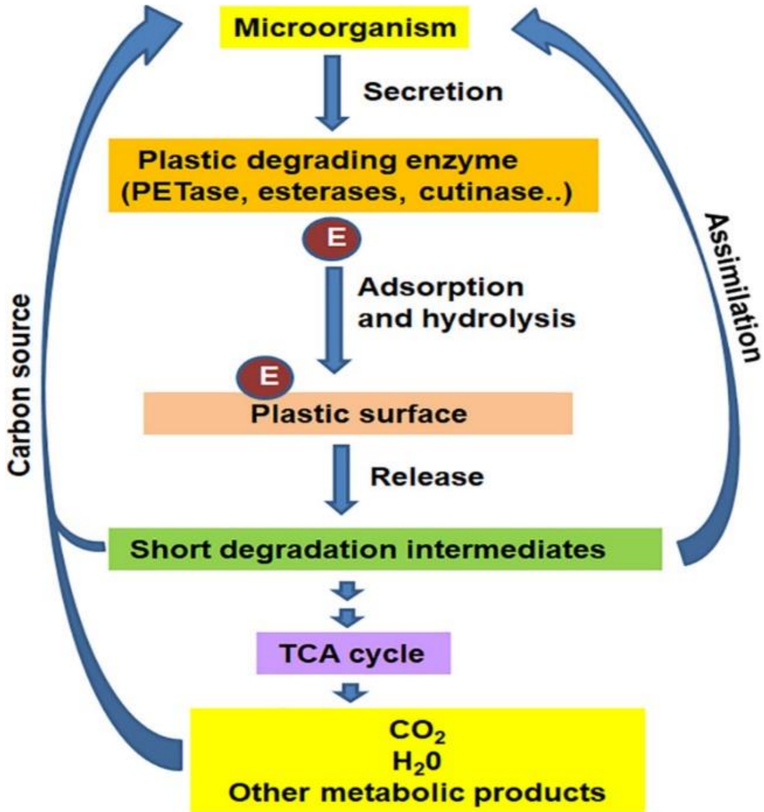

Figure 6. The general mechanism for biological degradation of plastic waste under aerobic conditions (Mohanan et al., 2020).

Numerous *Pseudomonas* sp. and *Bacillus* sp. have been linked to the partial breakdown of a broad range of petro-plastics, including Polyethylene (PE), Polystyrene (PS), Polypropylene (PP), Polyvinyl chloride (PVC), Polyethylene terephthalate (PET), and ester-based Polyurethane (PU) (Mondal et al., 2022). An innovative method for plastic breakdown, particularly for persistent non-hydrolyzable polymers, may result from research on the digestive enzyme(s) in plastic-degrading invertebrates and associated gut microorganisms. Implementing genetic engineering techniques to produce recombinant microbial strains and/or enzymes could be the best course of action to improve the biodegradation of synthetic plastic waste derived from petroleum.

Table 1: List of some Microorganisms that are capable of plastics degradation (Mohanan et al., 2020).

Examined polymer (polymer under examination)	Species	Source	Cultivation conditions	Polymer degradation		Reference
				In vitro conditions	Degradation efficiency	
Polystyrene	*Pseudomonas sp.*	Soil samples were taken from the plastic dump yard	Mineral medium with 0.85% NaCl and HIPS film at 30^0C, 150 rpm	30 days incubation at 30^0C	>10% weight loss	Mohan et al., 2016
Polypropylene	*Pseudomonas sp. Aspergillus niger*	Plastic dump yard	Mineral medium (B7) with 0.05% glucose and 0.05% sodium lactate at 30◦C	175 days incubation at neutral pH at 30^0C	60% weight loss	Cacciari et al., 1993
Polyethylene terephthalate	*Ideonella sakaiensis*	Polyethylene terephthalate recycling factory	Nutrient broth medium with PET at 30^0C	42 days incubation at 30^0C	Almost complete degradation achieved	Yoshida et al., 2016
Polyurethane	*Pseudomonas chlororaphis*	Microbial consortium from the Naval Research Laboratory, Washington, DC, United States	LB (Luria broth) medium at 30^0C, 180 rpm	6 h incubation at 23^0C on plates with Impranil	A zone of clearance was observed	Stern and Howard, 2000

Conclusion:

In addition to discussing the effect of plastic on the animal world, this study offers probable sustainable solutions to save Mother Earth and its faunal beings from plastic pollution. The life cycle of plastic needs to be extended through an integrated waste management system, minimizing its negative effects on the environment and according to the hierarchy of waste management, which is based on the four R: reduce, reuse, recycle, and recover.

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Chapter- 18

An Environmental Pollutant: Bisphenol A (BPA), Posing a Risk to Human Health

Kaushik Sarkar

Keywords: Bisphenol A, environmental pollutant, endocrine disrupter, multisystem toxicity.

Abstract:

Every day, we come into contact with various chemicals produced by humans and found in the natural world. These substances are referred to as environmental pollutants. Even while certain chemicals are not dangerous, they might pose a risk if handled or misused. We can absorb harmful substances through our skin or breathe them in, ingest, or drink them. Bisphenol A (BPA) is one of the most significant substances we eat regularly. One synthetic organic chemical is BPA. It belongs to the group of phenol derivatives chemically. Commercial uses include the production of polycarbonate plastics for water and infant bottles, among other things, and epoxy resins for the inner coating of food and drink cans (soft and heavy). Studies have shown that consuming foods, beverages, and water tainted with BPA exposes people to the chemical. BPA's potential health risks have been investigated in humans and animals. Since it exhibits estrogenic effects in a variety of animal models, it is regarded as an endocrine disruptor. Nevertheless, BPA also causes different forms of neuromuscular, behavioral, developmental, and reproductive toxicity in laboratory animals. One could argue that ingesting BPA daily increases the risk of disease development in all people. Because of this, such substances constantly endanger our lives, both directly and indirectly. To ensure that our society is safe for future generations, we should aim to limit BPA exposure through reduced consumption, even though we are unable to stop BPA exposure from the environment at this time.

Introduction:

Both naturally occurring and artificially created chemicals have made a significant contribution to prosperity. Some of these chemicals, nevertheless, have also been shown to seriously harm both the environment and people (Samal et al., 2017; Mondal et al., 2022). While not all chemicals are dangerous, they can still be dangerous if handled or used improperly. To cause illness, our bodies need to absorb a specific quantity of a dangerous substance. Inhaled, eaten, drunk, or absorbed through the skin are all ways that harmful chemicals can enter our bodies. Individuals react differently to exposure to these chemicals. Sometimes illness happens only if we are exposed to a harmful substance for a long time. Several factors play a role in whether we get sick from contact with chemicals, such as the kind of chemical we are exposed to, how much of the chemicals we were in contact with, how long the contact lasted, how often we were exposed, how it entered our body, and finally our health

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risk. This brief review of BPA explains some of the connections between chemicals and potential health risks. We will undoubtedly learn about BPA from this article and the potential health risks that come with being exposed to it daily at home and work.

BPA is a synthetic organic compound. Many plastics and plastic additives are made of it as their building block (Biedermann et al., 1998; NTP, 1982; Vom Saal and Meyers, 2008). It is utilized in the manufacturing of epoxy resins and polycarbonate plastics. Plastic products of all kinds, including water bottles, bottles for nursing babies, soft and hard drink containers, etc., are mostly made of polycarbonate plastics. Moreover, BPA is frequently utilized in the production of various plastic goods, including dental sealants, optical lenses, medical equipment, CDs, DVDs, electrical equipment, sports safety equipment, and a host of other household appliances (Burridge, 2003; NTP, 1982). When BPA-contaminated food, drink, or water is consumed, humans are exposed to BPA. According to Biles et al., 1997 and NTP, 1982, certain dental sealants and composites may also be significant sources of BPA exposure for people (Figure 1). Both humans and certain animal models have been used to study the potential health risks of BPA.

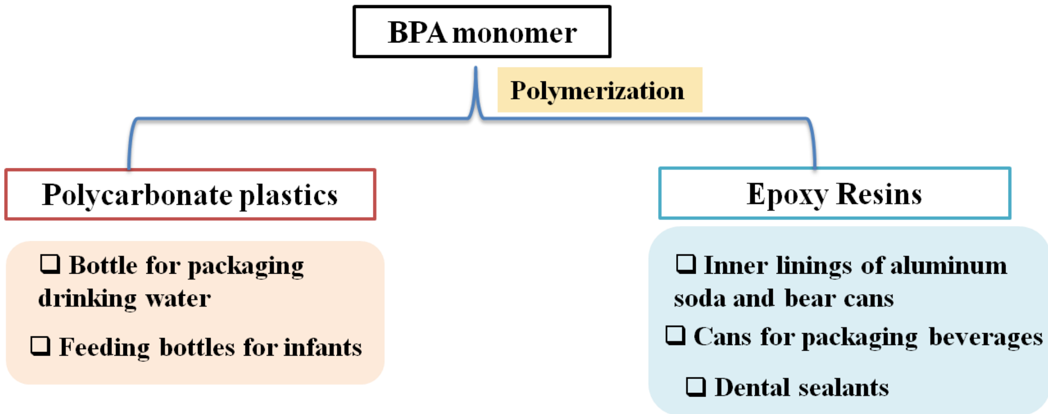

Figure 1. Industrial applications of bisphenol A (BPA).

In animal models, it exhibits multisystem toxicity (Della et al., 2023) (Figure 2). The mode of action of BPA appears to mimic that of the female hormone estrogen (Krishnan et al., 1993; Matsumoto et al., 2005; Rudel et al., 2001). As a result, BPA can be regarded as a synthetic chemical that disrupts hormones. It causes a variety of reproductive and behavioral toxicities as a result of its estrogenic activities (Chitra et al., 2003; Krishnan et al., 1993; Patisaul et al., 2006; Patisaul et al., 2009; Savabieasfahani et al., 2006). Additionally, it has harmful effects on the liver (Inoue et al., 2003; Bindhumol et al., 2003). According to reports, BPA affects the function of coronary smooth muscle in addition to its estrogenic properties (Asano et al., 2010). Rats' intestinal and atrial contractility are both decreased by BPA (Pant et al., 2011; Sarkar et al., 2016).

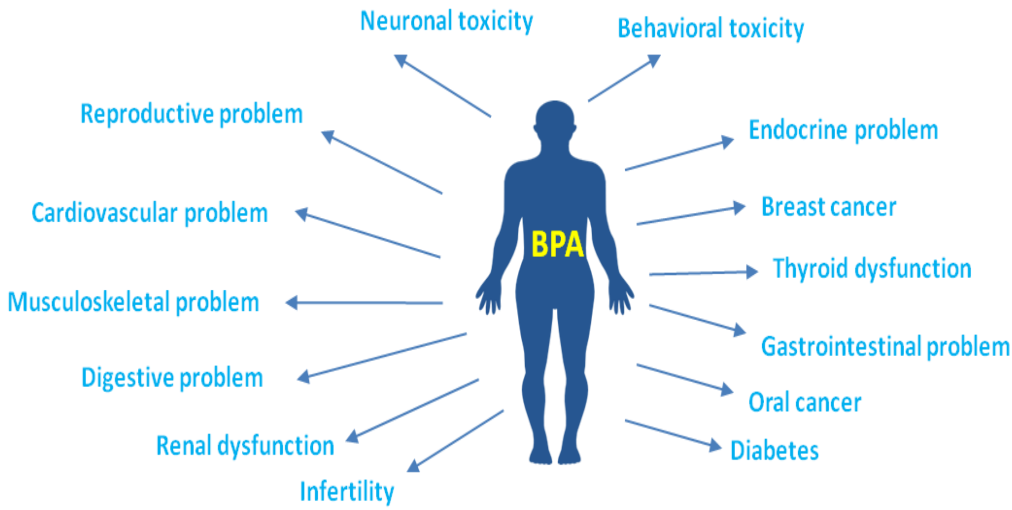

Figure 2. Adverse effect of BPA on human health.

Estrogenic activities of BPA:

Endocrine disrupting chemical (EDC) is an external substance that tampers with the body's natural hormone production, release, transport, metabolism, binding, action, or elimination. These hormones are in charge of preserving homeostasis and controlling developmental processes (Wetherill et al., 2007). Based on conventional bioassays, BPA has been deemed a weak environmental estrogen because of its ability to bind to α and β estrogen receptors (Gould et al., 1998; Kuiper et al., 1998; Pennie et al., 1998). According to certain earlier studies, low levels of BPA exposure cause disruptions in tissues that respond to androgen or estrogen, as well as in the thyroid, immune system, and developing nervous system (Richter et al., 2007; Vandenberg et al., 2008; Wetherill et al., 2007) (Figure 3). In a variety of target tissues, including the pancreas, BPA has also been demonstrated to interfere with the normal function of the estrogen nuclear hormone receptors (Adachi et al., 2005). According to Steinmetz et al., 1998, there is also evidence that ovariectomized rats' uterine and vaginal epithelial cells proliferate when exposed to single, high doses of BPA (up to 150 mg/kg BW). In response to BPA exposure, other organs such as the pituitary and mammary glands also showed estrogenic responses (Colerangle et al., 1997). Therefore, it is likely that the description of BPA as a weak oestrogen will understate the effects of BPA exposure on various target organs.

Toxicokinetics of BPA:

Toxicological studies of BPA have determined that the maximum tolerated dose for BPA is 1000 mg/kg body weight (BW)/day (Morrissey et al., 1987; Welshons et al., 2003). The US-EPA used a safety factor of 1000 to determine a reference dose of 50µg/kg/day. Usually, the NOAEL is used to calculate a reference dose; however, in the case of BPA, the LOAEL was used since no NOAEL was well known and adverse reactions were observed even at the lowest dose that was given (Soto et al., 2006). The toxicity profile thus indicates that the proper level to use in risk assessment of human exposures is 50 mg/kg/day. The US-EPA chose this value to serve as the foundation for determining a reference dose of BPA (US EPA 1984a, 1984b, 1984c, 1987; NTP 1982, 1985a, 1986a).

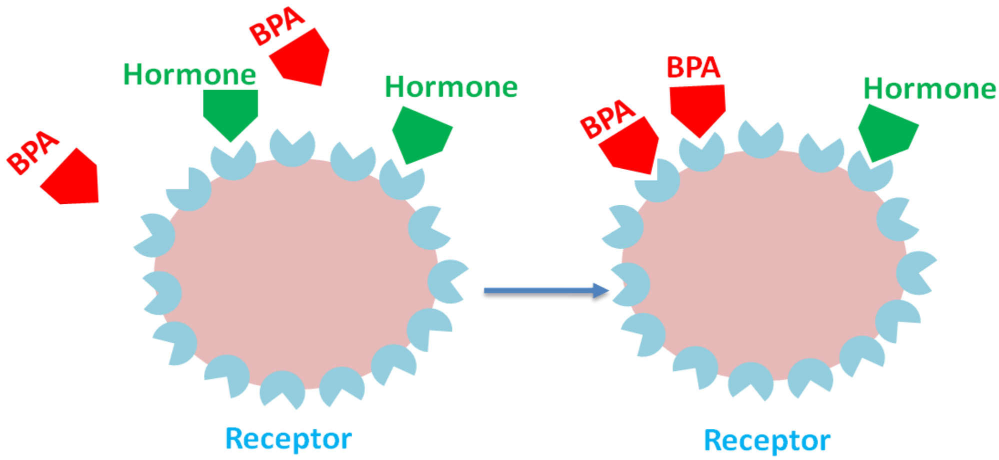

Figure 3. Endocrine disrupting effect of bisphenol A (BPA).

Impact of BPA on the functions of various organ systems:

The toxicological profile of BPA has revealed that it may have an impact on human and laboratory animal organ systemic functions. However, the way the scientists presented their research on the toxicity of BPA was contentious. While some research groups have found significant health effects from BPA, others have not mentioned it. In the majority of instances, BPA exhibits mild estrogenic activity along with primarily producing reproductive and developmental toxicity in laboratory test animals. It has also been reported that some "free" BPA is absorbed in the intestine following oral ingestion. BPA causes gastrointestinal problems in both humans and test animals because of these factors. However, an outline of the toxicity of BPA on several organ systems is provided in this section; these are detailed below.

Role of BPA on the reproductive system:

The toxic effects of BPA on male and female reproductive systems have been reported by various scientists controversially. Findings suggest that high levels of BPA reduced sperm count, motility, sperm mobility, and vitality, anomalies in spermatogenesis, etc. (Li et al., 2010a; Li et al., 2010b; Li et al., 2009, Salian et al., 2009c). Moreover, BPA has been shown to affect the levels of estradiol, LH, FSH, and testosterone in the serum (Watanabe et al., 2003; Salian et al., 2009c; Della et al., 2006; Herath et al., 2004; Zeng et al., 2022). Research carried out in 2006 by Kato et al., demonstrated that BPA alters the expression of certain genes in the testis. After oral exposure to BPA for five weeks, a study by Chitra et al., 2003, revealed a significant increase in the relative weight of the ventral prostate and a significant decrease in the number of epididymal sperm and the relative weight of the testis and epididymis. Furthermore, research conducted in 2011 by Mendoza-Rodriguez et al., indicates that oral BPA exposure in rats during lactation and pregnancy may cause abnormalities in the estrus cycle in addition to increasing the thickness of the uterine stroma and epithelium in the offspring. Additionally, according to certain studies, BPA changes the expression of ERα and PR and impairs DNA synthesis in the uterine epithelium (Markey et al., 2005; Mendoza-Rodriguez et al., 2011; Signorile et al., 2010; Newbold et al., 2007; Fernandez et al., 2010; Berger et al., 2010). It lowers fertility, ovarian dysfunction, puberty at a younger age, and uterine weight (Adewale et al., 2009; Rubin et al., 2001; Cabaton et al., 2011; Zoeller et al., 2005; Tachibana et al., 2007). Also, it has been documented that BPA exposure in the neonatal period alters hypothalamic-pituitary hormone secretion, reduces the number of oocytes in each ovarian cycle, degrades oocyte quality, and other effects (Savabieasfahani et al., 2006; Mok-Lin et al., 2010; Fujimoto et al., 2011; Takeuchi et al., 2004).

Role of BPA on brain and behaviour:

According to certain studies, BPA causes neurotoxicity during development, anxiety, changes in sexual behavior, and other side effects (Stump et al., 2010; Cox et al., 2010; Poimenova et al., 2010; Tian et al., 2010). Scientific evidence suggests that during utero exposure BPA changes maternal, exploratory, and emotional behavior (Poimenova et al., 2010). Additionally, BPA also inhibits the growth of neuronal stem cells, decreases the amount of dopamine transporter (DAT) in the putamen, increases serotonin (5-HT) levels in the hippocampus, and increases the number of oxytocin neurons in the paraventricular nucleus (Kim et al., 2009; Tian et al., 2010; Matsuda et al., 2010; Adewale et al., 2011; Xu et al., 2010b; Xu et al., 2010c). Several studies indicate that oral exposure to BPA alters maternal behavior, and inhibits the miniature inhibiting postsynaptic currents in brain neurosynapse in a concentration-dependent manner through GABA(A) receptors (Palanza et al., 2008; Choi et al., 2007). Serotonin metabolites and dopaminergic neurotransmission are dynamically altered when low doses of BPA are introduced into neurons (Miyatake et al., 2006; Honma et al., 2006). On the other hand, long-term BPA exposure causes memory impairment linked to decreased acetylcholine (ACh) and choline acetyltransferase (CAT) production (Miyagawa et al., 2007). BPA acts as a xenoestrogen and blocks sodium currents through postsynaptic neuronal membranes by binding to nicotinic ACh receptors, according to research by Nakazawa and Ohno (Nakazawa et al., 2001).

Role of BPA on metabolism and cardiovascular system:

There have also been conflicting reports from earlier studies regarding the impact of BPA on the cardiovascular system and metabolism. Studies have evaluated how BPA may interact with the metabolism of fat and carbohydrates. Alonso-Magdalena et al., 2010 reported that exposure to BPA in rats during the gestation period reduces glucose tolerance; and increases insulin resistance, plasma insulin, leptin, triglycerides, and glycerol levels (Alonso-Magdalena et al., 2010). Other findings conclude that BPA increases the female body weight, adipose tissue weight, etc. (Ryan et al., 2010; Somm et al., 2009; Miyawaki et al., 2007). Rats exposed to BPA during pregnancy have lower glucose tolerance and higher levels of insulin resistance, plasma insulin, leptin, triglycerides, and glycerol were reported by Alonso-Magdalena et al., 2010. Other studies have found that BPA increases body weight, female circumference, adipose tissue weight, and so on (Ryan et al., 2010; Somm et al., 2009; Miyawaki et al., 2007). While there is a positive correlation between fasting glycemia and urine levels of insulin resistance, BPA is also linked to diabetes and modifies alkaline phosphatase activity (Hong et al., 2009; Lang et al., 2008; Melzer et al., 2010). Subsequent investigations revealed a link between human exposure to BPA and an increased risk of cardiovascular disease. According to reports, BPA reduces the activity of acetylcholinesterase (AChE) in cardiac muscle and atrial contractility via the NO-dependent guanylyl cyclase pathway (Pant et al., 2011; Aboul et al., 2015). Although the effects of BPA on Maxi-K potassium channels are unknown, Asano et al. (2010) reported that BPA increased the activity of these channels, which are sensitive to both estrogens and estrogen receptors (Kca 1.1).

Role of BPA on the intestine:

There is an abundance of information on how BPA affects intestinal smooth muscle function in humans and rodents. Nevertheless, a study by Braniste et al., 2010, revealed that BPA causes gastrointestinal inflammation and visceral pain in ovariectomized female rats and reduces intestinal permeability in a dose-dependent manner (Braniste et al., 2010). Other findings suggest that BPA is absorbed into the gut and is primarily eliminated as BPA-glucuronide through the bile system (Inoue et al., 2003). Nonetheless, the primary organs where the BPA-conjugation occurs are the liver and the intestine (Inoue et al., 2001; Pritchett et al., 2002). Additionally, some free BPA is reabsorbed into the intestine after being metabolized by the body (Hanioka et al., 2008). Because of these, BPA may interfere with the intestine's regular function and raise AChE activity in small intestinal smooth muscle (Sarkar et al., 2013). The results of our study indicate that BPA affects both adrenergic and non-adrenergic non-cholinergic signals, which in turn alters small intestinal motility (Sarkar et al., 2016). Thus, it is evident that BPA has a markedly negative impact on several organ systems in both human and animal models. To determine the toxic effects of BPA, this review focuses on a few short of its negative effects on particular organs.

Conclusion:

This review article has made it clear that BPA poses significant health risks to us daily, risks that have been thoroughly investigated by numerous research teams. The fact that BPA functions as an endocrine disruptor, or has a weak estrogenic property, makes it the most effective component of the chemical. So that it can easily cause toxicity to the reproductive system. It impacts the heart, liver, intestines, and other organs in addition to its estrogenic action. Thus, it can be concluded that ingesting these chemicals in the form of foods, drinks, and other liquids increases the risk of disease development in humans. These kinds of chemicals are a constant threat to our lives. Therefore, although we are unable to completely stop BPA exposure from the environment at this time, we should try to limit our exposure to these harmful chemicals by consuming fewer packaged foods and beverages as well as fast food to ensure the safety of our society for future generations.

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Chapter- 19

Impacts of Microplastics on Zooplankton

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Keywords: Zooplankton Diversity, Microplastics, Coastal Estuarine, Pollution.

Abstract:

In the aquatic food chain, microplastics (MPs) are ubiquitous. The presence of microplastics in water and the physicochemical properties of water can likely affect aquatic biota. The physicochemical environment determines the structure of zooplankton community. The pollution of aquatic ecosystems by microplastics is widespread. Aquatic zooplankton and various larger animal species (reptiles, birds, mammals) have been affected due to consumption of plastic fibres through food chains. Concentration of aquatic pollution increasing day by day with microplastics resulting from urban sewage discharges, industrial effluents, and anthropogenic activities. Microplastics are absorbed by fish that consume plankton, which is amplified by other organisms. In total, we have surveyed 57 research papers on microplastics in zooplankton. Zooplankton diversity of an area can be used to assess water contamination, particularly nutrient-rich eutrophication of that particular area. Microplastics may interfere with the production of endocrinological hormones in humans. In future, this will be a great hazard to human beings. Microplastic (<5mm in length) may be polyethene or polypropylene or polystyrene in nature and may be white or red or blue in colour. The study examines the water, the importance of zooplankton to the aquatic ecosystem, and the microplastic concentration report. As a result of this assessment, national and international authorities will be able to assess a range of stakeholders, make decisions and build policies that will benefit many stakeholders.

Introduction:

Aquatic, microscopic zooplankton can swim in a vertical position and make dynamic movements but can not navigate or move against a powerful stream (Odum, 1996; Mukherjee, 2020). Biological communities depend heavily on them because they influence the majority of aquatic ecosystems' functional features, including food chains and matter cycling (Murugan et al., 1998; Karmakar, 2021). Polluted waters can be improved and the quality of the environment monitored with zooplankton bioindicators (Dadhick and Saxena, 1999; Bera,

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2021). Water bodies can be compared to identify contaminants by comparing their quantity, variety, structure, size, and reproduction of zooplankton (Sharma and Sharma, 2017; Mukhopadhyay et al., 2000; Saha & Sarkar, 2022). Industry's expansion, rising energy consumption, irresponsible destruction of natural resources, environmental pollution and increased garbage disposal have all contributed to the increase in garbage disposal over the past few decades (Gautam et al., 2016; Bhattacharya et al., 2016; Samal et al., 2017; Chakraborty et al., 2019; Mondal et al., 2022).

The world's oceans are becoming increasingly polluted by plastic. Plastic is one of the world's most serious waste disposal issues (Bhattacharyya et al., 2022; Madhu et al., 2022). Plastics Europe estimates that approximately 5% of annual global production, or 360 million tonnes in 2018, will end up in the ocean, accounting for the vast majority of marine debris (Derraik, 2002). When plastic enters the ocean, it breaks down into tiny pieces known as microplastics (less than 5 mm), which then break down into nano-plastics (less than 100 nm) (Arthur et al., 2009). Microplastics (MPs) are primary particles formed in tiny sizes, such as granulates used in cosmetics, washing powders, cleaning solutions, or pellets (Fendall and Sewell, 2009). MPs become common as a result of their endurance and may take decades to disintegrate (Moore, 2008; Barnes et al., 2009; Aytan et al., 2020).

Once MPs are eaten by zooplankton, they may get into the food chain and have toxic effects on the environment because they soak up toxic, persistent, and bioaccumulative pollutants (Setala et al., 2014; Martins and Sobral., 2011). Some research (Steer et al., 2017; Botterell et al., 2019) has shown that filter feeders and zooplankton eat MPs. This means that pollutants linked to MPs may enter human diets through the food chain (Zarfl and Matthies, 2010). Experiments have shown what happens to zooplankton when they eat MPs. Their reproduction, survival rates, growth, eating habits, and life cycle are all affected (Botterell et al., 2019). Kvale et al. (2021) say that when zooplankton eats MPs, it affects the ocean's biological rates related to dissolved oxygen.

The soil and water ecosystems are constantly exposed to dangerous organic and inorganic compounds from both man-made and natural sources. Some network variables affecting water quality are temperature, pH, the amount of oxygen in the water, etc. Limnological factors can have different effects on aquatic life in many ways. Most of the time, limnological and biological standards are used to see if water quality meets standards and laws. When these things are too high, they could hurt aquatic life and people's health (Mukhortova et al., 2021). The data from many peer-reviewed articles and later studies on the estuary ecosystem showed that MPs, zooplankton assemblages, and limnological parameters greatly affect the water quality and trophic condition, which may affect the ecosystem's ability to work.

Materials and Methods:

There has been a search conducted of the scientific literature utilising the search engines Google Scholar, Internet Archives, and Academia Edu, along with keywords such as Zooplankton Diversity, Microplastics and Coastal Estuarine. We studied manuscripts between

December, 2021 to October, 2022. All remaining relevant references were reviewed, and spurious hits, such as papers without microplastics and zooplankton, were ignored. Microplastic consumption by zooplankton in the laboratory is mainly investigated from the perspective of feeding, reproduction, growth, development, and lifespan. 57 articles regarding zooplankton and microplastics were surveyed for our review works.

Diversity of zooplankton and its role:

Numerous zooplankton species, including *Daphnia, Cyclops, Cypris*, and *Brachionus*, were frequently reported in the surveyed articles. Most scientists have found several groups of zooplankton. Of these, Rotifera, Cladocera, and Copepoda are the three hugest. *Brachionus* represented Rotifera by the genera *Keratella, Asplanchna, Polyarthra, Lecane*, and *Filina*, Cladocera by the genera *Diaphanosoma, Ceriodaphnia, Daphnia, Moina, Bosmina*, and *Acroperus*, and Copepoda by the genera *Heliodiaptomus* and *Mesocyclops* (Patra and Madhu, 2009; Midya et al., 2018; Chakraborty and Halder Mallick, 2020).

The Bay of Bengal had an intra-seasonal study on zooplankton abundance to clarify the area's fertility as a new fishery site. The 22 species that make up the zooplankton population. When it came to both the number of species and their abundance, Copepoda dominated the landscape. Copepods, protozoan zooplankton, arrow worms, larvaceans, cnidarians, ostracods, and the liaceans were also widely spread in these regions (Sahu et al., 2021). In total, 53 species of zooplankton were found in estuarine waters. These species were calonoidia (13), ciliate (8), cyclopodia (6), crustacean larval forms (3), harpacticoida (3), foraminifera (3), mollusca (2), chaetognatha (2), and siphonophores. Copepodite, ctenophore, doliolids, isopods, ostracoda, cladocera, ctenophore, decapoda, and fish larvae were also found, but in smaller numbers. It was found that zooplankton density peaked in the summer but decreased during monsoons. However, during the rainy season, their numbers are reduced by the abrupt drop in temperature and mineral dilution (Mukherjee, 2020).

Quantitative research on the physicochemical properties of zooplankton shows that the number of zooplankton changes a lot from season to season (Patra and Madhu, 2009; Dutta et al., 2014). It has been found that the physical and chemical properties of a body of water greatly affect how many zooplankton live there. Also, it has been noticed that seasonal changes have a big effect on how physicochemical parameters change over time (Maity, 2019; Das et al., 2022).

The species composition and spread of plankton are strongly affected by changes in physicochemical factors and the food supply. The results of this study show that physicochemical properties greatly affect how zooplankton are made up. Midya et al (2018) have found 41 different kinds of zooplankton in the Lentic estuarine ecosystems of Tajpur and New Digha (Bay of Bengal). There are two types of species: rotifers (12) and arthropods (29). No caducean species were found. There were five types of dominant species. *Calanus finmarchicans*, *Oncaea* sp., *Microsetella* sp., *Pseudodiaptomus hickmani* and *Acartiella* sp. So, a type of calanoid copepod is found in many estuarine wetlands. The most common species were both *Paracalanus* sp. and *Eucalanus crassus*.

The zooplankton species present at those sites have discontinuous distribution patterns that are strongly similar. Maity (2019) observed *Cyclops* sp., *Daphnia* sp., *Nauplius* stage, *Brachionus* sp., and other zooplankton species at the mouth of the Haldi River, where industrial effluents are discharged. *Cosmocalanus darwinii* is the most common species in the Bay of Bengal.

Table 1. Zooplankton's importance in aquatic biology.

Sl no	Feature	Function
1	Living fish food	Fish that feed on zooplankton have historically been regarded as major food sources.
2	Bio indicator	The best indication for determining the extent of water pollution, particularly nutrient-enriched eutrophication brought on by residential sewage pollution and pesticide toxicity, has also been determined to be zooplankton.
3	Mosquito population reduction	By preventing mosquito oviposition and larval development, they aid in the reduction of the mosquito larval population.
4	Trophic dynamics	Live-feed Zooplankton reduces the foraging energy required by their predators by making organic material available to higher trophic levels in a bigger pellet.
5	Larviculture and ornamental fish culture feed	Zooplankton is employed as a live food source in the culture of ornamental fish and freshwater larvae.

Types and shapes of MPs:

The three primary forms of plastic litter identified in prior studies were microplastic (5mm), and mesoplastic (5-25mm), and macroplastic (>25mm). Coastal areas, factories, and floodplains have all been found to contain microplastic, but the concentrations vary widely (Bhattacharyya et al., 2022). According to data collected thus far, the most common types of microplastics in the environment are polyethene (PE) and polypropylene (PP). Particles made of polyethene, polypropylene, and polystyrene are examples of microplastics frequently detected in cosmetic and pharmaceutical products (Horton et al., 2017). Plastics exposed to the air undergo photooxidation when exposed to ultraviolet (UV) radiation; as a result, they become brittle and break down into small pieces of plastic called microplastics. In aquatic environments, the process of plastic decomposing into smaller and smaller pieces occurs very slowly (Zhang, 2017). Depending on where they come from, microplastics can come in many different forms or morphologies, such as pellets, threads, or fragments. These forms are known as "morphologies" (Klein et al., 2015).

Botterell and his colleagues (2022) determined that the sizes of the MPs fragments present in the zooplankton samples ranged from '8 to 286 μm, with a mean size SE of 41±6 μm' in their study of MPs in zooplanktons. 75% of the MPs measured 'less than 50 μm' in length.

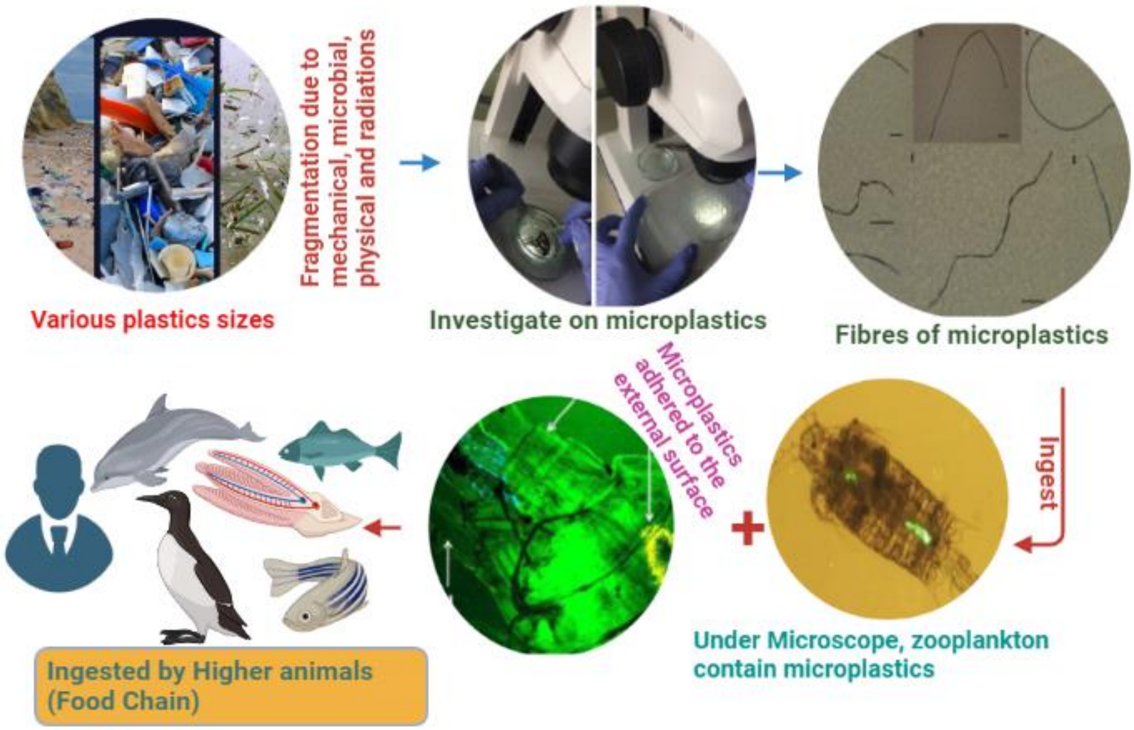

Figure 1. Plastic waste is reported in marine areas and on beaches. A microscopic image of microplastics (MPs) in various sizes. Fluorescence microscopy indicates that zooplankton can ingest different-sized MPs and may attach to their skeletons.

Microplastic influencing factors:

The natural environment has been contaminated by an excessive amount of waste made of plastic as a direct result of human activities and poor management. Plastic debris, once it has been released into the environment as a whole, is prone to fragmentation via UV degradation as well as physico-chemical and biological processes. This results in the debris finally breaking down into minute particles that are referred to as microplastics (MPs) (Thompson et al., 2004). According to Thompson et al. (2009), the abundance of microplastic that becomes accessible to a greater number of organisms will rise over time. This is because larger pieces of macroplastic will continue to degrade and break as time passes.

It has been predicted that the highest chance of encountering microplastics will occur in shelf-sea regions, whilst in other areas of high plastic occurrence, such as oceanic gyres, the likelihood will be relatively low due to low primary productivity and lower abundance of organisms (Clark et al., 2016). Several laboratory studies have shown that high abundance/concentrations of microplastics lead to increased ingestion (Kaposi et al., 2014; Cole and Galloway, 2015; Messinetti et al., 2017). In the field, Frias et al. (2014) found the microplastic abundance ranged from 0.01-0.32 cm3 m-3 and the zooplankton abundance ranged from 0.02-0.51 cm3 m-3 in coastal waters of Portugal.

Microplastics ingestion by zooplankton:

Microplastics are defined as fragments of plastic that are less than 5 millimetres in size and have become one of the most pervasive and widespread contaminants of marine ecosystems around the world. It has been extensively reported that marine biota, such as mussels, worms, fish, and seabirds, consume microplastics; nevertheless, despite their essential ecological function in marine food webs, the impact of microplastics on zooplankton has received insufficient attention.

Because of their comparable size, microplastics have the potential to be mistaken for a species' natural prey or to be passively absorbed during the course of regular feeding behaviour. It has been demonstrated that many species of zooplankton are capable of ingesting microplastics ranging in size from 0.5-816 µm (Cole et al., 2013; Lee et al., 2013; Cole and Galloway, 2015; Desforges et al., 2015). Cole et al. (2013) found that 13 out of 15 zooplankton introduced to beads made of polystyrene (7.3-30.6 µm) demonstrated the ability to consume MPs. They also observed live zooplankton and discovered that copepods, euphausids, and doliolids consumed MPs via filter-feeding. MPs were found on the external surfaces of zooplankton in both its living and preserved forms species such as 'copepods, decapod larvae, and euphausids. It was discovered that 13 zooplankton taxa, including 'holoplankton, meroplankton, and microzooplankton,' can consume polystyrene beads in the absence of natural food sources. According to Kvale et al. (2021), MPs are a nutrient-poor byproduct consumed by zooplankton alongside other food sources that primarily reduce primary producers' consumption of zooplankton and the nutrients associated with it. They demonstrated the possibility of an additional anthropogenic deoxygenation driver in which zooplankton ingestion of MPs reduces primary producers' grazing.

It is believed that the gape size of the mouthparts of the species is responsible for the size limitation of the microplastics that are eaten. Because smaller microplastics (15 µm) were consumed more frequently by the copepod *Calanus finmarchicus* than bigger microplastics (30 µm), this suggests that for this species, smaller microplastics had a better bioavailability (Vroom et al., 2017). Meroplankton were also found to exhibit size selectivity in their communities. According to Cole and Galloway's research (2015), Pacific oyster larvae of all ages were able to eat polystyrene beads ranging in size from 1.84 to 7.3 micrometres; however, only the larger larvae were able to ingest beads measuring 20.3 micrometres. According to the findings of Deforges et al. (2015), the *Euphausia pacifica*, the North Pacific krill, which is approximately 22 millimetres in length, preferentially ingests particles with a size of 56 micrometres, while the copepod, *Neocalanus cristatus*, which is roughly 8.5 millimetres in length, ingests particles that have an average size of 816 micrometres.

In the form of spherical beads, which are employed in cosmetics, and as fibres rinsed out from garments, microplastics can reach the environment directly through wastewater treatment plants (Thompson, 2015; Napper and Thompson, 2016). Because of the effects of weathering and deterioration on bigger plastics, microplastics can also take the form of pieces with an irregular shape.

On the other hand, microplastic spherical beads have been utilised almost exclusively in the context of laboratory-based research (Cole et al., 2013, Lee et al., 2013, Cole and Galloway, 2015). The fact that the microbeads were easily consumed by the majority of species is evidence that this particular shape is bioavailable to a diverse collection of taxa. A recent investigation conducted by Vroom et al. (2017) looked into the ingestion of microplastic pieces (less than 30 micrometres in size) in addition to microbeads. They discovered that both juvenile and adult *Calanus finmarchicus* were able to consume the fragments without any difficulty. In addition, Choi et al. (2018) discovered that sheepshead minnow (*Cyprinodon variegatus*) larvae were able to easily consume irregular polythene shapes that ranged in size from 6-350 μm.

According to Vroom et al. (2017), the natural ageing processes that occur in marine environments, such as weathering and biofouling, can cause changes in the physical and chemical properties of microplastics. According to Lambert et al. (2017), these processes will cause the degradation of microplastics, resulting in a reduction in their size as well as the creation of an irregular form and surface, which will ultimately result in an increase in their overall surface area. Adsorption causes the formation of a layer consisting of both organic and inorganic substances as soon as microplastics are released into the marine environment.

Effects of Microplastics on zooplankton:

The effects on feeding & life span:

According to Cole et al. (2013), microplastics can obstruct feeding appendages and restrict food intake. In an experiment with natural algae assemblages and polystyrene microbeads, copepods that consumed polystyrene microbeads significantly decreased their herbivory (Cole et al., 2013; Cole et al., 2015). Using a microplastic model, Cole et al. (2015) detected a significant shift in the size spectrum of algal prey consumed by copepods exposed to 20 μm microplastics. In response to the consumption of smaller prey items, there was a substantial reduction in the amount of carbon biomass consumed, resulting in a predicted loss of carbon of -9.1 ± 3.7 μg C copepod^{-1} day^{-1} (Cole et al., 2015; Botterell et al., 2019).

It is possible to experience an energy deficit if feeding behaviour or food intake decreases. This could negatively affect larval growth and development until adulthood. The copepod *Tigriopus japonicus* has been shown to extend its nauplius phase as a consequence of reduced feeding on algal prey caused by microplastic ingestion (Lee et al., 2013). Ingestion of polystyrene microbeads (2-5 m) by veligers of the marine gastropod Crepidula onyx not only leads to slower growth rates but also results in earlier development on the seabed at a smaller size, which might adversely impact post-settlement success. This research was conducted by Lo and Chan (2018).

Reduced eating, an insufficient supply of nutrients, or an obstructed or injured digestive tract are all potential causes of continuous loss of energy inputs, which can ultimately lead to mortality. Not only did the death rate of copepodites grow when chronically exposed to microplastics over the course of two generations in copepods, but the mortality rate of nauplii also increased (Lee et al., 2013). It's possible that this could have an impact on recruitment for subsequent generations, which would, in the end, lead to a smaller population size and, as a result, less food available for higher trophic levels.

Effects on reproduction process:

The process of reproduction requires a lot of energy, and if an animal does not get enough to eat, it could have an influence on their ability to reproduce. Several studies (White and Roman, 1992; Williams and Jones, 1999; Teixeira et al., 2010), among others, have demonstrated that a scarcity of food can lead to a decrease in the number of eggs that are laid by copepods. According to the findings of Lee et al. (2013), the fertility of *Tigriopus japonicas* copepods was significantly reduced after being exposed to repeated polystyrene microbead concentrations over the course of two generations. They also discovered that a significant number of egg sacs did not mature properly.

Biomagnification of MPs:

These previously contained MPs have the potential to be eroded by the wind and water. Then make their way into waterways and, ultimately, the estuarine aquatic environment. In addition, precipitation can potentially sweep MPs into drainage systems that have been produced due to tyre wear on roads (Kole et al., 2017). Plastic pellets, the forerunner of larger plastic products that are sometimes accidentally spilt during transportation, are yet another significant contributor to the problem of MPs pollution (Bandyopadhyay et al., 2023). Plastic pellets are also referred to as "nurdles" (Thompson, 2015).

MPs are anticipated to bioaccumulate in species at higher trophic levels by combining direct ingestion and trophic transfer. This is likely to be the primary mechanism. It is difficult to determine whether or not MPs have the ability to bioaccumulate in the food webs of marine mammals. The moderate to high microplastic bioaccumulation that has been projected in some lower trophic level marine species underscores the health dangers of toxic exposure to estuarine aquatic fauna that is heavily dependent on fish as well as coastal communities that are greatly dependent on seafood. This modelling work provides a technique to analyse microplastics' bioaccumulation potential and impact in the estuarine aquatic environment (Saha et al., 2022). This assessment aims to support risk assessment and inform plastic waste management (Alava, 2020).

It is possible that these MPs are consumed as a result of indiscriminate feeding behaviours, such as suspension feeding, in which prey are frequently consumed in a non-selective manner

(Cole et al., 2013). Previous studies have shown that certain species of zooplankton can adjust their diets to prioritise eating one type of algae over others and plastic beads (Ayukai, 1987). In addition to this, it has been discovered that the copepod, *Calanus helgolandicus*, when subjected to both MPs and algal prey, preferentially consumes algal prey of a smaller size (Cole et al., 2015). This change in feeding behaviour gives rise to the hypothesis that copepods are modifying their eating behaviour in order to avoid ingesting MPs.

Color-MPs and zooplankton relationships:

Due to their resemblance to prey items, the colour of MPs has the potential to boost their bioavailability. This is especially true for species that rely on their eyes for hunting (Wright et al 2013). However, the vast majority of tests have been conducted with pale-coloured microplastics, which numerous species of zooplankton readily consume (Cole et al., 2013; Cole et al., 2015). According to Desforges et al. (2015), the MPs fragments discovered inside a type of euphausiid and copepods were mostly black, blue, and red. MPs may be white or transparent also. On the other hand, there was no discernible difference in particle colour between the species. In a similar vein, Steer et al. (2017) discovered that the digestive systems of fish larvae contained mostly blue MPs (66%) and discovered that this matched the colour ratio of MPs in the surrounding environment, showing that there is no discrimination based on colour.

Discussion:

There is a wide variety of feeding behaviours that zooplankton are capable of displaying. These behaviours are determined by the life stage, species, and availability of prey. The majority of the zooplankton increase their chances of finding food by producing a feeding current that moves across the water. According to Phuong et al. (2016), microplastics that are present in an aquatic environment have the potential to be colonised by aquatic creatures and to absorb chemicals from their surroundings onto their surfaces. Over a period of a day, the consumption of algae by copepods was hampered by microplastics. This variable will have an effect on the zooplankton's ability to make use of the microplastics that are there. Ingestion has been explored as a pathway for the passage of microplastics between different trophic levels in a number of studies. On the other hand, there is a very limited amount of study being done on bioaccumulation of microplastics at the moment. In order to generate reliable risk assessments, it is essential to have a solid understanding of the potential consequences of microplastics across all levels of biological organisation. It is vital to have a better understanding of the harmful features that microplastics possess, both physically and chemically, at the cellular and organism levels in order to improve the information that is used for risk assessments. This, in conjunction with an additional study on how the presence of environmentally relevant microplastics and pollutants impacts complex activities such as motility, reproduction, prey selection, and eating behaviour, is essential to understanding the impact and risk to populations as well as the ecosystem. According to the findings of our review research, the form, size, and colour of microplastics might have a negative effect on the eating behaviour, reproduction, growth, development, and lifespan of zooplanktons. The fact that feeding rate, swimming speed, and reproduction are all altered at concentrations of MPs that are both environmentally relevant and unreasonably high in the laboratory suggests that these endpoints are sensitive and possibly have the ability to operate as a bioindicator to detect MPs levels in habitats. Daphnids survival rate, feeding rate, and fecundity were all dramatically reduced. It has been stated in a number of articles that when copepods were exposed to MPs, they experienced a reduction in both their feeding rate and their fertility. This may have a detrimental effect on copepod populations in the long term. The larvae of molluscs and barnacles, brine shrimp, and euphausids appear to be somewhat tolerant to MPs, which suggests that these species would be more dominant when confronted with extended MPs pollution. This is in contrast to daphnids and copepods, which appear to be very sensitive to MPs.

Future Research Prospects:

This review aimed to determine whether or not the most recent data was published to support the idea that microplastics (MPs), and bioaccumulate and biomagnify over a general marine food web, which is a notion that is frequently inferred in the literature on estuarine aquatic MPs contamination. There is a lack of data regarding microplastics' origin, distribution, and how they make their way into water. It is essential to do in-depth research on the aquatic biota since zooplankton are also at risk of exposure to potential toxins, and this risk can be passed on to higher trophic levels, reducing the overall level of food safety. Implementing circular economy principles can offer sustainable solutions to minimize plastic pollution, protecting the delicate balance of marine environments and supporting the resilience of zooplankton communities (Saha, 2023; Mukherjee et al., 2022; Rosenboom et al., 2022).

Conclusion:

This review focuses on the presence of MPs in zooplankton biota and the seasonal variation of those MPs in coastal estuaries. The majority of the researchers discovered that zooplankton population dynamics exhibited irregular fluctuation patterns. These patterns were attributed to the physical and chemical qualities of the body of water. There are a significant number of canals used for waste disposal in coastal estuarine regions. As a result, when a pollutant alters a significant portion of the water body, only a few zooplankton species become extremely dominant, and these plankton serve as an indicator of the specific water body. There is some evidence that zooplankton, an important component of the pelagic food web, might be used to transfer MPs to trophic levels higher up. This is yet another troubling finding from the review.

Conflict of interest:

The authors state that they do not have any competing interests.

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Chapter- 20

Sustainable Management Practices for Fish Waste in Madanpur and Simurali Fish Markets

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Keywords: Sustainable management, Fish waste, Waste management, Fisheries sustainability, Circular economy.

Abstract:

Fish is a vital source of protein in India, and the Indian fishing industry plays a pivotal role in the nation's economy. India ranks as the world's second-largest fish producer, yielding approximately 4.3 million metric tons of fish annually. To meet this high demand, fish production continues to rise, resulting in a significant amount of fish waste. In India, nearly 2 million metric tons of fish waste are generated annually, with West Bengal contributing a substantial 1,770.310 tons in 2019. Our research concentrates on the Madanpur and Simurali fish markets in the Nadia district. These markets generate substantial quantities of fish waste, often mismanaged due to the lack of awareness among fishermen. Various forms of waste, including fish scales, swim bladders, and fins, are prevalent. Our survey report underscores the need for proper management of these waste materials to ensure sustainable growth and mitigate the environmental pollution resulting from fish waste. Fish scales, in particular, serve as a valuable source of chitin and collagen, finding applications in cosmetics, pharmaceuticals, and the food industry. Additionally, fish waste can be processed into fish food, offering a balanced diet for Thai Magur and ornamental fishes. In today's context, it is imperative to educate stakeholders about fish waste management and raise awareness about the adverse environmental impact of neglecting this critical issue. By addressing these challenges, we can harness the full potential of the Indian fishing industry while promoting environmental sustainability.

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Introduction:

In recent times, there has been a drastic increase in the utilization of natural resources. From 1970 to 2017, the consumption of natural resources surged from 92.1 billion to 127 billion, reflecting a remarkable 254% hike (Guterres et al., 2019). Fishery, being an age-old activity, has significantly shaped human society (Ormanci et al., 2019; Sanyal et al., 2023). The Indian fishery industry alone generates approximately 2 million metric tons of fish waste, encompassing swim bladders, fish debris, scales, fins, and bones. India stands out as a major fish-producing hub, exporting around 11.5 lakh fish in 2015-2016, with the potential to yield 5.5 lakh tons of waste (Ahmad, 2019). Fish waste is characterized by a high organic content, making its management a costly affair. Effluents rich in fish waste can lead to eutrophication (Amirkolaie et al., 2011; Saha et al., 2017; Mondal et al., 2022). However, these fishery wastes harbor the potential to be transformed into eco-friendly products through certain processes, thereby offering a sustainable solution (Eseroghene & Ikechukwu, 2018). This book chapter aims to shed light on the production of fish wastes in Madanpur and Simurali fish markets situated in the Nadia district, exploring their plausible economically and environmentally sustainable applications.

Survey on fish waste in Madanpur and Simurali fish market:

India holds the position of being the second-largest fish-producing country, with an impressive capability to yield approximately 4.3 million metric tons of fish (Mukherjee et al., 2022a). Madanpur and Simurali serve as prominent fishing hubs in the Kalyani and Chakdaha regions, respectively. The fish market in Madanpur enjoys local popularity and is often bustling with activity. Typically, 12 fishermen occupy the main market area, while an additional 7-8 are situated along the roadside near the entry point. In comparison, the Simurali fish market, although less locally renowned than Madanpur, boasts greater diversity due to its involvement in fish import and export activities. Apart from being one of the significant markets in Nadia for international trade, Simurali also hosts a local fish market catering to the needs of the community. The Simurali local fish market is characterized by more confined space, yet it remains highly congested, accommodating around 30-32 fishermen.

The rate of waste production is generally lower, primarily due to a lack of awareness among the populace. A considerable number of people remain uninformed about the potential by-products of fish waste (Mukherjee et al., 2022b). Post-fish sales, many individuals are unsure about how to effectively utilize fish waste, such as rubbish and scales. Consequently, there is a general lack of interest in managing these waste products. It is during this period that fish waste collectors become pivotal figures in the process. They willingly collect the waste at no cost to the sellers and, in turn, generate a significant income from it. Those who are slightly more informed about the value of fish waste compensation receive a monthly sum ranging from 200 to 250 rupees. However, a substantial portion of fish sellers, unaware of the potential economic benefits, perceive the waste collector's role as merely ensuring the cleanliness of the area, deeming it sufficient. This survey was conducted during the months of June and July 2022.

Figure 1. Simurali fish market.

Figure 2. Madanpur fish market.

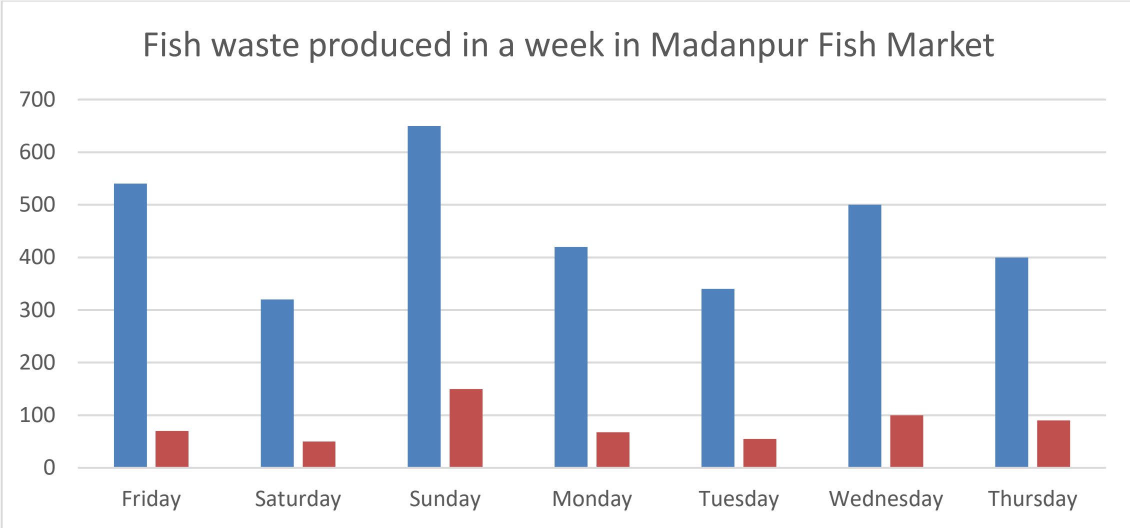

Figure 3. The fish waste production chart in which the blue line denotes the total amount of fish present in the fish market denoted as kg and the orange line signifies the production of fish waste.

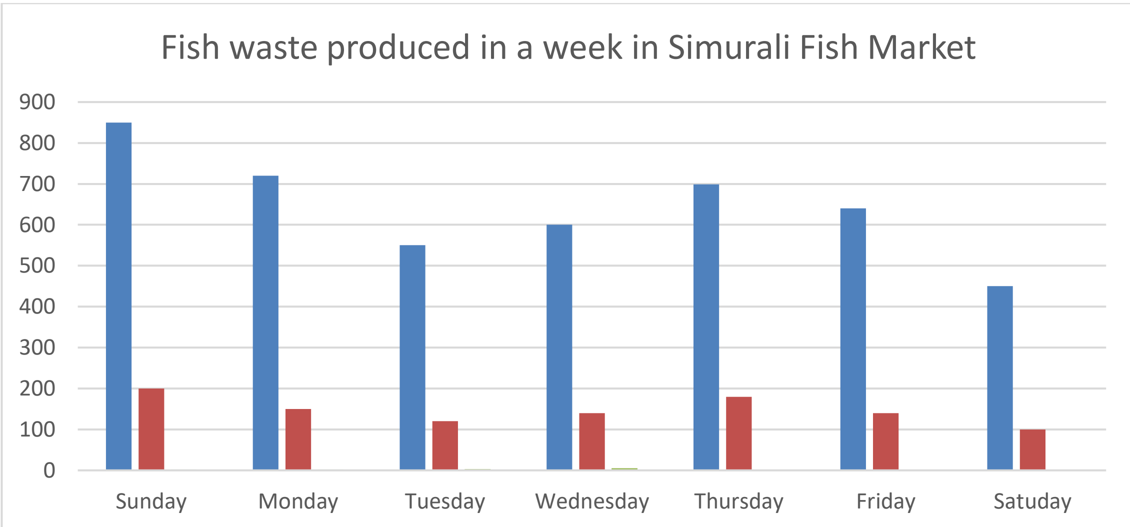

Figure 4. The fish waste production chart in which blue line denotes the total amount of fish present in fish market is denoted as kg and the orange line signifies the production of fish waste.

Appropriate uses of fish rubbish for sustainable growth and economical approach:

After conducting a survey between Madanpur and Simurali fish markets, we identified mainly three types of fish waste products, such as scales, digestive organs of fish, and swim bladders.

Fish scale:

Fish scales, a key component of fish refuse, are also a major source of pollution (Rahman et al., 2018). Despite their environmental impact, there is a high market demand for fish scales, leading to a systematic chain from collection to manufacturing. This business primarily focuses on the scales of Indian major carps such as *Labeo* and *Cirrhinus*. The process begins with scale collectors gathering scales from fish markets, cleaning them, and sun-drying the scales before supplying them to middlemen or retailers. The middlemen then purchase the scales at rates ranging from 60-70 rupees/kg to 80-100 rupees/kg, depending on seasonal demand. The scales are subsequently sold directly to companies, which may choose to export them, sell them to other companies, or use them in manufacturing various products. Additionally, fish scales are openly sold online, expanding their market reach. Leveraging biotechnological processes, fish scales can be transformed into a valuable resource, simultaneously reducing their environmental toxicity (Coello, 1996).

Figure 5. Fish rubbish produced in Madanpur and Simurali fish market.

The biotechnological industry plays a crucial role in this transformation, extracting collagen and chitin from processed fish scales. Collagen, a structural protein found in fish scales, finds application in the pharmaceutical industry. Gelatin, a fibrous protein derived from collagen, is used in the pharmaceuticals, food, and photography industries (Jamilah, 2002; Liu et al., 2008). Chitin, another significant component of fish scales, is produced through deproteinization and deamination processes. Chitin has diverse applications in medicine, food preservation, and as food additive (Takarina, 2017). This innovative circular economy approaches not only adds value to fish scales but also contributes to sustainable practices in the fishing industry (Saha, 2023).

Figure 6. Collected fish scales dried by middle woman.

Figure 7. Fish rubbish grinding machine for preparing fish feed.

Fish swim bladder:

Processed swim bladder stands out as one of the most valuable fish by-products in South-East Asian countries. Isinglass, an extract from fish swim bladders, is a gelatinous substance highly prized for its applications in the cosmetic, beer, and wine industries. Locally referred to as fish maw, the dried swim bladder holds significant economic importance (Akhilesh, 2022). In Kolkata, West Bengal, prominent traders like JB Group and Basu International export high-quality dry fish maw to Hong Kong and China at competitive market prices. Various types of fish maws, including those from dried Bhetki, dara, eel, yellow Croaker, among others, are sought after in the international market.

Typically, fish maws undergo a sun-drying process before being either packed for export or stored in a dark place. Some traders opt to use chemicals for preservation, ensuring an extended shelf life, while others prioritize maintaining a 100% natural product by avoiding preservatives. This strategic approach to processing fish maws not only caters to the diverse demands of international markets but also highlights the versatility and significance of fish by-products in the global trade landscape.

Conclusion and awareness:

Awareness plays a pivotal role in effective waste management, especially within the fishing industry. A significant number of fish sellers and fishermen lack knowledge about the recycling processes and potential by-products of fish waste. This lack of awareness can result in severe issues such as water and soil pollution. During our survey, instances of rotten fish were encountered, and due to insufficient knowledge, fish sellers were either giving them away for free or disposing of them improperly. The inappropriate handling of fish waste not only results in economic losses but also contributes to environmental pollution. To address this challenge and promote sustainable development and economic growth, it is imperative to instigate proper awareness and education programs. Workshops and awareness programs for fish sellers can be organized to enlighten them about the extraction, management, processing, and potential uses of fish waste. By enhancing the knowledge of those involved in the fishing industry, we can ensure the proper utilization of fish rubbish, minimizing economic losses and mitigating environmental pollution for the long-term benefit of communities and ecosystems.

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Chapter- 21

Insights into the Adverse Effects of Bisphenol A on the Environment and Human Health

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Keywords: Plastics, non-biodegradable, Bisphenol A, Cancer.

Abstract:

Plastic, an integral part of our daily lives, is present in various items such as carry bags, packaging materials, and medical supplies like syringes. Despite contributing to scientific advancements, the non-biodegradable nature of certain plastic polymers poses environmental concerns. Bisphenol A (BPA), widely used in plastic manufacturing, has been banned due to its harmful impact on both the environment and human health. Its replacement, bisphenol F (BPF), is now employed. This study investigates the toxicity of BPA, BPF, and their combination on primary producers, specifically eukaryotic green algae. The escalating global plastic consumption, compounded by the persistent presence of BPA in aquatic environments, necessitates attention to prevent plastic pollution from affecting future generations. Plastic and nanoplastic materials are pervasive in soil and the environment, posing health risks to humans through air, water, and soil pathways. Plastic particles enter the food chain via small fish in lakes and seas. Crucially, interactions between BPA and natural substances or environmental stressors can yield both positive and negative effects, as evidenced by in vitro and in vivo studies. It is imperative to consider these interactions when assessing BPA exposures and their health implications, as they significantly influence endpoint measurements and cellular responses. This article emphasizes the adverse effects of plastic pollution on the environment and human health, while also exploring emerging remedies to mitigate BPA's impact.

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Introduction:

Industrial chemicals, including epoxy resin, polycarbonate plastics, and various polymer compounds, are frequently synthesized using bisphenol A (BPA) (Ma et al., 2019). BPA is ubiquitous in the environment due to its large-scale production and diverse applications (Abraham & Chakraborty, 2020). Research has extensively investigated BPA incidences, human exposure, and toxicity (Rochester, 2013). To comply with stringent regulations governing BPA use, numerous bisphenol analogues, such as bisphenol S (BPS), bisphenol F (BPF), and bisphenol AF (BPAF), are being developed as substitutes (Chen et al., 2016). This review consolidates current knowledge on the presence of bisphenol analogues (excluding BPA) in consumer goods, food, human exposure, biomonitoring, and the environment (Sonavane & Gassman, 2019; Rochester & Bolden, 2015). Recent attention has focused on BPA and its substitutes, such as BPS, BPF, and BPAF, due to their widespread use and presence in the environment, raising concerns about human health (García-Recio et al., 2022; Khan et al., 2023; Valentino et al., 2016). Research indicates that BPS, like BPA, functions as an endocrine-disrupting chemical (EDC) (Catenza et al., 2021; Minatoya & Kishi, 2021). Epoxy resins containing BPA are prevalent in consumer products like food containers, dental sealants, PVC pipe coatings, baby bottles, and canned goods. BPA, as an environmental contaminant, can potentially leach into food and water, warranting investigation (Di Donato et al., 2017; Huo et al., 2015). Despite the abundance of BPA research, limited information exists about BPS (Wu et al., 2018). This study examines literature on BPS, primarily published between 2010 and 2023, alongside information on human exposure, toxicities, and environmental dispersion (Abdulhameed et al., 2022). The findings reveal the widespread distribution of BPS in the environment, albeit often at lower concentrations than BPA in various media, such as water, sewage waste, household dust, air, consumer goods, and human urine (Guo et al., 2023). Various entry points, including digestive, respiratory, and cutaneous tracts, expose individuals to BPA. Endocrine disruptors like BPA adversely affect tissues and organs, including the immune, reproductive, and neuroendocrine systems, acting as estrogen substitutes and anti-androgens (Longnecker, 2009). This review aims to gather recent research on BPA, providing a comprehensive overview of its exposure status and associated health impacts on the liver, kidneys, reproductive system, metabolism, immunological system, and neurobehavioral development (Liu et al., 2021).

Physical and Chemical Properties of BPA:

Bisphenol A (BPA) is an organosynthetic molecule with the molecular formula $(CH_3)_2C(C_6H_4OH)_2$, having a molecular weight of 228 Da. The scientific designation for Bisphenol A is 4,4'-dihydroxy-2,2-diphenylpropane, with CAS number 80-05-7, in accordance with the International Union of Pure and Applied Chemistry (IUPAC) (Figure 1). With two hydroxyphenyl groups, Bisphenol A (BPA) belongs to the class of bisphenols and diphenylmethane derivatives. The two methyl groups replace the methyl hydrogen in the carbon tetrahedral bond (Li et al., 2015). First synthesized by Russian chemist Aleksandr P. Dianin in 1891 through the combination of phenol and acetone with an acid catalyst, BPA gained prominence in the 1950s for its reaction with phosgene, yielding polycarbonate—a transparent, rigid resin widely used in thermal paper, dental compounds, safety and medical equipment, and food and drink packaging (Eladak et al., 2015). While less soluble in water, BPA exhibits greater solubility in acetic acid, diethyl ether, and ethanol. Despite its short half-life of less than a day in the air, BPA persists for around 4.5 days in water and soil. Although not meeting the criteria for classification as a persistent organic pollutant (POP) due to its brief half-life, BPA is frequently listed in POP categories due to its accumulation in human tissues and organs and its involvement in various disorders (Delfosse et al., 2012).

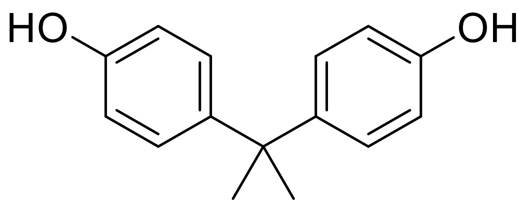

Figure 1. Structure of Bisphenol A (BPA).

BPA manufacturing:

BPA is a significant industrial chemical primarily employed as a raw ingredient for epoxy resin and polycarbonate, which, being clear and durable, is extensively used in everyday consumer products. BPA-containing epoxy resins play a crucial role in the production of thermal paper used in sales receipts, as well as in lining water pipes and the interiors of many food and beverage cans (Konieczna et al., 2015). The conventional commercial-scale production of BPA typically involves the use of a potent mineral acid catalyst, such as hydrochloric acid. Due to the highly corrosive nature of hydrochloric acid, industries must employ corrosion-resistant materials. Consequently, cation exchange resin has emerged as an alternative catalyst currently in use, effectively reducing corrosion in equipment. The reaction occurs in a fixed-bed column reactor filled with cation exchange resin, where two moles of phenol and one mole of acetone undergo the reaction process (Konieczna et al., 2015).

Moreover, a sophisticated wastewater treatment facility is necessary for the mineral acid-catalyzed process. The wastewater produced in this process requires treatment involving calcium precipitation, lime neutralization, and subsequent biotreatment due to the presence of hydrochloric acid. Certain components containing thiol groups can enhance both the yield and rate of BPA production. As the reaction advances, the proton from the acidic catalyst electrophilically attacks the acetone molecule. During this stage, the acetone-acetone reaction, also referred to as dimerization, may generate undesired by-products, potentially altering the reaction mechanism. Consequently, the formation of Mesityl oxide leads to an increase in impurities, triggering additional phenolic reactions and complicating the process (Figure 2). It is therefore expected that phenolic impacts will exert further effects on human health (Ćwiek-Ludwicka et al., 2015).

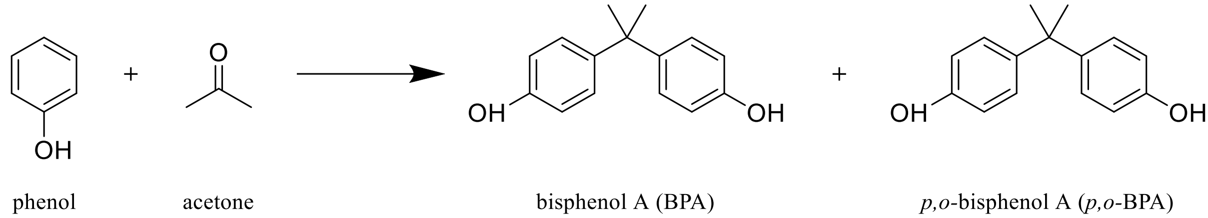

Figure 2. Chemical reaction for preparation of Bisphenol A (Adapted from Ćwiek-Ludwicka et al., 2015).

Bioconcentration and Bio-accumulation:

Persistent organic pollutants (POPs), which are organic substances resistant to degradation and prone to bioaccumulation in the environment, exert adverse effects on human health. Despite their harmful nature, POPs are still employed in the production of pesticides, medications, and fertilizers, leading to soil, water, and air contamination. Elevated levels of POPs have been identified in human and animal tissues and blood. Among these pollutants, Bisphenol A (BPA) stands out. BPA can be released into the environment either directly or indirectly throughout the various stages of a product's life cycle, including manufacturing, usage, and disposal (Cimmino et al., 2020). The entry of BPA into the human body occurs through ingestion, inhalation, and integumentary contact (skin and eye), highlighting multiple pathways of exposure.

BPA, existing in powder or crystal form, can be released into foods and beverages from plastic items, particularly under acidic or basic conditions. The accelerated entry of BPA into the human body occurs at elevated temperatures, such as when heating stored food in plastic packages and baby bottles. Additionally, high concentrations of vegetable oils and interaction with basic or acidic substances promote BPA release from polymeric materials (Vandenberg et al., 2007). BPA, with the ability to traverse the placental barrier, has been detected in fetal and maternal serum, as well as in placenta (Ziv-Gal et al., 2016). The substance can permeate the fluids and tissues of the human womb and can be ingested through touch or inhalation. Thermal paper, as in receipts, releases BPA upon skin contact, leading to elevated plasma and urine BPA levels in individuals with frequent thermal paper exposure, such as cashiers (Hormann et al., 2014). Other sources of exposure include the burning of household garbage, releases from municipal wastewater treatment facilities, and the degradation of plastic products. Recent studies on metabolism and toxic kinetics reveal that BPA is rapidly absorbed through the mouth and subsequently conjugated with glucuronic acid in the liver (Andra et al., 2016). Accumulating in various animal and human tissues, BPA disrupts physiological processes, raising concerns about its bioaccumulation in the modern world (Valentino et al., 2016).

Types of plastics and their application:

In contrast to the tens of atomic mass units commonly present in other chemical compounds, the size of these molecules is exceptional, ranging in the hundreds or even millions of atomic mass units, as detailed in the chemistry of industrial polymers. The primary factors contributing to the unique qualities associated with plastics, such as their capacity to be molded and shaped, are the size of the molecules, their physical state, and the structures they assume (Rhodes, 2018). There are primarily six types of plastics (Figure 3).

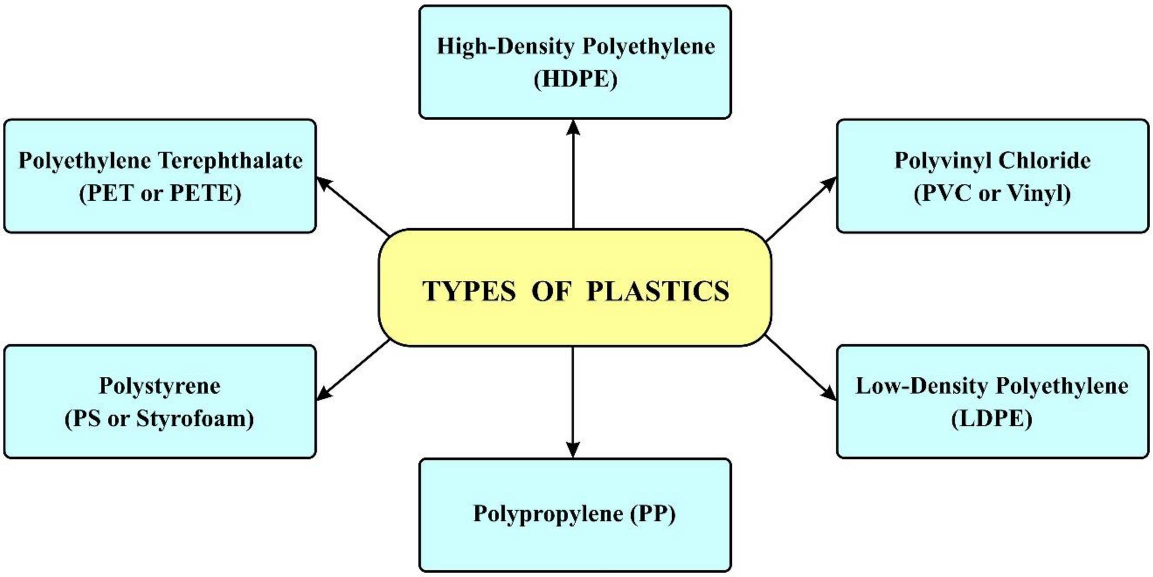

Figure 3. Shown above 6 different types of plastics these include: Polyethylene Terephthalate, Polypropylene, Polystyrene (PS) or polystyrene, high-density polyethylene, Vinyl or Polyvinyl Chloride (PVC).

Polyethylene Terephthalate (PET or PETE), one of the most commonly used plastics, is utilized in various applications. It is employed in food packaging and textiles, particularly in the production of polyester. PET is known for its robustness, lightweight nature, and general transparency. Examples of its use include beverage bottles, food containers (such as salad dressing, peanut butter, honey, etc.), and polyester clothes or rope (Ganesan et al., 2022).

Polypropylene (PP), known for its strength and durability, surpasses other plastic varieties in heat resistance, making it ideal for food packing and storage containers designed for heat applications. Highly flexible, it maintains its strength and shape over an extended period. Examples include straws, bottle caps, prescription bottles, containers for hot meals, packing tape, disposable diapers, and DVD/CD boxes (Hubai et al., 2022).

Polystyrene (PS), commonly known as Styrofoam, is an inexpensive and efficient insulating material extensively utilized in the construction, food, and packaging industries. Similar to PVC, polystyrene is considered a hazardous substance capable of releasing toxic pollutants such as the neurotoxic styrene. These pollutants can be readily absorbed by food items and, subsequently, consumed by individuals. Applications of polystyrene include cups, takeaway containers, product packaging for transportation and delivery, egg cartons, cutlery, and building insulation (Edwards et al., 2022).

High-density polyethylene (HDPE), one of the three main forms of polyethylene alongside low-density and linear low-density, constitutes a significant portion of global plastic usage. Its robustness and resistance to moisture and chemicals make it ideal for applications such as pipelines, cartons, and other construction materials. Examples encompass rigid pipes, toys, buckets, park chairs, detergent bottles, cereal box liners, and milk cartons (Schwarz et al., 2019).

Vinyl, or Polyvinyl Chloride (PVC), is a robust and rigid plastic widely utilized in building and construction due to its resistance to chemicals and elements. It finds applications in high-tech fields such as cables, benefiting from its non-conductive nature (Deng et al., 2022). Its immunity to germs, ease of cleaning, and suitability for single-use applications make it prevalent in medical settings to prevent infections (Deng et al., 2022). However, it is crucial to acknowledge that PVC, throughout its lifecycle, releases harmful pollutants such as lead, dioxins, and vinyl chloride, rendering it the most threatening plastic to human health (Thakur et al., 2023). Various everyday items, including credit cards, oxygen masks, rain gutters, toys for both humans and animals, plumbing pipes, teething rings, and IV fluid bags, fall under this category (Roosen et al., 2022).

LDPE, or low-density polyethylene, is an HDPE variant that is softer, clearer, and more malleable. It is often utilized in corrosion-resistant work surfaces, among other items, and beverage carton liners. Examples include drinking cups, bubble wrap, sandwich and bread bags, plastic wrap, waste bags, and cling wrap (Mortula et al., 2021).

Plastics that do not fall into any of the other six categories or are combinations of various types are collectively classified in this category. We incorporate them because comprehending the significance of the #7 recycling code, encountered occasionally, is essential. The critical aspect in this context is the frequent non-recyclability of these polymers. Illustrative items encompass translucent plastic flatware, infant and sports bottles, gadgets, CDs, DVDs, and lighting fixtures (Endres, 2019).

Plastic waste disposal and its management:

Plastic trash, commonly referred to as plastic pollution, is defined as "the accumulation of microplastic particles (e.g., plastic bottles, grocery bags, food wrappers, and others) in the natural ecosystem, negatively impacting animals, wildlife habitat, and humans." This term also encompasses the substantial amount of plastic that remains unrecycled, often ending up in landfills or, in developing countries, deposited in unregulated disposal sites (Hoang, 2022). Halting the influx of plastic waste into the ecosystem necessitates systemic reform. Globally, less than 10% of the seven billion tons of plastic waste generated has been recycled (Samal et al., 2017; Ayeleru et al., 2020; Mondal et al., 2022). Enormous quantities of plastic waste are released into the environment or transported over long distances for disposal or incineration.

The most prevalent type of plastic debris in the environment is cigarette butts, which contain small plastic fibers in their filters (Akan et al., 2021).

To manage plastic waste globally, various techniques have been attempted to decompose or convert it into more manageable forms. Incineration, involving the ignition of plastic waste, produces harmful fumes. Recycling, illustrated in Figure 4, transforms plastic waste into valuable forms; however, this process incurs energy loss, leaving the plastic essentially unchanged. Landfilling, another disposal method, fails to achieve anticipated plastic degradation due to a lack of oxygen for bacterial breakdown. Constructing infrastructure by combining plastic with bitumen and producing gasoline from plastic emerge as potentially superior approaches to plastic waste management. Among these technologies, biodegradation, as cited by Sarkar et al. (2022), is considered the most environmentally benign and cost-effective method of plastic deterioration.

The majority of plastic water bottles, which can take thousands of years to disintegrate, are discarded, contributing to the pervasive issue of "plastic fog" in the world's oceans. This phenomenon encompasses 171 trillion microplastics, potentially weighing almost 2.3 metric tonnes if retrieved. Degradation of plastic bottles in the atmosphere results in the formation of microplastics, infiltrating our food and water and posing a significant health risk. Additionally, plastic releases toxic compounds, adversely affecting animals and disrupting both human and animal food chains. Widespread disposal habits, such as drinking half a bottle and discarding it, contribute to the ubiquitous presence of plastic bottles in cities. Packaged in plastic for accessibility and hygiene, these bottles are consumed at a staggering rate, with an individual using 4-6 plastic water bottles daily, totaling significant environmental impact. Recognizing that plastic is derived from petroleum, the production of a billion plastic bottles requires 24 million gallons of oil, and plastic takes nearly 700 years to decompose. Despite these environmental concerns, 80% of plastic bottles are not recycled, emphasizing the urgent need for sustainable practices. Recycling one ton of plastic saves 5.74 cubic meters of landfill space and reduces recycling and disposal costs. The entire life cycle of plastic bottles, from production to disposal, contributes substantially to pollution, encompassing litter, environmental degradation, and carbon emissions. A recommended alternative is filtered water from an under-sink reverse osmosis system (Jung et al., 2022). Implementing circular principles in manufacturing and waste management can minimize the release of harmful substances, promote sustainable practices, and contribute to the overall well-being of ecosystems and human populations (Saha, 2023).

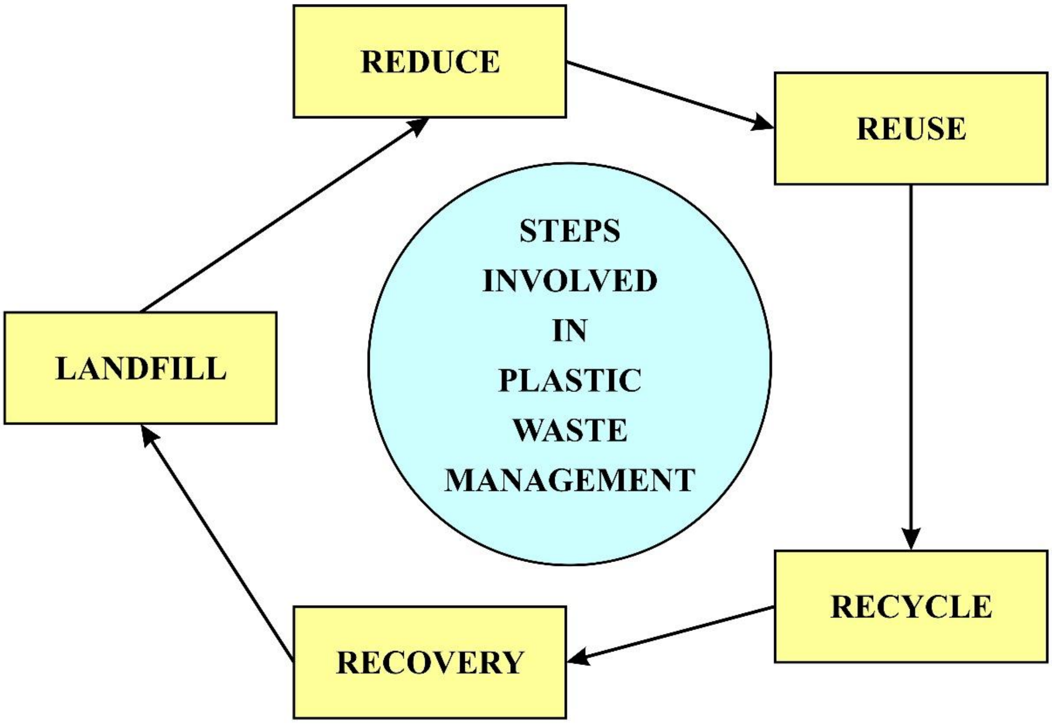

Figure 4. Processes that are involved in plastic waste management.

Biodegradation:

Biodegradation by Fungi:

Fungi, as natural decomposers, exhibit a remarkable ability to break down diverse organic compounds, including Bisphenol A (BPA). Research demonstrates that specific fungal species can efficiently biodegrade BPA under suitable conditions, providing a natural and eco-friendly alternative to chemical-intensive methods. White-rot fungi, known for their broad pollutant-degrading capacity, show promise in addressing the adverse effects of BPA on human health and the environment. Noteworthy studies highlight the effectiveness of white-rot fungi species, such as *Stereum hirsutum* and *Heterobasidium* spp., in degrading BPA, with significant resistance observed at a concentration of 100 ppm. Degradation to approximately 99% occurred within 7 to 14 days. Another investigation focused on the treatment of BPA using manganese peroxidase (MnP) and laccase from lignin-degrading fungi, revealing MnP's rapid elimination of BPA within an hour. Laccase, when combined with HBT, eradicated estrogenic activities within 6 hours. The sustained absence of estrogenic activities after 48 hours demonstrated the efficacy of ligninolytic enzymes in mitigating BPA's adverse effects (Lee et al., 2005).

Utilizing white-rot fungi for BPA biodegradation offers advantages over alternative methods, presenting a natural and sustainable approach applicable directly to contaminated environments. However, challenges, including environmental factors like pH and temperature, as well as the presence of other contaminants, must be considered. Despite potential impediments such as cultivation cost and time, white-rot fungi employ enzymes like lignin peroxidase (LiP), MnP, and laccase to transform BPA into simpler, less harmful compounds. LiP oxidizes and cleaves BPA's aromatic rings, forming intermediates like benzoquinones, while MnP oxidizes BPA to BPA-quinones. Laccase also plays a role in this transformation process (Tsutsumi et al., 2001). Previous research has demonstrated that *Trametes hirsuta*, through intracellular and extracellular enzymes such as laccase and cytochrome P-450 monooxygenase, can convert BPA into various metabolites. This enzymatic process involves polymerization, hydroxylation, dehydration, and bond cleavage, producing intermediate products that are either harmless or less hazardous, suggesting the potential for bioremediation (Li et al., 2023).

Biodegradation by immobilized enzyme:

An effective strategy demonstrating potential involves utilizing immobilized enzymes for BPA degradation. These enzymes, affixed to solid substrates such as polymers or matrices, allow for repeated use, enhancing both stability and catalytic efficiency through techniques like covalent bonding, adsorption, encapsulation, and cross-linking. Covalent bonding, though providing robust immobilization suitable for highly stable applications, can be laborious and costly (Zdarta et al., 2018). Adsorption offers another method for enzyme immobilization, relying on weak electrostatic or hydrophobic interactions to bind enzymes to the support material; however, this approach may lead to unstable immobilization and reduced activity due to weak attachment (Dong et al., 2012). Encapsulation involves trapping enzymes within microspheres or capsules, providing a protective shield against external factors, potentially enhancing stability but possibly limiting substrate diffusion and causing decreased activity.In industrial and environmental biotechnology, recent research highlighted challenges associated with laccase enzyme stability and reusability. In comparison to its free form, laccase covalently bound onto SiO2 supports exhibited better stability and endurance, with relative activity above 80% after 30 successive reaction cycles. Complete BPA degradation was achieved within 5 hours of incubation, attributed to the immobilized laccase's enhanced efficiency, particularly in the presence of TX-100 (Zdarta et al., 2018).

These results underscore the viability of enzyme immobilization to enhance laccase's stability, reusability, and effectiveness across diverse applications (Chang et al., 2019). Another study illustrated the effectiveness of *Trametes versicolor* laccase immobilized on Ba-alginate beads in degrading bisphenol A (BPA) under optimal conditions: 40°C, 2 mg/L BPA concentration, and 50 minutes. Both Box-Behnken design (BBD) and artificial neural network (ANN) accurately predicted degradation efficiency, with BBD achieving 83.48% and ANN achieving 84.33%. Statistical analysis confirmed the reliability of both models (R2: 0.98 for BBD, 0.97 for ANN; MSE: 9.88 for BBD, 38.25 for ANN). Immobilized laccase displayed superior storage stability, retaining 68.64% and 44.62% of activity compared to free laccase (Abdul Latif et al., 2022).

Biodegradation by bacterial strains:

The investigation into bisphenol A (BPA) biodegradation involved isolating bacterial strains from deserts and arid soils in southern Tunisia. Ten bacterial strains, including *Pseudomonas putida*, *Pseudomonas aeruginosa*, *Enterobacter cloacae*, *Klebsiella* sp. and *Pantoea* sp., exhibited high BPA removal potential in mineral salt medium (MSM) containing 1 mM BPA, with removal rates ranging from 36% to 97%. Strain G320 (*P. putida*) demonstrated exceptional efficiency, achieving a 97% removal rate within a 4-day incubation period at 30^0C. With a concentration increase to three millimoles per liter, strain G320 exhibited a half-life of two days and complete degradation within eight days. GC–MS analysis verified BPA biodegradation compounds and an algal toxicity test evaluated their toxicity. The detoxification process was validated by analyzing the effects of BPA biodegradation metabolites on *Tetraselmis* sp. strain V2 algae in terms of dry weight, cellular structure, and chlorophyll levels, emphasizing the potential of desert soil bacteria for BPA detoxification and the utility of algal species in toxicity assessment (Fawcett et al., 2021).

Predicted environmental distribution of BPA:

The anticipated environmental distribution of Bisphenol A (BPA) revolves around various ecological compartments due to its widespread use and potential environmental persistence. BPA, a synthetic compound commonly found in plastics, epoxy resins, and other consumer products, can enter the environment through multiple pathways when disposed of or leaked. In aquatic environments, BPA can infiltrate water bodies through industrial effluents, urban runoff, or improper disposal of plastic waste, potentially contaminating and adversely affecting aquatic life forms such as fish, invertebrates, and algae. Studies have suggested bioaccumulation of BPA in aquatic organisms, potentially causing disruptions in endocrine systems and reproductive functions (Mora Lagares & Vračko, 2023). Furthermore, BPA can leach into soil from landfill sites, agricultural activities (e.g., through the use of plastic mulches), and the decomposition of plastic materials, influencing microbial communities and potentially impacting plant growth. Soil-water interactions may also allow BPA to enter groundwater, posing risks to drinking water sources. Airborne BPA particles may result from various sources, including industrial emissions, thermal degradation of plastics, or volatilization from products containing BPA, depositing onto soil and water bodies and contributing to the overall environmental load (Bandopadhyay et al., 2018). Understanding the predicted environmental distribution of BPA involves assessing its mobility and transformation in different ecosystems, considering factors such as temperature, pH, and the presence of other pollutants that can influence its fate and behavior in various environmental matrices. Moreover, the persistence of BPA in different compartments varies, with some studies suggesting potential degradation by microorganisms or environmental factors like sunlight (Dueñas-Moreno et al., 2022). Predicting the environmental fate of BPA involves complex modeling that considers its movement across various environmental compartments, potential transformation pathways, and interactions with biotic and abiotic factors. This predictive analysis helps in comprehending the potential risks associated with BPA exposure and in formulating strategies for its mitigation and management in natural ecosystems (Im & Löffler, 2016).

Toxicity of BPA:

Aquatic toxicity through BPA:

Not all nations have implemented regulations to limit the use of bisphenol A (BPA) in plastics that come into contact with food industry products because some people are still unaware of the risks that BPA can pose to the human endocrine system. The usage of bisphenol A in the manufacturing of plastics that come into contact with food is not currently subject to any legislation, necessitating thoughtful consideration. Notably, developed countries like Japan and significant developing nations such as India, Nigeria, Indonesia, Bangladesh, Pakistan, Egypt, and Mexico lack such rules. Forty nations have taken some action to limit the manufacturing of these plastics or, at the very least, the amount of BPA they contain, aiming to prevent BPA from entering the plastics (Thoene et al., 2018). Multiple studies conducted in India have demonstrated the presence of BPA in various water sources, indicating its potential danger to aquatic organisms. For instance, research carried out in rivers, lakes, and coastlines has revealed detectable levels of BPA contamination, focusing on diverse water bodies, including the Ganges River and its tributaries. Internationally, research from different countries has underscored the pervasive nature of BPA contamination in aquatic environments. Studies conducted in the United States, Canada, China, and European nations have consistently found BPA residues in water bodies, showcasing the global prevalence of this chemical and its threat to aquatic ecosystems. These studies often assess BPA levels, persistence, and resultant toxicity on various aquatic species, emphasizing widespread concerns about its impact on biodiversity and ecosystem health (Kumkar et al., 2023). Regarding the actual impact on aquatic life, studies have shown adverse effects on organisms due to BPA exposure. Fish, in particular, have been extensively studied, with research demonstrating disruptions in their reproductive systems, altered hormone levels, reduced fertility, and developmental abnormalities resulting from exposure to BPA-contaminated water. Moreover, BPA's ability to bioaccumulate in aquatic organisms raises concerns about its potential transfer through the food chain, posing risks to higher trophic levels, including organisms consumed by humans. Efforts to mitigate BPA's impact on aquatic environments have involved stricter regulations, improved wastewater treatment processes, and exploration of eco-friendly remediation methods (Canesi & Fabbri, 2015). Furthermore, research into alternative materials and chemicals to replace BPA in various industries aims to reduce its environmental footprint and mitigate its adverse effects on aquatic ecosystems. Understanding the global and local implications of BPA contamination in aquatic environments is crucial for implementing effective policies, conducting further research, and adopting sustainable practices to safeguard the health of aquatic ecosystems and the species reliant upon them (Abu Hasan et al., 2023).

Toxicity of BPA on human:

An essential industrial chemical, bisphenol A (BPA), extensively utilized in polycarbonate and other polymer manufacturing, has raised global concerns due to its estrogenic properties, acting as an endocrine disruptor upon entering biological systems. Linked to human cancer (Ni et al., 2022) and potential harm to brain tissues, thyroid glands, and reproductive systems, BPA prompts a critical examination of its impacts. This review delves into the emerging field of BPA biodegradation in natural environments, shedding light on recent studies extracting BPA-degrading microbes from diverse sources, including water bodies receiving industrial waste and landfills (Karabulut & Gulay, 2022). Amidst the BPA controversy, bridging the knowledge gap between research assessing BPA's harm and studies utilizing naturally occurring microorganisms for effective BPA elimination becomes paramount. Closing this gap is instrumental in devising strategies to employ BPA in plastics production without environmental accumulation (Babu et al., 2013).

Effects on human endocrine system:

In humans, one of the most intricate and coordinated systems is the endocrine system. BPA, a detrimental endocrine-disrupting chemical (EDC), inhibits or modifies the production, secretion, discharge, and transportation of various hormones and enzymes, impairing the system's efficacy by substituting transportation proteins along with indigenous hormones (Oriakpono & Nduonofit, 2021). This modification alters the quantities of associated as well as free hormones in plasma. Furthermore, BPA disrupts the physiological processes of organs by affecting the function of neuroendocrine cells. Research has indicated that bisphenol A (BPA) can lead to increased blood levels of estradiol in females and decreased testosterone in males, impacting mental health and causing sex-specific behavioral abnormalities and mental disability (Greca et al., 2019). In males, the neuroactive hormone Dehydroepiandrosterone (DHEA) is lowered, potentially contributing to the depressive-like phenotype and the emergence of unsettled and depressed inclinations. A compilation of earlier research on the endocrine disruption caused by BPA is used to evaluate its powerful consequences (Rybczyńska-Tkaczyk et al., 2023).

Effects on human reproductive system:

Several theories propose various ways in which BPA harms the reproductive system, drawing evidence from both in vitro and in vivo investigations (Meli et al., 2020). Specifically, BPA is widely believed to possess estrogenic and antiandrogenic properties that can interfere with the hypothalamic-pituitary-gonadal axis and modify usual epigenetic motifs, potentially causing adverse effects on the reproductive system. BPA's activity can impact the mechanisms of gonadotropin-releasing hormone (GnRH) discharge, gonadotropin release, and signaling stimuli for the development of spermatogonia cells in the Sertoli cell line. Changes in gonadotropin levels, particularly a decrease in the serum concentration of LH, lead to Leydig cells producing less testosterone (Gerona et al., 2013). Typically, testosterone is converted into DHT, responsible for spermatogenesis, spermatozoa transportation, and retention before ejaculation via the male reproductive tract. Moreover, Sertoli's cells continue to operate when testosterone is transformed by aromatase to estradiol. As demonstrated in young rats exposed to high estrogen doses, low testosterone levels and altered estradiol catabolism result in elevated estradiol levels, impairing sperm production (Divakaran et al., 2014).

Leydig cells are believed to express estrogen receptors (ERα), while Sertoli cells, pachytene spermatocytes, and circular spermatids in the mature rat and male testis possess ERβ receptors. Molecular research indicates that Bisphenol A (BPA) acts as a specific ER modulator, functioning as either an agonist or antagonist of estrogen hormones depending on the tissue (Xing et al. 2022). In vitro studies demonstrate that BPA's interaction with estrogen receptors alters their ability to recruit tissue-specific co-activators, crucial for eliciting tissue-dependent responses (Desai et al. 2022). Additionally, BPA has been shown to exhibit an affinity for the membrane-associated G protein-coupled estrogen receptor (GPER), akin to estradiol's primary affinity. This chemical interaction with the GPER receptor, expressed in the pituitary and hypothalamus, can induce rapid, non-genomic effects (Desai & Jagtap, 2022).

Instead, recent research has revealed that BPA functions as an antagonist of the androgen receptor, blocking the control of androgen-dependent transcription by endogenous androgens and suppressing the growth of Sertoli cells. These processes are performed by inhibiting the amino- and carboxyl-terminal sections (AR N/C) of AR and strengthening its interactions with nuclear receptor co-repressor (NCoR) and whispering mediator for the thyroid hormone receptors (SMRT) (Michałowicz et al., 2014).

Other harmful effects:

There is a notable increase in the prevalence of many cancer types, which appears to be associated with BPA, including testicular, ovarian, uterine, prostatic, and breast cancer. According to the findings of several in vivo investigations, the elevated estrogenic function demonstrates the carcinogenic mechanism resulting from the action of BPA. Ongoing studies focus on the triggering of carcinogenesis and the formation of malignant cells by BPA. Despite their low affinity for each other, BPA adheres to ER and triggers cellular reactions. The receptor loses the capacity to bind and retain co-repressors. The type and expression levels of ER-regulated targets determine the tissue and cellular specificity of the BPA response because the BPA–ER complex regulates co-regulators in a manner inconsistent with BPA's affinity for ER. BPA can induce genomic reactions at concentrations below those where it is anticipated to attach to nuclear ERs (Freire et al., 2019).

Research studies have demonstrated a direct correlation between BPA exposure and oxidative damage, immunological response, and inflammation. The relationship between BPA and the activation of apoptosis in the cell, along with the destruction of mitochondria, led to a methodical breakdown, altering the numbers of immune cells and the functioning of both adaptive and innate immune systems due to prenatal exposure to BPA. This exposure also elevated pro- and anti-inflammatory cytokines as well as chemokines while decreasing T regulatory (Treg) cells. Exposure to BPA may induce an increase and deterioration in the development of both male and female T1D (Mortensen et al., 2014).

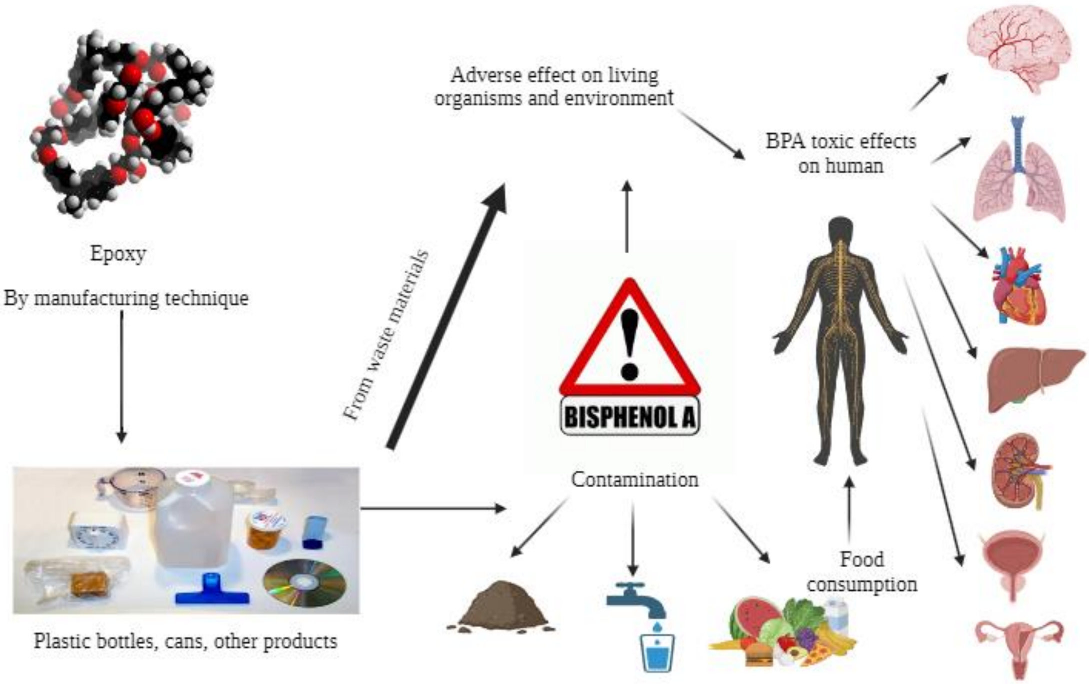

Figure 5. Illustration depicting the intricate interplay of Bisphenol A on the environment and human health, revealing nuanced insights.

BPA biomonitoring and guidelines:

According to biomonitoring research, 93% of analyzed urine samples had detectable amounts of BPA, indicating common exposure in the US. The rapid metabolism of BPA in the body suggests frequent exposures among Americans, as evidenced by its elevated detection rate. Younger children and individuals under six have higher BPA exposures than older adults and children (VomSaal et al., 2014). Epidemiological information worldwide on BPA's impact is lacking. In studies on the US general population, those with recent BPA exposure (measured by urinary BPA levels) are more likely to develop hepatic enzyme anomalies, cardiovascular disease, type 2 diabetes, and immunological conflict (Saha et al., 2022a; Saha et al., 2022b). Although the mechanisms by which BPA negatively affects health are not well understood, some connections are believed to be related to non-estrogenic effects. Exposure to BPA during pregnancy is linked to lower birthweights. The two indicators use the most extensive nationwide representation of urine BPA levels over time for children and women of reproductive age. Indicator B11 displays the median and 95th percentile of total BPA levels in the urine of women aged 16 to 49. For adolescents aged 6 to 17, Indicator B12 shows the median and 95th percentiles of BPA amounts in urine (Woudenberg et al., 2014).

The general public's primary exposure to BPA occurs through food consumption. The recommended BPA dose by the US Environmental Protection Agency (EPA) is 50 μg/kg BW/day. In 2015, the EFSA revised the TDI from 50 μg/kg BW/day to 4 μg/kg BW/day due to its adverse health effects (Teeguarden et al., 2015). BPA usage faced restrictions globally as its worsening health impacts emerged. In 2008, the US Food and Drug Administration considered a No Observed Adverse Effect Level (NOAEL) of 5,000 ng/kg body weight/day through food intake. Several EU member states prohibited its use in food containers for children under three, with some extending the ban to other products. Denmark banned BPA in food-related packaging, including cups and bottles, in 2010. EU Commission Directive No. 8/2011 banned BPA in baby bottles from March 1, 2011 (Manzoor et al., 2022).

Conclusion & Future directions:

The industrial component, BPA, finds extensive use in the production of epoxy resin, polycarbonate plastics, and various polymer-based materials, making it omnipresent in the environment due to its widespread applications. This study emphasizes dietary intake as the primary route of BPA exposure for individuals, with minimal impact from personal care product usage. Further investigations are warranted to assess BPA and its metabolites' presence in the human body, along with establishing recommended exposure levels. Biomonitoring studies indicate rapid and continuous BPA exposure in both humans and animals.

In-depth research is essential to comprehend the fate of these substances, particularly in economically disadvantaged countries, and to elucidate the long-term negative health effects of BPA exposure. A comprehensive analysis of existing data reveals a concerning, albeit not entirely clear, association between Endocrine-Disrupting Chemicals (EDCs) and human cancers. BPA, acting as an estrogen mimic under various circumstances, influences ovarian morphology, leading to cystic ovaries and heightened proliferative lesions that may signify an increased risk of ovarian cancers. Evidence suggests that early exposure to BPA during mammary development is associated with an elevated risk of breast cancer.

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Chapter- 22

Impact of environmental pollution on reproduction of Tilapia: an indispensable perception for understanding SDGs

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Keywords: Pollution, heavy metal, physicochemical parameter, tilapia, histopathology.

Abstract:

Fish and the fishery economy play a pivotal role in global sustenance and economic stability. Understanding the impact of physicochemical parameters and heavy metal toxicity on Tilapia reproduction is imperative for achieving the Sustainable Development Goals (SDGs). Numerous water bodies, referred to as "bheri," located in North 24 Parganas, are grappling with substantial environmental contamination. The pollution in this region stems from diverse industrial, sewage, agricultural, and petroleum activities prevalent in the area. Consequently, investigating the contamination of fish with heavy metals becomes imperative for the well-being of the populace residing in a country surrounded by water bodies. This study aims to ascertain and compare the concentrations of heavy metals (Lead, Cadmium, Mercury, and Copper) in distinct water samples obtained from various zones within North 24 Parganas. The current investigation seeks to explore the impact of physicochemical parameters and the toxicity of heavy metals on the reproductive processes of tilapia collected from diverse sampling sites in North 24 Parganas. The samples were categorized into two groups: one from severely polluted water bodies (designated as the intoxicated group) and the other from uncontaminated water bodies (designated as the control group). The results revealed a noteworthy disparity between the intoxicated group and the control group. The histological examination of fish organs (Ovary, testes, and brain) was documented. In the testes of the intoxicated group, degenerative changes and a reduced number of seminiferous tubules were observed. The ovaries exhibited deformities in their normal shapes, and severe lymphocytic infiltration, and the brain displayed neuronal degeneration along with a significant loss of granular cells. Hence, our present investigation aims to raise awareness within communities regarding the environmental pollution affecting edible aquatic organisms. We advocate for the enhancement of water quality in these water bodies and the implementation of government laws and regulations about the safeguarding of these aquatic environments.

Introduction:

Fish represents one of the most crucial, healthiest and economical protein sources in developing nations (Mukherjee et al., 2022a). As fish represent a vital source of nutrition for a significant portion of the world's population, their well-being directly correlates with food

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security and poverty alleviation—two key SDGs (Mukherjee et al., 2022a). This chapter delves into the intricate relationship between environmental factors, heavy metal contamination, and the reproductive patterns of Tilapia fish in diverse aquaculture ponds. The significance of this research extends far beyond the realm of aquaculture, tapping into broader themes crucial for sustainable development. This chapter also explores the outcomes of market surveys, shedding light on the economic implications of Tilapia farming practices (Mukherjee et al., 2022b). Additionally, it delves into the concept of circular economy, emphasizing the need to balance resource utilization in aquaculture for long-term environmental health (Saha, 2023). Biodiversity and conservation efforts are crucial components discussed, emphasizing the delicate ecological balance and the importance of responsible aquaculture practices in preserving diverse aquatic ecosystems (Saha & Sarkar, 2022). Overall, the chapter contributes valuable insights into the intricate web of environmental, economic, and conservation aspects shaping the future of aquaculture and sustainable development.

Fish may exhibit a preference for an optimal environmental condition conducive to their growth and reproduction. Consequently, to maintain the water body's suitability for fish development and reproduction, it is imperative to routinely monitor physicochemical parameters. Any adverse alteration in these parameters can induce stress in fish. If such alterations increase arithmetically, the fish stress may intensify geometrically. Presently, the contamination of aquatic environments by heavy metals poses a threat to both the environment and its inhabitants when their concentrations surpass safe limits. Fish play a crucial role in assessing potential pollution risks (Lakra & Nagpure 2009; Magar & Bias 2013; Sanyal et al., 2023). Fish exposed to pollutants, particularly heavy metals such as Cd, Hg, Pb, and Cu, may experience acute or chronic toxicity, impacting various physiological processes, including reproduction (Sanyal et al., 2015; Sanyal et al., 2017; Mondal et al., 2022; Saha et al., 2022; Roy et al., 2022). The robust reproductive process of fish serves as a vital indicator of their ability to sustain themselves (Zulfahmi et al., 2018). While many heavy metals are considered essential nutrient elements that positively enhance fish growth and feed utilization (Ghazi et al., 2022), exceeding the maximum tolerable limit poses hazards not only to fish health (Jezierska et al., 2009) but also to human consumers and ecological systems (Sarkar et al., 2016).

Histopathological alterations or cellular changes in tissues such as the brain, ovary, and testes have received considerable attention in assessing the effects of environmental pollution (Blazer, 2002). Traditionally, there has been less focus on endocrine, neural, and gonadal histology—all of which impact reproduction. Several environmental chemicals act as endocrine disruptors, affecting fish reproduction, prompting an interest in assessing fish reproductive health (Carnevali et al., 2018). Water pollution occurs when pollutants are discharged directly or indirectly into lakes, rivers, etc., without the removal of harmful substances. This pollution adversely affects fish and other organisms inhabiting the water. Environmental pollutants, especially heavy metals, may elevate disease incidence by reducing the organism's immune state, as well as reproductive and developmental processes (Kaoud & El-Dahshan 2008).

Hence, determining and recognizing the level and toxicity of these metals in water bodies is essential for informed decision-making.

The objective of this study is to ascertain and compare the concentrations of heavy metals (Pb, Cd, Hg, and Cu) in diverse water samples collected from various zones of North 24 Parganas. Additionally, this study aims to explore the effects of physicochemical parameters and heavy metal toxicity on the reproduction of tilapia collected from distinct sampling sites in North 24 Parganas. To date, there is no available data on heavy metal pollution in certain areas of North 24 Parganas' water bodies. Among the sampling sites, three locations are situated outside the industrial belt, making them suitable control zones for our experiment. Lastly, a critical aspect of our study underscores that industrialization is the primary cause of water pollution and the deterioration of fish health. Water samples were obtained from severely polluted water bodies and from those not exposed to pollution, intending to raise awareness in societies regarding environmental pollution affecting edible aquatic animals. The elevated pollution levels caused by heavy metals and the threats they pose to consumers and public health cannot be overstated. Therefore, this work seeks to create awareness of the harmful effects of heavy metal consumption, propose measures to reduce pollution by heavy metals and advocate for the enforcement of laws and regulations protecting the aquatic environment and human life.

Materials and Methods:

Study area:

The study was conducted in a sewage-fed aquaculture pond situated in Kolkata and the northern 24 Parganas. To execute the current investigation, five locations were designated. The initial sampling point (Site-I) is situated in Gobardanga, North 24 Parganas. The second sampling locale (Site-II) is positioned at Mochlondopur, North 24 Parganas. The third sampling site (Site-III) is found at Khariberi, North 24 Parganas, West Bengal. Notably, Site-I, Site-II, and Site-III are all situated outside industrial zones. The fourth sampling position (Site-IV) is identified at Salt Lake City. This body of water is situated 5.7 km from Dhapa, 5.4 km from Chemical & Petrochemical Industries, Canal S Rd, Tangra, and 20.2 km from the Kolkata leather complex. The fifth sampling location (Site-V) is Dhapa Manpur, North 24 Parganas. This aquatic site is located 1 km from Dhapa, 4.8 km from Chemical & Petrochemical Industries, Canal S Rd, Tangra, and 12.5 km from the Kolkata leather complex. Sites IV and V are aquacultural reservoirs within the eastern Kolkata wetland.

Collection of water samples:

The investigation spanned twelve months, commencing in August 2022 and concluding in July 2023. Samples were collected biweekly on the initial and mid-month days of each month, totaling 24 sampling occasions.

Collection of fish samples:

Tilapia serves as a valuable reservoir of crucial amino acids, fatty acids, vitamins, and minerals. They enjoy favorable reception among consumers, prove economically feasible, and boast low-fat levels. Consequently, we opted for Tilapia. Aquatic specimens were gathered in their living state from five distinct sampling locations and subsequently conveyed to the laboratory.

Analysis of physicochemical parameters of water:

The properties of water, specifically pH, dissolved oxygen, biological oxygen demand, carbon dioxide, alkalinity, nitrite, and phosphate, were determined. The assessment of each of these elements followed prescribed protocols, as delineated in the conventional procedures (APHA, 1998).

Analysis of Heavy metal Toxicity of water:

Heavy metals (Copper, cadmium, lead, mercury) were assessed utilizing an atomic absorption spectrophotometer (APHA, 1998).

Histopathological studies:

To examine the histopathology of the testes, ovaries, and brain, adult Tilapia fish samples were procured from the designated region and transported live to the laboratory. Upon dissection, the respective fish organs—testes, ovaries, and brain—were promptly excised and immersed in a 20% formalin solution for 24 hours. The tissues underwent standard dehydration through a graduated alcohol series, followed by clearing in xylene, and eventual embedding in paraffin wax. Subsequently, sections measuring 5-6 µm in thickness were meticulously cut, processed, and subjected to staining with hematoxylin and eosin. Finally, a solution of Canada balsam was applied, and the specimens were covered with a glass slide. Microscopic examination and photography were conducted as per the methodology outlined by Mohamed (2009).

Results:

Histopathological analysis of selected organs:

Testis:

Histopathological analysis of the testicular tissue in the contaminated group revealed that the Tilapia's testes exhibited a departure from their optimal seminiferous tubule shape, along with the presence of remnants of primary and secondary spermatocytes. The testicular structures exhibited pronounced congestion within interstitial capillaries within regions affected by pollution.

Ovary:

Under microscopic examination, Tilapia's ovary exhibited significant lymphocytic infiltration. As per our investigation, it is evident that Tilapia's gonads are experiencing distortion from their optimal forms.

Brain:

The histological cut in the brain depicted pronounced congestion and an increase in glial cell growth.

Table 1: Analysis of physicochemical parameters of water samples.

Parameters	Study area (mean value)					Standard value IS:10500 (2012)	Stress
	Site-I	Site-II	Site-III	Site-IV	Site-V		
pH	7.6	7.4	7.1	6.8	6.4	7-9.5	<4, >11
DO (mg L^{-1})	6.26	6.10	5.73	4.78	4.12	3-5	<5
BOD (mg L^{-1})	3.21	3.68	4.83	6.45	7.13	3-6	>10
CO_2 (mg L^{-1})	3.37	3.76	4.42	6.89	8.31	0-10	>12
Nitrite (mg L^{-1})	0.001	0.013	0.09	0.12	0.18	0.02-2	>0.2
Phosphate (mg L^{-1})	0.21	0.38	1.01	2.83	2.96	0.03-2	>3

Table 2: Analysis of heavy metals toxicity of different water bodies.

Parameters	Study area (mean value)					Standard value IS:10500 (2012)	
	Site-I	Site-II	Site-III	Site-IV	Site-V	AL	PL
Cadmium (mg/l)	BDL	BDL	BDL	BDL	0.02	0.003	No Relaxation
Copper (mg/l)	0.07	0.09	0.49	1.9	2.03	0.05	1.5
Mercury (mg/l)	BDL	BDL	BDL	0.002	0.003	0.001	No Relaxation
Lead (mg/l)	BDL	BDL	BDL	0.02	0.18	0.01	No Relaxation
*BDL: Below Detection level, AL: Acceptable level, PL: Permissible level							

Discussion:

Effect of physicochemical parameters of waterbodies on fish health:

Fish typically maintain a blood pH averaging 7.4, which is conducive to their life. A pH within the range of 7 to 8.5 is considered optimal for biological productivity. Fish may experience stress in water with a pH ranging from 4.0 to 6.5 and 9.0 to 11.0. In the ongoing investigation, the pH values for Sites I, II, and III are recorded as 7.6, 7.4, and 7.1, respectively.

These values are considered ideal for fostering fish growth and reproduction. Conversely, Sites IV and V exhibit pH values of 6.8 and 6.4, indicating suboptimal pond productivity and diminished fish growth.

Dissolved oxygen (DO) is imperative for the growth and survival of fish, with 5.0 mg L-1 being deemed adequate in fishponds. The current study indicates a slight disturbance in DO levels at Sites IV and V. However, in the other three water bodies, namely Sites I, II, and III, DO levels surpass the desirable limit.

Under conditions of low DO, elevated CO_2 levels impede fish oxygen uptake, leading to respiratory problems and stress. The current investigation, particularly at Site V where DO levels are low, reveals excessively high CO_2 content, posing a threat to fish growth.

The biochemical oxygen demand (BOD) in fish ponds varies between 3.0 and 6.0 mg/l across all ponds. BOD serves as a measure of oxygen required by microbes to degrade organic matter under aerobic conditions. The elevated entry of cattle and domestic sewage from non-point sources, along with an increase in phosphate in village ponds, may contribute to the high organic load in these ponds, resulting in elevated BOD levels. In the study, BOD levels at Sites IV and V can surpass the desirable limit, signifying a critical condition of oxygen depletion and indicating water pollution.

In most natural water bodies, nitrite content tends to be low. However, in cases where a water body is contaminated with high organic pollution and experiences low DO, nitrite content may rise to toxic levels. In our study, Site V exhibits nitrite levels reaching up to 0.18 mg/l, and Site IV records 0.12 mg/l, both considered sublethal to fishes. When fish absorb nitrite, it reacts with hemoglobin to form methemoglobin. Since methemoglobin is not an effective oxygen carrier, continued absorption of nitrite leads to hypoxia and cyanosis.

Phosphate levels are exceptionally high in Sites V and IV. Elevated levels of nitrates and phosphates in water bodies indicate substantial eutrophication in these locations. These phosphates catalyze extensive algal blooms in water bodies, contributing to heightened contamination. The primary sources of phosphate include detergents and soaps used for household cleaning, bathing, and laundry, while nitrates are present in the discharge of treated domestic sewage water.

Effect of heavy metal on fish reproduction:

Water contamination has a profound inhibitory impact on the reproductive processes of fish. Various contaminants, including heavy metals, industrial byproducts, pesticides, and agricultural residues, exert histopathological influences on the reproductive tissues of fish gonads. As per IS:10500 (2012), the established upper limits for lead and cadmium in surface water stand at 0.01 mg/l and 0.003 mg/l, respectively. Upon scrutinizing our findings, it becomes evident that the concentrations of cadmium, lead, copper, and mercury in a water specimen surpass the permissible thresholds at Site V. In Site IV, cadmium is undetectable, but lead, mercury, and copper in the water sample may exceed acceptable levels. Conversely, Sites

I and II exhibit no traces of Cd, Cu, Cr, Pb and Hg, indicating an absence of heavy metal contamination. Site III, however, presents a scenario where only copper surpasses the desirable limit.

Consequently, the distortion of Tilapia gonads from their ideal conformations serves as an indicator of heavy metal pollution at Sites IV and V. Observable deformities in the testes and ovaries at these locations are likely attributed to the presence of diverse pollutants, particularly near Dhapa, Chemical & Petrochemical Industries, and Kolkata leather complex. The histological examination of gonads in this study distinctly validates that pollution, particularly from heavy metals, profoundly impacts Tilapia gonads and reproductive processes, manifesting as disruptions in gonadal development. The various contaminants, such as heavy metals and industrial residues, induce histopathological effects on fish gonads, potentially disrupting germ cell development and diminishing the fish's reproductive capability.

Conclusion:

There existed compelling proof of a connection between variations in physicochemical parameters and the contamination of water bodies with heavy metals, impacting fish reproduction. The presence of metals in fish tissues is contingent upon various factors, including environmental conditions (pH, alkalinity, dissolved oxygen, carbon dioxide), exposure duration, and species-specific living and feeding behaviors. In aquatic ecosystems, industrial discharges represent a potential origin of heavy metal contamination in the aquatic milieu. In contemporary times, human-induced pollution of aquatic ecosystems has escalated the imperative for investigations discerning the repercussions of heavy metals on the resident species. Surveillance initiatives aimed at measuring bioaccumulation function as indicators for fish in locations tainted by providing insights into the prevailing environmental conditions. Histological alterations furnish a more comprehensive evaluation method for gauging fish health and the impact of pollution on individual biochemical parameters. Metal contamination has the potential to harm aquatic organisms at the cellular level, potentially disrupting the ecological equilibrium. The current investigation attested to the necessity for enhanced water quality management and regular environmental monitoring at Site V and Site IV, both being aquacultural ponds within the East Kolkata wetland, supplying fish to various markets in Kolkata. Consequently, the government must enforce laws and regulations safeguarding these aquatic habitats, thereby ensuring human well-being. As heavy metal contaminants within aquatic organisms can undergo biomagnification and persist in the food chain, there is a consequential transfer to the human body, making contemporary heavy metal toxicity a significant global concern for consumers of fish.

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Chapter- 23

Scientific Mud Crab Culture Practices in Sundarbans Delta: A Step Towards the Betterment of Sundarbans People

Biplab Bhowmik*, Lisa Basu, Priya Roy

Keywords: Mangrove ecosystem, Traditional Fish farming, Mud Crab culture, Sundarbans.

Abstract:

Sundarbans means 'beautiful forest'. This largest mangrove ecosystem is home to a huge species diversity—from mammals to reptiles, birds to fishes, crabs to zooplanktons. This densely populated area becomes increasingly vulnerable due to devastating cyclones, floods, and rising sea levels, which most significantly affect the lives of the people in the Sundarbans. Mud crab farming has become a beacon of hope for those belonging to the Sundarbans. This farming paves the way for employment opportunities, supports the economic lifestyle of the people, and helps establish women's empowerment in such adverse areas. This small-scale, profitable business has a high market demand in both national and international markets. This farming requires little capital and has low labour costs. If the traditional way of farming can be combined with science-based, improved practices of mud crab culture, it can be highly beneficial for the future. These scientific methods can be instrumental in increasing production rates, elevating the protein value of crab meat, and combating mud crab diseases to reduce mortality rates. Thus, mud crab farming can be a profitable alternative livelihood for the disaster-prone people of Sundarbans, exploiting its underutilized and unutilized brackish water resources by developing appropriate management practices through participatory planning and capacitating the community for implementing the same.

Introduction:

Sundarbans is the largest delta with a mangrove forest ecosystem formed by the confluence of the Ganges, Brahmaputra, and Meghna Rivers in the Bay of Bengal. This coastal ecosystem is one of the richest biodiversity zones in India (Chakraborty & Ghosh, 2019; Saha & Sarkar, 2022; Biswas et al., 2023). The people of Sundarbans utilize these local bio-resources as their

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livelihood option (Sardar et al., 2016). Around 50% of people live below the poverty line in this delta. Among mud farmers, 41.67% belong to the BPL category (Sil, 2016). Therefore, mud crab farming in Sundarbans serves a foremost function in the livelihood of the local, thriving coastal community. The mud crab, or mangrove crab (scientific name: *Scylla serrata*), is the most commercially traded seafood for aquaculture in mangrove and coastal areas of Sundarbans (Hasanuzzaman et al., 2022). Mud crab culture is a promising self-help industry nowadays because of its high economic value. This is the simplest form of aquaculture practice and shows high potential due to several reasons (Apine et al., 2023). These crabs are known for their nutritional richness of crab meat and their meat-rich chelate legs. Crab meat has high medicinal value to treat protein deficiency diseases, especially in children. Crab meat is also a rich source of minerals that serve as components of bones, soft tissues, and co-factors or co-activators of various enzymes that are essential for human metabolism. Mud crabs have a high tolerance to a wide range of temperatures and salinities. Thus, it shows high potential in the export business (Nanda et al., 2021; Shen & Lai, 1994; Rahman et al., 2017). Mud crab culture turns itself into a profitable business due to high productivity, low labour costs, etc. During the peak season of November to February (83.33%), the majority of crab farmers practiced intensive culture (67.67%) (Sathiadhas & Najmudeen, 2004). Not only the mud crab farmers, but their families also actively participate in mud crab farming. Mud crab culture has become a potential strength and source of income for the coastal communities of Sundarbans. However, the maintenance and cultural processes are still in their primitive stages. Very little effort has been made to understand the biology, morphology, and maintenance of mud crabs and their impact on the socio-economic development of this region (Roy et al., 2021; Rahman et al., 2017).

Traditional way of mud crab farming:

Since 1990, mud crab farming has begun as an alternative livelihood in the Sundarbans Delta. Mud crab farmers mainly follow the fattening method of culture, especially in the three districts of West Bengal—South 24 Parganas, North 24 Parganas, and Purba Medinipur. In these regions, crab fattening locally is known as chamber chas. In this process, the newly moulted crabs, or ‘empty crabs’, are held and reared for a period of about 10–45 days until they are full of meat and of marketable size (Paul, 2022). In the fattening process, newly moulted crabs of weight 550 grams are used. Farmers generally use small tidal ponds or pens for the fattening process. The short and profitable cultural period has made the fattening process more popular (Roy et al., 2021).

Scientific culture processes for mud crab farming:

Mud crab farmers in Sundarbans choose the fattening process over any other longer-culture process due to the high production rate within a short time period. Yet, ICAR suggests some longer culture processes with a duration of 6–8 months to promote economy and product efficiency and to make the farmers aware of and adopt these time-taking processes (Roy et al., 2021).

Design a suitable nursery:

To grow crablets from megalopae, a suitable nursery building is the most necessary thing. In the Sundarbans, mud crab farmers mostly use earthen ponds with hapa nets as a nursery. Hapa nets are square/ or rectangular net cages with a 1-2 mm mesh opening (Ut et al., 2007). These nets remain submerged in the earthen ponds, with the lower base of the nets attached to the bottom of the ponds. Water depths of 80-120 cm are maintained in those ponds (Ye et al., 2011). Zooplankton populations are established within the pond as a food source for megalopae. Sometimes, earthen ponds without a hapa system are used as nursery grounds for crablets (Antony et al., 2019). These ponds are securely covered with fine nets to stop the crawling of crablets away from the ponds. In recent years, tanks have also been used as a nursery for mud crab farming (Rodriguez et al., 2007). These tanks are rectangular in shape with a flat concrete base and are covered with an overhead shed to protect the crablets from direct sunlight and rainfall (Syafaat et al., 2021).

Grow-out system:

Grow-out cultures are generally pond-based, lengthy processes. Wild-collected crablets of 50–100g in size are stocked in grow-out ponds. These culture ponds are 0.5-2 ha in size. The juvenile crabs are stocked at a rate of 0.5–0.7 m^2/s. Trash fish is the primary source of food for the juvenile crabs (Maheswarudu et al., 2008). Sometimes, the trash fish is mixed with fish oil, flour, or probiotics for feeding purposes (Islam et al., 2018). In this system, the crablets grow to a desirable size after 5–6 months. Regular monitoring of the pH, water salinity, and health of crablets is necessary. Low-salinity water (5–12 ppt) may cause a decrease in the survival rate of stocking. Paddle wheel aerators (2 HP) are also used in the ponds to improve water circulation (Liew et al., 2023).

Box culture method:

Innovative box culture methods of crab farming are expanding rapidly throughout the Sundarbans. This box crab technology has become popular day by day in Haldia and Nayachar along the Haldi River in East Midnapur. Locally, this culture method is called ‘box crab technology’ or ‘box method’. This box crab farming is usually done in freshwater ponds. In this method, male crabs can be cultivated in 10–12 days, whereas female crabs take 25–26 days (Kalidas et al., 2020). A bridge-like structure with some gaps made of bamboo was placed over the pond. The boxes hung in those gaps. Medium-sized plastic boxes are used in this method. Crablets are stocked in these plastic boxes (Lalramchhani et al., 2020). The boxes will be hung in such a way that they remain submerged in the pond water. Only one-time food (trash fish) is fed to crablets as the primary food (Chakraborty, 2019).

Polyculture:

In polyculture, mud crabs can be successfully cultured with one to three species, including milkfish, tilapia (*Oreochromis* spp.), shrimp, and other marine species (Lalramchhani et al., 2020). The stocking rate of each species depends on the season. Mollusks, low-value fish, and zooplankton, serving as natural fish, mainly provide mud crabs and shrimp as food sources (Shyne Anand et al., 2018). The growth and survival rates of mud crabs in polyculture are similar to those in monoculture. Close monitoring of pond water and species is necessary in this method to prevent any diseases (Mahmud & Mamun, 2012).

Vertical Ras System:

The vertical RAS system in mud crab farming is a novel technology. This culture method is specially designed for indoor farming. It is also helpful for mud crab farmers who cultivate away from seawater. This vertical RAS system is nothing but a specially designed vertical stacked box within which sand filters, biofilters, and UV filters are placed. Its biosecurity facility helps protect the culture procedure from pathogens. It is also used to minimize water usage. Besides its modernized facilities, the notable disadvantage of this system is that it is very costly to invest in and maintain (Yxtung, 2020).

Mud crab farming- a way of women's empowerment:

In Sundarbans, where the female literacy rate is approximately 14%, and there are no large-scale industries or significant work opportunities, mud crab culture helps women stand on their own feet (Hasanuzzaman et al., 2022). Women directly or indirectly participate in mud crab culture, with most of them involved in feeding crablets, preparing crab foods, and assisting their husbands. Some of them also contribute to pond preparation for culture (Roy et al., 2023). Their participation provides them with an opportunity to be independent, confident and serves as a source of income. Women's involvement also promotes the growth of family income (Ghosh & Sahu, 2016).

Conclusion & Discussion:

In the vast expanse of the Sundarbans, the landscape of mud crab farming is continually evolving, marking new milestones with each passing day. Amidst this dynamic progress, a series of challenges loom on its path. The emergence of various parasitic diseases casts a formidable shadow over the flourishing mud crab farming industry, introducing a substantial threat to its sustained growth. Furthermore, the inadequacy of wild seed collection has the potential to act as a hindrance to the intricate cultural process. A noteworthy constraint is evident in the perceived dearth of proper skills and commercial techniques within the domain of mud crab farming. This deficiency, if unaddressed, may impede the industry's potential for further development. However, on a hopeful note, the integration of improved technologies and innovative cultural methods into the existing practices holds the promise of offering a highly desirable solution. These advancements are not only anticipated to surmount the existing challenges but also to elevate the overall quality of life for the resilient communities inhabiting the Sundarbans region.

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Chapter- 24

'Sustainable Aquaculture' and 'Rural Women'

Pratap Mukhopadhyay*, Urna Banerjee

Keywords: Rural women, population, migration, aquaculture, inevitable roles.

Abstract:

According to the current population census, India ranks second with a net population of 144 crore 18 lakhs 77 thousand 249 in total. Among these, men account for 74 crores 44 lakhs 79 thousand 293 (51.6%), while females make up 69 crores 73 lakhs 97 thousand 957 (48.4%). Due to gender inequality and the substantial population difference, the participation rate has been consistently decreasing from male to female populations. This trend reflects a clear suppression of the inherent expertise of females. Migratory compulsions, influenced by various factors, have further contributed to this situation. However, extensive efforts by various fisheries extension and cooperative bodies, such as NFDB, KVKs, NGOs, etc., have yielded practical outcomes. These initiatives have successfully addressed the significant gender gap in aquaculture, utilizing natural resources optimally. The crucial role played by women in bridging this gap is of utmost importance. Failure to sustain this progress could lead to undesirable consequences and act as a barrier to achieving the top position in fish culture for our country, including our motherland Bengal, in the long run.

Introduction:

Aquaculture, which is generally a rural activity involving the farming of fish, crustaceans, edible mollusks, and aquatic plants of economic value under controlled or semi-controlled conditions, has a long history in India (Boyd et al., 2020; Sanyal et al., 2023; Mukherjee et al., 2022a; Mukherjee et al., 2022b). From almost a subsistence level of farming activity in the early '60s, India is now the second-largest producer of fish, registering a sixteen-fold increase during the last six decades. To a great extent, the contribution to this transformation process has been from freshwater aquaculture, which has grown from about 0.40 million tonnes in 1980 to 12 million tonnes at present (Sahoo et al., 2023). Today's aquaculture is diverse and varied; the diversity of aquaculture production is reflected in terms of holding units like ponds, raceways, pens, and cages; management levels like semi-intensive, intensive; monoculture or polyculture of species, static systems, or flow-through systems. Its spectacular growth so far has been possible mainly because of (i) sustained application of scientific principles generated through

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research efforts in various disciplines, including fish seed production, culture technology, genetics, nutrition and feeding, disease diagnostics, etc., (ii) inheritance of a strong gene pool involving multiple indigenous species, and (iii) the existence of diverse aquatic ecosystems, including ponds, tanks, lakes, reservoirs, canals, streams, rivers, and deepwater rice environments, etc. (Mallick & Panigrahi, 2018; Boyd et al., 2020).

The scenario, however, is altering with the changing environment; competition for resources such as land, water, and essential inputs like feed and fertilizer is likely to affect the context and content of the aquaculture sector in the country. The gradual implementation of stringent codes of conduct for responsible aquaculture and HACCP in the farming system for safe production plans all appear to be highly challenging for researchers, and development agencies, including farmers, faced with the task of ‘producing more from less, for more’. This situation becomes more complex, especially in rural Bengal, with sizable groups of the male population migrating to nearby and distant cities for the betterment of their socio-economic conditions and livelihood options. This has led to the imbalance of adequate manpower to carry on aquaculture activities (Jahncke & Schwarz, 2008). In this connection, it may be stated that, unlike conventional agricultural activities where men and women jointly participated in equal contributions, aquaculture showed a major diversion, where it was fully overruled by male dominance completely. Consequently, this migration has created a significant vacuum in the field of aquaculture and allied activities, which needs to be filled up immediately; otherwise, this traditional economic and welfare activity of finfish and shellfish rearing would face a tremendous hurdle in their smooth and uninterrupted continuation shortly. Following this acute significance of manpower shrinkage, which has led to a major crisis, rural women have shown a dominant will force to enlighten a new hope and, side by side, bridge the gap efficiently, reflecting real 'magic' in this very particular field, both in a war-footing basis and efficient manner (Jaikumar et al., 2023; Ross, 1989; Das et al., 2020).

Sustainable aquaculture initiatives in the Sunderban area have gained traction, promoting both economic growth and environmental balance (Saha & Sarkar, 2022). Rural women play a pivotal role, engaging in sustainable practices that harmonize with the delicate ecosystem, ensuring the longevity of this vital region. Sustainable aquaculture ensures responsible practices, safeguarding marine ecosystems. Circular economy, sustainable aquaculture, and empowering rural women intersect in a harmonious narrative of environmental stewardship and social equity (Saha, 2023). Embracing circularity minimizes waste, promoting resource efficiency. Rural women, pivotal in these endeavors, play transformative roles, contributing to resilient communities and equitable growth. Together, they form a tapestry of sustainable development, fostering a balanced and thriving future.

Inevitable roles of women:

Unlike crop farming activities in conventional agriculture, where women's participation has been and still is considered a normal phenomenon from seed sowing to harvesting, rural aquaculture activities have remained predominantly male-dominated, as mentioned earlier

(Pattnaik & Lahiri-Dutt, 2020). In the changing environment, due to the frequent migration of rural men in search of alternative livelihood options and prosperity in nearby and distant cities for jobs or trading purposes, leaving their homes for prolonged periods, some spirited rural women—mostly housewives—have stepped forward under such challenging conditions to contribute by gradually acquiring vocational skill development training in aquaculture-based farming systems facilitated by farmer-supportive agencies, enabling them to stand on their own with dignity. Fortunately, Krishi Vigyan Kendras (KVKs) and local research and development institutions of the Indian Council of Agricultural Research (ICAR) started working with these women, providing hands-on capacity-building training in ecological aquaculture (Ananth et al., 2019). This training included various aquatic bioresources such as Azolla, lotus, ipomoea, lily, and makhana (*Eurayle ferox*). Additionally, it incorporated seasonal leafy vegetable farming on pond dykes and, in some instances, integrated duck farming at certain locations to make these women self-reliant. They began working together, shouldering responsibilities jointly in the agro-ecological farming of indigenous small and medium fishes, utilizing locally available bio-inputs like green manure, farm-made neem-based phytoremediation products, and traditional knowledge from elderly farmer-scientists in the villages. Despite facing multiple challenges, this small beginning gradually allowed them to systematize production processes at reasonably low input costs, reviving local production and showcasing their missionary zeal and capabilities in bringing forth the latent potential of rural women to contribute generously towards steady family earnings (Das et al., 2023).

Now, organizations such as the National Fisheries Development Board (NFDB), the State Directorate of Fisheries, and various NGOs working in this sector have come forward with a spectrum of benefits for the development of fish seed production in situ. This includes input availability at the doorstep, fry to fingerling stage rearing, and farm-made chowmein-type pelleted fish feed preparations using local agro-based residues like oilseed cakes, rice polish, and corn dust. These women leaders, forming self-help groups with the cooperation of local panchayats, now have access to unconventional and unnoticed water resources, such as canals, swampy ponds, village ditches, and wetlands, most of which remained unutilized until now. Equipped with the required training, sincerity, seriousness, periodic exposure to successful farms and hatcheries, and developing expertise in mobile communication through the use of Android handsets, these dedicated women leaders have already developed competence in various aspects of aquaculture. This includes fish breeding, pond preparations, spawn/fry rearing, fingerling raising, farm-made feed formulation, processing, storage, and scientific application in farm ponds and tanks. They are well-versed in procedures for emergency care of fish, health, and disease diagnosis, thereby strengthening the fish production system more robustly (Bower et al., 2017). Their actual nurtured or equipped strengths are reflected through their inner passion and drive to continuously engage with local fisheries or aquaculture institutions, Krishi Vigyan Kendras, and various aquaculture-related capacity-building centers. This marks the beginning of harnessing the potential of half of the population, whose contributions could not be fully realized for achieving the dream of 'Atmanirbhar Bharat' and bringing about magical changes in the quality of life in rural areas, including Gangasagar block of Sundarbans, some coastal villages of Tamluk in Purba Medinipur, and Kaliaganj block in Uttar Dinajpur district in the North Bengal region, which, hopefully, are successful to a greater extent. The role of this women's section in various aspects of aquaculture, such as fish rearing, hatchery management, ornamental fish nourishment, fish processing, etc., along with each phase from pond preparation to marketing, processing, and exporting them overseas, strengthened by intensive scientific and technical hands-on training from prestigious fisheries or aquaculture training centers, despite having limited educational qualifications (as proven by degrees from educational entities like colleges and universities), is discussed below in the following discussion.

In induced fish spawning, seed production, and hatchery management:

Among all other fishes to be cultured, cyprinids, especially the major carp, rank first on the list of priorities due to their profound supremacy and strong emotional connection in the traditional dishes of the entire regions of the eastern and northeastern belts. The main disadvantage of such cultures, despite several pros like ensuring a high probability of recycling organic wastes, followed by high competency in culturing with other species, is the release of eggs in their natural environments in captivity, which remains at stake (Bais, 2018). Induced breeding helps solve this problem to obtain the seeds and resume this cycle of culture by capturing brood fishes from the culture sites and consequently injecting them with hormones that suppress the role of gonadotropin-inhibiting hormone (GnRH), thereby easing out the release of Gonadotropin-releasing hormone (GRH) (Sahadan et al., 2021). Selecting the proper dosage of hormones for fishes, injecting them in two phases in females and one in males at a 45-degree angle above the lateral line, striping the abdomen, and releasing the eggs, mixing them with the sperms gently with a sterilized quill, and then finally allowing the fertilized eggs to produce the spawns are now at the fingertips of women, replacing or shouldering their men to a great extent (Jhingran & Pullin, 1985).

As, owing to the various life stages of fishes, the cultures are broadly sectioned into three distinct groups viz., spawn to fry, fry to fingerling, fingerlings to table-sized fishes, etc., rearing the spawns up to the grow-out phases by taking proper nourishment of them, monitoring their health and other aspects sincerely are also carried out extensively by rural women with their utmost efficiency through acquiring capacity building and enhancement expertise (Williams & Syddall, 2022). For farmers, fishery entrepreneurs, aquaculturists, etc., the main constraint faced is the timely procurement of quality fish seeds – the vital input to begin aquaculture, which has created a great burden among them in continuing their culture phase smoothly. The advent of modern hatcheries and their management lies only in this aspect, that is breeding them and successfully rearing their young ones under controlled conditions for getting healthy hatchlings. As we all know, hatcheries are composed mainly of two types of units viz., breeding unit and hatching unit. The management of the hatching pool encompasses scientific strategic measures for maintaining the healthy condition of the water containing the broken eggshells in its outer chamber by collecting them through the use of twined fibrous ropes made up of coconut fibers (generally similar to 'scrubbers'), to which the eggs can easily get adhered while moving along with the water current in the outer chamber of the hatching chamber. The significant roles of women in placing the nets of the hatching chamber and timely removal and cleaning of those scrubbers, including the management of water flow circulation, aeration systems, operational activities, and all such other related ancillary activities to keep its functional viability to the optimum are really to be adjudged in various parts of India extensively (Naish et al., 2007; Harper et al., 2013).

In pond management including the management of its water quality parameters:

Aquaculture involves more than just culturing and harvesting fish; it encompasses various tasks beyond these limits, extending to pre-stocking and post-harvesting management. In pre-stocking management, activities such as pond designing, removal of non-essential aquatic flora and fauna, and the construction of fences to deter crab entry are essential. Rural women actively participate in pond construction, selecting healthy cultivable fishes for stocking, and gaining intensive hands-on training in identifying urinogenital openings, dorsal fins, belly shapes, and sizes, making them fully compatible to compete with their fellow men or husbands in practical fields uniquely (Mramba & Kahindi, 2023; Ahmed et al., 2023).

In the next phase of the culture system, stocking involves introducing fishes into the water body in a definite proportion, covering each habitat (surface water, column water, or bottom water niches) appropriately. For single-species culture systems, determining stocking density is crucial, synchronized with size, carrying capacity, pond depths, and availability of natural feeds. Pond depth, ranging from 1.0 to 1.5m for nursery rearing, is a vital parameter for stocking specific age groups of fish. Rural women excel in assessing natural food organisms using secchi discs and plankton nets, defining the pond's suitability for fish culture, and showcasing their competence in pre-stocking activities (Ahmed et al., 2023; Jeanson et al., 2022; Harper et al., 2013).

Post-stocking management, dealing with activities after stocking and harvesting, is attributed to women for their acute and appreciable involvement in this sector. Fish, being a poikilothermic vertebrate, relies on ambient water quality parameters for nutrition. Aquaculturists must pay attention to water temperature, dissolved oxygen (D.O.), pH, salinity, and turbidity caused by Total Dissolved Solids (T.D.S.). A water temperature and D.O. below-prescribed limits (25-28ºC and 5mg/L, respectively) can be lethal to warm water fishes due to triggering aerobic and anaerobic reactions, leading to the generation of excess carbon dioxide and ammonia. Women, proficient in using pH meters, salinometers, Winkler method, digital D.O. meters, Secchi discs, and refractometers, demonstrate their capability to check water quality and fish health, contributing significantly to the field of aquaculture (Elliott et al., 2022; Harper et al., 2013).

In nutrition and feeding:

As it is widely acknowledged, the significance of food extends beyond mere sustenance for fishes; their effective growth and survival also hinge on the intricacies of biological tuning, encompassing factors such as particle size, color, odor, and more. All these allied considerations bear equal weight for the very same reasons. The incorporation of these elements into feed formulation demands specialized technical training. This pertains specifically to the domain of preparing natural fish food items, denoted as 'planktonic particles,' namely phytoplankton and/or zooplankton (Ragasa et al., 2022). This crucial aspect of feed formulation is exclusively entrusted to the expertise of women. They undergo extensive training, encompassing both theoretical knowledge and hands-on skills. This training covers a spectrum of tasks, ranging from effectively selecting feed ingredients to adeptly combining them with feed additives. The process extends to shaping the mixture into noodles, achieved through the utilization of hand/motor palletizers. Consequently, women are now recognized as 'experts' in these intricate and vital areas.

Including feeding, there are many more aspects of aquaculture, such as providing proper nutrients to enhance soil activity, maintaining the equilibrium of phytoplankton and zooplankton, checking the efficiency of aqua instruments to judge their optimal functioning, and conducting periodic water quality check-ups to prevent major deterioration, among other tasks. In all of these activities, women actively contribute, leading to a positive impact on the overall results. Insights can be gained from their involvement in preparing biofertilizers and organic manures. Women play a crucial role in strategically placing these materials in ponds for their gradual and sustained release. This is done either directly by the women themselves or indirectly by assisting their male counterparts. They organize related tasks and have rightfully earned recognition as 'qualified experts' due to their commendable contributions.

In today's aquacultural scenario, the exorbitant cost of fish feed poses a significant challenge for farmers, creating a comical burden as they strive for an uninterrupted continuation of their livelihood in aquaculture. This cost primarily stems from the reliance on industrially manufactured feeds, prompting the recommendation to opt for farm-made preparations utilizing local resources. This shift becomes imperative due to the farmers' dependence on very limited funding sources (Oliva-Teles et al., 2022). The home-based preparation of these feeds entails a series of simple steps that incur minimal economic and labor costs. Crucially, the involvement of rural female individuals is indispensable throughout this process (Fig. 1).

Azolla, a small floating rooted aquatic fern belonging to the taxonomic family 'Salvinaceae,' stands out as a common and valuable ingredient and supplement in fish feeds due to its exceptional nutritional profile. To cultivate Azolla, small ponds or traditional, underutilized ponds can be employed after clearing undesired weeds. Ditches, pits excavated in backyards, and similar spaces serve as suitable cultivation sites. These areas are then filled with a small, quantified mass of the stock (wild Azolla), which doubles in mass within a few days, creating an optimal nutrient medium for its expansion. Subsequent management of these organic feed ingredients necessitates daily monitoring of the cultured mass. If required, frequent additions to the nutrient medium become essential (Hamli et al., 2020; Abo-Taleb, 2019; Smith, 1988). Remarkably, these tasks are efficiently executed by rural housewives who have enhanced their vocational skills through active participation in training programs conducted widely in their native areas. This empowerment not only supports sustainable aquaculture but also strengthens the economic foundation of these communities.

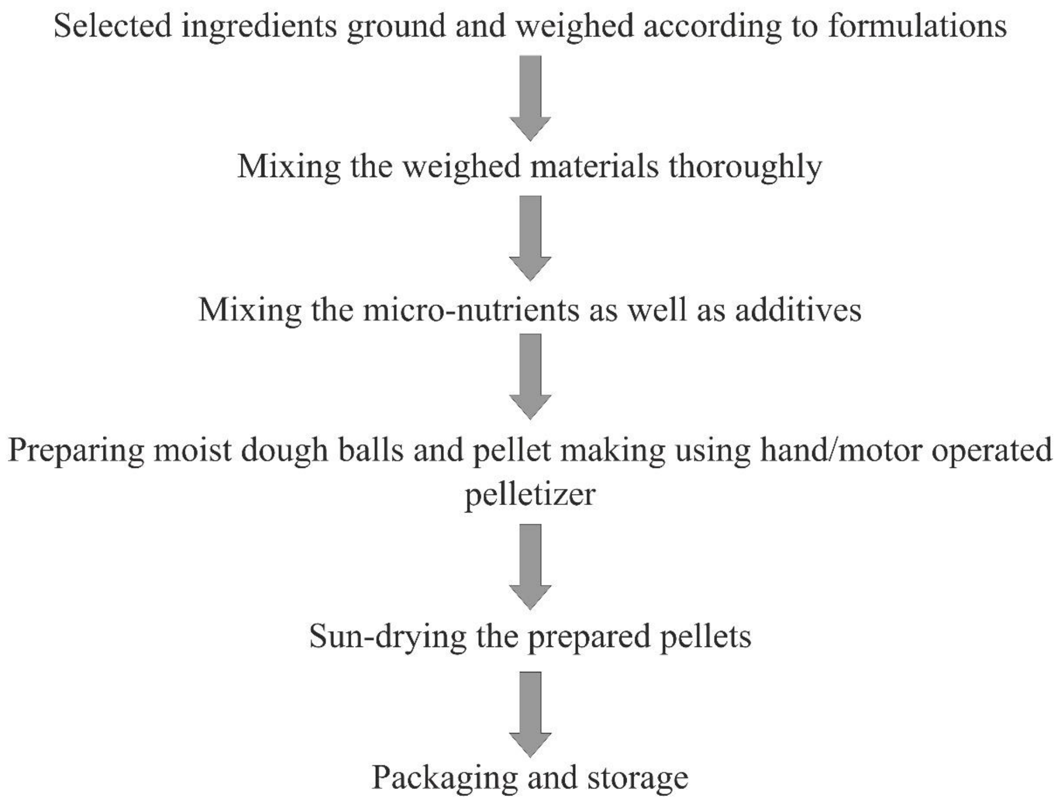

Figure 1. Flowchart showing the simple steps of fish feed preparation (farm-based).

In post-harvest and fish processing:

Post-harvest technologies seamlessly lead to processing techniques since, in most cases, products are marketed if not consumed immediately. In aquaculture, the cultivation of fish primarily serves exportation purposes. Processing doesn't always involve mechanical interventions; even a simple traditional sun-drying method is considered crucial. Its principle is to extend the shelf life of fish intended for consumption, as mentioned earlier. Similarly, mechanical means include packaging and wrapping fish in a vacuum, following the mechanisms of MAP (Modified Atmospheric Packaging) and CAP (Controlled Atmospheric Packaging). These methods prevent spoilage in the early stages after harvest. They involve introducing a mixture of gases with known compositions (Yesudhason et al., 2014; Nie et al., 2022). In CAP, the gases are controlled, while in MAP, they remain fixed or unaltered.

However, these techniques slightly contradict vacuum packaging, which entirely restricts air introduction to resist metabolic activities and oxidative phosphorylation within the muscular structures of the specimens (Otwell et al., 2006). Even in the post-harvest section, women play an active role in preserving harvested fish by allowing them to dry under the scorching rays of the sun. This simple technique, requiring minimal attention, is a regular habit among a large section of rural women in coastal sections of India, such as Digha Mandarmani beach areas, Purba-Midnapore, Sagar Islands in Dakshin 24 Parganas, etc. Harvested fishes are often noticed lying on horizontally placed bamboo poles in lines. In the fish processing sector, a significant section is solely concerned with turning fish fleshes into fillets and preparing various products and by-products. More than 40% of the workforce identified with these tasks comprises women (Sahu et al., 2018; Chandra & Sagar, 2003; Pradhan et al., 2023).

In ornamental fish and pearl farming:

‘Fish is only to eat’ – this concept is now totally in vogue. The commencement of technological advancement in every aspect of our daily life, such as health and nutrition, corporate careers, food production systems, and overseas trade, as well as in the fields of modern science, especially in biotechnological divisions, has, though, ended our lives in acute hustle (Mishra, 2019). Contradictorily, it has gifted us with a bio-diversified population of millions of fishes around us, featured with lustrous color patterns in their body. This, in turn, encourages us to keep them as ‘pets’ in our homes by domesticating them in small glass tanks in our residences (Pountney, 2023). Naturally, these populations are present within a million or shallow depths of water in the oceans or the coral reefs of either fresh, marine, or brackish water habitats, some of which even exhibit optical illuminations in their bodies in the form of bioluminescence (Thompson & Rees, 1995). These ornamental fishes, named so by comparing them with female ornaments, have become major stress relievers, dollar-earners, and great interests for trade for many (Priyashadi et al., 2022). Moreover, the cross-bred varieties of their several species are gaining more attraction than the native (parental) ones in the economic market. Hence, constructing aquariums for these fishes, rearing, and breeding them in domestication, and trading them suitably have now become just a ‘very simple activity’ for rural women (Pountney, 2023).

In the realm of ornamentals, pearls hold a distinct position among females due to their ornate appeal and their ability to enhance beauty significantly (Bustamante-Álvarez et al., 2021). Interestingly, despite belonging to the category of bivalves, which plays a crucial role in aquaculture beyond just fish, pearls have a unique allure. The roots of pearl familiarity extend back to ancient monarchies, where these prized embellishments adorned crowns, beds, and even some of the era's books. These pearls manifest in two primary types: those sourced from natural origins and those cultivated artificially to achieve diverse structures. Through controlled conditions, pearls can be synthetically generated by delicately inserting a bead into the mantle layer of bivalves. This is achieved by gently prying open their tightly conjoined valves using mechanical means. Following bead insertion, the valves remain undisturbed for several months, culminating in the formation of the ultimate pearl over an extended period. Engaging in this activity offers the advantage of the potential for lucrative financial returns, all achieved with a relatively modest capital investment. A second significant advantage lies in the fact that this cultivation practice can be carried out within household premises, easily accessible to housewives or other female individuals with the appropriate training (Yan et al., 2019; Forrest et al., 2009).

In ancillary activities:

The ancillary activities primarily include a. pond construction, aiding in clearing off the pond construction sites or associating with the valuable decision-making process to select the site of the construction of the fish ponds, b. net fabrication, c. vermicomposting, which involves sourcing out for the production of nutritious feed for the fishes (sometimes acting as a relevant source of nutrition to phytoplanktons) or its inclusion in the fish feeds, d. handling and marketing of fish. This is regarded as a chain of activities related to the selling of said products, involving suitable market research, and other relevant tasks (Sanchirico & Essington, 2021). In fishery or aquaculture, net fabrication mentioned first is a very important aspect. This is because the proper choice of net construction materials, their colors, and tensile strengths holds a crucial factor for governing the success of harvesting fish from the ponds. The color is more prioritized, drawing significant attention, as this color, in the case of gill nets, should be uniquely transparent for fooling the fish. This facilitates their slippage through the meshes and entangles them in their gill regions. Tensile strengths, on the other hand, are more effectively dealt with in the case of drag nets or seine nets, requiring a considerable labor force for filtering a certain section of water and collecting the fish from their bags. Among the most common types of nets being used in the rural grounds, the throw-out nets (cast nets or 'khepla jal' in local terms) are most common. The weaving and knotting of these types of nets are mainly done by women sections only (Azam et al., 2013; Haque et al., 2021). Handling and marketing of the fish, on the other hand, another important ancillary activity related to aquaculture, is regarded as the chain of activities related to selling said products, involving a suitable logistic series of supply-chain activities, indulging in a thorough critical survey of the market demands. In the domestic local markets, these fishes are generally marketed by the women communities, including their assistance in their transportation to the respective sites in the urban areas also (Jaikumar et al., 2023).

Conclusion:

In conclusion, the intersection of 'Sustainable Aquaculture' and the pivotal role of 'Rural Women' holds immense promise for addressing pressing issues related to nutritional security, economic viability, and ecological sustainability. The anticipated contribution of aquaculture to rural household nutritional security underscores the need for a focused effort on the development of production systems that are not only efficient but sustainable in the long term.

The future trajectory of aquaculture expansion should be guided by a commitment to enhancing the overall efficiency of natural resource utilization. This necessitates the establishment of farming systems grounded in primary renewable resources, striking a balance between economic viability and ecological soundness. The ongoing efforts to harness the potential of the rural women population are commendable, marking a crucial step towards realizing the vision of 'Atmanirbhar Bharat' and fostering transformative changes in the lives and livelihoods of rural communities. Moreover, the imperative to utilize all available water bodies for the production of aquatic food sources with high biological value cannot be overstated. This not only addresses nutritional needs but also underscores the importance of sustainable resource management. The introduction of social aquaculture, mirroring the successful model of social forestry, with a participatory approach involving local women, presents an intriguing prospect. This approach, particularly with the utilization of small indigenous fish species, serves a dual purpose—the conservation of endangered species and the production of affordable, high-quality edible animal products, contributing to the enhancement of human health in rural areas. In essence, the convergence of sustainable aquaculture and the active involvement of rural women offers a holistic and promising avenue for achieving the broader objectives of food security, economic empowerment, and environmental sustainability in the context of rural development. This synthesis not only underscores the interdependence of these themes but also highlights the potential for transformative change through collaborative and sustainable practices.

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Chapter- 25

Qualitative and Quantitative Assay of Coliform Bacteria in Different Water Samples & Their Role in Sustainable Development

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Keywords: Coliform Bacteria, Ganga, micro-organism, Sustainable Development, Water sample.

Abstract:

The research aims to provide valuable insights into the variation of coliform bacteria concentrations across different environmental water samples shedding light on potential sources of contamination and facilitating informed decision-making for water quality management and environmental health in the field of sustainable development. Our samples were collected from the Ganga, a pond and rainwater. Coliform bacteria, commonly used as indicators of faecal contamination, were analysed using standardized testing methods, such as the most probable number (MPN) technique, standard plate count (SPC) method and also biochemically by the IMViC test. The findings of this study contribute to our understanding of microbial ecology and support the development of targeted strategies for the prevention and mitigation of coliform bacteria-related risks in diverse settings. By MPN Test it is proved that all the 3 samples contain Coliform Bacteria, in the colony counting method 190 colonies are found in the Ganga sample while Pond and Rainwater samples contain 153 and 30 colonies respectively and the IMViC Test also concluded the presence of different strains of bacteria in the Ganga samples i.e., gave positive results.

Introduction:

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Coliform bacteria are a different group of microorganisms that inhabit water, soil, and the gastrointestinal tracts of mammals. They're extensively used as index organisms to assess the microbiological quality of water and food. Coliform bacteria are frequently associated with faecal impurity and can indicate the presence of pathogens that pose a threat to human health. Understanding the distribution, and characteristics of coliform bacteria is pivotal for assessing water quality, food safety and enforcing applicable public health measures.

Definition and Classification of Coliform Bacteria:

Coliform bacteria belong to the family Enterobacteriaceae and are characterized by their capability to ferment lactose with observable production of gas. They're generally facultative anaerobes, gram-negative rods, and include rubrics similar as *Escherichia*, *Enterobacter* and *Klebsiella*.

Role of Coliform Bacteria in Sustainable Development:

Coliform bacteria play a multifaceted role in sustainable development, contributing to water quality management, wastewater treatment, agricultural sustainability, environmental monitoring, and public health promotion. Properly managing coliform levels is integral to achieving a balance between human activities and environmental conservation for long-term well-being.

Sources and Transmission Routes of Coliform Bacteria:

Coliform bacteria can appear from a variety of sources, including sewage, domestic effluents, animal and human by-products. They can enter water systems through surface runoff, wastewater discharges, or defective septic systems. Spoilt food products, like raw vegetables and undercooked meat, can also be a source of coliform bacteria.

Health Risks Associated with Coliform Bacteria:

While not all coliform bacteria are pathogenic, their presence in water and food can indicate the possibility of harmful diseases. Some coliform species, similar to certain strains of *Escherichia coli*, can beget severe gastrointestinal infections, leading to diarrhoea, abdominal pain and might be fatal in elevated situations.

Microbial-mediated water pollution is seen as one of the great challenges to the aquatic environment worldwide. The influx of faecal matter, hospitals, industrial effluence and cattle farms increase the bacterial load in a given water body (Mondal et al., 2022). Coliform bacteria group is conventionally viewed as an indicator organism of microbial contamination. From the coliform, *Escherichia coli* is the indicator of faecal contamination. De Man-diphasic tube fermentation technique is one of the casually employed methods for the detection of coliforms through sugar lactose fermentation with the production of either acid or gases. Potability of water has been assessed by bacteria of faecal origin either absent or present within the tolerance level as specified by MPN/100 ml (Some et al., 2021).

It is believed that bacteria in patients' faeces cause and spread many human diseases such as cholera, typhoid fever, dysentery and gastroenteritis which contaminate food and water thereby rendering them unsafe for consumption. Coliform bacteria are the traditional microbiological indicators most commonly used to assess water quality. Two of the most commonly used pollution indicator bacteria that have been employed as hygiene metrics for the assessment of drinking water cleanliness are the total and faecal coliform counts (Aram et al., 2021).

The source of drinking water is surface waters, i.e., lakes and reservoirs, mostly in rural areas where water availability is a problem (Biswas & Saha, 2021; Bandyopadhyay et al., 2023). This fresh water is full of coliform bacteria nowadays. During the course of two years between 2018 and 2019, this study examined two drinking water reservoirs: Klingenberg and Small Kinzig Reservoir. In summer four orders of magnitude coliform bacteria were detected per 100ml than in wintertime and concentrations up to 2.4 × 104 bacteria per 100ml (Reitter et al., 2021).

River constituents can change their genetically linked physical, physiochemical, and biological characters due to the introduction of artificial constructions in them (Bhattacharya et al., 2016; Roy et al., 2022). Coliform bacteria are important quality indicators of water linked to human health. An investigation was done on eight weir stations constructed in Nakdong River, an important river in South Korea, to consider the relationship between coliform bacteria and water quality parameters. From 2012 to 2016 these sites' fifteen water quality parameters were studied by multiple regression and correlation analysis. The results for each station proved the analytical validity; the average adjusted R2 values for total and faecal coliforms were high, more than 0.6 and 0.8, respectively (Seo et al., 2019).

Comparison of antibiotic-resistant coliform bacteria occurrence between Czech and Slovak Republic hospital wastewater effluents was done. As a resistance mechanism and persistent virulence factor, it has also reviewed a few isolates that are resistant to antibiotics. The biggest amount of drug-resistant germs was found in samples taken from the hospital in the Czech Republic, Valašské Meziříčí. More than half of the resistant isolates were found to produce biofilm and they were also phenotypically multidrug resistant. TetA and TetE genes were found to be co-overexpressed together with efflux pump overproduction in 42% of isolates (Lépesová et al., 2020).

Aims and objectives:

The primary objectives are as follows-

- To quantify and compare the microbial load of coliform bacteria in different water samples including Ganga water, Pond water and Rainwater.

- To identify different strains of Coliform Bacteria.
- To identify different transmission routes and sources of coliform bacteria, aiming to focus on factors contributing to their presence continuity.

Materials and methods:

Sample Collection and Processing:

Samples were collected from Ganga, Pond and Rainwater samples were collected using standard sampling techniques.

Study design:

Selection of Study Sites and Sample:

The study was conducted in the metropolitan area of Kolkata and the water samples were collected from the river Ganga (Lat. 22.566^0, Lon. 88.339^0), a local pond (Lat. 22.535^0, Lon. 88.363^0) and from direct rainwater.

In the area from where the Ganga water is collected various human activities go around daily including washing clothes, bathing and also idol immersion, which might suggest that the Ganga water is highly polluted. On the other hand, the pond water was collected from a pond residing inside the Birla Industrial and Technological Museum (BITM), which is regularly cleaned and maintained so that it might be less polluted.

Enumeration and Identification of Coliform Bacteria:

MPN Test:

Soil surveys carried out on several sites in India showed that coliforms are present in potable water as a result of the presence of CO_2-releasing bacteria while they ferment lactose. An easy, fast, and cheap field test for screening of drinking water for the presence of faecal contamination which is based on the recognition of CO_2 gas by the new test is comparable to the standard MPN. It proved highly successful in the field when it was used to detect faecal pollution and monitor water quality during an outbreak of water-borne hepatitis A infection in the city of Gwalior.

Colony Counting Method:

After checking the presence of Coliform bacteria in the water samples to check the load of the present bacteria Colony Counting method is done.

Sterile Skimmed Milk agar plates are taken and 100µl of inoculum from each sample are added. Then using a sterile glass spreader, the inoculum is evenly spread on the agar plates. After that the inoculated petri plates are inverted and incubated for 48hrs at 37°C and results are observed.

IMViC Test:

The IMViC set is a group of four distinct tests that are widely employed to identify bacterial species, namely coliforms.

The letter in “IMViC” means one of the tests. “I” means indole; “M” is for methyl red; “V” is for Voges-Proskauer, and “C” is for citrate. The small letter “i” is an addition to improve pronunciation. IMViC is an acronym consisting of four different tests.

Indole Test:

It is grown on the sulphide-indole-motility (SIM), tryptophan broth, or the motility urease indole (MIU) medium. After the addition of Kovac’s reagent, the result is read. The appearance of red layer on the top of the tube after Kovács reagent has been added indicates a positive result. A negative result implies the absence of colour change at the top of the tube after adding Kovács reagent.

Methyl Red (MR) Test:

Methyl red and Voges–Proskauer tests are carried out in methyl red-Voges-Proskauer (MR-VP) broth where the added reagents vary depending on the tests. Presence of positive methyl red test is confirmed by turning red colour post methyl red reagent addition. No colour change after methyl red reagent has been added is indicative of negative methyl red test.

Voges Proskauer (VP) Test:

Negative VP reaction is indicated by no colour change following the addition of the first and second Barritt's reagents. The presence of red-brown colour after mixing Barritt’s A and Barritt’s B reagents is the indicator of a positive Voges-Proskauer’s test.

Citrate utilization Method:

The test is performed on Simmons citrate agar: Better the previous thing and greater the next. Absence of both growth and colour change in the tube denotes a negative citrate utilization test A positively reacted citrate is identified by growth and a blue colour change.

Results

MPN Test:

In this method air bubble confirming the presence of coliform bacteria is found in all the samples. But with varying sizes of the bubble. The increasing order of the bubble is Ganga>Pond>Rain. Therefore, the presence of bubbles in all the samples gives a positive test for MPN.

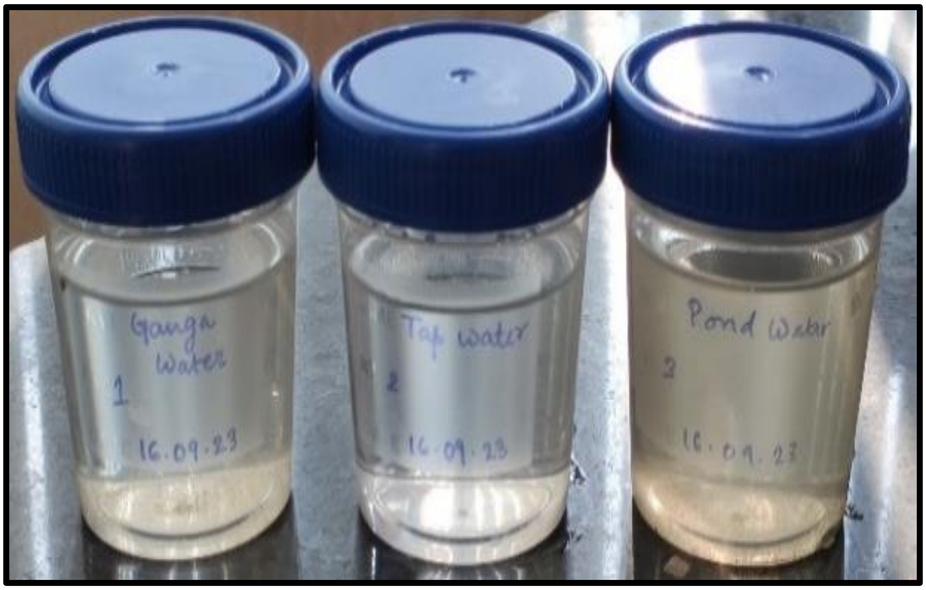


Figure 1. Collected water samples.

Figure 2. Gas bubble formation in the 3 Samples.

Colony Counting Method-After plating:

After 48 hours of incubation the following results are obtained.

Table 1: CFU count in agar plates.

Number of CFU found in the Skimmed Milk Agar Medium	
Ganga	190
Pond	153
Rain	30

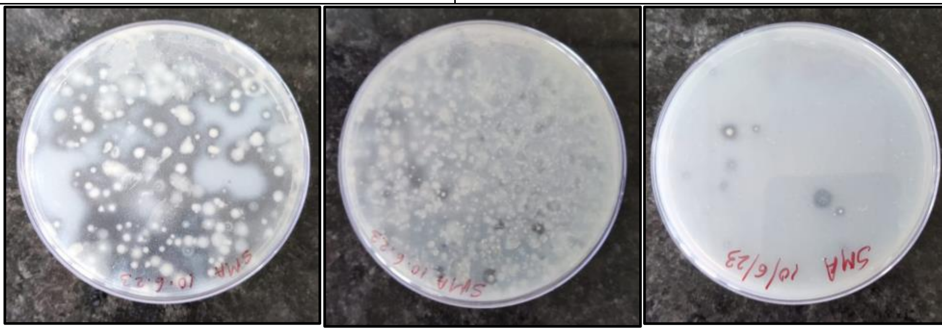


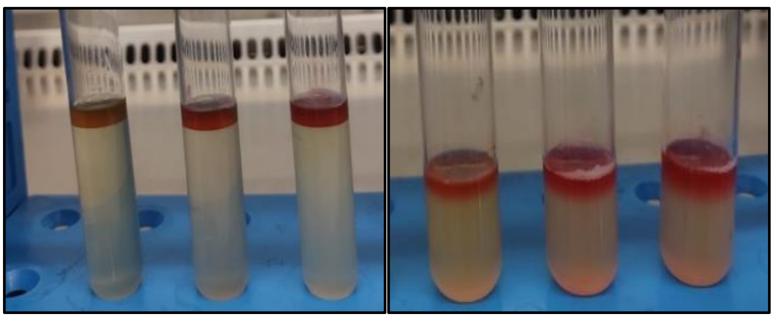
Figure 3. The colony was formed by plating the 3 Samples in petri dishes.

IMPVIC:

In the four different tests i.e. Indole Test, Voges Proskauer (VP), Methyl Red (MR) and Citrate Agar all the samples were tested and they gave different results according to different strains of bacteria present in the samples.

Table 2: Result of IMViC Test of the samples.

Samples	Indole	VP	MR	Citrate Agar
Sample 1	+	+	+	+
Sample 2	+	-	-	+
Sample 3	-	-	-	+



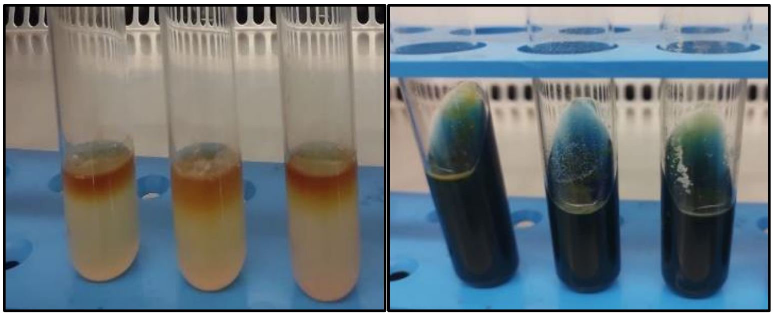


Figure 4. Results of IMViC.

Discussion:

Implications of the Findings:

In the first experiment i.e., the MPN Test which is a qualitative test, a bigger gas bubble is observed in the Ganga water compared to pond and rainwater when all three samples are inoculated in the same media and incubated at similar conditions for a particular period of time which implies that the concentration of Coliform bacteria in the Ganga water is much more than the other two samples. In the second experiment i.e., the Colony Counting method, 190 colonies of coliform bacteria are observed while pond water and rainwater contain 153 and 30 colonies respectively. By this quantitative method, it is seen that Ganga water contains more Coliform Bacteria compared to pond and rainwater.

At last, in the IMViC Test which is a biochemical test, Ganga water was detected positive for all four tests while pond water was positive for 2 tests and rainwater was for only one. This implies that Ganga water contains a various number of bacterial strains compared to pond and rainwater.

Conclusion:

This experiment concludes that Ganga water contains a high concentration of Coliform Bacteria mainly due to the day-to-day activities performed there. While the load of Coliform Bacteria in pond water is less since it is maintained periodically. The rainwater contains a slight or negligible number of coliform bacteria since there is no direct contamination pathway involved.

From this, we can say that Coliform Bacteria help to detect water pollution or otherwise serve as indicators of overall environmental health. Monitoring of these coliform levels helps to assess the safety of water for consumption and recreational activities.

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Chapter- 26

Environmental DNA: an Emerging Sustainable Tool for Ecological Monitoring

Piyali Chowdhury

Keywords: Environmental DNA, Biodiversity conservation, Metabarcoding, Sustainable development.

Abstract:

One can extract DNA from any environmental sample irrespective of the organism i.e., Soil, Water, Air. This DNA is identified as environmental DNA or eDNA. The application of the novel eDNA approaches, particularly NGS techniques, has evolved biodiversity surveys taking into account both the budget and the time. eDNA has revolutionized our thinking about biogeography. Results obtained from eDNA approaches have given some crucial insights into the study of ancient environments that are useful in the sustainable management of contemporary biodiversity in aquatic and terrestrial ecosystems. Advancements in eDNA technologies also enhance the knowledge of molecular ecology and make it possible to answer different ecological questions by using genetic methods.

Introduction:

Depletion in biodiversity is one of the most important concerning issues in the 21st century (Butchart et al., 2010). Anthropogenic disturbances are the main cause behind this worldwide depletion (Barnosky et al., 2011; Dirzo et al., 2014). Biodiversity loss has a great negative impact on human health and the sustainability of our planet (Diaz et al., 2014). Our knowledge about biodiversity is still incomplete or even undescribed for various taxa and geographical realms (Vié et al., 2009). Some International political agreements have also been made to pause the current loss in biodiversity (UNEP, 2011). However, all such efforts to save biodiversity exclusively depend on biological monitoring to acquire precise data on species distributions and population size on a particular ecological time scale. Physical identification can monitor species (viz., visual surveys, counting the number of similar species in a particular area) but this monitoring technique leads to some confusion due to the phenotypic plasticity and close similarity in related species. Thus, there are some species data flaws with errors (Daan, 2001; Sharfuddin et al., 2023). Moreover, different traditional techniques are supposed to be invasive to the studying species or ecosystem (Jones, 1992). Furthermore, morphological identification strongly depends on taxonomic expertise, which is seldom unavailable (Hopkins and

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Freckleton, 2002; Wheeler et al., 2004). All these limitations of traditional biodiversity monitoring techniques demand an alternative approach, one of them is eDNA technology. eDNA technology has a strong potential to combat many of these challenges associated with biodiversity monitoring (Baird and Hajibabaei, 2012; Kelly et al., 2014).

eDNA is used to refer to DNA extracted from environmental samples (Barnes and Turner, 2016a). eDNA can also originate from skin, saliva, mucus, sperm, secretions, eggs, faeces, urine, blood, roots, leaves, fruit, pollen and decayed bodies of larger organisms including entire microorganisms (Bohmann et al., 2017; Barnes and Turner, 2016b). Hence, eDNA is a mix of nuclear, mitochondrial and chloroplast DNA from various organisms (Taberlet et al., 2012). It enables the detection of any life-stage species and from both sexes. eDNA can be sampled from dead organisms before decomposition.

Scientists have highlighted the fact that eDNA derives not just from microorganisms but from a wide range of plants as well as vertebrates. Many ancient flora and fauna have left their extrachromosomal DNA traces in the sediments instead of fossilization (Pal et al., 2017; Bashar et al., 2022). DNA traces from woolly mammoth and moa birds (both are extinct) were found in sediments from Siberia and New Zealand (Willerslev et al., 2003). Modern plant DNA can be recovered from the surface soil. At the same time, another team has successfully sequenced DNA from extinct giant ground sloth and other Pleistocene animals from a dry cave in the Southwest US (Hofreiter M et al., 2003). Furthermore, it is shown that eDNA data and other proxies such as pollen, macrofossils, living mammals and plants seem to complement each other demonstrating a range of species that is wider than achieved by using the methods separately (Pawłowska et al., 2014). Hence, eDNA should be regarded as a supplementary, not a replacement, method of analysis of more orthodox environmental proxies. In this, we provided a simple description of eDNA so as to remove the distinction between various forms of DNA in fact, in contrast to the community DNA (Deiner et al., 2017). Also the separation of eDNA and community DNA is very fundamental as the eDNA might be from a different location or predator faeces or from the past presence and the community DNA points to organism presence at a certain time and location (Creer et al., 2016; Deiner et al., 2017). This chapter assumes for simplicity that eDNA is collectively regarded as including many sectors of DNA biodiversity research that involve faecal analysis and bulk samples when they apply to biodiversity research and ecosystem analysis.

Methods used in eDNA research:

DNA barcoding approach is used in eDNA research, in which the sequence of the mitochondrial cytochrome oxidase 1 (COI) gene is used as a marker. eDNA fragments are usually shorter (about 100bp) and sequences of mitochondrial, chloroplast or ribosomal RNA genes, aside from COI are used in the analysis (Diaz-Ferguson et al., 2014). For unknown taxa, target sequences are generally grouped by so-called molecular operational taxonomic units (MTOU$_{S)}$.

Sampling:

Most environmental samples contain a very low number of endogenous DNA molecules along with some contamination. eDNA can be extracted from a variety of sources viz. ice and permafrost, lake sediments, stagnant water etc. (Pederson et al., 2015; Creer et al., 2016) so, contamination remains one of the greatest experimental challenges to DNA research. Due to the variable collection point sampling methods for eDNA studies are also variable. The method of sampling and the volume and the number of samples taken depends not only on the type of substrate but also on the specificity of the taxa of interest and the environmental heterogeneity (Ruppert et al., 2019; Creer et al., 2016). Negative control samples are also required to overcome the contamination problem. Samples are stored at –20°C, in 100% ethanol or a cell lysis buffer for further use (Pinakhina et al., 2020)

DNA extraction from environmental sample:

Unbiased extraction from environmental samples demands a great effort as it contains a high level of biological complexity. To be able to extract DNA from the samples with equal efficiency invariable seems as theory, because of the variety of sample types. None of the generic extraction methods yield uniform performance across all environments and taxonomic groups (Pont et al., 2018; Cowart et al., 2018; Garlapati et al., 2019). Despite the fact that a large number of commercial and custom extraction protocols were modified for handling different combinations of sample types and organisms. Some of them are generics and have been applied for the eDNA studies in lakes, ancient sediments, and ice (Cristescu et al., 2018; Barnes et al., 2014; Erickson et al., 2016; Seymour et al., 2018) but increasing the knowledge of extraction bias will be appreciated.

Primer Designing:

The most critical part of eDNA metabarcoding research is primer designing. Typically, COI for metazoa and Ribulose bisphosphate carboxylase large chain (rcbL) for plants are used as the standard choice but 12s and 16s ribosomal RNA are also observed to be used in different taxa (. A good primer for eDNA metabarcoding should be short enough to amplify the degraded DNA samples, identical within but variable between species, with highly conserved regions to amplify as many species as possible without compromising the primer specificity to the target group (Epp et al., 2012) The most common sequencing platform in present days eDNA metabarcoding is Illumina (Jarman et al., 2018). Third-generation sequencing technologies have as well been used.

Bioinformatic analysis:

The end of the eDNA research is a bioinformatic analysis of the resulting data. Due to technological development, a large amount of data has been produced which required several programs for analysis as carriage provided by Alberdi et al. (2018). It consists of millions of reads which explain the genetic code of every strand of DNA that has been sequenced. These reads are aggregated in OTUs. OTUs were employed for the distinction of species/taxa via sequence similarity, but the traits of taxa such as ecological and physiological also need to be coupled with OTUs to get a key to identify them. Several programs are to enable this process, of inter-population, however, variation impedes them (Coissac et al., 2012; Cristescu, 2014; Deiner et al., 2017). OTU clustering is based on the similarity to a certain sequence and then grouping under similarity cutoffs, with 97–99% typically as a cutoff range.

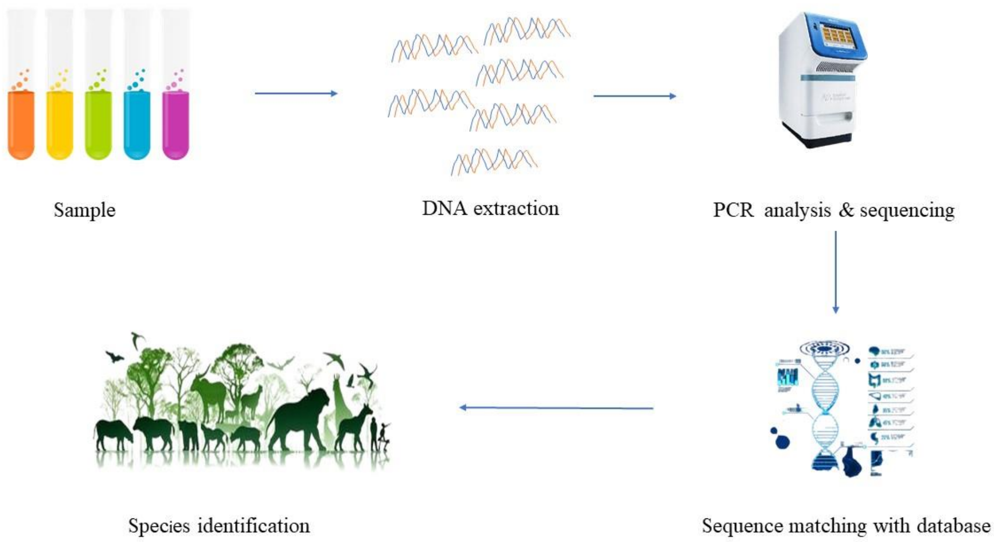

Figure 1. To identify species using environmental DNA (eDNA), samples are first collected from the environment, such as water, soil, or faeces. Subsequently, eDNA from organisms in each sample is extracted. The DNA sequences obtained are then multiplied through polymerase chain reaction (PCR) to ensure an adequate amount for analysis. Following amplification, the sequences are read on a sequencing machine, revealing the order of bases on the DNA strands. Finally, these sequences are compared and matched to known sequences in worldwide databases, facilitating the identification of the specific species present in the environmental samples.

Category of eDNA research:

eDNA research can be categorised into two main groups: targeted (species-specific) and multi-targeted (community) (Simmons et al., 2016).

Targeted (species-specific) eDNA research:

eDNA approach was highly successful in identifying a particular species, even in low abundance (Rees et al., 2014). With that in mind, specific primers were designed and only DNA of designated species was amplified to determine whether the species was present in the environment.

eDNA sample collected from aquatic habitats is rather homogenous and is usually perceived to reflect the diversity of species residing in and around the sampled habitat (Cristescu et al., 2018). The DNA can also be used to detect terrestrial organisms from water samples, for example, the DNA fragments of terrestrial organisms enter aquatic systems when they drink water (Rodgers and Mock, 2015)) or move through water (Ushio et al., 2017). DNA from extinct and extant mammals, birds and plants has been detected in soil/sediments or dry cave sediments reported by Hofreiter and Rompler (2010). Species-specific monitoring offers further information concerning a species, save for this purpose, which is species detection. Hence, it improves the comprehension of ecological and evolutionary effects resulting from environmental alternations (Giguet-Covex et al., 2014).

Multitargeted (community) eDNA research:

eDNA research is equally applicable in community monitoring as individual species monitoring. Nowadays researchers started the diagnosis of other species that they have ever used general PCR primers paired with cloning and Sanger sequencing (Minamoto et al., 2012) or high-throughput sequencing (HTS; Thomsen et al., 2012). Community monitoring at multiple targets (or metagenomics, metagenetics, metasystematics, or metabarcoding) is sometimes called multi-targeted (community) monitoring, or passive monitoring (Taberlet et al., 2012; Simmons et al., 2016). Much economic and effort are to have also because this study of using eDNA makes surveys of many species by one activity. For instance, one piece of research employed HTS to discriminate several earthworm species in soil samples and conjectured that the same technique could be applied to characterization of other soil-dwelling taxa. The multi-species monitoring capacity of eDNA makes it a promising tool for conservation biology (Yoccoz, 2012).

Application:

eDNA technology is widely used in ecosystem and biodiversity monitoring. This approach is truly relevant in several different environments both ancient and modern, terrestrial and aquatic. Here are some major applications of eDNA research:

Species monitoring:

The most explored field of eDNA research is its application in species monitoring. In addition to monitoring the target species and the whole community, the research on eDNA is also used in invasive species monitoring and monitoring of rare and endangered species. Besides the multitude of works on fish and amphibians, methodologies have been proposed for the identification of invasive freshwater mollusc species from Europe (Clusa et al., 2017), the Burmese python in Florida, and also the algae Codium fragile which can be traced back to Suringar and Hariot (1889) (Muha et al., 2019). The use of eDNA in the monitoring of rare species is as efficient as the eDNA monitoring programs that were accepted by environmental institutions. For instance, in 2014, Nature England, a non-governmental organization sponsored by the UK Department of

Environment, Food and Rural Affairs, approved the eDNA analysis protocol (Rees et al., 2014) for the detection of the crested newts Triturus cristatus, Laurenti, 1768, which is listed in the international Red Book.

Estimation of organism abundance:

Various studies have begun to explore the quantification of eDNA as a means of estimating organism abundance or biomass. For example, a study carried out in a Japanese lagoon suggests that the eDNA concentration of common carp is related to fish abundance (Takahara et al., 2012).

Population genetics and genomics:

Beyond presence/absence and abundance information, there is more information to be gained from eDNA surveys. eDNA research provides a great opportunity to study population genetics. Genetic analysis of eggshells, hair, faeces, feathers and other samples promotes advances in non-invasive genetic studies.

Functional genetics and genomics:

Remarkably low cost of biotechnology, mostly HTS, has allowed functional genomic analysis of relevant taxa that were previously limited to model systems (Steiner et al., 2013). Application in practice is for finding of adaptive or loci related to fitness, tracing the loci related to stress events and describing the molecular basis of inbreeding depression (Schwartz et al., 2007; Paige, 2010).

Control of the spread of the parasite:

EDNA technology is applicable in the containment of infectious parasitic invaders. Thus, a system has been developed for the detection and monitoring of *Schistosoma mansoni* by extracting eDNA from the water samples (Sengupta et al., 2019).

Detection of plant pathogen:

The application of eDNA method appears to be promising for the identification of plant pathogens in crops. Consequently, the Precision Biomonitoring campaign (Pinakhina et al., 2020) is a service for the detection not only of bacteria but also for fungi that belong to human health and plant threats represented in Cannabis samples.

Healthcare:

eDNA technology is employed in healthcare to detect fungi that can cause allergic reactions when their spores and mycelium fragments get airborne and hence become sources of infection. The deployment of metabarcoding can heat up the taxonomic coverage of fungi dwelling in the air by 10 times more than microscopy (Banchi et al., 2018). Tong et al. (2017) proved such analysis of fungal diversity in air samples in hospitals can be of importance in providing for preventing potential infections and for the selection of the best decontamination procedures.

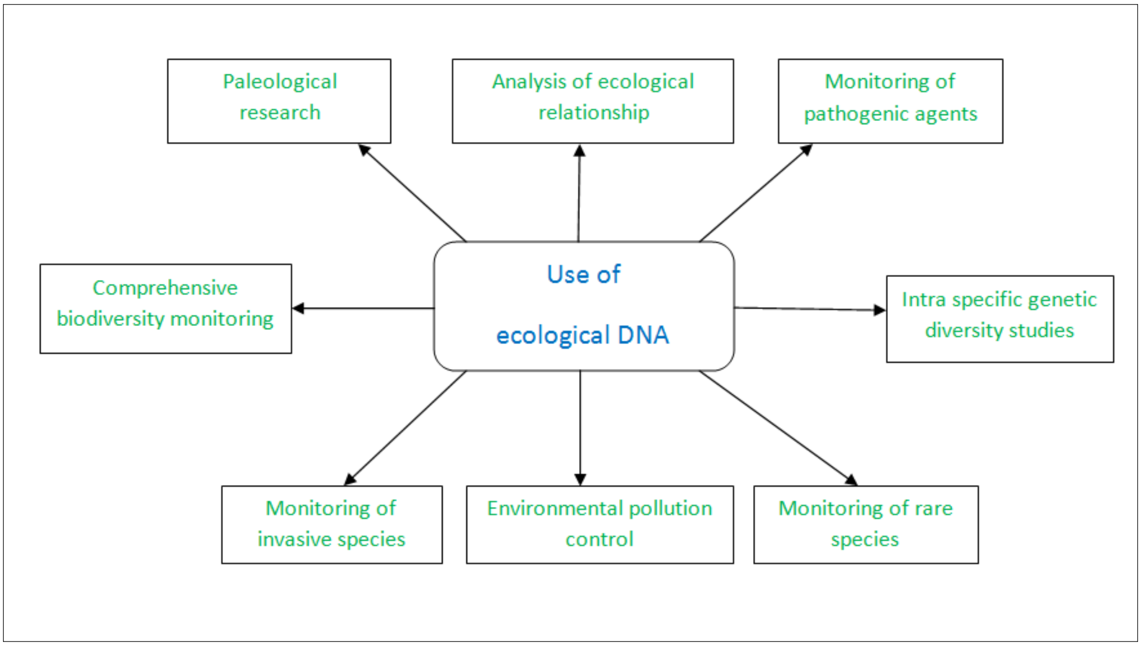

Figure 2. The main areas where eDNA studies are applied for sustainable monitoring.

Challenges:

Nowadays eDNA method is widely used in various aspects of biodiversity conservation. But this technology also faces some challenges viz. degradation of DNA, marker problem, contamination in the sample, inhibition of Taq polymerase by impurities present in eDNA samples etc.

Opportunities:

The evolution of DNA sequencing technologies has broadened eDNA use possibilities, with the advances to be expected in the future. While initial eDNA studies relied on clone-based subsequent Sanger sequencing of PCR products, the impact of new emerging sequencing techniques is obvious (Shokralla et al., 2012) and eDNA would be fully integrated into ecologist tools (Baird and Hajibabaei, 2012; Taberlet et al., 2012; Valentini et Besides, new generations of modern technologies including next generation sequencing techniques as PacBio RS invented by Pacific Bioscience or Nanopore-based sequencing by Oxford Nanopore Technologies, carbon nanotube chips (Mahon et al., 2011) and real-time laser transmission spectroscopy (Egan et al., 2013; Li et al., 2 Traditionally eDNA has been used in the specific context of species or communities to analyse single markers. But going forward, we will explode out into meta-genomic surveys of entire ecosystems with the goal of predicting spatial and temporal biodiversity patterns (Davies et al., 2012; Kelly et al., 2014). This is what we want ultimately - to apply the eDNA through the most holistic method for the sake of the planet and living creatures. Environmental DNA will only be handy in detecting biodiversity, providing quick and quality assessments of species' present status, their distribution, abundance and the overall size of their population. These aspects suitably render conservation decisions. Thus, it will never involve direct action against the biodiversity crisis which so far is a more challenging problem demanding mostly political will, determination, and activity.

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Chapter- 27

Revolutionizing Leather Industry Wastewater Treatment: A Game-Changing Approach for Sustainable Environmental Management

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Keywords: Environment sustainability, leather industry, sustainable development goals, wastewater treatment, 4R strategies.

Abstract:

The substantial volume of wastewater generated by the leather industry, laden with high levels of pollutants, poses a significant environmental threat. Without proper treatment, the discharge of such wastewater could have severe and detrimental effects on the environment. The treatment of wastewater in the leather industry is pivotal for mitigating environmental impacts and represents a cornerstone of sustainable environmental management. The industry not only minimizes its environmental impact but also aligns with and contributes to various sustainable development goals (SDGs). The industry's commitment to responsible practices is demonstrated by employing diverse methods such as BOD, chlorides, COD, Cr (III), heavy metals, sulfates, and TDS. This includes adsorption, biochemical/biological treatment, chemical precipitation, Electro-coagulation, Fenton oxidation, hybrid processes, ozonation, electro-oxidation, photo-catalytic ozonation, and physical treatment. Moreover, a sustainable approach involves the recovery of valuable substances from the treated wastewater. The solid waste generated, particularly after chromium removal, contains minerals such as phosphorus (P) and potassium (K), which are categorized into 4R (reduce, reuse, recycle, and recover) dimensions. Integrating advanced wastewater treatment methods and resource recovery processes in the leather industry not only helps mitigate environmental impacts but also aligns with broader sustainability objectives, embodying a responsible and forward-thinking approach to wastewater management. Combining effective wastewater treatment in the leather industry is a cornerstone of sustainable environmental management. The emphasis on recovering valuable substances and repurposing solid waste underscores a holistic and responsible approach toward resource utilization. This comprehensive strategy indeed reflects a commitment to environmental stewardship and sustainability in the leather industry.

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Introduction:

The leather industry, though not one of the largest globally, holds significance in regional economies and has historical roots as one of the oldest industrial practices (Chen et al., 2023). Tanning, a key process within the industry, serves to transform raw animal hides into stable leather products and prevent decay (Dowlath et al., 2021). This process involves three main stages: collection and pre-treatment of raw hides, tanning with appropriate agents, and final drying and finishing before the end product reaches the manufacturers (Saxena et al., 2017; Mwondu, 2017). Mineral and vegetable tanning are the two main types, with chrome tanning, a form of mineral tanning, still predominating in the leather industry (Hu et al., 2011; Adiguzel-Zengin et al., 2017).

The leather-making process involves substantial water usage, as hides are transformed into leather in aqueous mediums containing various chemicals (Hansen et al., 2021). Approximately 40-45 liters of water are utilized per kilogram of rawhide processed into finished leather (Sundar et al., 2001). However, a significant environmental concern arises as about 90% of the total water used in the manufacturing process of pesticides is released into the environment as waste (Gruiz, 2015; Wang et al., 2016). This highlights the importance of addressing water consumption and implementing effective wastewater treatment measures in the leather industry for environmental sustainability (Karuppiah et al., 2021).

The significant amounts of waste generated from lethal manufacturing processes contain substantial chemical oxygen demand, biochemical oxygen demand, suspended and dissolved solids, chromium, surfactants, and other toxic materials (Azom et al., 2012; Jahan et al., 2014; Das et al., 2022). The complexity and wide-ranging nature of the leather industry, coupled with the extensive use of chemicals, make the treatment of tannery wastewater challenging (Wang et al., 2018). The need for isolation and separate treatment of each departmental flow necessitates considerable investments in terms of equipment and land, further emphasizing the intricate nature of addressing environmental concerns in the lethal processing sector (Ghulam & Abushammala, 2023).

Various methods exist for treating tannery wastewater (Droste & Gehr, 2018; Zhao & Chen, 2019). Physicochemical techniques commonly employed in wastewater treatment can be applied to tannery wastewater, either in the whole process or in specific steps (Elabbas et al., 2016). However, these processes may incur high costs. The selection of treatment operations is influenced by the contamination level in the water, which is directly involved in the production process, legal compliance for water discharge, and considerations such as a communal wastewater treatment plant sending water, the municipal collector, or the potential for reuse within the production process (Deghles & Kurt, 2016). The complexity of these factors underscores the need for a tailored and strategic approach to tannery wastewater treatment (Lofrano et al., 2013).

Wastewater treatment involves a range of methods, including physicochemical and biological processes, and often a combination of both. Conventional methods for wastewater treatment include physical techniques such as aerobic and anaerobic treatment, chemical processes such as precipitation, oxidation, ozonization, electrochemical methods, and mechanical treatment. The industry addresses pollutants such as COD, BOD, TDS, Cr(III), chloride, sulfate, and heavy metals. In tannery wastewater treatment, some facilities may opt for a comprehensive approach, employing various treatments on-site (Kowalik-Klimczak & Gierycz, 2014; Jahan et al., 2014: Thakur et al., 2021). This can involve separating different streams, chemically treating tanning yard wastewater to precipitate chromium, physically treating tanning yard wastewater to precipitate chromium, physically treating chloride-laden soaking wastewater, and employing biological treatment for the remaining effluent. Alternatively, tanneries may choose to conduct pre or partial treatment before sending the effluent to a central or municipal treatment plant (Stoller et al., 2013). Consequently, wastewater treatment becomes a pivotal aspect of mitigating impact and a cornerstone of sustainable environmental management (Yong et al., 2016).

The leather industry, although economically significant for many emerging countries, presents a substantial environmental challenge characterized by elevated pollution levels (Kanagaraj et al., 2020). The discharge of untreated water laden with diverse chemicals intensifies this environmental impact, generating a significant volume of effluent throughout the leather-making process (Ricky et al., 2022). Addressing this environmental concern requires the effective treatment and detoxification of tannery wastewater (Saxena et al., 2017). While conventional methods exhibit limitations, this paper explores the potential of membrane technologies as a promising solution (Obotey Ezugbe & Rathilal, 2020). The comprehensive review encompasses an examination of environmental pollution and toxicity aspects of tannery wastewater, a discussion of traditional treatment methods, and an in-depth exploration of membrane technologies. The evaluation extends to advancements in membrane treatment approaches, considering both laboratory and pilot/industrial scales. The paper underscores the potential role of membrane technologies in mitigating the environmental challenges associated with tannery wastewater. Furthermore, it explores integrating membrane treatments with physicochemical and biological methods, offering a nuanced perspective on sustainable solutions for the leather industry (Table 1). This commitment to responsible practices not only minimizes environmental impact but also aligns with various sustainable development goals (SDGs) (Zimon et al., 2020). Additionally, the industry’s focus on resource recovery, including valuable substances from treated wastewater and repurposing solid waste, further demonstrates a 4R (reduce, reuse, recycle, and recover) approach (Fan et al., 2020). Integrating advanced wastewater treatment methods underscores a forward-thinking approach to wastewater management, reflecting a dedication to environmental stewardship and sustainability in the leather industry (Hasan et al., 2023). The economic importance of the leather industry is clear, notably in countries like India where it significantly contributes to foreign exchange earnings. Nevertheless, the concentrated presence of tanneries necessitates continuous efforts to address potential environmental and health impacts. Regulatory measures and ongoing mitigation initiatives are essential for fostering sustainable development in the leather industry.

Table 1: Conventional waste treatment methods (Kowalik-Klimczak & Gieryoz, 2014; Gadlula et al., 2019).

Method	Advantages	Disadvantages
Precipitation	The precipitation of chromium (III) from wastewater is a common method used in water treatment to reduce its concentration to desired levels. The process involves introducing a precipitating agent that reacts with chromium (III) ions in the water, forming insoluble precipitates. These precipitates can then be separated from the water through processes such as sedimentation, filtration, or centrifugation.	The precipitation method for chromium (III) removal from wastewater, while effective in reducing chromium (III) concentrations, may not be selective enough. This lack of selectivity can lead to the co-precipitation of impurities or the inclusion of other metal ions along with chromium (III) in the precipitates. Such co-precipitation can result in a poor quality of the recovered chromium (III).
Activated Sludge	Activated sludge is a widely employed biological treatment process in wastewater treatment plants, offering several advantages and making it a popular choice for effectively removing pollutants from wastewater.	Activated sludge systems are sensitive to sudden increases in influent concentrations or flow rates, referred to as shock loads. The occurrence of foam and bulking sludge can transpire in activated sludge systems, especially when the microbial community is not well-balanced.
Biological methods	The reduction of chromium (III) in wastewater by approximately 94% indicates a substantial removal efficiency, suggesting that the treatment process is effective in lowering the concentration of chromium (III) to a significantly reduced level.	The pH of the effluent within the range of 6-9 is important for several reasons in the context of wastewater treatment, especially when dealing with chromium removal.
Ion exchange	The durability and ease of regeneration are important factors when considering the use of ion exchange beds in water treatment	The oxidation of chromium(III) to chromium(VI) before the process is probably driven by the desire to achieve a specific oxidation state

	processes. Ion exchange is a widely used method for removing and recovering specific ions from water.	for chromium. This conversion is often necessary for certain tanning processes in the leather industry, where chromium(VI) facilitates better fixation of the metal onto the leather fibers.
Sequencing Batch Reactor (SBR)	SBRs offer operational flexibility, enabling the execution of various treatment phases (fill, react, settle, and decant) within the same tank. BRs can attain high levels of treatment efficiency, ensuring the outstanding removal of organic matter, nutrients (such as nitrogen and phosphorus), and suspended solids. In comparison to continuous flow systems, SBRs may have a smaller footprint due to the consolidation of multiple treatment steps within a single tank.	SBRs require sophisticated control systems to manage the sequencing of various phases (fill, react, settle, and decant). The initial capital costs for constructing SBRs can be relatively high compared to those of some other wastewater treatment technologies.
Carbon adsorption	Selectivity concerning anions, particularly in the context of solutions containing sulfate, chloride, or bicarbonate anions, implies the ability of a purification method or material to preferentially target and remove specific anions while leaving others relatively unaffected.	The low sorption capacity of activated carbon and the frequent need for regeneration can be influenced by several factors related to the properties of the activated carbon and the specific application.
Solvent extraction	High-efficiency solvent extraction is crucial for various industrial processes, including the separation and purification of valuable substances from complex mixtures. Solvent extraction, also known as liquid-liquid extraction, is a widely used technique for selectively extracting target compounds from liquid matrices.	The requirement for a significant quantity of extractable organic substances, particularly when handling toxic and flammable solvents in solvent extraction processes, poses both challenges and considerations for industrial applications. While solvent extraction is a potent technique for separating and purifying

		compounds, utilizing substantial amounts of potentially hazardous solvents necessitates careful management to guarantee safety, regulatory compliance, and environmental responsibility.

Distribution of leather industry:

The era of industrialization has indeed yielded substantial economic benefits for both developing and developed nations. Leather tanning has flourished worldwide, finding significant footholds in countries such as India, Bangladesh, China, Pakistan, Turkey, and Brazil. In India, the tannery, tannery products, tannery garments, and footwear industries play a substantial role in the economy, ranking among the country's top 10 foreign exchange earners (Rhys-Taylor, 2018; Leather Dictionary, 2021). India's global position in the leather industry is significant, ranking second in the world for exports of leather garments, third for saddles and harnesses (UNIDO, 2000), and fourth for leather goods. A total export value of $3.68 billion in 2020-2022 underlines its significant contribution to international trade. India's role as a major exporter of finished leather (Figure 1) (UN Com-trade database, 2022), India has more than 2,000 tanneries and an annual production of around 2 billion square feet of leather (Bhardwaj et al., 2023). India's position as one of the largest producers of leather in the world is evident, with a significant concentration of tanneries in various states. Tamil Nadu is followed by West Bengal, Uttar Pradesh, Punjab, Maharashtra, Andhra Pradesh, and other states, highlighting the wide distribution of this industry across the country (Bhardwaj et al., 2023) (Figure 2). This underscores its significant presence and impact in the global leather market.

Environmental Impact on the Leather Industry:

Leather waste poses environmental concerns due to its slow decomposition, releasing pollutants into soil and water (Kanagaraj et al., 2015). Improper disposal can contribute to land and water pollution, impacting ecosystems (Zahoor & Mushtaq, 2023). Additionally, leather production itself has environmental impacts, including deforestation for cattle farming and chemical use in tanning (Jones et al., 2021). The global water crisis, driven by factors like freshwater decline and water quality degradation, requires concerted efforts in sanitation, conservation, and industrial wastewater management. Sustainable practices and proper treatment of industrial effluents are crucial for safeguarding water resources and mitigating environmental contaminants.

The leather production process involves various batch processes, generating pollutants. Hazardous chemicals such as sodium hydroxide, pentachlorophenol, and sulfuric acid are utilized in over 175 different substances during tanning (Masood & Malik, 2014). The type of hides and tanning methods impact wastewater quality. The leather industry has created a negative impact causing environmental pollution. During leather processing, the process of tanning, liming, and soaking causes around 70 percent pollution of BOD, COD, and total dissolved solids (TDS) (Islam et al., 2014). Soaking, liming, and deliming processes generate large exposure of wastewater with high amounts of sulfide, lime, ammonium salt chloride sulfate, and proteins. The wastewater contains a high amount of BOD and COD loads. Wastewater treatment contributes to the emission of volatile organic compounds (Noyola et al., 2006). The solid waste generated, particularly after chromium removal, contains minerals such as phosphorus (P) and potassium (K). Chromium removal is important because exposure to Chromium (VII) and chromium (III) can lead to cancerous disease (Ashar et al., 2022; Saha et al., 2022).

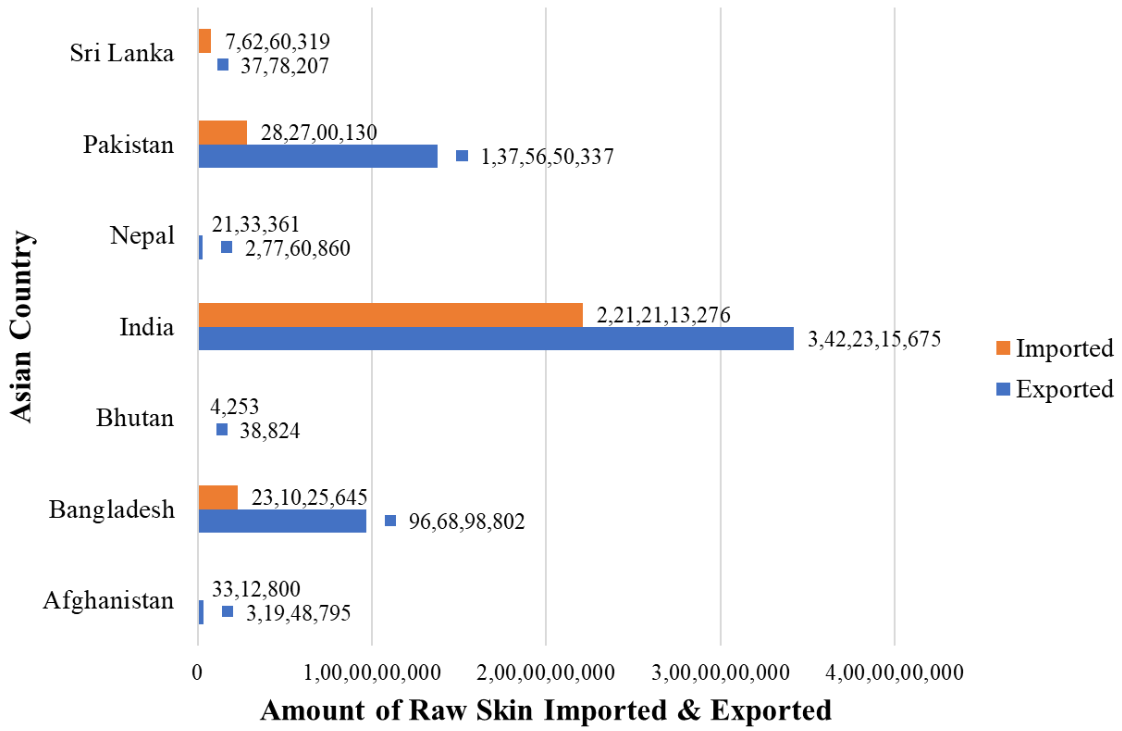

Figure 1. This diagram shows the import and export amount of raw skin in different countries of South Asia in 2000, 2005, 2010, 2015, 2019, and 2023. India is the highest importer as well as exporter of skin content throughout the world (UN Com-trade database, 2022).

Reduction/Recycling/Recovery/Reuse:

The leather industry can adopt sustainable practices for wastewater treatment through reduction, recycling, recovery, and reuse. Reducing water consumption is a crucial initial step in sustainable water management for the leather industry (Christopher et al., 2016). Precision in measurement and control, adopting technologies like low float processing and batch-type washing, and optimizing processes through compact recipes can significantly cut water usage by 30% or more (Liu et al., 2022). Recycling floats in specific processes, such as soaking, liming, unhairing, pickling, and chrome tanning liquors, holds great potential for substantial water savings in the leather industry (Liu et al., 2022). Implementing treatment installations for recycling can lead to a significant reduction in overall water consumption, ranging from 20-40% (Daigger, 2009). Biologically treated effluent presents an opportunity to substitute a portion of process floats, like those in the beam house process, with treated water (Lofrano et al., 2013). The effectiveness of this method depends on the type and efficiency of the treatment process. Membrane systems offer the potential for reusing treated effluents, given the effective removal of residual organic matter and the ability to manage the disposal of the concentrate. This technology enables a more advanced level of water treatment, allowing industries like leather production to recycle and reuse water in their processes. To maintain environmental sustainability in the overall wastewater treatment strategy.

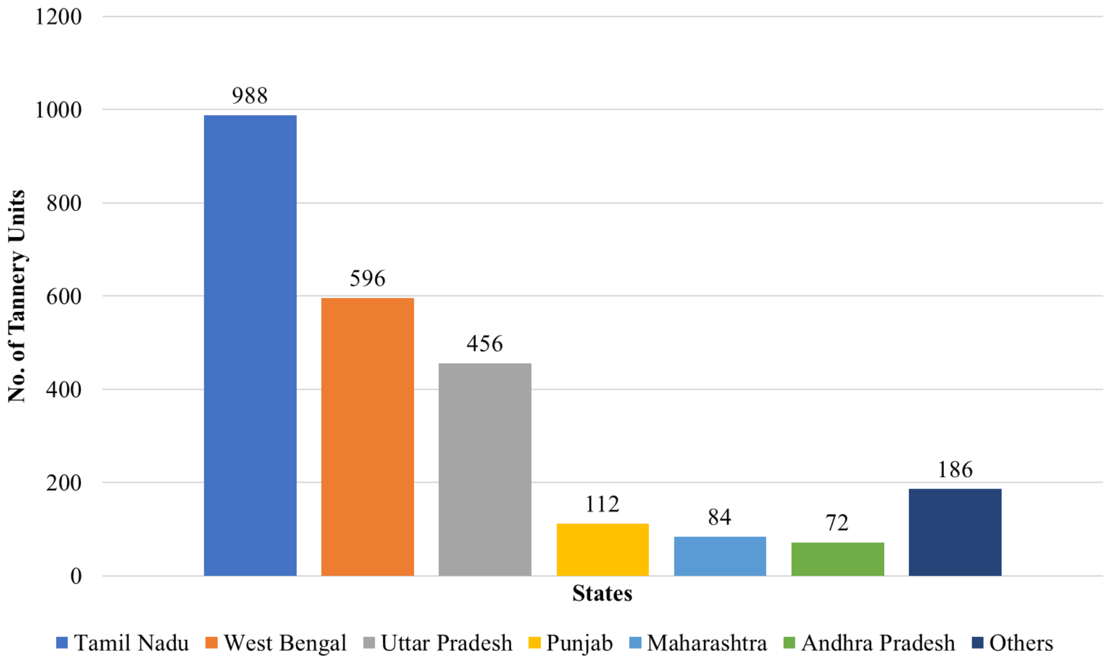

Figure 2. State-wise distribution of tanneries in India.

Sustainable Development Goals in the Leather Industry:

The leather industry plays an economically important role for other businesses but hurts the environment. For this purpose, the leather industry started 17 sustainable developmental goals. The United Nations defined these sustainable developmental goals in 2015 (Mukherjee et al., 2022). Sustainable manufacturing in leather is important in the long term for the reduction of the effects of waste materials on the environment (Omoloso et al., 2021). These include an increase in competitiveness globally (Smith & Ball, 2012), product safety (Gupta et al., 2018), quality improvement, and reduced operational costs (Roberts, 2014), as well as an increment in the health profile and safety of employees. The 2030 Agenda for Sustainable Development Goals encompasses a comprehensive approach, addressing People, Planet, Prosperity, Peace, and Partnerships (Lim et al., 2018). The integration of these goals into the leather industry, particularly focusing on Clean Water, Decent Work, Responsible Consumption, and Partnerships, demonstrates the potential for a positive impact on economic, environmental, and social aspects. The leather industry not only helps mitigate environmental impacts but also aligns with broader and long-term sustainability goals (Lim et al., 2018). Sustainable Developmental Goals embody a responsible and forward-thinking approach to wastewater management, which leads to the reduction of the harmful effects of wastewater from the leather industry on the flora and fauna of the ecosystem and human beings. A holistic and responsible approach towards resource utilization is included in these goals. Environmental stewardship lies in every manufacturing industry. For the sustainability of the industry, wastewater management and solid waste management should be emphasized. SDGs drive the leather industry towards circularity by promoting sustainable production, waste reduction, and responsible consumption, aligning with goals such as responsible consumption and production (SDG 12) and sustainable cities and communities (SDG 11) (Saha, 2023).

Tannery Effluent Treatment Technologies:

Wastewater treatment techniques for managing post-treated effluents (PTEs) emphasize effectiveness, effluent types, main parameters, and study specifics. Common treatment methods mentioned include coagulation/flocculation, advanced oxidation processes, biological treatment, membrane separation processes, adsorption, and hybrid methods (Christopher et al., 2016).

Coagulation/flocculation:

The tanning industry is one of the oldest industries in the world. For sustainable development, wastewater is treated in various ways for detoxification. In the physical method, firstly, filtration and then electrocoagulation are done. In this process, wastewater is treated with $FeCl_3$ (coagulant) at a dose of 150 mg/L at neutral pH for detoxification (Chowdhury et al., 2013).

Adsorption:

In the leather industry, dye is used to achieve deep colors on leather. Due to the use of dye, wastewater becomes colored, creating complexity in wastewater management. Adsorption is an advanced treatment that can enhance wastewater quality. The Plackett–Burman factorial design eliminates certain factors, essentially focusing on important parameters for adsorption (Gomes et al., 2016).

Chemical precipitation:

The leather industry is not environmentally friendly (Yusuf & Agustina, 2023). Chromium is used in the processing of animal hides. Chemical precipitation is mainly done to recover heavy metals and inorganic substances, i.e., chromium, from wastewater (Kurniawan et al., 2006). Once the pH is adjusted, the metal ions that were dissolved in wastewater are converted into insoluble solids. This is done by a chemical reaction by adding alkali, which helps to precipitate the metal as hydroxide. For example, when chromium ions precipitate, they precipitate as chromium hydroxide (Mella et al., 2013).

Ozonation:

Ozonation is a wastewater treatment method that involves the use of ozone (O_3), a powerful oxidizing agent, to treat water or industrial effluents. In the context of the leather industry, ozonation can be applied to treat tannery effluents. Wastewater treatment plants are mainly used to reduce organic materials such as BOD. Ozone is primarily used for discoloration of wastewater that is colored through residual dyes (Srinivasan et al., 2009).

Electro oxidation:

The leather industry generates a large amount of wastewater. De-liming is a process in which 4.5 L of wastewater is generated per one kg pelt. Electro-oxidation is mainly used to remove organic material from wastewater. The treatment is evaluated for Biological Oxygen Demand, Chemical Oxygen Demand, and Kjeldahl Nitrogen. Electro-oxidation is considered the most effective process to prepare de-liming wastewater for reuse for various purposes such as soaking, etc. (Sundarapandiyan et al., 2018).

Photo catalytic oxidation:

Wastewater from the leather industry contains various organic substances. The separation of this organic material is achieved through the solvent extraction process (Natarajan et al., 2013). In this process, two photocatalysts are employed: TiO_2 and ZnO_2. The experiment is conducted using UV radiation and follows the Box-Behnken design method. Three key parameters are essential in this method, namely the concentration of the catalyst, pH, and the use of hydrogen peroxide as a co-oxidant (Abdollahi et al., 2020).

Fenton oxidation:

Nowadays, biochemical processes are undergoing a trial process for detoxifying waste materials (Anastasi et al., 2011). Fenton's reagent (6g $FeSO_4$, 266g H_2O_2 in a liter of wastewater) is employed in the advanced oxidation process to degrade wastewater. In this treatment, a pH of 3.5 is required, and at 30^{o}C for 30 minutes under batch conditions, it leads to the reduction of BOD, COD, sulfide, and total chromium content (Mandal et al., 2010).

Biological treatment:

Biological wastewater treatment in the leather industry involves utilizing microorganisms to break down and eliminate organic pollutants from tannery effluents (Huang et al., 2015).

Hybrid treatments:

Advanced Oxidation and Nano-filtration are used together as a hybrid treatment for wastewater management. This treatment is employed to prepare wastewater for reuse.

Chromium (99.5%), COD (>99%), and TDS (>96%) are successfully removed by this process, but essential ions, i.e., Ca^{2+} and Mg^{2+}, are retained in the water (Pal et al., 2020).

Membrane Separation Process:

Membrane separation processes play a crucial role in removing dissolved compounds from tannery wastewater, employing methods such as reverse osmosis, nanofiltration, ultrafiltration, and microfiltration (Moreira et al., 2022). Scientific studies indicate that nanofiltration membranes effectively reduce the most pollution levels, followed by reverse osmosis membranes. Nanofiltration membranes can separate multivalent ions, while reverse osmosis membranes accumulate isolated monovalent ions. Ultrafiltration membranes eliminate solutes with molecular weights greater than 1,000 Da. Pore size alone does not determine pollutant elimination; membrane surface charge, influenced by pH, is also critical (Bhardwaj et al., 2023). However, membrane separation processes have drawbacks, including high energy consumption, leading to operational costs, and membrane fouling, reducing efficiency and increasing maintenance expenses. Chemical cleaning agents used for fouling removal may generate hazardous waste, requiring careful handling. Sensitivity to influent wastewater quality variations and the need for pre-treatment to prevent fouling are additional considerations (Gadlula et al., 2019).

Treated Effluent Reuse options:

The amount of pollutants allowed in treated tannery wastewater for reuse is governed by standards. These standards typically set thresholds for parameters such as total suspended solids (TSS), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) (Sugasini & Rajagopal, 2015). Waste reuse is crucial to sustainable water management, as regulated by global environmental organizations. The standards set by these agencies ensure that reused wastewater meets certain quality criteria, preventing adverse environmental impacts. Examples of regulatory agencies include the Environmental Protection Agency (EPA) in the United States, the Urban Wastewater Treatment Directive in the European Union, the Central Pollution Control Board (CPCB) in India, and the Ministry of Environmental Protection (MEP) in China (UNESCO, 2021). Waste recycling is also emphasized (UNESCO, 2021).

Conclusion:

In conclusion, the revolutionization of leather industry wastewater treatment represents a monumental stride towards sustainable environmental management. Through innovative technologies and approaches, such as advanced filtration systems, enzymatic treatments, and bio-based remediation processes, significant progress has been made in mitigating the adverse impacts of leather production on water resources and ecosystems. This game-changing approach not only addresses the longstanding challenges of pollution associated with leather manufacturing but also underscores the industry's commitment to environmental stewardship and corporate responsibility. Furthermore, the adoption of sustainable wastewater treatment practices in the leather industry offers multifaceted benefits. Beyond environmental conservation, it enhances operational efficiency, reduces regulatory compliance burdens, and fosters positive relationships with stakeholders and communities. By prioritizing sustainability in wastewater management, leather manufacturers can position themselves as leaders in responsible production, thereby gaining a competitive edge in the global market. However, continued collaboration between industry stakeholders, governments, and research institutions is essential to further optimize wastewater treatment processes, scale up innovative technologies, and ensure widespread implementation across the sector. Together, we can build a more sustainable future where economic prosperity and environmental protection go hand in hand, setting a precedent for other industries to follow suit.

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Chapter- 28

Present status and future outlooks of renewable energy in India for sustainable development

Puja Pal

Keywords: Energy Transition, Renewable Energy Policies, Sustainable development, Technological Advancements, Economic Viability.

Abstract:

The rapid industrialization and population growth in India have led to an unprecedented surge in energy demand, prompting a critical examination of sustainable energy sources. The present study delves into the current status and prospects of renewable energy in India, exploring its pivotal role in fostering sustainable development. The study encompasses an analysis of the current renewable energy landscape, government initiatives, challenges faced, and potential solutions. India has made significant strides in the deployment of renewable energy technologies, with a notable increase in solar and wind energy capacity. Government-led initiatives, such as the National Solar Mission and Wind Energy Mission, have played a pivotal role in promoting clean energy adoption. Despite these advancements, challenges like intermittency, grid integration issues, and financial barriers persist. The future perspectives of renewable energy in India are promising, driven by technological advancements, decreasing costs of renewable technologies, and a growing emphasis on sustainability. The adoption of energy storage solutions, smart grids, and digital technologies is poised to address the intermittency issues associated with renewables, enhancing their reliability and contribution to the energy mix. Moreover, this documentation explores the socio-economic benefits of renewable energy deployment, including job creation, improved air quality, and reduced greenhouse gas emissions. The transition to a cleaner energy paradigm aligns with India's commitment to global climate goals and contributes to the nation's resilience to climate change impacts. To summarize, the present status of renewable energy in India reflects commendable progress, with an optimistic trajectory for the future. Strategic policy frameworks, technological innovations, and international collaborations are essential components for overcoming existing challenges and unlocking the full potential of renewable energy for sustainable development in India. The current findings set the stage for a comprehensive exploration of the multifaceted aspects of India's renewable energy journey and its integral role in shaping a sustainable future.

Introduction:

In 1987, the term "sustainable development" was coined to describe progress that meets the demands of the present without compromising the ability of future generations to fulfill their own needs. It is an approach to advancing human well-being, considering social, ecological, and economic dynamics. Sustainable development encompasses the many tools and approaches that can be used to work towards the overarching aim of sustainability (Mensah, 2019; Mukherjee et al., 2022). After the nation experienced two oil shocks in the 1970s, 'self-

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sufficiency' in energy was found to be the primary motivator for renewable energy in the country. The Ministry of New and Renewable Energy (MNRE) is the Indian government's go-to ministry for all matters relating to new and renewable energy (Sangroya & Nayak, 2017; LeninBabu et al., 2023). To assist the country in meeting its energy demands, the Ministry's main objective is to develop and deploy new renewable energy sources. The Department of Science and Technology established the Commission for Alternate Means of Energy in March 1981 in response to the abrupt spike in oil prices, supply-side problems, and negative impacts on the monetary balance of payments (Difiglio, 2014).

Renewable energy and sustainable development:

Environmental responsibility is directly proportional to the adoption of renewable energy sources. Renewable resources refer to those resources that can be regenerated throughout time. They encompass the sun, wind, and geothermal heat, which are widely regarded as inexhaustible. The restoration of the supply of these resources occurs naturally over time (Figure 1). Hence, they possess the capacity to persist despite human-induced depletion. Their positive effects on productivity and human development can pave the way for progress in the following areas: climate change mitigation, access to pure energy, social and economic development, reduction of adverse health and environmental effects, and energy security (Strielkowski et al., 2021). Numerous academic institutions, economists, and—above all—stakeholders who stand to benefit from the global application of renewable energy technologies are interested in learning more about renewable power. Resource limitations, sustainable energy, biomass, and CO_2 emissions may all be used to support the idea that scientific interests are shifting from environmental sciences and energy sources to other fields. The role and position of renewable energy are becoming more widely recognized in the fields of computer science, mechanical engineering, science technology, and business economics (Kumar. J & Majid, 2020). Presently, the nation witnesses substantial strides in renewable energy adoption, notably in solar and wind sectors. The future outlook emphasizes the imperative of circular economy principles, promoting resource efficiency, and minimizing environmental impact (Saha, 2023). Harnessing renewable resources aligns with India's commitment to sustainable development goals, emphasizing a shift from linear to circular energy systems.

The perpetual utilization of energy sources derived from fossil fuels (coal, oil, and gas) posed significant challenges due to the exhaustion of fuel reserves, emissions of greenhouse gases and other environmental ills, geopolitical and military disputes, and the volatile nature of fuel costs (Figure 2). Unfavourable consequences will result from these concerns, which present an irreparable peril to human societies (Perera, 2017). On the contrary, renewable energy sources represent the most viable and exclusive solution to the escalating challenges. In 2023, the energy industry in the United States is expected to release 4,790 million metric tonnes of carbon dioxide (CO_2), a 3% reduction from 2022. The decrease in energy output from coal-fired power plants may be attributed mostly to the increased generation of electricity from renewable sources like solar power. We predict that CO_2 emissions will drop by 1% from 2023 to 2024, continuing the current trend (Hodge & Nakolan, 2023).

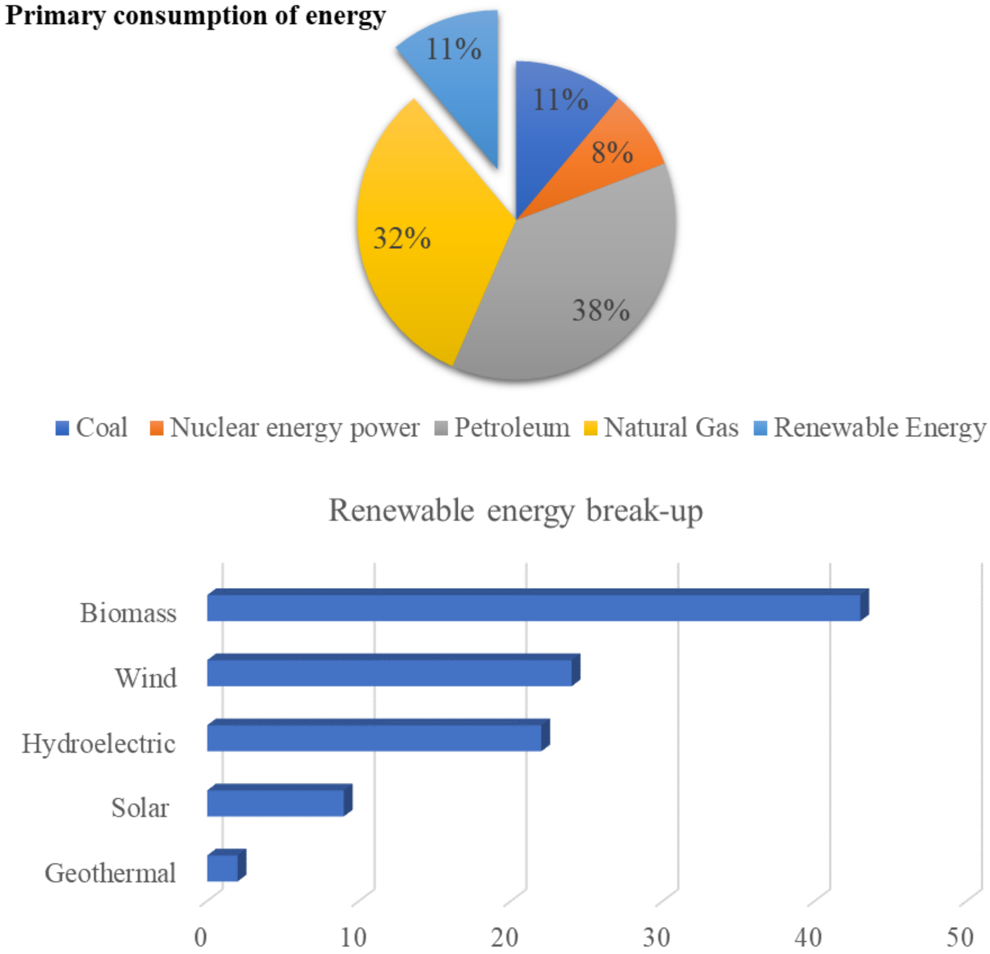

Figure 1. U.S. primary energy consumption by energy source, 2019. (Source and reproduced from EIA, US).

Sustainable in light of present and future economic and social requirements, renewable technologies are often regarded as eco-friendly options for generating electricity. The adoption of renewable energy technology presents a special opportunity to mitigate the consequences of climate change and the emission of greenhouse gases by substituting conventional sources of energy (those derived from fossil fuels) (Jaiswal et al., 2022). In contrast to the 5.5% rise of 2021, the main energy consumption grew by just 1.1% in 2022. With hydropower excluded, renewables made up approximately 7.5% of primary energy, up about 1% from 2021, while fossil fuels remained at 82% (Nasralla & Fletcher, 2023). Due to the high volatility of fossil fuel prices and the danger of supply interruptions, more energy customers globally are adopting on-site renewable energy systems and moving to electrified technologies across end-use industries. The global total final energy consumption (TFEC) increased by 16% between 2011 and 2021. In TFEC, the quantity of contemporary renewable energy grew from 30 exajoules (EJ) in 2011 to 50 EJ in 2021. The percentage of fossil fuels in TFEC decreased from 81.2% in 2011 to 78.9% in 2021 as the contribution from renewable energy sources rose; yet, throughout this time, the total amount of fossil fuels consumed increased by 35 EJ (REN21, 2023).

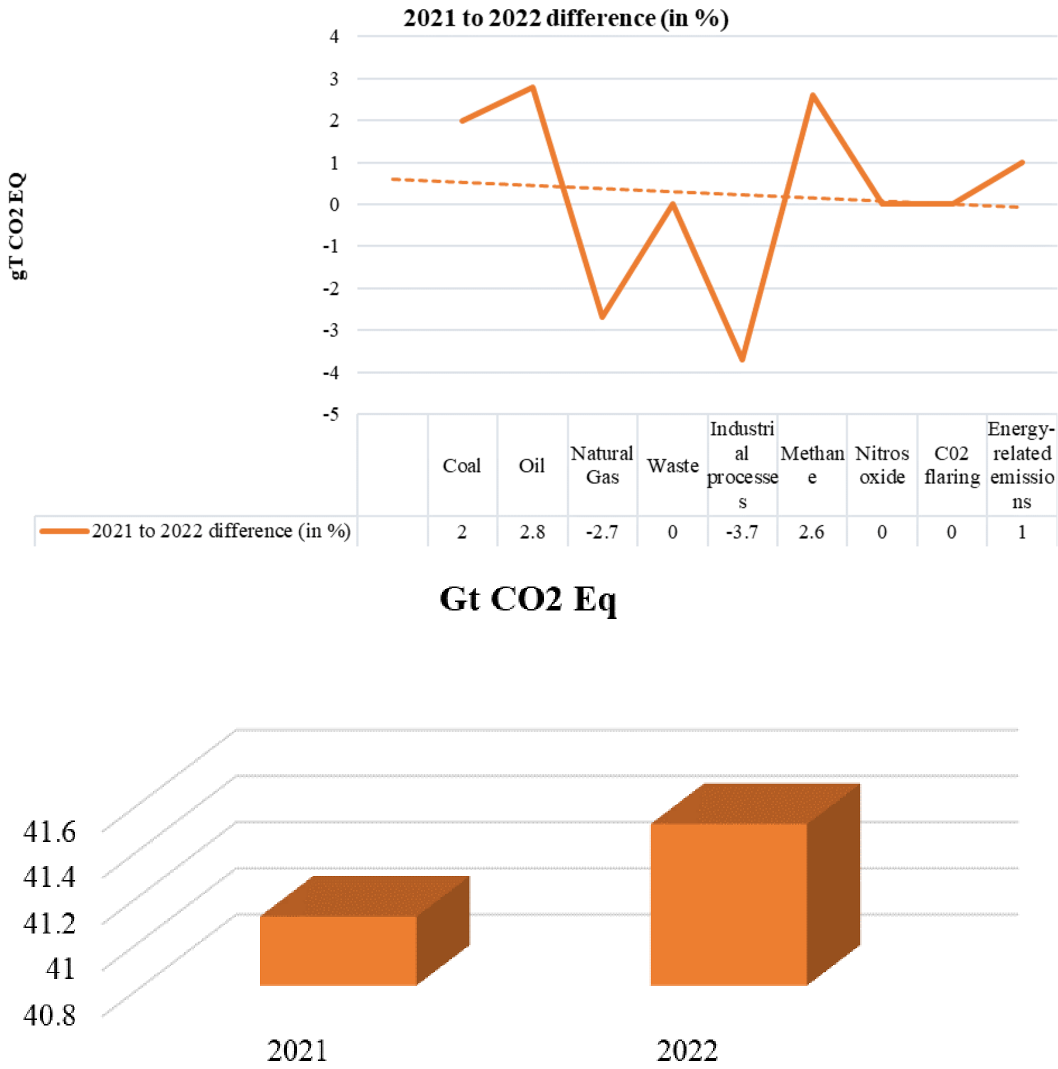

Figure 2. Carbon dioxide emission by source in the year 2021 and 2022. (Source and reproduced from: REN21).

Non-renewable resources are categorized as finite due to their extensive natural formation time. Once they are exhausted, they become inaccessible. Oil, natural gas, and coal are included in this category. One advantage of utilizing non-renewable resources to generate power as needed is the pre-existing availability of these resources in the market, along with the established infrastructure required for their utilization. Conversely, renewable resources exhibit a lesser detrimental impact on the environment in comparison. The combustion of coal and oil results in the emission of carbon dioxide gas into the Earth's atmosphere. This gas acts as a greenhouse gas, contributing to the retention of heat and exacerbating the ongoing global warming phenomenon, thus further compromising the stability of the planet's climate system (Krautkraemer, 1998). As long as precipitation occurs, water can also be thought of as a renewable natural resource. The necessity of water conservation measures has been highlighted by shifting weather patterns. Natural energy is mostly met by coal, foreign oil, and petroleum right now, which is not only not renewable and therefore not a lasting answer to the energy problem but is also bad for the environment. Renewable energy technologies turn natural energy into energy that can be sold. India needs to make sure it has enough energy without hurting its economy, which means it needs to switch from non-renewable energy sources like coal and crude oil to renewable energy sources (Nordhaus et al., 1973; Rahman & Wahid, 2021).

The primary objective of sustainable development is to simultaneously attain human development objectives and ensure the continued provision of vital natural resources and ecosystem services by natural systems. The ultimate objective is to establish a societal framework wherein individuals' fundamental necessities can be fulfilled while also safeguarding the ecological equilibrium of the planet. The pursuit of sustainable development is predicated upon the imperative of striking a harmonious balance between the advancement of material prosperity, the protection of ecological integrity, and the promotion of social well-being (Bridger & Luloff, 2022). As per the Brundtland Report of 1987, sustainable development can be defined as the process of achieving development that fulfills the requirements of the current generation while ensuring that the capacity of future generations to fulfill their own needs remains intact. Contemporary deliberations on sustainable development notably encompass economic growth, social progress, and environmental preservation, with a collective focus on ensuring the well-being of future generations (Jarvie, 2016).

Under bilateral or cooperative methods, the following list of renewable energy activities will be taken into consideration for selling carbon credits under the Article 6.2 mechanism, as given by the National Designated Authority responsible for the adoption of the Paris Agreement (NDAIAPA) (Ministry of Environment, Forest and Climate Change, 2023):

i. Renewable energy with storage (only stored component)
ii. Solar thermal power
iii. Offshore wind
iv. Green Hydrogen & Ammonia
v. Tidal energy
vi. High Voltage Direct Current Transmission

Sustainability and renewable resources in India:

India is actively adopting and harnessing the potential of renewable energy sources. The organization has formally declared its objective of achieving carbon neutrality by the year 2070. Moreover, as stated by the Ministry of Power, it is anticipated that the nation will fulfill 62% of its energy demands by the year 2030 through the utilization of 500 GW of non-fossil fuel sources (Kumar, 2023). Nevertheless, to effectively accomplish its ambitious objective and facilitate the shift towards clean energy, the nation necessitates the assistance of advancements in renewable energy. The field of renewable energy has experienced rapid expansion. The ninth-largest economy is that of India. Due mostly to the nation's consistent economic expansion, energy demands are increasing at a rate of 2.8% annually. With around 1028 million people, India's population is expanding at a 1.58% yearly pace. It's possible that traditional energy sources could run out soon. Thus, energy from a source that is quickly replenished by a natural process and is not susceptible to depletion on a human time scale is actually what is meant to be understood as renewable energy. 37% of India's total energy consumed accounts for the renewable resource (Birol & Kant, 2022; Chilakapati & Manohar, 2023).

India has made significant progress in the pursuit of sustainable development by embracing renewable energy sources, with solar energy emerging as a prominent contender. Based on the data provided by the National Investment Promotion and Facilitation Agency, it is seen that as of May 2023, India's non-fossil fuel capacity reached a significant milestone of 178.79 gigawatts. This figure represents a substantial increase of 396% over the preceding 8.5 years (Singh, 2023). The REN21 Renewables 2022 Global Status Report says that India is ranked fourth in the world for installed renewable energy capacity, which includes large hydropower plants. It is also ranked fourth for wind power capacity and fourth for solar power capacity. In 2022, it achieved the most significant increase in renewable energy installations with a year-over-year growth rate of 9.83% (REN21, 2023). The operational solar energy potential has grown exponentially over the past 9 years, reaching 70.10 GW as of July 2023, which is a 30-fold increase. The installed capacity of renewable energy, including big hydro, has increased by around 128% since 2014. India's non-fossil fuel production has had a remarkable growth of 396% during the past 8.5 years, reaching a total of around 176.49 GW, which includes huge hydro and nuclear power. This accounts for over 43% of the country's overall capacity as of July 2023 (PTI, 2023).

The installed capacity of all of India, excluding captive capacity, as of March 31, 2022, was 399496.61 MW. This includes 46722.52 MW of hydropower, 236108.72 MW of thermal power, 6780 MW of nuclear power, and 109885.38 MW of renewable energy. It also takes into account the addition of new capacity, the up-rationing or de-rationing of existing capacity, and the retirement of outdated and inefficient units at the end of 2021–22. Except for major hydro, the generation from renewable energy sources (RES) increased at a compound annual growth rate (CAGR) of 12.80% between FY2011–12 and FY2021–22, from 51226.05 GWh to 170912.30 GWh (*General Review 2023*, 2023).

The objective of achieving economic growth using energy-intensive methods is a shared aspiration across all nations. Energy intensities are useful metrics for assessing the overall energy consumption throughout a manufacturing chain, as they provide a means to describe the total quantity of energy utilized. To have a comprehensive understanding of the total energy consumption of an economy, it is advantageous to amalgamate sector-specific energy intensities with the corresponding output requirements of these sectors. The variation in both the amount and structure of demand, along with the shifting energy intensities across different industries, leads to a corresponding change in energy consumption. The degree to which a product or sector is affected by changes in energy prices can be observed by the measurement of the energy required per unit of production, commonly referred to as energy intensity or specific energy consumption (Sorrell, 2015). A comprehensive comprehension of the impact of fluctuations in energy prices on aggregate energy consumption can be achieved by employing temporal analysis or conducting historical investigations on energy intensities. The paradox of energy lies in its indispensable role in sustaining human existence and advancement, juxtaposed with the adverse consequences arising from unregulated developmental endeavors heavily reliant on fossil fuel consumption, hence detrimentally affecting the environment. The energy demands of a nation are perpetually escalating as a consequence of population growth, industrialization, and various societal and economic determinants. The escalation of energy consumption presents two primary concerns. Firstly, the accompanying pollution has the potential to induce unforeseen alterations in the Earth's climate system, resulting in significant ramifications (Osobajo, 2020). Secondly, the utilization of non-renewable fossil fuels as the predominant energy source exacerbates the issue since their finite nature poses long-term sustainability challenges. Discussions about money and the imperative of economic growth occupy a prominent position, irrespective of individuals' concerns over the future of the planet. Researchers have undertaken investigations into nuclear power and other environmentally sustainable energy sources as a means to identify a viable replacement for fossil fuels and other non-renewable resources (Liddle & Huntington, 2021).

India's energy composition is characterized by coal accounting for around 60% of the total energy supply, followed by oil at 27%, natural gas at 7%, lignite at 4%, hydropower at 3%, and nuclear power at 0.22%. Utilizing renewable energy has a positive effect on business operations. Additionally, they are crucial to any country's efforts to improve economic growth and living standards. The use of fossil fuels and renewable energy sources may both benefit economic growth in G7 nations. There exist notable disparities in residential energy consumption patterns between rural and urban areas in India, as well as among various income categories within urban settings (Kumar. J & Majid, 2020). A significant proportion of rural Indian households, precisely 86.1%, continue to utilize fuelwood and dung cakes for cooking purposes. A total of 3.5% of households located in rural areas utilize liquid propane gas as their primary cooking fuel. Paraffin serves as the primary lighting source in 50.6% of rural households, whereas electricity is utilized by 48.4% of these residences. Approximately 270-

300 million metric tonnes (Mt) of fuelwood are annually utilized, whereas approximately 10.5 million metric tonnes (Mt) of kerosene are utilized, with 60% of this quantity originating from rural areas. The three main types of energy users are industry, residential, and agricultural. Together, they account for more than 85% of all electricity use, or 42.26%, 25.80%, and 17.35% of all non-utilities consumption (Figure 3) (*General Review 2023*, *2023*).

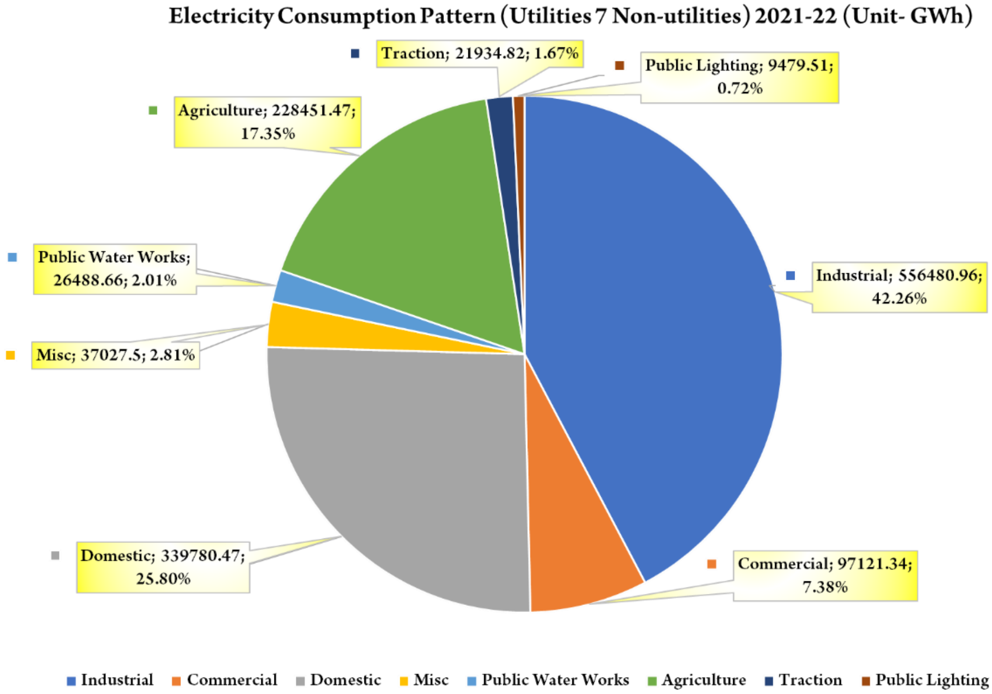

Figure 3. Electricity consumption patterns in 2021-2022 (*Data Source- General Review, 2023*).

The existing deficit in energy supply, the historical focus on conservation and fuel economy during the Industrial Revolution, and the shift from coal to oil in the energy sector collectively underscore the imperative for significant economic adjustments. There was a prior intention to augment the energy supply from several sources to promote its advancement and utilization. In recent times, there has been a notable movement in the emphasis of energy planning towards the establishment of sustainable energy systems. This shift is driven by the recognition of the evolving circumstances characterized by limited availability, high costs, and the unreliable nature of traditional energy sources. Consequently, energy planning now encompasses the exploration and development of alternative energy sources as well as the efficient use of energy resources (Holechek et al., 2022).

Solar energy:

Sunlight reaches Earth at a rate of 1.5 x 10^{18} kWh per year. In comparison to the world's present yearly energy usage, this is over 10,000 times greater. At its surface, the sun is about more than 5000°C hot. Continuous energy release from the sun is achieved through fusion reactions, which generate 3.94 x 10^{23} kW of power. The 93 million miles it takes for the sun's radiation to reach Earth is approximately 91/3 minutes. At an average of 340 watts per square meter, or 1.73 x 10^{14} kilowatts, the amount of power that the sun emits is far more than what the Earth gets. Clouds, dust, and "greenhouse" gases like ozone, carbon dioxide, and water vapor absorb around 20% of the radiation, while the remaining 30% is reflected into space. India experiences yearly global radiation levels that are similar to those in tropical and subtropical countries, ranging from 1600 to 2200 kWh/m^2. Approximately 6,000,000,000 GWh of energy might be produced annually (Rhodes, 2010).

The amount of solar energy that India receives each year—more than 5,000 trillion kWh—far exceeds the country's total yearly energy usage. With an annual range of 2300–3200 sunshine hours, the average daily radiation across the world is about 5 kWh/m^2. The energy concreteness is depleted, and the availability is intermittent, but it can now be consistently converted to usable heat or directly generated into electricity, so it can be used for many things. About 20,000 MW of gross potential energy is located in Karnataka. Of the 18 projects approved by the government, one with a capacity of 4 MW out of a total of 116 MW has been put into operation (Harinarayana & Kashyap, 2014).

In recent years, solar power has made a noticeable difference in India's energy landscape. Decentralized and distributed applications powered by solar energy have helped millions of people in rural India with their energy needs, including cooking, lighting, and more, all while being kind to the environment. The monetary and social advantages encompass enhancing the standard of living and fostering economic prospects at the grassroots level, mitigating the hazards of respiratory and ocular diseases, generating employment opportunities within the village, and alleviating the burdensome tasks faced by female folks with the need to gather firewood from distant locations and prepare food in smoky kitchens (Yadav et al., 2019). Furthermore, the solar energy sector in India has emerged as a significant contributor to the nation's capacity for power generation via grid interconnections. In addition to addressing the increasing need for energy in the country and contributing to the government's goal of sustainable development, it also strengthens the government's efforts to ensure energy security (Obaideen et al., 2021).

Assuming that Solar PV modules occupy 3% of the wasteland area, the National Institute of Solar Energy (NISE) has estimated that India's solar potential is approximately 748 GW. With the National Solar Mission (NSM) being a crucial component, solar energy has assumed a pivotal role in India's National Action Plan on Climate Change. The debut of NSM took place on January 11, 2010. With the help of the states, the CGI launched the National Solar Mission (NSM) to combat energy insecurity and promote environmentally friendly development. As a bonus, it will be India's big contribution to the international fight against climate change. The Mission wants to make India a world leader in solar energy by quickly making sure that the laws are in place so that solar technology can be used all over the country. India has promised that by 2030, it will cut the amount of pollution caused by its GDP by 45 percent compared to 2005 levels and get about 50 percent of its electricity from sources other than fossil fuels. This aligns with its Nationally Determined Contributions (NDCs) (Mitavachan & Srinivasan, 2012) (Figure 4).

Solar energy has been actively promoted throughout the country by the government. Among them are:

- Providing an automatic pathway for up to one hundred percent FDI,
- Projects that are scheduled to be operational by June 30, 2025, will not be charged for interstate sales of solar and wind power through the Inter-State Transmission System (ISTS).
- Certification of the Renewable Purchase Obligation's (RPO) trajectory to 2029–30,
- Standardization of solar photovoltaic system and device deployment notification,
- Creating a Project Development Cell to help bring in investment capital,
- To acquire power from grid-connected solar PV and wind projects, standard bidding guidelines are used.
- Power must be sent against a Letter of Credit (LC) or advance payment per government orders. This is to guarantee that distribution licensees will pay RE generators on schedule.
- The 2022 Green Energy Open Access Rules Notification: A Call to Action to Promote Renewable Energy.
- "The electricity (Late Payment Surcharge and related matters) Rules 2002" (LPS rules) became effective upon notification.
- The Green Term Ahead Market (GTAM) is going live to make it easier to trade renewable energy power, such as solar electricity.

According to the Renewable Capacity Statistics 2023 published by IRENA and the Global Status Report 2023 put out by REN21, India ranked fifth in solar PV installations globally at the end of 2022. Around 70.10 GW of solar power has been installed as of 30-06-2023. In recent years, India's solar power business has grown rapidly. In addition to addressing the increasing need for energy in the country and contributing to the government's goal of sustainable development, it also strengthens the government's efforts to ensure energy security (REN21, 2023).

India's government has set up several schemes to encourage the use of solar power in the country. Some of these are the Defence Scheme, the VGF Schemes, the Solar Park Scheme, the Bundling Scheme, the Grid Connected Solar Rooftop Scheme, and the Canal Bank and Canal Top Scheme. The above goals are what they want to achieve. There are also several legislative efforts aimed at improving solar power plants that are linked to the grid (Ministry of New and Renewable Energy, 2017).

In terms of solar power deployment, India is now ranked fifth globally. The country's solar plants have a total capacity of 70.10 GW dated 30-06-2023. The Ministry of New and Renewable Energy, Government of India (2023) reports that out of the total power production of 70.10 GW, ground-mounted solar projects will contribute 57.22 GW, rooftop solar operations will contribute 10.37 GW, and off-grid solar systems will contribute 2.51 GW (Solar overview, 2023).

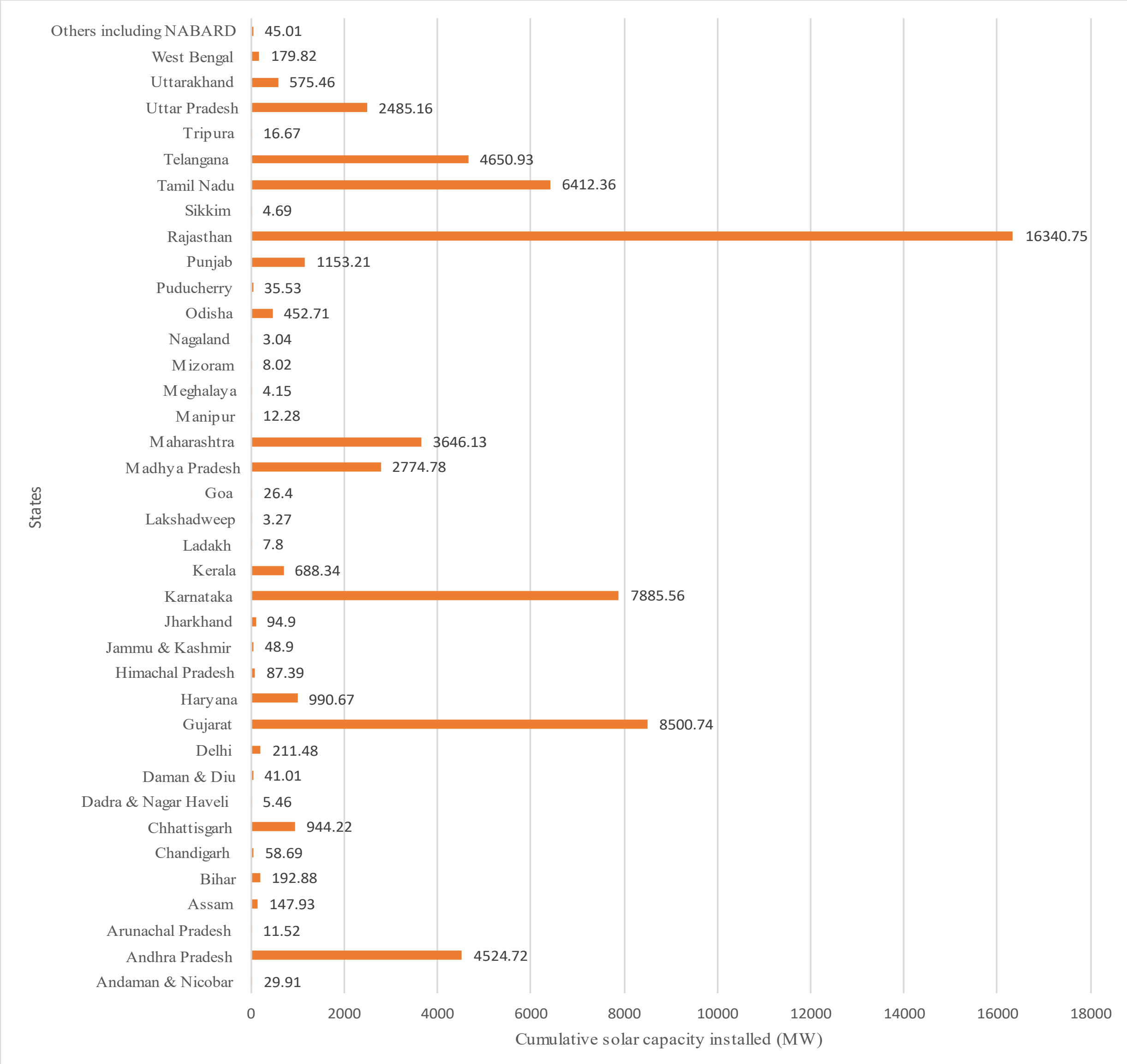

Figure 4. State-wise Cumulative Solar Installed Capacity in the country (as on 31-12-2022) (Source and reproduced from Annual Report, 2022-23, Ministry of new and renewable energy, Govt. of India).

Wind energy:

Wind power has grown at a faster rate than any other renewable energy source in India. Onshore and offshore wind power plants in India take advantage of the country's extensive coastline. The total installed power capacity of wind energy in India was 41.666 GW as of 30 September 2022. There is great promise for wind power to meet India's electricity demands and stimulate the economy. The Muppandal Wind Farm is India's biggest wind farm. A handful of Indian wind farms are among the world's ten biggest wind parks, demonstrating the country's enormous wind energy potential. Wind farms in India are among the most advanced and efficient in the world, and the country's wind energy sector is highly developed (Bhatti, 2021).

In recent times, the Ministry of New and Renewable Energy has revealed significant findings regarding the wind energy capacity of India. This discovery highlights the country's commitment to sustainable energy practices and reveals which states have the most wind power potential. Also, the Ministry laid out new plans to make sure the wind power industry is more environmentally friendly and to increase its usage. As of April 2023, India's installed wind energy capacity was 42.8 GW (onshore wind), putting it fourth globally behind the US, Germany, and China. According to the National Institute of Wind Energy's wind resource assessment, the country's total wind power potential is 1,164 GW at 150 meters above ground level and 695.5 GW at 120 meters. As far as wind power potential (in GW) at 120 m above ground level is concerned, the top-performing Indian states are Gujarat (142.56), Rajasthan (127.75), Karnataka (124.15), Maharashtra (98.21), and Andhra Pradesh (74.90) (Figure 5) (Dey et al., 2022; Ministry of New and Renewable Energy, 2023).

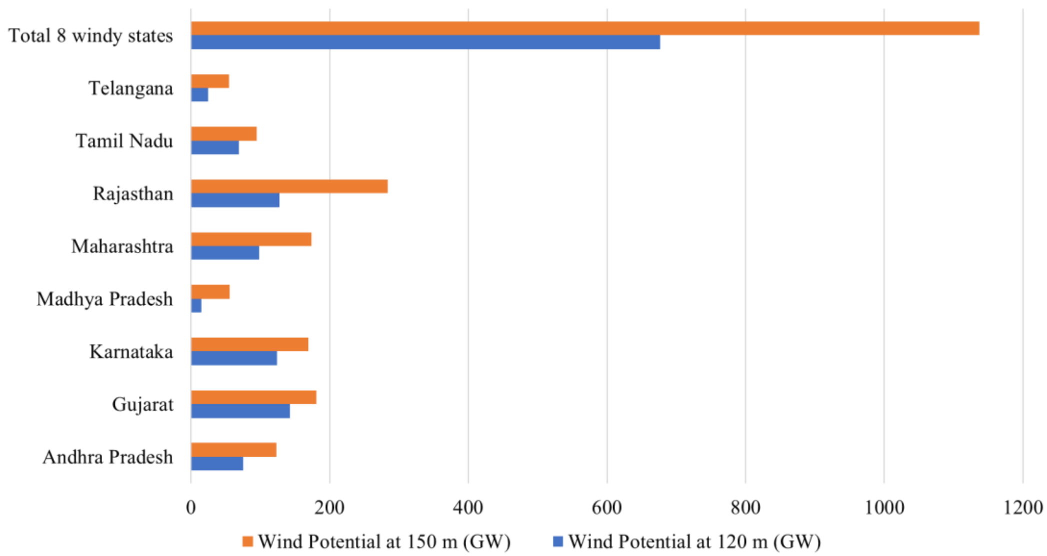

Figure 5. Potential of wind energy in different states of India (*Source: Ministry of New and Renewable Energy, 2023*).

Offshore wind farms are man-made structures set up at great distances from land. One major benefit of land-based installations is the stronger, more consistent wind experienced at lower elevations. Although located on land, nearshore wind farms are just a short distance from the water. The site's ability to harness both land and maritime breezes for energy generation is a major selling point. Using wind power has many advantages. Once set up, this renewable energy source requires very little maintenance because it is non-perishable. Petrol is superfluous (National Grid, 2022). Additional benefits might be found below:

– After commissioning, there is a short gestation period before power generation begins. As soon as generation starts, power is freely available.

– Power generation is more cost-effective due to the absence of input costs and almost nonexistent recurring charges.

– Environmentally speaking, wind power does not produce any harmful byproducts.

– The generation process is ongoing, unlike diesel power. Never put money into anything.

Reduced electricity generation and late payments to energy suppliers are examples of discom risks, and general challenges impacting distribution corporations. Meeting demand requires overcoming installation challenges and delivering electricity from wind farms to urban areas. Therefore, it might significantly lower the price of expanding the country's transmission network to link areas with abundant wind resources to big population centers. Local wildlife could be affected by wind farms. Research is still necessary to lessen the wind's influence on animals, even if wind energy projects are less harmful to wildlife than other energy ventures (Gandhi et al., 2022).

Launched in 2014, the National Wind Energy Mission aims to stimulate the growth of wind energy in India. In 2022, the mission aims to install 60 GW of wind power capacity. In 2015, the Indian government initiated the National Offshore Wind Energy Policy to promote the establishment of wind power facilities in rural and isolated regions. Wind-solar hybrid power plants: In 2018, the government introduced the Wind-Solar Hybrid Policy to promote the development of power facilities that integrate both wind and solar energy sources (Kandpal & Dhingra, 2021).

Hydro energy:

India has been utilizing hydropower for approximately 120 years. The history of hydropower in India commenced in 1897 with the commissioning of the first tiny 130 kW hydro project in the Darjeeling hills. The second project proposed in 1902 in the Mysore region of Karnataka was the 4500 kW Sivasamudram project, intended to provide electricity to the Kolar gold mines. Subsequently, other minor hydro projects were established throughout the nation's mountainous regions. The nation had a 1362 MW installed capacity before its independence (1947), including 508 MW of mostly small- and medium-sized hydropower dams. The MNRE estimates that small hydropower plants have a 20 GW potential nationwide (IREDA, 2023).

About 37% of all power generating capacity and more than 53% of electricity generation in 1947 came from hydropower. In India, hydropower began to lose ground to coal-based power generation in the late 1960s, and its proportion of capacity and generation dropped sharply. About 11% of electricity generation capacity in August 2023 came from hydropower, with a capacity of 46,865 MW (megawatts) (Figure 6). Hydropower accounted for 12.5% of India's energy generation in the year 2022-2023. By 2023, India possessed an operating pumped storage capacity of around 4745.6 MW. Furthermore, there were roughly 57,345 MW of pumped reservoir capacity in different stages of advancement in research and development (Sati et al., 2022).

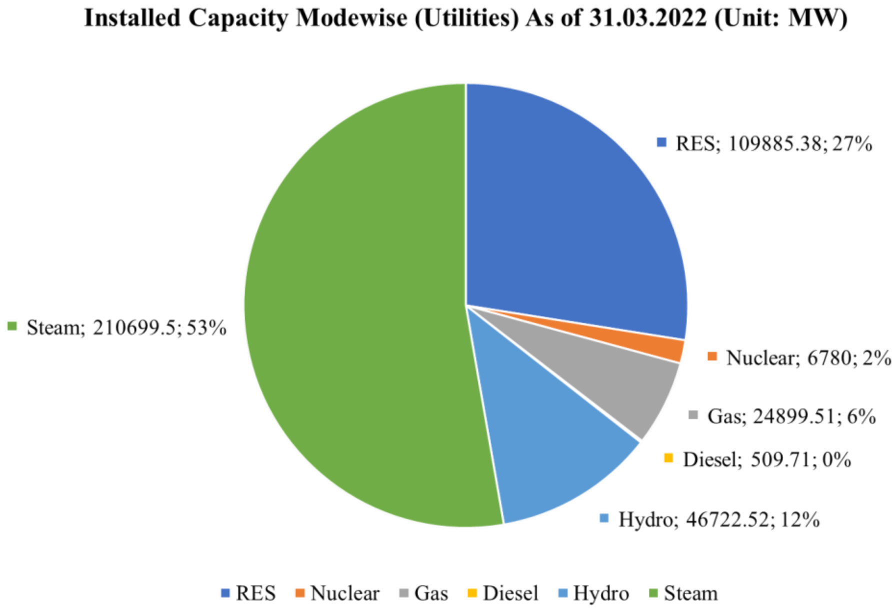

Figure 6. Electricity installed capacity in 2021-2022 (*Source- General Review, 2023*).

Small and large hydropower projects are the two general categories into which hydropower projects fall. Hydro projects in India that have a station storage of up to 25 MW are classified as Small Hydro Power (SHP) projects.

- Micro: up to 100 KW
- Mini: 101 KW to 2 MW
- Small: 2 MW to 25 MW
- Mega: Hydro projects with installed capacity ≥ 500 MW
- Thermal Projects with installed capacity ≥ 1500 MW

The Ministry of New and Renewable Energy has authority over small hydropower (up to 25 MW), while the Ministry of Power, Government of India, is in charge of larger hydro projects. With more than two-thirds of all renewable electricity produced worldwide, hydropower is currently the most popular renewable energy source. The installed hydropower capacity worldwide increased by 26 GW (gigawatts) in 2021 to 1360 GW. Hydropower produced 4,250 TWh (terawatt hours) of clean electricity globally, which is more than all renewable energy sources put together and 1.5 times the EU's total electricity usage (Nouni et al., 2006; Gupta et al., 2021).

However, the International Energy Agency (IEA) estimates that 45 GW of yearly capacity addition is needed to fulfill net-zero targets by 2050 and limit global temperature rises to 1.5°C. This is a significant shortfall. It would take 30 GW a year to limit temperature increases to 2°C. China accounted for around 80% of the newly constructed hydroelectric capacity in 2021. Three times as much hydropower was added to the grid in 2020—4.7 GW of pumped storage hydropower. The rate of increase in hydropower generation capacity worldwide in 2021 was a little over 1.9 percent, which is not far from the 2 percent average yearly growth needed to reach the targets outlined in the Paris Agreement (Gielen et al., 2019).

Challenges of hydropower:

Large storage hydropower projects have significant negative social and environmental effects in addition to producing low-carbon electricity. They cause the uprooting of thousands of people, interfere with the ecology of rivers, lead to extensive deforestation, initiate the loss of aquatic and terrestrial biodiversity, and have a detrimental impact on agriculture, food systems, and water quality. Although dam construction is still ongoing in developing nations, it is progressing more slowly now that the finest locations have been chosen and alternative renewable energy sources like wind and solar are receiving more investment and policy attention. The majority of India's new hydropower projects are being developed in the vulnerable Himalayan mountains, where the risk of catastrophic floods and landslides has increased (De Faria et al., 2017).

Recent abrupt flooding in the Dhauliganga, Rishiganga, and Alaknanda rivers in Uttarakhand (Dist. Chamoli) in February 2021 resulted in numerous fatalities and significant damage to several hydropower projects. The Central Electricity Authority (CEA) reported that severe rains in July 2023 caused hydropower projects to be shut down and sustained damage, resulting in a total revenue loss of over INR 1.6 billion. There is a consensus that the extent of the loss was increased by the development of hydropower projects, highways, railway lines, and mining operations without proper appraisals and by the disregard for cumulative impact and disaster potential assessments, even though the exact cause of the 2021 flash floods—glacier crash, avalanche, and landslide—and by these actions (The Times of India, 2021).

Sikkim's Teesta-V hydropower facility was named a worldwide hydropower sustainability model in 2019. NHPC Limited owned and operated the 510 MW power station, which met or surpassed international good practice in all 20 performance categories. The Indian government and industry must promote openness by incorporating civil society, especially project-affected communities, to make hydropower planning sustainable. Large, 'smart' hydropower projects may address the economic, environmental, and social issues of local and downstream communities, as well as national economic advantages (IHA, 2019).

Green Hydrogen:

India has stated its goal of achieving energy independence by 2047 and net-zero status by 2070. It is anticipated that green hydrogen will play a significant role in meeting these objectives. The process of electrolysis, which involves splitting water into hydrogen and oxygen using electricity from renewable sources such as solar, wind, or hydropower, produces green hydrogen. This method yields a clean, emission-free fuel with the potential to replace fossil fuels and reduce carbon emissions. Green hydrogen can also be produced using biomass, which is gasified to generate hydrogen. The sustainability and purity of these two manufacturing methods make green hydrogen an appealing alternative for the transition to a low-carbon future (Yadav & Shahi, 2023).

The demand for green hydrogen is rapidly increasing due to its potential to decarbonize various industries, including transportation, shipping, and steel. Green hydrogen can replace traditional fossil fuels in transportation, significantly reducing greenhouse gas emissions. It can also be used in industries to produce ammonia, methanol, and steel, which currently heavily rely on fossil fuels. As a backup energy source for renewable energy plants, green hydrogen offers a steady and reliable energy supply. Among its many applications, green hydrogen can be utilized in fuel cells for energy production and powering vehicles. It can also be used in the production of chemicals and fertilizers, heating systems, and other processes. Hydrogen fuel cells, known for their increased efficiency and energy density, are a preferred alternative to traditional combustion engines in vehicles. Additionally, microgrids, providing energy independence to remote areas, can benefit from green hydrogen (Kazi et al., 2021).

The significance of green hydrogen in India's journey towards energy independence cannot be overstated. Utilizing renewable energy sources like solar, wind, and hydropower to produce green hydrogen enhances energy security and reduces dependence on fossil fuels, ensuring a consistent and reliable energy source. Domestic production of green hydrogen eliminates the need for costly and hazardous imports. Moreover, creating green hydrogen from waste biomass provides additional revenue streams for farmers and neighbouring communities. Consequently, India has initiated the National Green Hydrogen Mission with a budget of Rs. 19,744 crores, aiming to produce 5 million metric tonnes of green hydrogen annually (Sheth, 2023).

In conclusion, green hydrogen holds great promise in reducing carbon emissions, decarbonizing various industries, and achieving energy independence. Its sustainable and environmentally friendly generation makes it a compelling option for the transition to a low-carbon future, utilizing renewable sources such as solar, wind, and hydropower. In industrial and transportation applications, green hydrogen provides a stable and predictable energy source, replacing traditional fossil fuels. Its capacity to reduce dependence on fossil fuels and provide a consistent and reliable energy source makes it essential for achieving energy independence (Marouani et al., 2023).

An estimated 5 million metric tonnes (MMT) of hydrogen are annually utilized in India for various industrial applications, including metal extraction and refinement, methanol production, ammonia generation for fertilizers, and petroleum refining. Most of this hydrogen, also known as "grey hydrogen," is currently produced through steam reforming of naphtha, natural gas, and other fossil fuels. Hydrogen gas is also produced as a byproduct of the chlor-alkali industry. Water electrolysis, utilizing grid energy, produces some hydrogen for specialized applications (The Economic Times, 2023).

Another crucial intervention would be to increase the production and usage of high-performance electrolyzers in sufficient quantities. Currently, only 2-4 GW of commercial electrolyzers are produced globally each year. Over the past three years, several business organizations and national governments have announced intentions to deploy more than 200 GW of electrolyzer capacity by 2030. Consequently, the global capacity to create electrolyzers is expected to rise rapidly. To ensure supply chain stability and reduce dependency on imports, India must establish a robust local environment for electrolyzers' production. The Mission recommends domestic industry support to ensure significantly lower costs for India's electrolyzer production, enhancing the competitiveness of Made in India Green Hydrogen in international markets (Halder et al., 2024).

The use of green hydrogen and its derivatives has not yet replaced fossil fuels and their derived feedstock due to adverse cost economics, lack of uniform standards and regulations, supply issues, and the high infrastructure required for the transition. However, based on current trends and analyses, it is likely that Green Hydrogen will soon become cost-competitive for use in industry, mobility, and other sectors. This is attributed to technological advancements, decreased costs for renewable energy and electrolyzers, and aggressive national strategies by some major economies (*Green Hydrogen Cost Reduction*, 2020).

Government initiatives:

The Indian government is taking the following steps to strengthen the country's renewable energy industry:

- Green growth was identified as one of the seven priority nodes, known as SAPTARISHI, in the Budget for the fiscal year 2023-2024.
- Pumped storage projects received increased support in Budget 2023–2024, including the requirement to provide a complete framework for their development.
- The objective of the Union Budget 2023–24 is to construct resilient cities for the future. States and municipalities will be encouraged to adopt urban design modifications and efforts to transform their cities into "sustainable cities of the future."
- The Indian government has provided significant support to the industry and has spurred unprecedented growth by setting a target to reach net-zero emissions by 2070 and increasing its renewable energy goal to 500 GW by 2030 during the COP26 summit.
- A federal sector grant of US $1.02 billion (about Rs. 8,300 crore) has been allocated in the Budget 2023-24 for the development of ISTS infrastructure in Ladakh, which would facilitate the generation of 13 GW of renewable energy.
- On November 19, 2022, Prime Minister Mr. Narendra Modi inaugurated the 600 MW Kameng Hydro Power Station in Arunachal Pradesh. The project is located in the West Kameng District of Arunachal Pradesh and covers a distance of about 80 kilometers, with a budget of around Rs. 8,200 crores (US$ 1 billion).
- On November 9, 2022, Ms. Nirmala Sitharaman, the Minister of Finance and Corporate Affairs, approved India's ultimate Sovereign Green Bonds structure. This authorization will strengthen the objectives of the Nationally Determined Contributions (NDC)

outlined in the Paris Agreement and attract domestic and international finance for environmentally friendly projects.

- Solar Energy Corporation of India (SECI), which promotes the renewable energy industry, earned Rs. 1,000 crore (US$ 132 million) in the Union Budget 2022–2023. The government budgeted Rs. 19,500 crore (US$ 2.57 billion) for a Production Linked Incentive (PLI) to boost high-efficiency solar module production.
- India and Nepal have decided to create a Joint Hydro Development Committee in February 2022 to examine the viability of hydropower projects.
- At the Cop-26 Summit in Glasgow in November 2021, India's PM pledged to satisfy 50% of its energy demand from renewable sources by 2030 and develop 500 GW of renewable energy.
- The Ministry of Power introduced new regulations in October 2021 to alleviate the financial burden on stakeholders and ensure timely cost recovery in power generation.
- The Indian government passed further renewable energy laws in August 2021. The government's recent legislation aims to encourage large energy customers like businesses to utilize renewable energy.
- In July 2021, the Ministry of New and Renewable Energy will launch the second phase of the Rooftop Solar Programme to promote rooftop solar (RTS) systems in rural areas. The plan aims to build 4,000 MW of residential rooftop solar (RTS) electricity by 2022 with financial help. NTPC Renewable Energy Ltd., a fully-owned subsidiary of NTPC, received MNRE approval to establish a 4,750 MW renewable energy park in the Rann of Kutch in Khavada, Gujarat. Indian Railways, the nation's largest electricity generator, aims to cut emissions by 33% by 2030. Energy-efficient practices and the broad usage of clean fuels will achieve this.

The Indian government plans a $238 million National Mission on advanced ultra-supercritical technology for greener coal use. The government has allocated a total of US$ 4.63 billion for hydroelectric projects aimed at supplying power to communities in the Jammu and Kashmir region between 2018 and 2021.

Union Budget 2023: Priority 5: Green Growth:

The Prime Minister has articulated a vision for "LiFE," which stands for Lifestyle for Environment, aiming to catalyze a movement towards a lifestyle that is mindful of the environment. India is steadfastly progressing towards achieving the goals of 'panchamrit' and achieving net-zero carbon emissions by 2070, as a means to facilitate a transition towards a green industrialized and socioeconomic landscape. This Budget further emphasizes our commitment to promoting sustainable economic development through green growth:

- The National Green Hydrogen Mission, with a budget of Rs 19,700 crore, aims to enable the shift of the economy towards low carbon intensity. It will also help reduce reliance on imported fossil fuels and position the country as a leader in both technology and the market in this emerging industry. The government aims to achieve an annual production of 5 million metric tonnes (MMT) by the year 2030.

- The Ministry of Petroleum & Natural Gas has allocated Rs 35,000 crore for priority capital investments in energy transition, net-zero targets, and energy security.
- Viability Gap Funding will be provided to assist Battery storage systems with a capacity of 4,000 MWH in Energy Storage Projects. A comprehensive structure for Pumped Storage Schemes will be developed.
- The construction of an inter-state transmission line will be undertaken to evacuate and integrate 13 GW of renewable energy from Ladakh. This project would require a capital expenditure of Rs 20,700 crore, with federal assistance of Rs 8,300 crore.
- A Green Credit Programme will be established by the Environment (Protection) Act. This will encourage environmentally conscious and adaptable behaviors by corporations, people, and local organizations and facilitate the mobilization of supplementary resources for these endeavors.
- The "PM-PRANAM" program, which stands for "Programme for Restoration, Awareness, Nourishment, and Amelioration of Mother Earth," would be initiated to encourage States and Union Territories to promote the use of alternative fertilizers and achieve a balanced use of chemical fertilizers.
- Under the GOBARdhan project, 500 new 'waste to wealth' factories will be set up to promote a circular economy by converting organic waste into valuable resources. The proposal entails the establishment of 200 compressed biogas (CBG) plants, with 75 plants located in metropolitan areas and 300 plants in community or cluster-based settings. The entire expenditure for this initiative amounts to Rs 10,000 crore. Eventually, a requirement will be implemented for all organizations that promote natural and bio-gas to have a 5% CBG mandate. Funding will be provided for the gathering of organic matter and the delivery of organic fertilizer.

Future of renewable energy in India:

India faces two main challenges: environmental and energy-related. India plans to increase the share of renewable energy sources in its future energy systems. Technologies for renewable energy evolve along with commercial and technical advancements. India, which has abundant renewable energy resources, is expected to develop and implement projects on a massive scale. India ranks sixth globally in terms of renewable energy production and fifth globally in terms of solar energy production. By 2025, the government wants to increase the capacity of renewable energy to 175 GW, which will be made up of 100 GW from solar, 60 GW from wind, 10 GW from biofuel, and 10 GW from hydropower. By achieving this goal, India would overtake several wealthy nations to rank among the world's top users of green energy. India's government has stated in its Proposed Nationally Determined Contribution to the United Nations Framework Convention on Climate Change that the nation aims to achieve 50% of its total electrical capacity from non-fossil fuel-based energy sources by 2030 (Kumar et al., 2010). Every economy depends on the daily energy needs for things like computers, industrial equipment, lighting, heating, communications, and transportation. After the US and China, India is the third-largest consumer of energy globally. India uses 37% more energy per person than the world average. India's energy system is primarily based on the production of power from coal and the transportation and industrial use of oil. For the next generation to live in a cleaner, greener, and safer environment, a nation must prioritize energy security, economic growth, and environmental preservation. India has realized how important it is to acknowledge and value efforts aimed at advancing renewable energy sources and sustainable development. Ultimately, there are a lot of long-term benefits to renewable energy. India has a lot of potential for renewable energy to narrow the gap between supply and demand. Going into the future, vehicles powered by hydrogen and electricity will be the most practical options. The limitations of clean energy sources will be easily surmounted if this is done (Kumar. J & Majid, 2020; Strielkowski et al., 2021).

Fast Facts:

- The Paris Climate Accord, signed by over 180 nations, aims to restrict global temperature rise to less than 2°C (3.6°F) beyond pre-industrial levels by 2100. After the Trump administration withdrew from the Paris Agreement on Nov. 4, 2020, President Joe Biden signed an executive order to rejoin on Jan. 20, 2021.
- The 2020 COVID-19 pandemic encouraged a decrease in fossil fuel prices due to record-low usage. After the Ukraine-Russia war began in early 2022, oil prices surged and remained high.
- A 15-year-old tree produces 700 shopping bags.
- More than 2.5 million plastic bottles are used by Americans every 30 minutes. Despite being recyclable, most of these bottles are thrown away.
- Leaving your tap running while brushing your teeth uses around 4.68 liters of water. A 15-minute shower uses 25-50 litres.
- Overnight computer monitor use emits 9 million tonnes of CO_2 annually. We must cut human carbon dioxide emissions by 45% from 2010 levels by 2030 and reach net zero by 2050 to prevent a climatic disaster.
- Denmark is the Earth's most eco-friendly nation, followed by Luxembourg, Switzerland, and the UK. Denmark has a centuries-old culture of sustainability, and world-class renewable energy is also available.
- Although China and India are major polluters, they plant more trees than any other country. With 80% of animals in forests and 20% of global emissions from deforestation, we must maintain forests.
- Approximately 71% of the Earth's surface is covered by water. The seas contain around 96.5% of the Earth's water, while the ice caps store around 2%. The residual water is

present in many water bodies such as wetlands, streams, ice caps, glaciers, and lakes, and as water vapor in the atmosphere, as well as in our taps. Just 1% of the Earth's water is potable for human consumption.

- The collective weight of the ants on Earth surpasses that of all human beings. The worldwide population exceeds 7 billion individuals, whereas the number of ants amounts to over 100 trillion.
- Recycling a single aluminum can conserves sufficient energy to power a television for three hours. Within the duration of reading this text, a total of 50,000 aluminum cans with a capacity of 12 ounces are manufactured.
- The Great Pacific Garbage Patch is a swirling and convoluted gyre comprised of refuse and detritus. Spanning an area twice the size of continental America, this region extends from the West Coast of North America to Japan along the Pacific Ocean. It is estimated to hold around 100 million tonnes of rubbish.

Conclusion:

In conclusion, the examination of the present status and future outlooks of renewable energy in India reveals a dynamic landscape shaped by technological advancements, policy interventions, and the pursuit of sustainable development goals. The country has made substantial progress in harnessing renewable sources, with notable achievements in the solar and wind energy sectors. However, challenges persist, including grid integration issues, financial barriers, and the need for enhanced storage solutions. Looking forward, the future outlook appears promising with the continued commitment to ambitious renewable energy targets and the adoption of innovative technologies. The intersection of sustainability and economic viability emerges as a focal point, emphasizing the importance of striking a balance between environmental conservation and economic growth. Renewable energy plays a crucial role in India's journey towards sustainability, aligning with global initiatives. The chapter underscores the significance of comprehensive policies, technological innovation, and international collaborations to propel India into a greener and more sustainable energy future. As the nation strives for energy security and environmental resilience, the evolving landscape of renewable energy in India remains a beacon of hope for a sustainable and equitable future.

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Chapter- 29

Unlocking the Potential: A Comprehensive Review of Environmentally Sustainable Applications for Agro-Based Spent Mushroom Substrate (SMS)

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Keywords: Spent Mushroom Substrate (SMS), Agro-waste Utilization, Animal Feedstock, Environmental application, Sustainable agriculture.

Abstract:

Agro-industrial residues represent both a challenge and an opportunity in sustainable agriculture. Spent mushroom substrate (SMS), a byproduct of mushroom cultivation holds immense potential for various environmentally sustainable applications. This review critically examines the current state of knowledge regarding the utilization of SMS in agriculture and related fields. The potential of SMS as a soil amendment to enhance soil fertility and productivity is explored, highlighting its role in improving soil structure, nutrient availability, and microbial diversity. Additionally, the suitability of SMS as a substrate for the cultivation of various crops, including vegetables, ornamentals, and medicinal plants, is evaluated, emphasizing its contribution to sustainable crop production and resource conservation. Furthermore, the utilization of SMS in bioenergy production, bioremediation, and waste management are discussed, underscoring its role in promoting circular economy principles and mitigating environmental pollution. The review also addresses key considerations and challenges associated with the widespread adoption of SMS-based practices, including nutrient management, potential contaminants, and economic feasibility. Moreover, emerging trends and innovative approaches for maximizing the value of SMS are identified, such as its utilization in biopolymer production, nanotechnology applications, and integrated agroecosystem management. The review concludes by highlighting the importance of interdisciplinary collaboration and holistic approaches to harness the full potential of SMS for sustainable agriculture and environmental conservation. Overall, this review provides valuable insights into the diverse applications of SMS and offers recommendations for future research directions and policy interventions to promote its widespread adoption and integration into agroecological systems.

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Introduction:

Mushrooms are fascinating macro-fungi with distinguishing sporocarp that may be either hypogeous (underground) or epigeous (aboveground) and big enough to be viewable in unaided sight and to be plucked by hand. Agricultural waste refers to the residues left behind after various agricultural activities, and it can be generated both before and after processing. The term "lignocellulosic" is often used to describe such waste because it primarily consists of three main polymers: cellulose, hemicellulose, and lignin (Treuer et al., 2018). The composition of agricultural waste can vary depending on the type of crop, farming practices, and processing methods (Banerjee Banerjee et al., 2021). Examples of agricultural waste include crop residues (such as stalks, leaves, and husks), straw, bagasse, and other by-products of farming and processing activities (Adebayo & Martinez-Carrera, 2015). With around 160,000 of the 1.5 million known fungi species producing study-worthy sporocarps (Hawksworth, 2012; Murugesan, 2017), approximately 7,000 of the 16,000 recognized mushroom species are edible (Hawksworth, 2012). Among them, 3,000 are primary edible mushrooms, and around 700 are recognized for their health benefits (Chang & Wasser, 2017; Li et al., 2021). Interestingly, 200 mushroom species are considered super-foods globally (Kalac, 2016), but only 35 are commercially cultivated, with 10 reaching the status of industrial production in various countries (Aida et al., 2009; Xu et al., 2011; Chang & Wasser, 2017). Many Asian countries generate substantial amounts of agricultural waste, and the list of examples includes palm oil waste, paddy straw, sugarcane bagasse, corncob, EFB, cottonseed hulls, wheat straw, hay, and cocoa hulls (Yadav & Samadder, 2018; Bhattacharyya et al., 2020). China is indeed one of the largest producers of mushrooms globally, India is a significant producer of mushrooms, with both edible and medicinal varieties being cultivated, Malaysia has been actively involved in mushroom production, and Ireland has also been recognized as a notable producer of mushrooms (Saha & Khatua, 2024). A significant gap between the demand and production of mushrooms in Malaysia leads to substantial imports from China. Demand for mushrooms in Malaysia is reported to be around 50 tons per day, and the current local production is stated to be 24 tons per day. In 2012, Malaysia imported a considerable quantity of mushrooms from China: Approximately 2.71 million tons of fresh mushrooms, and Approximately 3.11 million tons of dried mushrooms (Lee et al., 2009b; Amin et al., 2014). The average production from each mushroom farm in Malaysia is 100 tons of fresh mushrooms annually (Phan & Sabaratnam, 2012). China produces 1.5 million tons of mushrooms per year and is expected to increase production by 65% in the next 10 years (Royse et al., 2017). Mushroom production in Ireland gained momentum in the 1980s. The key breakthrough was the development of a method for producing high-quality mushrooms at a low cost. This made Irish mushroom production competitive in European markets (Williams et al., 2001). The agricultural waste generated in these countries provides a valuable resource that can be repurposed as substrates for mushroom cultivation. Mushroom cultivation typically involves the use of organic materials as substrates or growing mediums. The lignocellulosic nature of many agricultural residues makes them suitable for breaking down into a nutrient-rich substrate for growing mushrooms. The production rate of agricultural waste in mushroom-producing countries can vary and may not always be readily available. This review provides a general overview of how agricultural waste is generated and can be used in the context of mushroom cultivation (**Table 1**).

Table 1: The production rate of agricultural wastes in mushroom-producing countries.

Types of agricultural waste	Production rate (million tonnes)	Management methods	Year	Country	References
Food waste	11	Disposed	2019	Canada	Tsa et al., 2023
SMS	4	Burning	2007	China	Kim et al., 2011a
Sugarcane bagasse	620	Disposed, burning	2018	India	Sadh et al., 2018
Empty fruit bunch	76.9	Disposed	2012	Indonesia	Embrandiri et al., 2013
Wasted crops	30	Burning	2022	Iran	Khouzani & Ghahfarokhi, 2022
Food waste	60	Disposed	2004	Ireland	Saba et al., 2016
Food waste, manure, maize waste	5.3	Disposed	2022	Poland	Hajdu et al., 2022
Livestock, poultry, and food	292.4	Landfilling	2012	USA	Loehr, 2012
Manures and slurry	43	Landfill	2021	United Kingdom	Chancharoonpong et al., 2021

Agricultural residues and waste, often referred to as Agro-based SMS (Sustainable Management Systems), present a significant yet underexplored resource with vast potential contributions to soil health, agricultural practices, and waste management (Van Zuydam, 2021). Agricultural activities generate substantial amounts of waste in the form of crop residues, by-products, and post-harvest remnants (Aruya et al., 2016). While traditionally considered as a challenge for disposal, there is a growing recognition of the multifaceted benefits embedded in these agricultural residues (Aruya et al., 2016). One of the primary focuses of this review is the potential of Agro-based SMS to enhance soil health and fertility (Leong et al., 2022). The organic matter content, nutrient composition, and microbial activity found in many agricultural residues can contribute significantly to soil structure and fertility (Bhupinderpal-Singh & Rengel, 2007). Exploring methods to harness these benefits can lead to improved soil water retention, reduced erosion, and enhanced nutrient availability, ultimately fostering sustainable and resilient agricultural ecosystems (Hou et al., 2020). The utilization of Agro-based SMS extends beyond soil health to impact overall agricultural productivity (Sarkar et al., 2022). Integrating these residues into innovative farming practices, such as organic mulching, cover cropping, or bioenergy production, can optimize resource utilization and promote sustainable intensification (Sarkar et al., 2020). The high production rate of agricultural waste, especially when it reaches critical levels, poses significant challenges and can have adverse effects on the environment. The challenge of managing and properly utilizing large amounts of agricultural waste is indeed a critical environmental concern. Discarding agricultural waste through disposal and burning methods can lead to environmental pollution and other negative impacts. Developing alternative methods for utilizing agricultural waste is crucial for sustainable waste management and environmental conservation (Barh et al., 2018). Mushroom cultivation involves several processes, from substrate preparation to harvest (**Figure 1**).

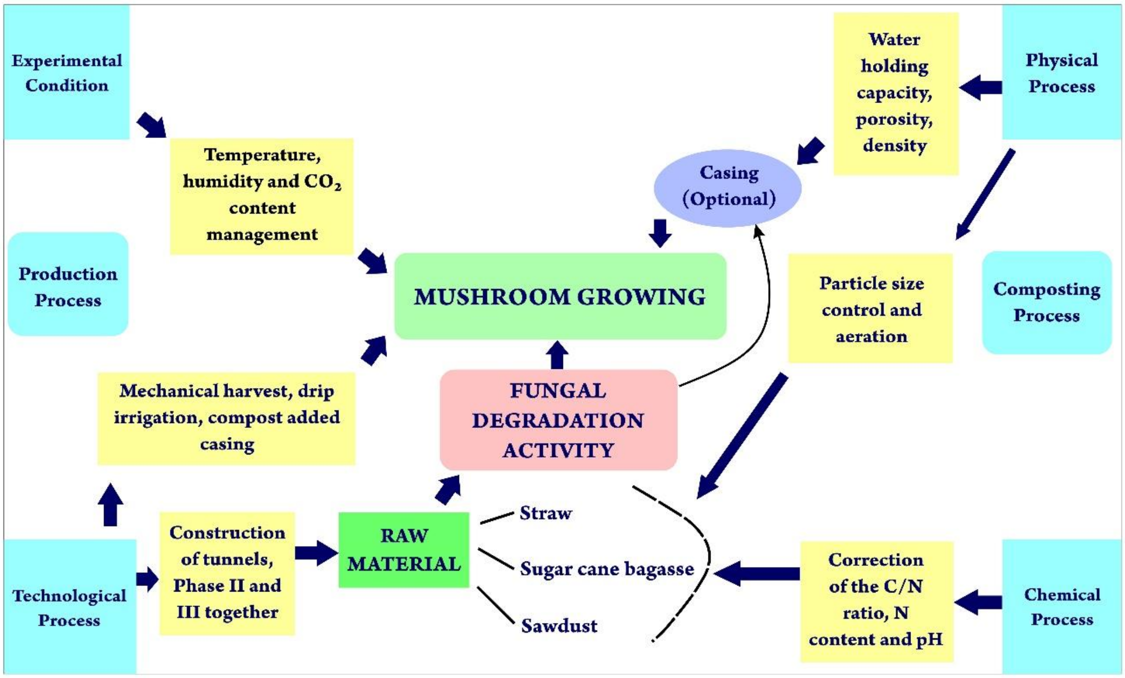

Figure 1. Scheme of mushroom cultivation and various processes.

Spent Mushroom Substrate (SMS):

Spent Mushroom Substrate (SMS) refers to the substrate or growing medium that has been used for mushroom cultivation and has completed its lifecycle, no longer supporting mushroom growth. This substrate is "spent" because the mycelium has consumed the available nutrients, and the substrate is exhausted. Spent Mushroom Substrate (SMS) is abundantly generated in mushroom farms after the harvesting period of mushroom fruiting bodies (Moon et al., 2012). SMS refers to the residual biomass waste that is generated from the process of mushroom production. For every 1 kilogram of fresh mushrooms harvested, the cultivation process results in the generation of approximately 5 kilograms of SMS (Lin et al., 2014; Zisopoulos et al., 2016). The residue from Spent Mushroom Substrate (SMS) is often treated as waste and discarded after the harvesting of mushrooms in many countries (Chiu et al., 1998). The challenge of managing the substantial amount of Spent Mushroom Substrate (SMS) in mushroom farms is a common issue faced by cultivators (Rasib et al., 2015) (**Figure 2**).

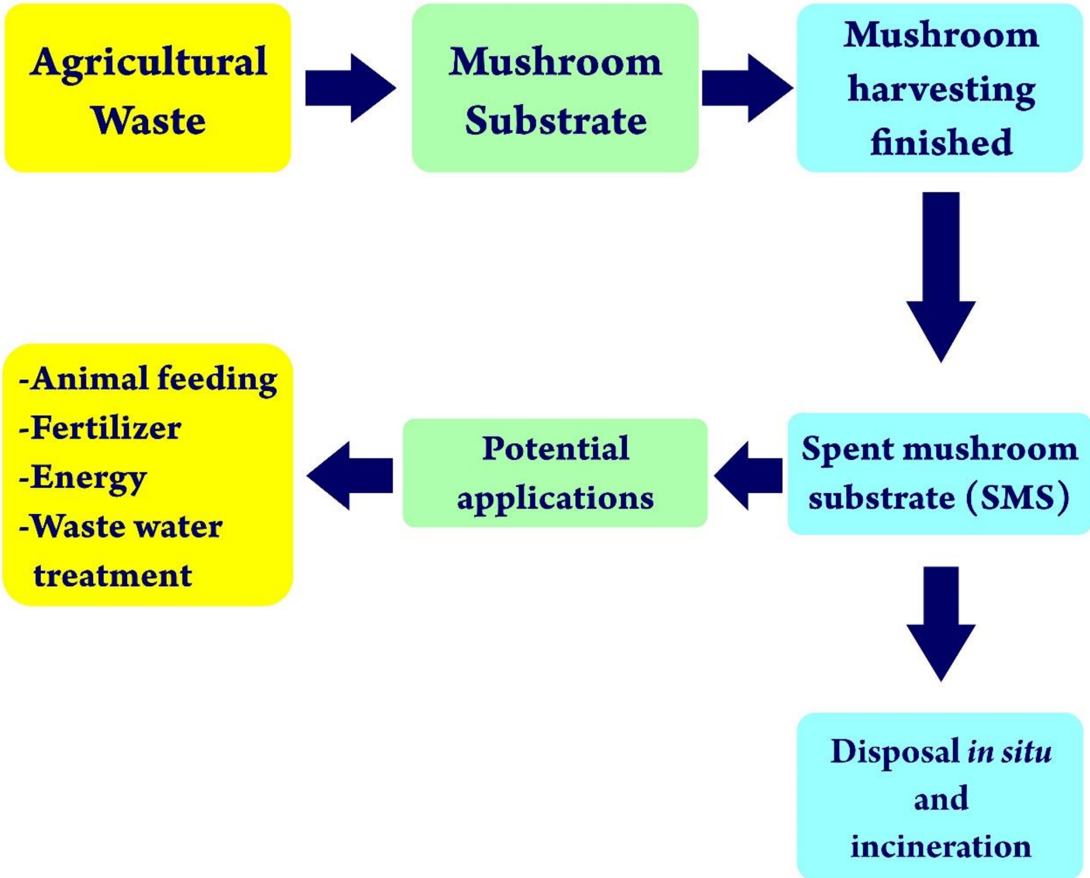

Figure 2. The management of SMS in the mushroom industry.

Concerns regarding the disposal of Spent Mushroom Substrate (SMS) have persisted and intensified over recent decades. The escalating trend of mushroom production, alongside the substantial generation of SMS as solid waste, underscores the challenges and opportunities inherent in managing agricultural residues. With an estimated annual production of around 5 million tons of SMS as solid waste, effective and sustainable waste management practices within the mushroom cultivation industry are imperative (Chiu et al., 1998). The annual production of approximately 660,000 tons of *Pleurotus eryngii* Spent Mushroom Substrate (SMS) in Korea serves as a testament to the magnitude of mushroom cultivation in the country. *Pleurotus eryngii*, commonly referred to as king oyster mushroom or king trumpet mushroom, stands as a popular edible mushroom species cherished for its culinary excellence and nutritional richness (Kim et al., 2012). Traditional methods of managing agricultural residues, such as employing SMS on farmland as fertilizer or disposing of it on land or through incineration, are still prevalent. However, each practice bears its own set of implications, with the choice often influenced by factors like local regulations, farm practices, and environmental concerns (Williams et al., 2001). The active pursuit by mushroom industries and researchers of low-cost potential applications for Spent Mushroom Substrate (SMS) with minimal environmental impact underscores ongoing efforts to tackle waste management challenges and discover sustainable solutions. The reviewed literature primarily delves into the major applications of SMS, which encompass animal feedstock, fertilizer, energy production, and wastewater treatment.

Utilization of Agricultural Waste for Mushroom Cultivation:

Mushroom cultivation using agricultural wastes as substrates offers several environmental benefits and can contribute to minimizing pollution in plantations and farms. The cultivation techniques for mushrooms can vary significantly between countries and even among different types of mushroom substrates. The choice of cultivation technique depends on factors such as the type of mushroom species, the availability of resources, climate conditions, and local agricultural practices (Marlina et al., 2015; Yang et al., 2016). The emphasis on utilizing low-value agricultural waste to enhance the nutritional quality of mushrooms underscores the growing importance of sustainable and innovative agricultural practices (Sardar et al., 2017). The research focuses on mushroom cultivation using agricultural waste and extends to various mushroom species, each with its unique characteristics and requirements. *Pleurotus spp.* (Oyster mushrooms), *Flammulina velutipes* (Enoki mushrooms), *Volvariella volvacea* (Straw mushrooms), and *Lentinula edodes* (shiitake mushrooms) are among the key species that researchers investigate for their potential in utilizing agricultural waste (Reis et al., 2012; Pala et al., 2012). The cultivation of mushrooms on various types of agricultural waste has been demonstrated and has gained significant attention in recent years. Corn waste, in particular, is recognized as a good substrate for mushroom production (Chukwurah et al., 2012). The use of corn cob as a main substrate for mushroom cultivation in India, and the reported high biological efficiency of approximately 93.75%, highlight the success and suitability of this agricultural waste material for mushroom production (Naraian et al., 2009). The use of paddy straw as a mushroom substrate, particularly in the cultivation and production of *Pleurotus spp.* (oyster mushrooms), has indeed been a common and established practice for many years (Thiribhuvanamala et al., 2017). Mushroom cultivation is indeed a widespread agricultural practice, and mushrooms are cultivated in numerous countries around the world. The countries you mentioned—China, Japan, The Netherlands, Spain, Malaysia, and others—are notable for their significant contributions to the global mushroom cultivation industry. China holds a prominent position as the world's largest producer and exporter of edible mushrooms such as *Pleurotus spp.*, *Lentinula edodes*, and *Agaricus bisporus* (Phan & Sabaratnam, 2012). The estimate of around 2000 types of edible mushrooms is a general approximation (Falandysz, 2013), and the actual number of known edible mushroom species may vary. The diversity of edible mushrooms is vast, and new species continue to be discovered and studied. The genus *Pleurotus*, commonly known as "oyster mushrooms," is indeed one of the well-known and widely cultivated genera in the world of edible mushrooms (Jayakumar et al., 2011). Mushroom cultivation in India has seen growth and diversification, with various regions adopting different species based on local climatic conditions, substrate availability, and market demand (Randive, 2012). Diverse mushrooms are, with varieties like oyster, king oyster, white button, shiitake, straw, and wild mushrooms offering various flavors and textures. Each type has its unique culinary and nutritional attributes (Amin et al., 2014; Islam et al., 2009). *Pleurotus spp.*, including *P. Sajor caju*, *P. Eryngii*, and *P. florida*, are widely cultivated and popular among mushroom enthusiasts (Alam et al., 2008; Moonmoon et al., 2012). These species are favoured in Asian countries not just for their culinary appeal but also because they are relatively easy to cultivate (Phan & Sabaratnam, 2012). Pleurotus spp. thrive in tropical regions and are known for their low-maintenance cultivation. Their ability to grow on various agricultural wastes, such as straw and other plant materials, makes them economically and environmentally beneficial (Pala et al., 2012). *Agaricus bisporus* and *Lentinula edodes* hold a dominant position in mushroom cultivation worldwide. Their widespread popularity is due to their versatile culinary uses, adaptable growing conditions, and global acceptance in various cuisines (Phan & Sabaratnam, 2012). Shiitake's popularity in Asia extends beyond culinary use; it's highly regarded as a medicinal mushroom, believed to have various health benefits. While its roots are in Asia, it has indeed found its way to other regions like North America and Europe, where it's appreciated both for its distinctive flavour in cooking and potential health-promoting properties (Melo de Carvalho et al., 2010). The different types of substrates for mushroom cultivation (**Table 2**).

Composition of Spent Mushroom Substrate (SMS):

Spent mushroom substrate (SMS) composition is significant for various applications, particularly in agriculture and waste management. After mushrooms have been harvested, the remaining substrate still contains valuable organic matter. It can be repurposed as a soil amendment, contributing to soil fertility and structure. Additionally, SMS has the potential for use in bio-energy production or as a feedstock for other industrial processes. The recycling of spent mushroom substrate is a sustainable practice with multifaceted applications (Lee et al., 2009). The composition of sawdust-based spent mushroom substrate (SMS), which includes various components like NDF (neutral detergent fiber), ADF (acid detergent fiber), hemicellulose, cellulose, lignin, carbohydrates, crude protein (CP), ether extract (EE), ash, dry matter (DM), calcium (Ca), and phosphorus (P). This complex composition makes it a rich resource with potential applications in different fields, such as agriculture and bio-energy. The nutrient content, especially in terms of organic matter and minerals, can contribute to its value in soil enhancement (Kwak et al., 2008). The nutrient composition of paddy straw-based spent mushroom substrate (SMS) with higher dry matter (DM) and crude protein (CP), along with slightly lower neutral detergent fiber (NDF), suggests its potential as a valuable agricultural resource (Kim et al., 2011). These attributes can enhance soil fertility and structure, making it beneficial for crop production. Agro-waste, with its high carbon and nitrogen content, provides

Table 2: Various Types of Substrates for Mushroom Cultivation.

Substrates	Mushroom types	References
Rice straw, wheat straw, rice + wheat straw, agricultural lime + wheat straw, agricultural lime + rice straw, quicklime + rice straw	*Pleurotus floridanus*	Youssef et al., 2023
Saw dust of mango, jackfruits, jam, kadom, mahogany, shiris, and coconut.	*Pleurotus flabellatus*	Islam, 2009
Sawdust, peat of coconut husk, narrow leaf cattails, bagasse	*Pleurotus ostreatus*	Vetayasuporn, 2006
Paddy straw, wheat straw, soybean straw, sugarcane bagasse, cotton waste, coconut coir pith	*Calocybe indica*	Porselvi & Vijaykumar, 2019
Sugarcane bagasse with cow dung, horse manure, chicken manure, cotton seed hull, sugarcane trash	*Lentinus edodes*	Desisa et al., 2022
Paddy straw, wheat straw, sugarcane bagasse	*Pleurotus pulmonarias*	Pant et al., 2006
Panicum repens, *Pennisetum purpureum*, *Zea mays*	*Pleurotus citrinopileatus*	Liang et al., 2009
Paddy straw, rubber tree straw	*Pleurotus eryngii*	Moonmoon et al., 2010
Paddy straw	*Pleurotus sapidus*	Singh & Sing, 2012
Onion waste, tea waste, paddy straw, wheat straw, sugarcane bagasse	*Pleurotus sajor-caju*	Banik & Nandi, 2004
Paddy straw	*Volveriella volvacea*	Ahlawat et al., 2010

favourable conditions for the performance of mushroom fruiting bodies. This balanced carbon-to-nitrogen ratio is crucial for the growth and development of mushrooms (Harith et al., 2014). Agro-waste, such as agricultural residues and by-products, not only serves as an environmentally friendly substrate but also contributes to the sustainability of mushroom cultivation. When considering the application of spent mushroom substrate (SMS) for fertilizer, it's crucial to assess and manage nutrient levels. Understanding the nutrient composition of SMS helps ensure that it aligns with the specific needs of the crops or plants it is being used for. Balancing nutrient ratios and considering factors like nitrogen, phosphorus, and potassium content is essential to maximize the benefits of SMS as a fertilizer. The nutrient composition of the spent mushroom substrate (SMS) can vary based on the mushroom species cultivated and the type of substrate used (Kamthan & Tiwari, 2017; Mohd Hanifi et al., 2018) (Table 3).

Table 3: Composition of Spent Mushroom Substrate (SMS).

Substrate	Composition
Bean straw	Carbohydrates (31.3%), Moisture (85.8%), Ash (9.4%), Crude protein (37.6%), Crude fat (2.6%), and Crude fiber (9.3%)
Paddy straw	Carbohydrates (42.3%), Moisture (90.4%), Ash (90.4%), Ash (1010%), Crude protein (38.1%), Crude fat (1.0%), Crude fiber (1.70%)
Wheat straw	Cellulose (40%), Hemicelluloses (39%), Lignin (13%) and Protein (1%)
Rice straw	Cellulose (41%), K_2O (0.3%), P_2O_5 (0.25%), SiO_2 (6%), total nitrogen (0.8%), and pH 6.9
Sugarcane bagasse	Ash (1-4%), Cellulose (35-40%), Hemicellulose (20-25%), Lignin (18-24%), Nitrogen (0.7%), and Waxes (0.7%)
Cotton waste	Moisture (88.1%), Ash (6.1%), Crude protein (21.6%), Crude fat (8.4%), and Crude fiber (9.3%)

Food security assurance:

The excerpt highlights the importance of food security and the role mushrooms can play in addressing nutritional, pharmaceutical, and economic aspects (WHO, 2012). The challenges of hunger, food shortages, and the "perfect storm" of scarcity predicted by 2030 underscore the need for sustainable solutions (The Guardian, 2009; The Guardian, 2011). The emphasis on awareness and cultivation, especially in regions facing high food insecurity like African and developing Asian countries, reflects a proactive approach to addressing global nutritional challenges (Pandey et al., 2018; Sustainable Development Goals, 2020). The pursuit of alternative, cost-effective, and protein-rich food sources has led to the exploration of edible fungi, particularly mushrooms of the Basidiomycetes class (Mukherjee & Nandi, 2004). Mushroom cultivation, as an indoor crop utilizing vertical space, offers advantages like land efficiency and waste utilization. Notably, mushrooms are a potent protein source, with production efficiency nearly 100 times higher than traditional agriculture (Sing et al., 2011). Approximately 50% of edible mushrooms are considered functional food, contributing to both nutrition and potential health benefits (Food Revolution Network, 2016). China leads the world in mushroom production, surpassing 20 million tons, constituting over 80% of global production. The mushroom industry continues to play a significant role in addressing protein needs and sustainable food production (Dai et al., 2009; Li, 2012). Mushroom farming has become a global phenomenon, spanning over 100 countries, and its production is steadily increasing at an annual rate of 6–7%. In developed European and American nations, mushroom cultivation has evolved into a high-tech industry marked by significant mechanization and automation (Sing et al., 2011), reflecting advancements in agricultural practices. This shift underscores the importance and widespread adoption of mushrooms as a valuable and sustainable agricultural product. The Asia Pacific region takes the lead in the global mushroom production market. China, being the largest producer of mushrooms worldwide, not only

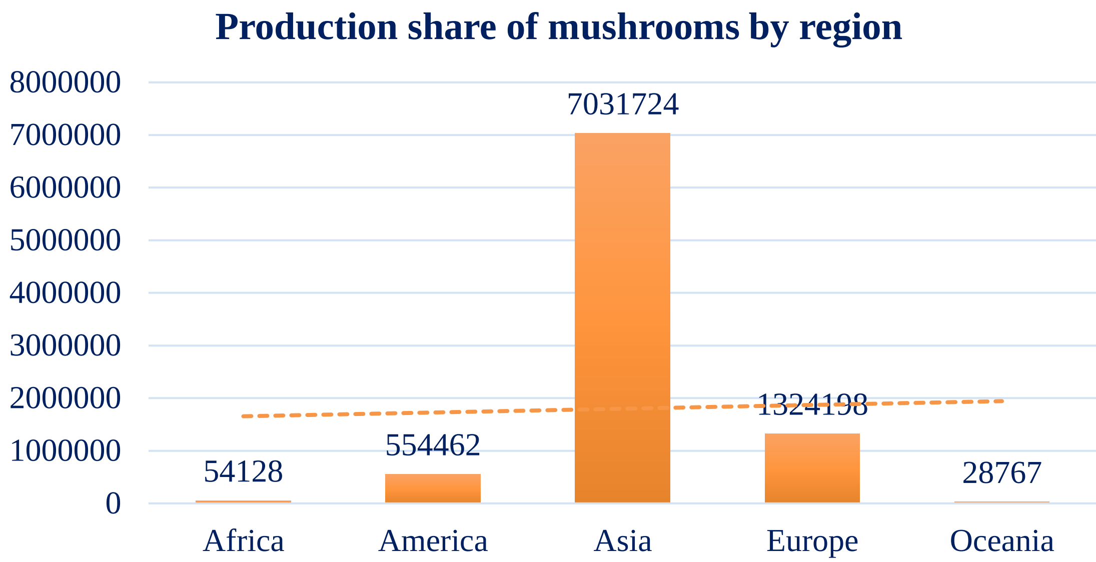

Figure 3. Region-wise production of mushrooms.

contributes significantly to the overall production but also boasts a higher per capita consumption compared to any other country (FAO, 2018; Faostat Production database, 2018) (Figure 3). This underscores the prominence of the region, especially China, in shaping the dynamics of the mushroom industry.

China stands out as a global leader in the production of various mushroom varieties, including *Lentinula edodes*, *Volvariella volvacea*, *Agaricus bisporus*, and others (Wu et al., 2013). The consumption patterns differ among countries, with China, the EU, and India relying significantly on domestic sources, while the United States, Japan, Australia, and Canada combine domestic production with substantial imports (USITC, 2010). In Africa, where food insufficiency and malnutrition persist, mushrooms emerge as a potential solution, offering a protein-enriched alternative to staple foods with low micronutrients (Ishara et al., 2018). Nigeria provides a notable example where mushrooms contribute to combating poverty, hunger, and malnutrition. Similarly, the People of Bamenda Highlands turn to mushrooms for food security during shortages (Fongnzossie et al., 2020).

International forums, such as those dedicated to edible, medicinal, and wild mushrooms, aim to uplift the global mushroom industry (Chang, 2006; Fortune Business Insights, 2019). Key players in the mushroom market include Monterey Mushrooms, Inc., Weikfield Foods Pvt. Ltd., and others (Fortune Business Insights, 2019). However, challenges like pathogenic issues, political and financial obstacles, and weak government policies hinder mushroom production in developing nations.

Sustainable use of SMS as an agro-industrial resource:

Spent mushroom substrate (SMS) refers to the residual material left after the cultivation of mushrooms. It is essentially a by-product of the mushroom farming process (Phan & Sabaratnam, 2012). Instead of being discarded as waste, SMS can be utilized in various ways to contribute to sustainable agriculture and the efficient use of agro-industrial resources (Kivaisi et al., 2010). SMS is rich in organic matter and nutrients, making it a valuable soil amendment. It can enhance soil structure, water retention, and nutrient content. SMS can be added to compost piles to enhance the nutrient content and accelerate the composting process. Mixing it with other organic materials creates a balanced and nutrient-rich compost that can be used as a natural fertilizer for plants. The spent mushroom substrate can be used as a feedstock for bioenergy production through processes like anaerobic digestion or combustion. While the substrate has been used to grow one batch of mushrooms, it may still contain residual nutrients suitable for growing other crops. Depending on the mushroom species and the cultivation process, SMS may have residual nutritional value (Mohd. Hanafi et al., 2018). The spent mushroom substrate has been explored for its potential in environmental applications, such as bioremediation (Ghose & Mitra, 2022) (Figure 4).

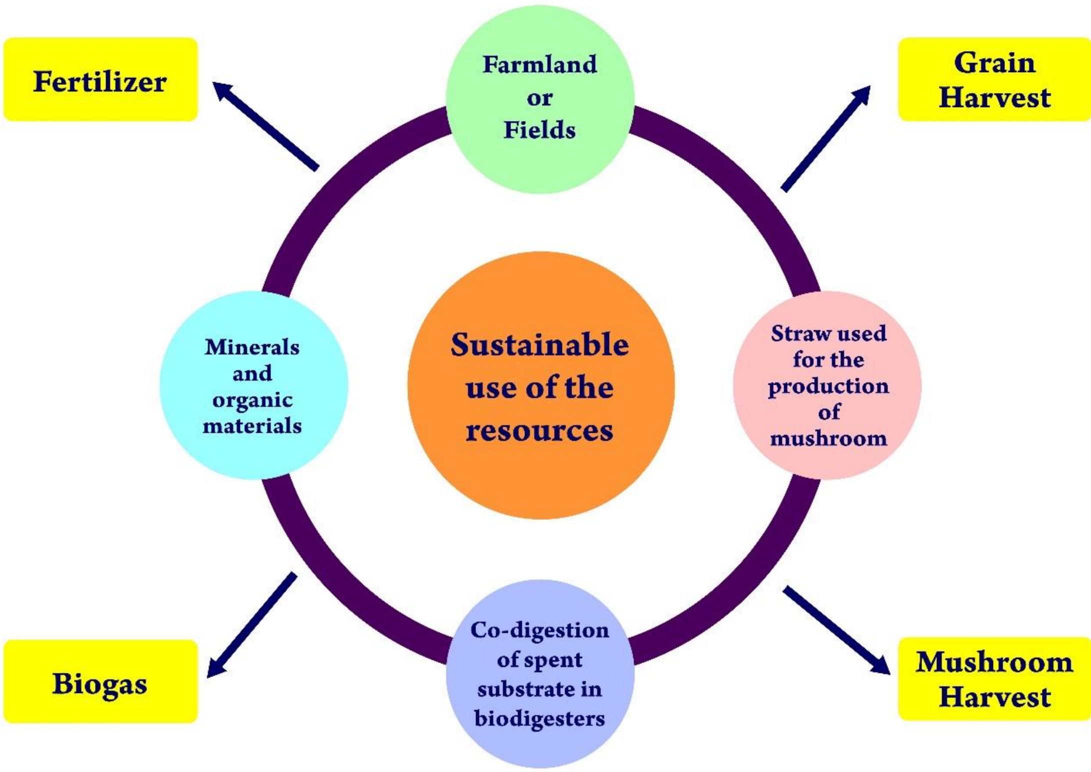

Figure 4. Sustainable use of agro-industrial resources.

Lignocellulolytic Enzyme Production by Mushroom Using Agro-Industrial Wastes:

The decomposition of lignocellulosic materials, a crucial process in the terrestrial carbon cycle, involves various decomposers such as bacteria, micro-fungi, mushrooms, earthworms, and woodlice (Eichorst & Kuske, 2012; Cragg et al., 2015; Bredon et al., 2018). Lignocellulose, consisting of cellulose, hemicellulose, and lignin, requires the collaborative action of multiple carbohydrate-active enzymes due to different bonding functions (Lombard et al., 2014; Andlar et al., 2018). The degradation process involves both hydrolytic and oxidative enzymes, with hydrolytic enzymes breaking down cellulose and hemicellulose, while oxidative enzymes participate in lignin degradation (Lopez-Mondejar et al., 2016; Madeira et al., 2017; Kumla et al., 2020) (**Figure 5**). This synergistic activity is essential for the efficient breakdown of lignocellulosic biomass in the environment.

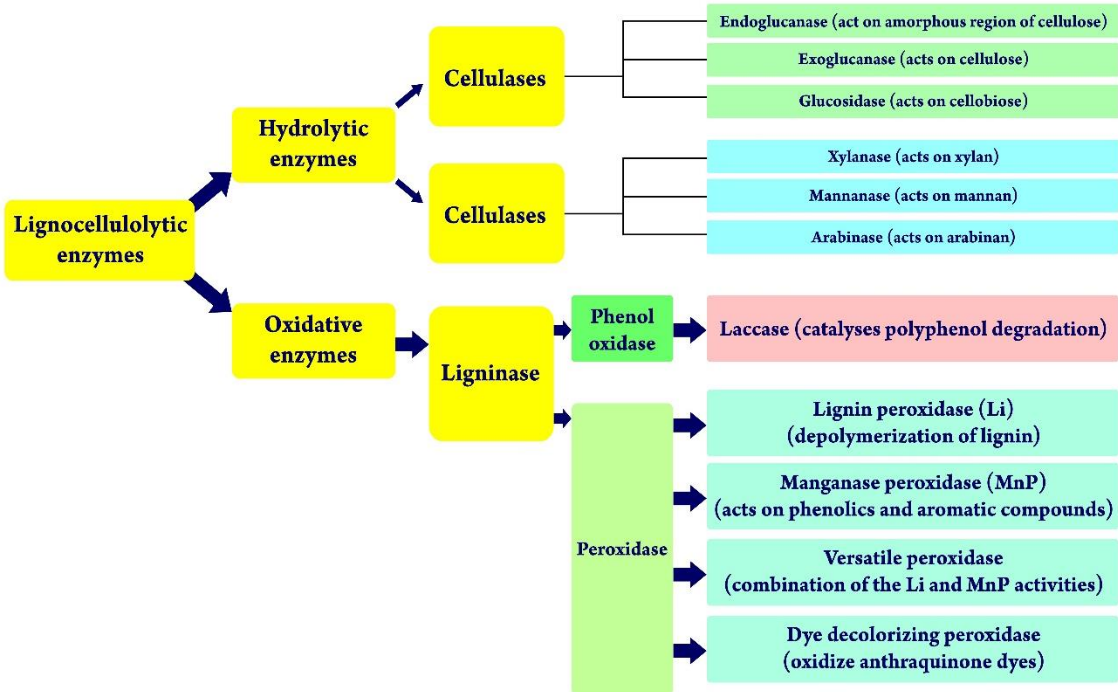

Figure 5. Scheme of enzymes involved in the lignocellulosic degradation process.

Application of Spent Mushroom Substrate (SMS):

SMS as Animal feedstock:

The lignocellulosic biomass such as paddy straw, wheat straw, and barley straw is utilized as a ruminant feedstock due to its rich nutrient content. These agricultural residues are excellent sources of fiber, providing energy and promoting digestive health in ruminants. The high fiber content, including cellulose and hemicelluloses, supports the complex digestive systems of animals like cows and sheep (Rezaei et al., 2015; Amerah, 2015). Ruminants are herbivores with a specialized digestive system that allows them to efficiently break down and extract nutrients from plant materials. Their stomach is divided into multiple compartments, including the rumen, where microbial fermentation of fibrous plant material occurs. This fermentation process helps break down complex carbohydrates like cellulose into simpler compounds that the ruminant can digest (Jami & Mizrahi, 2012). While cattle may be inclined to consume paddy straw, a challenge lies in its high silica content. Silica can negatively impact feed digestibility, affecting the overall nutritional value of the straw for cattle (Drake et al., 2002). The high silica content in paddy straw can limit its digestibility for ruminants, impacting its overall utility as a feed source. While ruminants have specialized digestive systems capable of breaking down fibrous materials, excessive silica can hinder the efficiency of this process. The nutritional value derived from paddy straw may be lower compared to other feed options (Sarnklong et al., 2010; Van Kuijk et al., 2015). Mushrooms are a nutritious food source and can be included in a balanced human diet (Furlani & Godoy, 2008; Stamets, 2011). The increasing consumption of mushrooms, whether fresh or preserved, is likely due to their versatility, nutritional benefits, and culinary appeal (Jayakumar et al., 2011). Mushrooms offer a unique flavour and texture, and they are a good source of vitamins, minerals, and protein. Optimizing the production efficiency and reducing the cost of supplemental feed for ruminants, like dairy cattle, is crucial for both smallholder and commercial farmers. Understanding and balancing components such as neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin, ash, cellulose, hemicellulose, and protein in the forage or supplemental feed can contribute to improved digestibility for ruminants (Fazaeli et al., 2014; Van Wyngaard et al., 2015). Utilizing SMS in ruminant feeding is a valuable approach (Fazaeli et al., 2014). The components like fiber, cellulose, and hemicellulose in SMS contribute to the structural composition of forage, promoting proper digestion in ruminants (Rezaei et al., 2015; Amerah et al., 2015; Gimeno et al., 2015). Integrating SMS into the diet helps support the complex digestive processes of these animals, ensuring a balanced and nutritionally adequate feed for their well-being (Yang et al., 2016; Zhang et al., 1995). The higher ruminal degradability and lower neutral detergent fiber (NDF) content in agro-based SMS make it a promising candidate for developing additional supplements for ruminant animals (Aldoori et al., 2015). The SMS obtained from various mushroom species is suitable for ruminant feedstock due to its content of essential nutrients such as polysaccharides, vitamins, and trace elements like iron (Fe), calcium (Ca), zinc (Zn), and magnesium (Mg) (Medina et al., 2009; Zhu et al., 2012; Fazaeli et al., 2014). These components make mushroom-derived SMS a nutritionally valuable option for ruminants, comparable to commercial animal pellets. The content of amino acids and dietary protein is vital in the diets of ruminants. The addition of SMS to the diet of elk has been observed to enhance their physiological condition during growth. Specifically, *P. florida* straw-based SMS demonstrated a higher degradable value compared to *P. sajor-caju*-SMS. The utilization of *P. ostreatus* corn straw-based SMS has shown positive effects, improving the chemical composition of straws and enhancing the growth performance of feedlot lambs (Galaviz-Rodriguez et al., 2010; Park et al., 2012). The utilization of agro-based SMS in feeding ruminants offers a valuable approach to enhancing their diet (**Table 4**).

Table 4: Utilization of agro-based SMS in feeding ruminants.

Types of mushroom	Substrates types	Findings	Feeding trial	Remarks	References
Agaricus bisporus	SMS 15%	No remarkable differences were noticed in the carcass and internal organs of the claves that received the SMS.	Holsteins male calves	The result was taken after 170 days of SMS feeding.	Fazaeli et al., 2014
Agaricus bisporus	SMS 10%,20%,30%	Nitrogen balance and digestibility were normal up to 20% SMS.	Sheep	Above 20% may show some imbalance in nutrient uptake. The result was taken after three weeks of observation.	Fazaeli et al., 2006
Agaricus bisporus	Wheat straw, poultry manure, calcium sulfate, sugar beet molasses, and urea.	Used in the diet of finishing calves in pellet form.	calves	The total mixed ratio in marsh form can negatively affect the feed intake.	Fazaeli et al., 2014
A.blazei	SMS 0.2% - 1.0%	0.2% SMS showed the best result in weight gain, and feed conversion.	Broiler chicks	Data taken up to 42 days and above 0.4% of SMS reduced animal performance.	Machado et al., 2006

Cordyceps militaris	SMS 0.2%	Increased final body weight.	Crossbred growing pigs	Other body parameters like IgA, and IgG were the same till 6 weeks.	Boontium et al., 2019
Flammulina velutipes	fresh SMS	Decreased protozoa in the rumen.	Holstein steers.	Negatively effect. protozoa population and methane emission.	Rangubhet et al., 2017
Ganoderma lucidum	Hot water extract of SMS	It enhanced murine function.	mice	After 30 days, it was observed that 0.84g/kg dose had an optimal effect in all aspects.	Liu et al., 2018
Ganoderma lucidum	Hot water extract of SMS	It enhanced milk quantity, immunity, and antioxidant capacity.	Holstein cows	The given data was taken after 60 days of SMS feeding.	Liu et al., 2015
G. chalceum	Hot water extract of SMS	It enhanced milk protein, quantity, triglyceride level, and hematology parameters.	Chinese Holstein cows	The given data was taken after 60 days of SMS feeding.	Liu et al., 2015
Grifola frondosa	SMS	No remarkable effect on body weight, feed efficiency, or biochemical	Wistar rats	Fecal weight and protein content were slightly higher than the control.	Tasaki et., al. 2013

		parameters.			
Hypsizygus marmoreus	SMS fermented with Bacillus subtilis	Egg production, egg mass, egg white, feed conversion, and viability were the same.	Laying hens	After 12 weeks of observation feed intake increased.	Kim & Song, 2014
Lentinula edodes	SMS fermented with Bacillus subtilis	Increased final weight, daily gain, feed conversion, and immunity.	Weaned piglets	The data was reported after 33 days.	Liu et al., 2020
Pleurotus sajor-caju	Rice straw fermented with SMS	Increased nutrient content, degradability of dry matter, and milk yield.	Alpine dairy goats	The data was reported after 28 days.	Fan et al., 2023
Pleurotus sajor-caju	SMS 0.5- 2%	SMS up to 0.67% improved the weight gain till the first 21 days.	Broiler chicken	Above 0.67% may show some imbalance.	Azevedo et al., 2015
Pleurotus ostreatus	SMS 10 %	After 60 days, increased the digestibility of crude fat.	Male sika deers	It can be replaced by the intake of organic matter.	Yuan et al., 2022
Pleurotus ostreatus	SMS co-fermented with feed and whole plant rice.	No adverse effect on the slaughter.	Liuyang black goats	After feeding for 60 days the meat quality was improved.	Huang et al., 2022

Pleurotus ostreatus	SMS fermented or not with Lactobacillus brevis.	No adverse effect till 13 days.	Hanwoo steers	Could replace formulated feed concentrate.	Baek et al., 2017
Pleurotus ostreatus	SMS	Up to 5% had no effect.	geese	After 8 weeks, it favors effective sensory attributes.	Chang et al., 2016
Pleurotus ostreatus	SMS (5, 10, 15 and 20%)	SMS ratio (up to 15%) decreased slaughter, empty body, and carcass weights, dressing, and leg lean.	Awassi sheep	The data was reported after 70 days.	Kim et al., 2015
Pleurotus ostreatus	SMS substituted wheat bran	SMS improved feed intake	broilers	Til 8 weeks, SMS did not affect breast, thigh, drumstick, back, neck, wings, and shoulder weight.	Foluke et al., 2014
Pleurotus ostreatus	SMS 10% fermented or not with lactic acid bacteria	Fermented SMS enhanced the growth compared to non-fermented SMS.	Postweaning claves	Data were taken up to 60 days.	Kim et al., 2011
Pleurotus ostreatus	SMS with rice bran and	3% SMS enhanced the	Berkshire pigs	After 7 weeks daily feed	Song et al., 2007

	barley bran 3,5,7%	growth, carcass trait, meat quality, and fatty acid concentration of meat.		intake and feed conversion increased.	
Pleurotus ostreatus	Fresh SMS	No negative effect of up to 15% SMS.	Awassi lambs	It can replace barley.	Aldoori et al., 2015
Pleurotus eryngii	Microbially fermented SMS 50%	Enhanced growth and carcass traits.	Hanwoo steers	After observing 12.6 months it can be concluded that it could be successfully replaced as part of conventional roughage.	Lee et al., 2017
Pleurotus eryngii	SMS (5, 10, 15 %) fermented with Bacillus subtilis	Egg production, egg mass, egg white, feed conversion, and viability were the same.	Laying hens	After 7 weeks yolk colour was more intense.	Kim et al., 2012

SMS did not improve the nutritional quality of agricultural by-products; it may not be considered ideal forage for ruminants in that context. Applying biological treatment can be effective in improving the digestion of straws and increasing digestibility for ruminant animals. Biological treatment has the potential to improve the nutritional composition of straws for ruminant animals. It can lead to an increase in crude protein and fat content while reducing the amount of crude fiber (Mahesh & Mohini, 2013; Abdel-Aziz et al., 2015). The high fibrinolytic activity of SMS from *A. bisporus* species is advantageous as it can significantly increase the degradation of forages for ruminants. This fibrinolytic activity is crucial in breaking down complex fibers in forages, making them more digestible and nutritionally available for ruminant animals during the digestive process (Kwak et al., 2009; Ayala et al., 2011).

Certain types of SMS have low nutrient composition and are deemed incompatible for use as ruminant feedstock; modifications may be necessary. Applying biological treatment is a viable strategy to enhance the nutrient composition and ruminal digestibility of SMS that may initially have lower nutritional value. The complex relationship among rumen microorganisms, conformation, and biological activity warrants further studies (Liu et al., 2015). Using SMS in combination with conventional roughage has the potential to improve forage quality, especially in Asian countries. To address this, conducting large-scale research would be practical and beneficial (Kim et al., 2015).

SMS for Fertilizer:

The nutrient content and generally non-toxic nature of SMS make it feasible for use as a bio-fertilizer, supporting plant growth. The nutrients present in SMS can contribute to soil fertility, promoting healthier and more robust plant development (Sendi et al., 2013). The main components of SMS that make it suitable for use as fertilizer include calcium, nitrogen, ash, and protein (Lou et al., 2017; Owaid et al., 2017). These components contribute to the nutrient content of SMS, providing valuable elements for plant growth and soil fertility. Numerous studies have demonstrated the feasibility of using SMS in horticulture applications, both alone and in combination with other materials (Nakatsuka et al., 2016; Lou et al., 2017). The attention to reusing SMSs for soil improvement is well-founded, given their richness in nitrogen (Lou et al., 2017). The ability of SMS to modify soil structure is noteworthy, as it can play a role in preventing the transport of pesticides or facilitating their dispersion. The utilization of SMS from *Lentinus edodes* as a replacement for mulch is promising, given its favourable physicochemical characteristics and biological activity in pesticide degradation (Gao et al., 2015). The richness of *Lentinus edodes* SMS in organic and essential plant nutrients enhances its utility for soil improvement and mulching. The results of a 42-day incubation of mushroom cultivation demonstrate a significant enhancement of mineral nitrogen in the soil (Lou et al., 2017). Phosphorus (P) is a major nutrient essential for plant growth. The application of SMS in improving soil structure can serve as an effective additive of phosphorus for soils (Zhu et al., 2012). The richness of SMS in phosphorus makes it a valuable addition to agricultural land. When applied, SMS contributes to enhancing soil organic matter and nutrient contents, particularly phosphorus (Lou et al., 2015).

SMS can serve as a bio-fertilizer for the cultivation of *Pleurotus spp*. (oyster mushrooms) and potentially other mushroom species (Owaid et al., 2017). Many studies have explored the use of SMS for growing crops, including pineapple, tomatoes, and lettuce (Adedokun and Orluchukwu et al., 2013; Lopes et al., 2013; Paredes et al., 2016). The addition of pig manure to SMS is a practical approach that can increase the nutritional content of nitrogen (N), phosphorus (P), and potassium (K) (Meng et al., 2018). This enhanced nutrient profile makes the combination suitable for use as fertilizers, providing a balanced mix of essential elements for plant growth (Zhu et al., 2013). The significant differences in yield were reviewed in plants cultivated on soil treated with SMS from *A. bisporus* and *Pleurotus spp*. The revision that soil treated with SMS can enhance plant yield compared to non-treated soil reinforces the positive impact of using SMS in agriculture (Alvarez-Martin et al., 2016). The example from Zhang et al. (2012), reporting higher yields of tomatoes and cucumbers in soil treated with SMS compared to non-treated soil, supports the notion that SMS application can positively impact crop productivity. The evidence indicating a positive effect of SMS on the growth of vegetables and its use as a replacement for mineral fertilizers is noteworthy. Additionally, the higher grain yield observed for maize treated with micronutrients from SMS, resulting in an 11.5% increase compared to non-treated ones, further supports the potential of SMS in improving crop yields. The finding that SMS led to a higher grain yield for maize when used as a source of micronutrients indicates its potential as a micronutrient fertilizer. The conversion of SMS into a micronutrient fertilizer through a bio-sorption process, leading to improvements in soil structure, quality, and sorption capacity, underscores the versatility and potential benefits of SMS in agriculture (Tuhy et al., 2015). Mixtures or improved agro-based SMS can serve as effective bio-fertilizers for various crops, enhancing their cultivation (Table 5).

Integrating SMS using new formulations and methodologies presents added advantages, including the potential to lower production costs and minimize the environmental impact of its over-growing accumulation. Further studies are crucial to explore new biological material drying methods and identify new types of biomass for the production of micronutrient fertilizer components. The strategy of exploring new biological material drying methods and diverse biomass sources is anticipated to lead to an increase in the portfolio of new micronutrient fertilizer products (Tuhy et al., 2015).

Table 5: Mixtures or Improved Agro-based SMS as Bio-Fertilizers for Different Crop Cultivations.

Types of mushroom	Mixture/improved substrates	Crops trials	Findings	Remarks	References
Agaricus bisporus	SMS + peat moss	*Brassica oleracea var. Alboglabra*	SMS can decrease the amount of peat moss for culture thus it is also cost-effective.	50% SMS and 50% peat moss should be used, SMS alone cannot work as a growing media	Sendi et al., 2013
Agaricus bisporus	SMS of Agaricus crop + SMS of *Pleurotus* crop	Lettuce	SMS improved soil fertility and	Mineral fertilizers also show the same results	Paredes et al., 2016

			nutritional contents		
Agaricus bisporus	Wheat straw	Italian grass	SMS increased the yield by up to 300%, and also enhanced the growth.	It can be used as a replacement for peat.	Paula et al., 2017
Agaricus bisporus	Bio-sorption of SMS	Maize	SMS increased the nutrient contents.	SMS shows better growth than NPK	Tuhy et al., 2015
Agaricus bisporus	SMS + Talc	*Trichoderma viride, rhizobium japonicum*	SMS was found to be a good carrier for shelf life and survival.	Talc gave maximum propagules.	Shitole et al., 2014
Agaricus subrufescens	Fresh SMS	Tomato crops	SMS increased the yielding capacity as well as the fruit size.	Yield was higher or equal as compared to other fertilizers.	Lopes et al., 2015
Hypsizygus marmoreus	SMS + cotton seed hull + wheat bran	*Pleurotus ostreatus*	25% SMS showed the best result.	Economically effective	Wang et al., 2015
Lentinula edodes	Wheat straw-based SMS	*Solanum lycopersicum*	SMS showed significant potential in germination, yield, growth, and biochem-ical	SMS potentially contributes to minimizing the carbon footprints of the mushroom	Kumar et al., 2022

			parameters.	production sector.	
Pleurotus ostreatus	Sawdust based SMS	Pineapple	SMS showed two times higher fruiting bodies than the control.	Performed better than control soil	Adedokon et al., 2013
Pleurotus ostreatus	Fresh SMS	-	SMS changed the soil structure and porosity.	SMS developed granular aggregates in the soil.	Nakatsu et al., 2016
Pleurotus ostreatus	Sawdust based SMS	Fluted pumpkin	SMS showed higher values of N, P, and K.	SMS improved the number of vines, vine length, and leaf structure.	Orluchukwu et al., 2016
Pleurotus sp.	SMS of Agaricus crop + SMS of Pleurotus crop	Lettuce	SMS improved soil fertility and nutritional contents	Mineral fertilizers also show the same results	Paredes et al., 2016
Pleurotus florida	Saw dust with paddy straw and tea	*Capsicum annum*	SMS alone resulted in a maximum increase of phosphorus in soil.	SMS can decrease the usage of chemical pesticides so, it is environment ally effective.	Ignatius et al., 2021
Volveriella volvacea,	Fresh SMS	*Capsicum annum*	SMS showed	SMS of Volveriella	Yang et al., 2019

Pleurotus ostreatus			higher growth and disease control.	showed greater results than SMS of Pleurotus.	

SMS for energy production:

Agro-industrial biomass, particularly lignocellulosic materials, is renewable, abundant, and represents a unique natural resource for bioenergy production. Its use in bio-energy processes contributes to sustainable energy practices, utilizing organic materials derived from agricultural processes to generate power or produce bio-fuels (Rezania et al., 2017). The utilization of SMS for energy production not only offers a sustainable management solution but also helps divert SMS from landfills. This approach contributes to minimizing environmental impact, as the energy production from SMS generally produces minimal acid gas emissions such as nitrogen oxides (NOx), sulfur oxides (Sox), and hydrogen chloride (HCl) (Finney et al., 2009). According to the literature, the application of SMS in energy production emerges as a promising alternative for mushroom producers. This approach not only helps minimize SMS production on-site but also promotes the sustainable growth of mushrooms. The use of SMS in bio-ethanol production can mitigate environmental issues arising from the mushroom industry (Kapu et al., 2012; Ryden et al., 2017). The lower lignin content in SMS, resulting from the degradation process during mushroom production, is advantageous for energy production (Phan & Sabaratnam, 2012). The example you provided, highlighting the efficient combustion of SMS in pellet form with a combination of coal tailing (up to 91.7% efficiency), underscores the practical advantages of using SMS in energy production (Finney et al., 2009). The highly degradable nature of SMS is advantageous, and the co-digestion of SMS with wheat straw has proven to be efficient in enhancing methane production (Lin et al., 2014). Hydrogen production from SMS using *Clostridium thermocellum* for lignin degradation showcases the versatility of SMS in bio-energy applications. The ability to harness hydrogen through microbial processes not only provides an alternative energy source but also addresses the challenge of lignin, which is often less accessible in traditional energy production methods (Lin et al., 2016). As reported by Wu et al., SMS contains a high yield of reducing sugar, indicating its potential as a carbon source (Wu et al., 2013). The usage of SMS in energy production holds significant potential due to its various favourable characteristics, such as high degradability, reduced lignin content, and the presence of reducing sugars (Table 6).

Table 6: Application of SMS in energy production.

SMS type	Findings	Energy	References
SMS	The concentration of ethanol produced and the substrate concentration.	Ethanol	Asada et al., 2011
Sorghum-based SMS	The yield of 63.9 g/kg dry matter means that for every kilogram of dry matter in the substrate, 63.9 grams of ethanol is produced.		Ryden et al., 2017
SMS and kelp seaweed	A process involving co-pyrolysis of sewage sludge (SMS) with 10% kelp seaweed. The presence of oxygen-containing groups in biochar can influence its reactivity and surface properties. These groups might include carboxyl, hydroxyl, and carbonyl functional groups. They can affect the biochar's ability to adsorb substances and play a role in its overall chemical reactivity.	Bio-char	Sewu et al., 2017
SMS with pig manure and rice straw	The biochar derived from sewage sludge (SMS) is rich in nutrients such as phosphorus (P), potassium (K), sodium (Na), and nitrogen (N). The nutrient content in biochar can have significant implications for its potential use as a soil amendment or fertilizer.		Chang et al., 2017
SMS-based biochar	The biochar derived from sewage sludge (SMS-biochar) has been observed to reduce 43% of total nitrogen (TN) and 66% of chemical oxygen demand (COD). These results suggest that biochar has the potential to be an effective treatment for wastewater or other environments with high levels of nitrogen and organic pollutants.		Lou et al., 2017
Oil shale semi-coke SMS	The bio-oil produced from the co-processing of sewage sludge (SMS) and shale semicoke has high carbon and hydrogen content, along with lower oxygen content.	Bio-oil	Jiang et al., 2017
SMS with chemical vapour deposition of SiO_2	The mixture (presumably the product of co-processing sewage sludge and shale semicoke) has a high oil fraction yield and contains toluene and xylene.		Zhang et al., 2017

SMS	In the context of producing bio-crude (bio-oil or liquid hydrocarbons from biomass), having an effective hydrogen-to-carbon (H/C) ratio above 1 is considered favourable for the quality of the product.	Biocrude	Jasiunas et al., 2017
SMS with *Clostridium thermocellum*	The addition of sewage sludge (SMS) has led to an accumulation of 28% more, specifically 5.06 g/L, of reducing sugars. Reducing sugars typically include monosaccharides and some disaccharides that can reduce certain chemicals, such as Fehling's solution.	Hydrogen	Hu & Zhu, 2017
SMS	There has been an improvement in sugar yield and a reduction in lignin content, and as a result, the maximum amount of butanol produced was 30.21 g/L.	Butanol	Zhu et al., 2016
Co-digestion of SMS and dairy manure	Sewage sludge (SMS) is a suitable feedstock for biogas production, and the high degradability of SMS has a positive influence on anaerobic digestion.	Methane	LUo et al., 2018
Spent mushroom compost and wheat straw	The maximum production (perhaps of biogas or another product) was achieved at a carbon-to-nitrogen (C/N) ratio of 30 and a temperature of 55 °C, with a specific production rate of 44.1001 ml/g.	Biogas	Najafi & Ardabili, 2018

Several important factors need consideration for energy production using SMS: 1. the type of biomass directly influences the yield of energy production. Different biomass sources may have varied compositions affecting their suitability for specific energy production processes; 2. The choice of mushroom species can impact the availability of lignocellulosic parts in the biomass and subsequently influence the sugar ratio. Understanding these variations is crucial for optimizing energy production; 3. Determining the optimum ratio of biomass to SMS is essential for enhancing production rates. Achieving the right balance in the mixture is key to maximizing energy yield; and 4. Co-digestion of SMS with suitable lignocellulosic biomass can be a strategic approach to increase the overall yield of energy production. This synergistic combination enhances the efficiency of the energy generation process (Hanafi et al., 2018). Considering and optimizing these factors contributes to a more efficient and effective utilization of SMS in energy production processes. While the utilization of SMS in energy production offers significant benefits, it’s important to acknowledge that the production yield may be impacted by the generation of certain by-products.

SMS for wastewater treatment:

Several studies have reported that SMS is used as an effective material for treating various pollutants from wastewater (Xu et al., 2012; Song et al., 2014; Garcla-Delgado et al., 2017). SMS proves to be a promising carbon source for nitrogen removal from wastewater due to its efficient characteristics. The addition of SMS has been shown to enhance nitrogen removal significantly, with reported increases from 46.9% to 87.8% (Yang et al., 2017). As discovered by Karas et al. (2016), the fresh mushroom substrate of *P. ostreatus* demonstrated efficiency in removing ortho-phenylphenol and imazalil from wastewater generated in citrus fruit-packaging plants. The use of immobilized SMS from *Pleurotus ostreatus* for the removal of Cd(II) from synthetic wastewater demonstrates the potential of SMS in adsorbing heavy metals (Jin et al., 2018). The study finding that the bio-sorption capacity of immobilized SMS from *Pleurotus ostreatus* for Cd(II) removal is dependent on pH value, initial concentration of Cd(II), and contact temperature in a batch system is significant. The observed maximum adsorption capacity of 100 mg/g, by the Langmuir isotherm model, provides valuable insights into the factors influencing the efficiency of Cd(II) removal using immobilized SMS. The development of SMS from *A. bisporus* as a strategy to improve volatile fatty acids (VFAs) bio-production from waste-activated sludge is noteworthy. This approach not only enhances the efficiency of VFA production but also has the potential to reduce operational costs (Zang et al., 2017).

The effectiveness of oyster mushroom (*P. ostreatus*) in reducing heavy metal and PAH contents in soil compared to the control *M. maximus* grass highlights the potential of certain mushroom species in remediation processes (Yan & Wang, 2013; Zhou et al., 2014; Toptas et al., 2014; Asemoloye et al., 2017). The recent work by Nakajima et al., where active enzymes were extracted from spent mushroom compost, including cellulases, β-glucosidase, dextranase, amylase, and laccase, highlights the potential for repurposing mushroom by-products. The finding that *Pleurotus sp.* exhibited the highest decolorizing capacity among the tested fungi underscores the enzymatic capabilities of mushroom-derived materials (Nakajima et al., 2018). While SMS (spent mushroom substrate) has various beneficial applications, there are challenges associated with its use for the treatment of different types of wastewater. Considering the characteristics of SMS is crucial, and the origin of the mushroom plays a significant role in enhancing adsorption capacity. While SMS-derived adsorbents can be effective for certain pollutants in water, their performance might be limited in high ranges of pollution. The assumption is reasonable; the application of SMS-based adsorbents may face limitations in industrial and refinery wastewater treatment due to the specific characteristics of these effluents. Applying Sewage Sludge (SMS) as a casing layer in mushroom cultivation involves using treated sewage sludge as a top layer covering the substrate to create an environment suitable for mushroom fruiting (Figure 6).

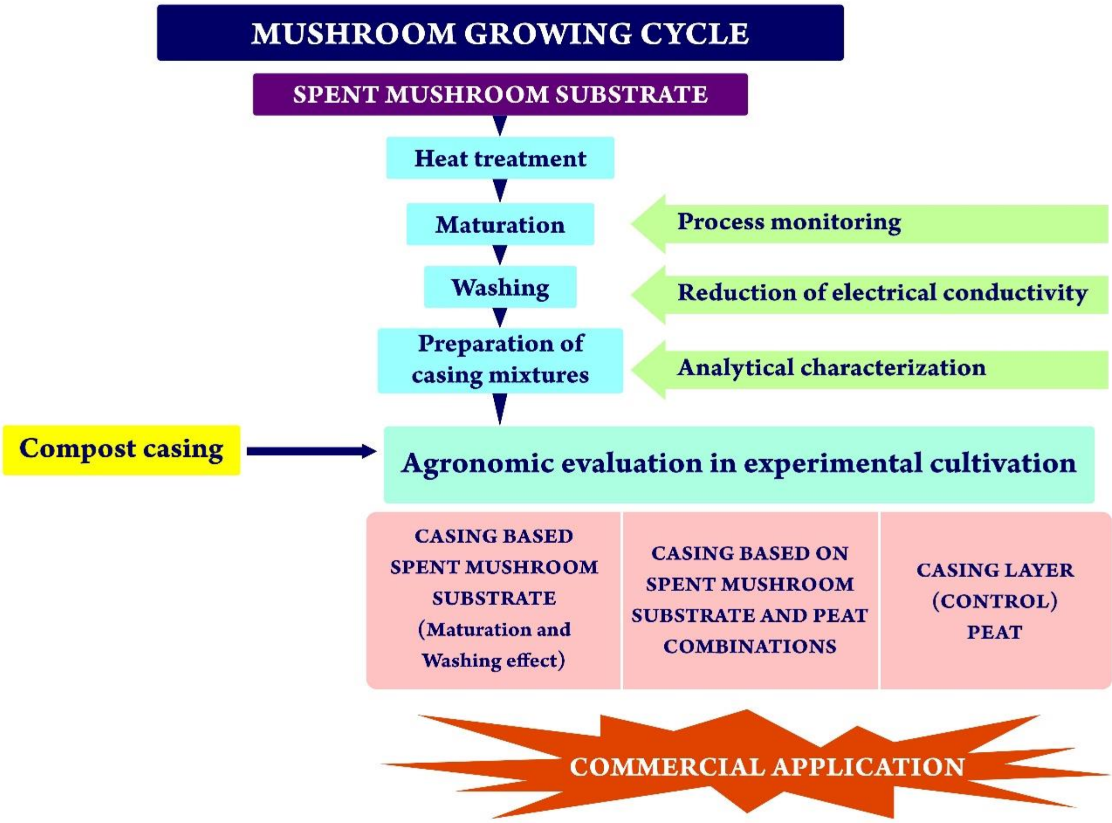

Figure 6. Application of SMS as a casing layer in mushroom cultivation.

Other applications of SMS:

The disposal of spent mushroom substrate (SMS) poses a significant challenge for mushroom-producing countries, as highlighted by Medina et al. One of the major concerns is finding environmentally friendly ways to manage and dispose of SMS to prevent environmental pollution (Medina et al., 2009). The issue of generating a substantial amount of spent mushroom substrate (SMS) in the mushroom industry, approximately 20% for each 1 kg of mushroom beds, presents a significant challenge (Stamets, 2011). The versatile application of spent mushroom substrate (SMS) extends beyond ruminant feedstock, fertilizers, energy production, and wastewater treatment. It also holds potential as a feed additive for aquaculture-farmed fish (Van Doan et al., 2017). The use of spent mushroom substrate (SMS) in the cultivation of fungi through solid-state fermentation for the production of enzymes such as xylanase, amylase, cellulose, and β-glucosidase are an interesting application (Grujic et al., 2015). This demonstrates the potential of SMS as a substrate for fostering fungal growth and enzyme production, adding another dimension to its utility in biotechnological processes. The study conducted by Liu et al., suggesting the use of spent mushroom substrate (SMS) as an antioxidant for the prevention of diabetes, highlights the potential health-related applications of SMS (Liu et al., 2017; Saha et al., 2022). Circular economy maximizes the value of spent mushroom substrate by transforming it into valuable resources like organic fertilizer or livestock feed, mitigating waste and promoting sustainable resource use (Saha, 2023). The other applications of spent mushroom substrate (SMS) are diverse.

Conclusions:

A diverse array of mushroom species, including *Pleurotus spp.*, *F. velutipes* and *V. volvacea*, showcase versatility in cultivation. These mushrooms thrive when cultivated with various agro-residues such as paddy, rice straw, and grass plants. The leftover material from mushroom cultivation, known as Spent Mushroom Substrate (SMS), is a valuable resource rich in nutrients. It contains organic matter, essential minerals, and residual mycelium, making it an excellent choice as a fertilizer. When applied to soil, SMS can enhance soil fertility, improve its structure, and contribute to the overall nutrient content. Spent Mushroom Substrate (SMS) demonstrates the ability to absorb a wide range of organic and inorganic compounds, as well as heavy metals, cost-effectively. The nutritional quality of Spent Mushroom Substrate (SMS) is influenced by the specific mushroom species cultivated on the substrates. Different mushroom species contribute varying amounts of nutrients to the substrate during cultivation. The observation that the growth of *Pleurotus djamor* on maize stover did not enhance the nutritional quality of Spent Mushroom Substrate (SMS) suggests its incompatibility for use as ruminant feedstock. Agro-based Spent Mushroom Substrate (SMS) holds promise for sustainable applications, serving as an eco-friendly alternative in various fields. Its potential lies in agriculture, where it can enhance soil fertility and structure. Additionally, SMS can be utilized in bioremediation, contributing to environmental cleanup efforts. However, considerations should address proper disposal methods, potential contaminants, and optimizing application rates to avoid ecological imbalances. In conclusion, while SMS presents environmentally sustainable opportunities, careful management and research are essential to fully realize its benefits while minimizing potential drawbacks.

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Chapter- 30

Securing Coral Reefs: Integrating Sustainable Development Goals in the Anthropocene

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Keywords: Coral reef conservation, Sustainable Development Goals (SDGs), Anthropocene, Ecosystem, Biodiversity.

Abstract:

Amidst escalating threats to coral reefs during the Anthropocene era, an urgent call emerges for a holistic strategy that seamlessly integrates Sustainable Development Goals (SDGs), ensuring the conservation and sustainable development of these vital ecosystems. Employing an interdisciplinary lens, this chapter delves into the current state of coral reefs, shedding light on the critical need for immediate action. The study emphasizes the transformative potential of SDGs as a guiding framework for policies and initiatives aimed at fortifying resilient ecosystems and uplifting the communities intricately tied to coral reef ecosystems. Drawing on diverse case studies and successful conservation models, this chapter discerns key strategies essential for realizing SDGs in the intricate context of coral reefs. The synthesis of ecological and socio-economic perspectives contributes to a nuanced understanding of the multifaceted challenges and opportunities entwined in securing the sustainability of coral reefs within the Anthropocene. The study underscores the imperativeness of collaborative efforts, innovative solutions, and policy coherence to effectively navigate the intricate issues surrounding coral reefs, offering a blueprint for the integration of SDGs into practical conservation and sustainable development initiatives. As coral reefs teeter on the brink of irreversible decline, this research advocates for a comprehensive and dynamic approach that transcends disciplinary boundaries, promoting the vitality of these ecosystems and the well-being of the communities reliant upon them.

Introduction:

Humans are predominantly ruining and changing the environment. These changes are seen in marine to terrestrial ecosystems (Carpenter et al., 2009). National and international trades, human migration as well as migration of invasive species, and unnecessary land acquisitions led to the destruction of the habitats of numerous species (Reid et al., 2010). Amidst the

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irrational activities of humans, Coral was severely affected both directly and indirectly. Over the past 50 years, we have witnessed a ground-breaking decline in their habitat. Besides coastal pollution and overfishing, ocean deacidification and global warming added fuel to the depletion of corals. This destruction of corals deeply impacted the income coming from tourism and fishery services (Moberg & Folke, 1999). Corals are social animals providing shelter for millions of species and they play a major role in tourism in the coastal regions. The galloping emission of greenhouse gas paves the way for the destruction of coral reefs by the mid-century. Corals are colonial organisms and coral reef is formed by various individual polyps. They thrive at a temperature of 18^0C-30^0C and require a set of physiological conditions in clear shallow water (Hoegh-Guldberg, 1999). As light and salinity (32-40%) are required for the growth of corals they are found mainly in the Tropic of Capricorn and Tropic of Cancer. It has been recognized by IUCN/UNEP/WWF that coral reef acts as a life-supporting system by showing a high productivity rate in the ocean (Sue, 1988). Due to the brutal activities of humans' a dramatic decline in the number of healthy coral reefs has been observed. Jameson et al (1995) showed that a rapid decline in the number of coral reefs had occurred in around 93 countries (Jameson et al., 1995). Wilkinson has investigated that 10% of the world's coral population has already disappeared and an additional 20% may disappear in the ensuing future (Wilkinson, 1993). Coral reefs in the Indian Ocean have already witnessed a 20% loss in their number (Sarkar & Ghosh, 2013). It is evident and reported that nearly 1.2 million species that depend on coral reefs may be extinct in 40 years. Therefore, the urgency to conserve corals became very clear. Here we will discuss several strategies to maintain corals by reducing ocean acidification and global warming and increasing coral resiliency (Costanza et al., 1997). We then will administer several combined steps to sustain the number of corals as well as our environment. Several biological, ecological, and socio-economic strategies are developed to combat these issues to maintain coral reef sustainability. Integrated coastal zone management should be implemented to sustain corals by mitigating several human-borne problems (Souter & Lindén, 2000).

State of Coral Reefs in the Anthropocene:

Corals have been at stake for several years. The main reasons behind coral reef depletion are divided into two categories -one arises from anthropogenic origin and the other is from natural calamities. These two threats are inextricable and sometimes assumed as only one. Some anthropogenic threats are considered natural. For example- the bleaching of coral due to the rising temperature of the sea is linked to global warming which is caused by human activities. Therefore, these types of threats are included in anthropogenic origin (Hoegh-Guldberg, 1999). High human population densities in the coastal region are becoming a burden for the corals living (Sue, 1988). Besides this, overexploitation of fish, coastal development, and pollution caused by anthropogenic activities make corals most vulnerable nowadays (Figure 1).

Overexploitation of Fish:

Fishing is regarded as the most potential threat to coral reefs. Overexploitation of predatory and herbivorous fish leads to undesirable coral reef configurations. It was estimated by Bryant et al. (1998) that throughout the world 36% of the coral reefs are at acute risk due to overfishing by using some deadly fishing techniques which include dynamite, cyanide, muro-ami, and kayakas techniques (Bryant et al., 1998; Jennings & Polunin, 1996; Jameson et al., 1995). In southeast Asia and the East coast of Africa, the highly destructive blast technique of fishing is very common. This technique primarily includes dropping explosives into the sea and then picking up the concussive or killed fish by fishermen (Lundin & Lindén, 1993; Eric et al., 2014; Cesar et al., 1997). The blast collapses the skeleton of coral reefs in proximity making the flourishing ecosystem as debris. Therefore, productivity in coral reefs decreases with the death of many fishes and invertebrates residing on coral reefs (Jennings & Polunin, 1996). The increasing demand for aquarium fish cyanide fishing started in the 1960s in the Philippines. This is an illegal process of fishing greatly prevalent in Southeast Asia. Nowadays large predatory fishes like Napoleon Wrasse (*Chelinus undulatus*) and groupers (Serranidae) have become the target of cyanide blasts. Sodium cyanide is used to stupefy fishes to capture easily and therefore these fishes are easily exported to various markets in Europe (Bryant et al., 1998). Cyanide fishing is more dangerous than any other fishing technique because cyanide causes damage not only fishes but also to the coral itself. A higher dose of cyanide instantly kills corals and a lower dose of cyanide hampers the photosynthetic activities of the symbiotic zooxanthellae. As a consequence, bleaching of coral occurs and therefore growth of coral slows down (Jones & Steven, 1997; Jones & Hoegh-Guldberg, 1999). Muro-ami and kayakas drive netting techniques are considered a non-selective method of fishing technique because of the by-catch of undesirable organisms. Approximately 300 people are engaged in this technique by holding weighted scare lines or thrashing palm fronds to frighten fish and to catch them in a pre-set bag net. This technique leads to the damage of coral reef branching as well as to the coral reef substrate (Jennings & Polunin, 1996). Fishing decreases the abundance and distribution of fish populations throughout the coral reef and alters some marine species' genetic structures and composition. Further overfishing is responsible for eliminating the keystone species from the coral reef community which leads to community destruction (Jennings & Polunin, 1996). An increase in the number of the boring sea urchin *Echinometra matthei* in the Kenyan reef occurs due to the overfishing of triggerfish (Balistidae) (McClanahan & Muthiga, 1988). This increase results in a high rate of erosion of coral reefs. Not only fishes but also many mollusc species like the genus *Tridacna* (giant clams) have been said to be extinct in some parts of the Philippines. Many sea cucumbers (Holothuroidea) and sea urchins (Echinoidea) have vanished from several coral reefs in Galapagos (Bryant et al., 1998).

Coastal Development:

Limited space in coastal areas and the development of airports in coastal islands directly cause irreparable harm to coral reefs. Due to irrational landfilling to construct large hotels, building turbidity and sedimentation in the ocean have increased as soil washes away from the construction sites (Morrison et al., 2013). It was proved by Bryant et al. (1998) that nearly 30% of coral reefs are destroyed by coastal development. Thus, the construction of buildings in coastal zones leads to an increase in beach erosion altering water circulation patterns (Cesar et al., 1997). Sunlight needed for photosynthesis is blocked by sediment when it reaches the coral reef. Subsequently, the growth of the coral reef is also reduced. Sometimes corals die as soon as the sediment touches them (Nowlis et al., 1997). As the number of people is increasing at the seashore, a high amount of waste is also generated there. These wastes directly fall into the sea causing eutrophication and algal bloom eliminating corals from the sea (Jameson et al., 1995). Uncontrolled construction and mining of sand at the seashore inevitably cause more beach erosion, sometimes entire buildings have fallen into the sea destroying corals on these sites (Coughanowr et al., 1995). As terrestrial resources are limited, there is an urge to remove and mine corals from the sea to manufacture cement. Coral acts as the barrier of the sea to protect coastal zones from oceanic storms and lofty waves. But mining of corals changes the topography of corals and destroys them and also changes the pattern of water flow which causes more beach erosion (Oehman et al., 1993; Berg et al., 1998; Clark & Edwards, 1995).

Anthropogenic Involvement in Climate Change:

As population density increases innumerable factories are established and therefore pollution increases. An increasing concentration of CO_2 is involved in ocean acidification. Especially in summer when the temperature rises by 1^0-2^0C bleaching of coral occurs and therefore coral dies. The decline in the growth of coral, lower fecundity rate, and decrease in calcification occur due to mass bleaching. For that reason, the CO_2 level must be maintained under 480 ppm to 450 ppm (Hoegh-Guldberg et al., 2007). When $[CO_2]_{atm}$ approaches 480 ppm, a decrease occurs in the pH of the ocean and levels of aragonite which is the crystalline form of calcium carbonate required for the formation of the skeleton of corals (Hoegh-Guldberg, 2011). Corals are found to co-exist with the symbiotic photosynthetic dinoflagellate zooxanthellae. Bleaching of corals by ocean acidification or a rise in the temperature of the ocean causes the loss of these zooxanthellae or the complete loss of their photosynthetic pigment (Birkeland, 2015). Due to mass bleaching, these dinoflagellates do not produce energy by photosynthesis which is why the growth of corals and calcification rate is reduced, they show an inability to remove sediment and an increase in susceptibility to disease (Muscatine, 1990). Once these zooxanthellae are eliminated from the coral, they become white and “bleached” in appearance. High sea temperatures caused by human activities and high light intensity in the ocean are responsible for the elimination of these zooxanthellae from coral tissues. A bleached coral can regenerate its tissues and may remain in this form for several months or weeks (Glynn, 1991).

Coral reefs are also susceptible to man-made storms, and volcanic and tectonic activities. For these man-made unavoidable circumstances sometimes recovery of the reef ecosystem cannot be possible at all (Hughes, 1994).

Figure 1. Threats to coral reefs: bleaching, pollution, and other factors endanger marine life.

Sustainable Development Goals (SDGs) and Their Relevance to Coral Reefs:

Coral reefs are important ecosystems that provide a range of social and ecological services, including food, coastal protection, and tourism. However, they are under threat from a range of anthropogenic drivers of change, including climate change, overfishing, and pollution (Hughes et al., 2003). To address these threats, it is important to integrate the Sustainable Development Goals (SDGs) into coral reef conservation efforts (Figure 2). The relevance of the Sustainable Development Goals (SDGs) to coral reefs, particularly SDG 14: Life Below Water, SDG 13: Climate Action, and SDG 12: Responsible Consumption and Production, is crucial for the conservation of these ecosystems (Aswani et al., 2015).

SDG 14: Life Below Water

Life Below Water is particularly relevant to coral reef conservation. This goal seeks to conserve and sustainably use the oceans, seas, and marine resources for sustainable development. The targets and indicators for SDG 14 include reducing marine pollution, protecting and restoring marine ecosystems, and increasing the economic benefits to small island developing states and least-developed countries from the sustainable use of marine resources (Wilson & Forsyth, 2018). These targets are directly relevant to coral reef conservation efforts, as coral reefs are important marine ecosystems that provide a range of economic and ecological benefits. Coral reefs worldwide are facing impacts from climate change, overfishing, and pollution (Moberg & Folke, 1999). The conservation of at least 10% of coastal and marine areas, as outlined in SDG 14, is consistent with national and international law and is essential for the protection of coral reef ecosystems (Diz et al., 2018).

Achieving the targets under SDG 14 can significantly contribute to coral reef conservation. For example, effectively managing and protecting marine and coastal ecosystems can help reduce overfishing, destructive fishing practices, and habitat degradation, all of which threaten coral reefs. Additionally, enhancing marine biodiversity and maintaining healthy ecosystems can improve the resilience of coral reefs to stressors such as climate change and ocean acidification (Harborne et al., 2017). However, using SDG 14 as a framework for coral reef conservation also presents challenges and limitations. Despite efforts to establish marine protected areas (MPAs) and implement sustainable management practices, coral reefs continue to decline globally. Factors such as inadequate enforcement, insufficient funding, and lack of stakeholder engagement hinder the effective implementation of SDG 14 targets (Reimer et al., 2020). Moreover, the interconnected nature of marine ecosystems necessitates integrated approaches that address multiple stressors simultaneously, which can be complex and resource-intensive.

SDG 13: Climate Action

Climate change poses one of the most significant threats to coral reef ecosystems. Rising sea temperatures, ocean acidification, and extreme weather events associated with climate change have led to widespread coral bleaching, disease outbreaks, and reef degradation. SDG 13 emphasizes the urgent need to take action to combat climate change and its impacts. The targets and indicators of SDG 13 can help mitigate climate change impacts on coral reefs (Hoey et al., 2016). For example, Target 13.2 aims to integrate climate change measures into national policies, strategies, and planning. Indicators such as greenhouse gas emissions, carbon pricing, and climate resilience measures provide metrics for assessing progress in addressing climate change. Synergies between SDG 13 and other SDGs are essential for coral reef conservation. For instance, reducing greenhouse gas emissions (SDG 13) can mitigate ocean warming and acidification, which are major drivers of coral reef decline (Harvey et al., 2018). However, there may be trade-offs between climate action and other SDGs, such as economic growth (SDG 8) or poverty reduction (SDG 1), particularly in industries reliant on fossil fuels or land-use practices that contribute to deforestation and habitat destruction (Kleypas et al., 2021).

SDG 12: Responsible Consumption and Production

Unsustainable consumption and production patterns exacerbate coral reef degradation by increasing pollution, habitat destruction, and resource depletion. SDG 12 calls for promoting sustainable consumption and production patterns to minimize environmental impacts. Achieving SDG 12 targets can reduce pressures on coral reefs by promoting sustainable fisheries, reducing plastic pollution, and minimizing the ecological footprint of goods and services (Lamb et al., 2018). For example, Target 12.5 aims to substantially reduce waste generation through prevention, reduction, recycling, and reuse. Implementing measures such as banning single-use plastics, promoting eco-friendly alternatives, and improving waste management practices can help alleviate the burden on coral reef ecosystems. Individual and collective action is crucial for promoting sustainable consumption and production for coral reef conservation. Consumers can make environmentally conscious choices, such as avoiding products derived from unsustainable fishing practices or supporting businesses that prioritize sustainability. Governments, businesses, and civil society organizations play a vital role in implementing policies, regulations, and initiatives that promote responsible consumption and production practices (Cramer & Kittinger, 2021). By prioritizing targets related to marine conservation, climate action, and sustainable consumption and production, stakeholders can work towards safeguarding coral reefs for future generations.

Integrating SDGs into Coral Reef Conservation Strategies:

Coral reefs are invaluable ecosystems that support biodiversity, provide livelihoods, and protect coastlines. However, they are under threat from various anthropogenic activities, including overfishing, pollution, and climate change. To address these challenges effectively, integrating Sustainable Development Goals (SDGs) into coral reef conservation strategies is essential.

Holistic Approaches for Coral Reef Management

Holistic approaches to coral reef management emphasize the interconnectedness of social, economic, and environmental factors. Adopting an ecosystem-based management (EBM) framework allows for a comprehensive understanding of coral reef ecosystems and their interactions with human societies. EBM integrates ecological, social, and economic considerations into management decisions, promoting sustainable use and conservation (Obura et al., 2019).

One key aspect of holistic coral reef management is stakeholder engagement. Involving local communities, governments, NGOs, and the private sector ensures that management strategies are inclusive and address the needs of all stakeholders. Participatory approaches, such as community-based management and co-management arrangements, empower local communities to take ownership of conservation initiatives and promote stewardship of coral reefs (White et al., 2022). Furthermore, integrating traditional ecological knowledge (TEK) with scientific research enhances our understanding of coral reef dynamics and informs management practices.

TEK, accumulated over generations by indigenous and local communities, offers valuable insights into ecosystem functioning, species behaviour, and resource management strategies. Incorporating TEK into decision-making processes fosters cultural resilience and promotes sustainable resource use (Proulx et al., 2021).

Figure 2. Joining hands for coral reef conservation: Aligning SDGs 12, 13, and 14.

Implementing adaptive management strategies is crucial for addressing the dynamic nature of coral reef ecosystems and responding to emerging threats such as climate change. Adaptive management involves monitoring, learning, and adjusting management actions based on new information and changing conditions (Harvey et al., 2018). By embracing adaptive management principles, conservation efforts can become more resilient and responsive to environmental challenges.

Case Studies: Successful Implementation of SDGs in Coral Reef Conservation

Several case studies demonstrate the successful integration of SDGs into coral reef conservation initiatives worldwide. The Coral Triangle Initiative (CTI) for example, is a multilateral partnership aimed at conserving marine biodiversity and promoting sustainable development in the Coral Triangle region. Through collaborative efforts among six countries (Indonesia, Malaysia, Papua New Guinea, Philippines, Solomon Islands, and Timor-Leste), the CTI has made significant progress in marine protected area (MPA) establishment, sustainable fisheries management, and community-based conservation (Christie et al., 2016; Anugrah et al., 2020).

Another notable case study is the Great Barrier Reef Marine Park Authority (GBRMPA) in Australia, which manages the world's largest coral reef ecosystem. GBRMPA employs a multi-sectoral approach, integrating environmental protection, scientific research, tourism management, and stakeholder engagement. By implementing zoning plans, regulating fishing activities, and reducing pollution inputs, GBRMPA has contributed to the resilience of the Great Barrier Reef despite ongoing threats from climate change (Craik, 1992).

Furthermore, initiatives such as the Global Coral Reef Monitoring Network (GCRMN) and the International Coral Reef Initiative (ICRI) facilitate international collaboration and knowledge sharing to support coral reef conservation efforts worldwide (Dight & Scherl, 1997). By promoting data collection, capacity building, and policy advocacy, these initiatives contribute to the achievement of SDG targets related to marine conservation and sustainable use of ocean resources.

Challenges and Opportunities in Aligning Conservation Efforts with SDGs

Despite progress in integrating SDGs into coral reef conservation strategies, several challenges persist. One major challenge is the lack of funding and resources for conservation activities. Coral reef conservation requires substantial financial investment for research, monitoring, enforcement, and community engagement. Securing long-term funding commitments from governments, donors, and private sector stakeholders is essential for sustaining conservation efforts (Hoegh-Guldberg et al., 2018). Another challenge is the limited capacity and expertise in developing countries to implement effective conservation measures. Building local capacity through training programs, knowledge exchange, and technology transfer can enhance the effectiveness of conservation initiatives and empower local stakeholders to participate in decision-making processes (Marzo et al., 2023). Additionally, addressing the root causes of coral reef degradation, such as unsustainable fishing practices and coastal development, requires addressing broader socioeconomic issues such as poverty, inequality, and governance. Integrating coral reef conservation into broader development agendas and promoting sustainable livelihood alternatives can help address these underlying drivers of ecosystem degradation (Cramer & Kittinger, 2021).

Despite these challenges, there are opportunities to advance coral reef conservation through innovative approaches and partnerships. Leveraging advances in technology, such as remote sensing, artificial intelligence, and genetic sequencing, can enhance monitoring and management efforts (Hedley et al., 2016). Engaging with the private sector through corporate partnerships, eco-certification schemes, and sustainable tourism initiatives can mobilize additional resources and expertise for conservation.

Role of Stakeholders in Achieving SDGs for Coral Reefs:

Stakeholders play a pivotal role in the preservation and sustainable management of coral reefs. Government bodies are crucial for enacting policies and regulations to protect marine ecosystems, with 76% of countries reporting the existence of marine protected areas (MPAs). NGOs contribute significantly through advocacy, research, and community engagement initiatives (Ban et al., 2011). Private sector involvement, particularly in ecotourism and sustainable fishing practices, can drive economic growth while minimizing environmental impact. Indigenous communities offer traditional knowledge and practices for conservation efforts. Collaborative efforts among stakeholders are essential for achieving SDGs related to coral reef conservation, emphasizing the necessity of inclusive governance structures.

Government Initiatives and Policies:

Governments worldwide hold significant responsibility for preserving coral reefs through the formulation and implementation of policies and initiatives. The integration of SDGs into national and regional policies is essential for addressing the complex challenges faced by coral reef ecosystems (Fox et al., 2012). Governments have implemented marine protected areas (MPAs) as a fundamental strategy for conserving coral reefs. According to a report by the International Union for Conservation of Nature (IUCN), there are over 8,000 MPAs globally, covering approximately 7% of the ocean area. These MPAs serve as sanctuaries for marine biodiversity, including coral reefs, by regulating human activities such as fishing and tourism (Mora et al., 2006).

Furthermore, governments collaborate at international and regional levels to address transboundary issues affecting coral reefs. For instance, the Coral Triangle Initiative (CTI) is a multilateral partnership among six countries in the Indo-Pacific region aimed at conserving marine biodiversity, including coral reefs. Through CTI, governments coordinate efforts to combat illegal fishing, promote sustainable tourism, and enhance coral reef resilience through ecosystem-based approaches (Ban et al., 2011; white et al., 2014).

Non-Governmental Organizations (NGOs) and Conservation Efforts:

NGOs play a crucial role in coral reef conservation by complementing government efforts through community engagement, scientific research, and advocacy. These organizations often operate at local, national, and international levels, leveraging diverse expertise and resources to address coral reef threats. NGOs conduct scientific research to understand coral reef ecosystems better and develop evidence-based conservation strategies (White et al., 2022). For example, the Coral Reef Alliance (CORAL) conducts research on coral reef resilience and works with local communities to implement sustainable reef management practices. Through partnerships with scientists and stakeholders, NGOs contribute valuable data and insights to inform policy decisions and conservation actions (Pledge, 2017).

Moreover, NGOs engage in capacity-building and education initiatives to raise awareness about coral reef conservation among local communities and stakeholders. By empowering communities with knowledge and skills, NGOs promote sustainable livelihoods and foster stewardship of marine resources (Gurney et al., 2019). For instance, Reef Check Foundation conducts citizen science programs, where volunteers monitor coral reef health and contribute data to global reef monitoring efforts (Freiwald et al., 2021).

Community Involvement and Indigenous Knowledge:

Local communities, including indigenous peoples, are integral stakeholders in coral reef conservation due to their dependence on marine resources and traditional ecological knowledge. Community-based approaches to coral reef management empower local stakeholders to actively participate in decision-making processes and implement sustainable practices tailored to their socio-cultural context (Kothari et al., 2013).

Indigenous peoples possess invaluable knowledge about coral reef ecosystems acquired through generations of interaction with marine environments. Incorporating indigenous knowledge into conservation efforts enhances the effectiveness and resilience of management strategies. For example, indigenous communities in the Pacific Islands practice traditional marine resource management techniques, such as tabu (temporary fishing closures), to replenish fish stocks and conserve coral reefs (Vierros et al., 2010).

Furthermore, community-based organizations (CBOs) and local initiatives play crucial roles in mobilizing resources and implementing grassroots conservation projects. By fostering ownership and accountability among community members, these initiatives promote long-term sustainability and resilience of coral reef ecosystems (Ferse et al., 2010). For instance, the Locally Managed Marine Area (LMMA) Network facilitates knowledge sharing and collaboration among coastal communities to establish and manage marine protected areas (Jupiter et al., 2014). By integrating sustainable practices, indigenous knowledge, and community involvement into conservation strategies, stakeholders can effectively safeguard coral reef ecosystems for future generations (Rocliffe et al., 2014). However, addressing the multifaceted challenges facing coral reefs necessitates continuous commitment and coordination among stakeholders at all levels. Through collective action and innovation, stakeholders can pave the way towards a sustainable future for coral reefs in the Anthropocene era.

Technological Innovations and Research in Coral Reef Conservation:

Technological innovations have become indispensable in coral reef conservation efforts amidst the challenges of the Anthropocene. Remote sensing techniques, such as satellite imagery and drones, enable comprehensive monitoring of reef health and dynamics. Advanced genetic sequencing aids in understanding coral resilience and adaptation to stressors (Madin et al., 2019). Robotics facilitate underwater exploration and intervention, such as coral transplantation and debris removal (Cui et al., 2023). Furthermore, emerging technologies like artificial intelligence offer promising avenues for analyzing vast amounts of ecological data efficiently (Hamylton et al., 2020). Integrating these innovations into research frameworks enhances the efficacy of conservation strategies, aligning with Sustainable Development Goals for safeguarding coral reef ecosystems.

Remote Sensing and Monitoring Technologies:

Remote sensing technologies play a crucial role in monitoring the health and status of coral reefs over large spatial scales. Satellite imagery, aerial surveys, and underwater drones are among the tools used to collect data on coral reef ecosystems. These technologies provide valuable information on coral reef extent, habitat quality, water quality parameters, and the distribution of key species (Hedley et al., 2016; Obura et al., 2019). Satellite remote sensing offers a broad perspective on coral reef dynamics by capturing data on a global scale (Purkis, 2018). Satellites equipped with sensors capable of detecting changes in sea surface temperature, ocean colour and coral reef structure provide valuable insights into coral bleaching events, algal blooms, and habitat degradation. These data help researchers identify areas of concern and prioritize conservation efforts (Foo & Asner, 2019). Aerial surveys using manned or unmanned aircraft provide high-resolution imagery of coral reefs and their surrounding environments. These surveys enable researchers to map coral reef habitats, assess coral cover and diversity, and monitor changes over time. Aerial imagery combined with advanced image processing techniques allows for rapidly detecting coral bleaching, disease outbreaks, and other stressors (Giles et al., 2023).

Underwater drones, or remotely operated vehicles (ROVs), offer the ability to explore and document coral reef ecosystems at greater depths and in inaccessible areas (McLean et al., 2020). Equipped with cameras, sensors, and sampling devices, ROVs can collect detailed data on coral health, biodiversity, and habitat structure. These underwater robots provide researchers with real-time footage and data, reducing the need for costly and time-consuming field surveys (Aguzzi et al., 2024). Overall, remote sensing and monitoring technologies provide essential tools for assessing the health and resilience of coral reef ecosystems, guiding conservation efforts, and informing policy decisions.

Innovative Restoration Techniques:

The degradation of coral reefs has prompted the development of innovative restoration techniques aimed at enhancing coral resilience and promoting ecosystem recovery. Traditional restoration methods, such as coral transplantation and artificial reef construction, have been supplemented with novel approaches that leverage advances in science and technology. One such technique is coral gardening, which involves cultivating coral fragments in nurseries before transplanting them onto degraded reefs. Coral fragments are collected from healthy donor colonies, grown in underwater nurseries, and then transplanted onto degraded reefs to promote coral growth and recovery. Coral gardening has proven successful in restoring damaged reefs and increasing coral cover in various locations worldwide (Schmidt-Roach et al., 2023).

Another innovative approach is the use of 3D printing technology to create artificial coral structures that mimic natural reef habitats (Berman et al., 2023). These structures provide substrate for coral settlement and growth, offering a scalable solution for reef restoration in areas where natural substrate is limited. 3D-printed reefs can be customized to suit specific environmental conditions and support diverse coral communities (Yoris-Nobile et al., 2023).

Micro-fragmentation is another emerging restoration technique that involves breaking coral colonies into small fragments to accelerate growth and increase genetic diversity. By fragmenting corals into smaller pieces, researchers can stimulate rapid tissue regeneration and coral reproduction, leading to faster recovery of degraded reefs. Micro-fragmentation has shown promise in restoring coral populations impacted by bleaching events and other disturbances (Tortolero-Langarica et al., 2020). In addition to these techniques, researchers are exploring the use of probiotics, genetic engineering, and assisted evolution to enhance coral resilience to environmental stressors (Van De Water et al., 2022). These innovative approaches hold the potential to revolutionize coral reef restoration efforts and contribute to the long-term sustainability of these valuable ecosystems.

Cutting-edge Research Contributing to Sustainable Coral Reef Management:

Advances in scientific research are driving progress in sustainable coral reef management by providing insights into the complex interactions between coral reefs and their environment. Key areas of research focus include coral biology, reef ecology, climate modelling, and socio-economic dynamics. Studies on coral biology are shedding light on the physiological mechanisms that enable corals to survive and thrive in changing environmental conditions (Putnam et al., 2017). Researchers are investigating the genetic basis of coral resilience, the role of symbiotic algae in coral health, and the impacts of environmental stressors on coral physiology (Roth, 2014). This knowledge is essential for developing strategies to protect corals from bleaching, disease, and other threats.

Reef ecology research is advancing our understanding of the complex interactions between corals, reef organisms, and their surrounding environment. Scientists are studying coral reef food webs, nutrient cycling, and community dynamics to identify key ecological processes that sustain reef resilience. By quantifying ecosystem services provided by coral reefs, such as fisheries production and coastal protection, researchers can make a compelling case for reef conservation and management (Hoegh-Guldberg et al., 2017; Robinson et al., 2023).

Climate modelling efforts are improving our ability to predict the impacts of climate change on coral reefs and develop adaptation strategies to mitigate these effects. By simulating future climate scenarios, researchers can assess the vulnerability of coral reefs to rising sea temperatures, ocean acidification, and extreme weather events. These models help policymakers prioritize conservation actions and allocate resources effectively (Dixon et al., 2021; Donner et al., 2018).

Socio-economic research is examining the human dimensions of coral reef management, including the socio-economic drivers of reef degradation and the benefits of conservation initiatives to local communities. By engaging stakeholders in collaborative decision-making processes, researchers can develop more effective conservation strategies that align with the needs and priorities of coastal communities (Hilmi et al., 2019). Overall, cutting-edge research is essential for informing evidence-based decision-making and promoting sustainable coral reef management in the Anthropocene. By integrating scientific knowledge with technological innovations, policymakers, practitioners, and local communities can collaborate to safeguard coral reefs for future generations.

Future Prospects and Recommendations:

Coral reefs are facing unprecedented challenges in the Anthropocene era, necessitating innovative approaches and concerted efforts to ensure their survival and sustainable management. In this section, we discuss emerging trends in coral reef conservation, offer policy recommendations for integrating Sustainable Development Goals (SDGs), and outline a research agenda aimed at advancing coral reef sustainability (Figure 3).

Emerging Trends in Coral Reef Conservation:

Coral reef conservation efforts are evolving in response to the escalating threats posed by climate change, overfishing, pollution, and habitat destruction. Several emerging trends are shaping the future of coral reef conservation:

Climate Resilience Strategies:

With the increasing frequency and severity of climate-related events such as coral bleaching and ocean acidification, there is a growing emphasis on enhancing the resilience of coral reefs. This includes implementing restoration initiatives, such as coral gardening and assisted evolution techniques, to facilitate the recovery of damaged reef ecosystems (Comte & Pendleton, 2018).

Community-Based Conservation:

Recognizing the importance of local communities in coral reef management, there is a shift towards participatory approaches that empower stakeholders to actively engage in conservation efforts. Community-managed marine protected areas (MPAs) and co-management arrangements are gaining traction as effective strategies for safeguarding coral reef ecosystems while promoting socio-economic development (Obura et al., 2019).

Technological Innovations:

Advances in technology, such as remote sensing, underwater drones, and genetic sequencing, are revolutionizing coral reef monitoring and research. These tools enable scientists to collect high-resolution data on reef health, biodiversity, and ecosystem dynamics, facilitating evidence-based decision-making and adaptive management strategies (Anthony et al., 2020).

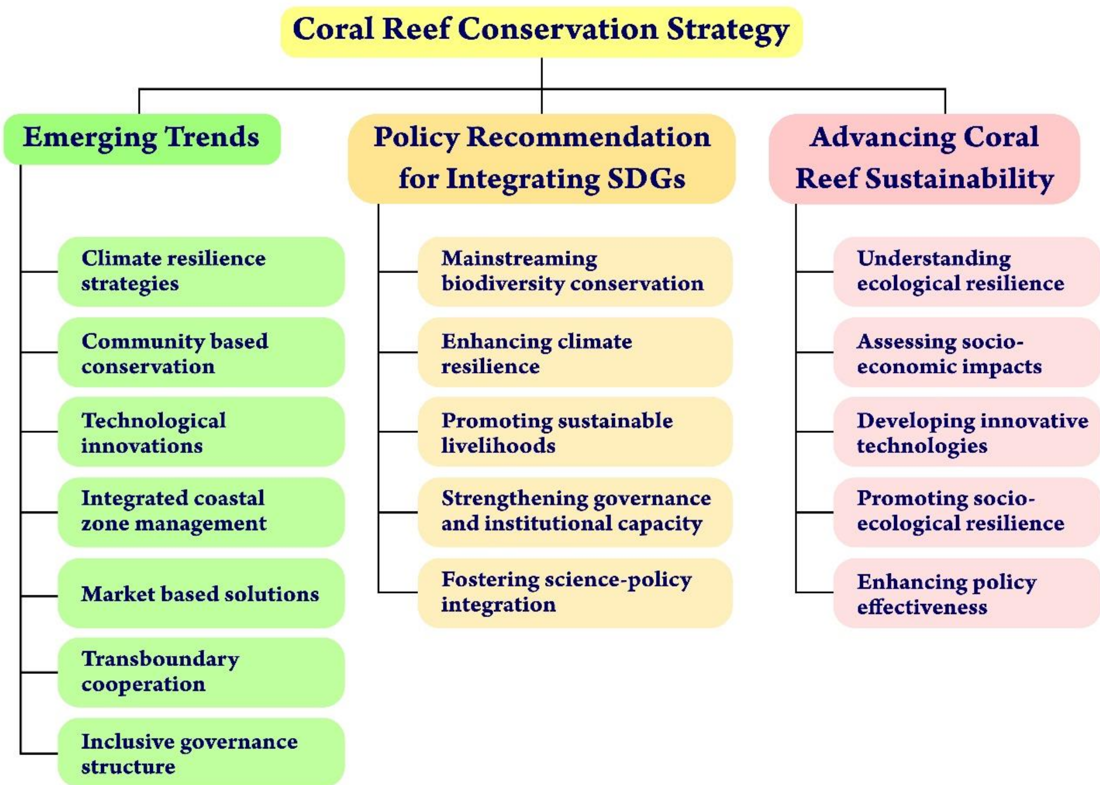

Figure 3. Coral reef conservation strategy emphasizing sustainable practices and marine protection measures.

Integrated Coastal Zone Management:

Recognizing the interconnectedness of coastal ecosystems, there is a growing emphasis on integrated approaches to coastal zone management that address the cumulative impacts of multiple stressors on coral reefs. Integrated coastal planning frameworks, incorporating ecosystem-based approaches and spatial planning tools, are essential for promoting sustainable development while safeguarding critical marine habitats (Green et al., 2014).

Market-Based Solutions:

The adoption of market-based mechanisms, such as payments for ecosystem services (PES) and eco-certification schemes, is gaining momentum as a means of incentivizing sustainable practices and promoting financial support for coral reef conservation initiatives. By valuing the ecosystem services provided by coral reefs, these mechanisms can help secure funding for conservation efforts and foster greater stakeholder engagement (Cicin-Sain & Belfiore, 2005).

Transboundary Cooperation:

Given the transboundary nature of coral reef ecosystems, there is a growing recognition of the need for regional cooperation and collaboration among neighbouring countries to address common conservation challenges. Regional initiatives, such as the Coral Triangle Initiative (CTI) and the Caribbean Challenge Initiative (CCI), facilitate knowledge sharing, capacity building, and coordinated action for the protection of shared marine resources (Rinkevich, 2015).

Inclusive Governance Structures:

Promoting inclusive governance structures that involve diverse stakeholders, including indigenous communities, women, youth, and marginalized groups, is essential for ensuring the equitable distribution of benefits and promoting social justice in coral reef conservation efforts. Incorporating traditional ecological knowledge and indigenous perspectives can enhance the effectiveness and legitimacy of conservation interventions (Esmail et al., 2023).

Policy Recommendations for Integrating SDGs:

The Sustainable Development Goals (SDGs) provide a framework for addressing global challenges and promoting sustainable development in the Anthropocene era. Integrating SDGs into coral reef conservation efforts requires a multi-dimensional approach that considers environmental, social, and economic dimensions. Key policy recommendations for integrating SDGs into coral reef management include:

Mainstreaming Biodiversity Conservation:

Incorporating biodiversity conservation objectives into national and regional development plans, policies, and strategies is essential for achieving SDG 15 (Life on Land) and SDG 14 (Life Below Water). This involves strengthening protected area networks, promoting sustainable fisheries management, and implementing ecosystem-based approaches to marine resource management (Keller et al., 2009).

Enhancing Climate Resilience:

Prioritizing climate adaptation and mitigation measures to enhance the resilience of coral reef ecosystems is crucial for achieving SDG 13 (Climate Action). This includes reducing greenhouse gas emissions, promoting renewable energy sources, and implementing nature-based solutions such as mangrove restoration and coral reef rehabilitation to mitigate the impacts of climate change (Kleypas et al., 2021).

Promoting Sustainable Livelihoods:

Promoting sustainable livelihoods for coastal communities is essential for achieving SDG 1 (No Poverty) and SDG 8 (Decent Work and Economic Growth). This involves investing in alternative income-generating activities such as ecotourism, sustainable aquaculture, and small-scale fisheries that reduce pressure on coral reef resources while providing socio-economic benefits to local communities (Morrison et al., 2020).

Strengthening Governance and Institutional Capacity:

Enhancing governance mechanisms and institutional capacity for coral reef management is essential for achieving SDG 16 (Peace, Justice, and Strong Institutions). This includes promoting transparent decision-making processes, strengthening regulatory frameworks, and fostering multi-stakeholder partnerships to ensure effective coordination and implementation of conservation initiatives (Hein et al., 2021).

Fostering Science-Policy Integration:

Promoting science-policy integration and knowledge exchange is essential for achieving SDG 17 (Partnerships for the Goals). This involves bridging the gap between scientific research and policy-making processes, fostering collaboration between scientists, policymakers, and practitioners, and ensuring that evidence-based recommendations inform decision-making at all levels (Beger et al., 2015).

Research Agenda for Advancing Coral Reef Sustainability:

Advancing coral reef sustainability requires a robust research agenda that addresses knowledge gaps, informs evidence-based decision-making, and fosters innovation. Key research priorities for advancing coral reef sustainability include:

Understanding Ecological Resilience:

Investigating the factors that influence the resilience of coral reef ecosystems to climate change and anthropogenic stressors is essential for informing conservation strategies and restoration efforts. This includes studying the interactions between corals, symbiotic algae, and other reef organisms, as well as identifying thresholds for ecosystem collapse and recovery (Hughes et al., 2003).

Assessing Socio-Economic Impacts:

Evaluating the socio-economic impacts of coral reef degradation on coastal communities and exploring alternative livelihood options is crucial for designing effective conservation interventions that promote human well-being and social equity. This includes assessing the economic value of coral reef ecosystem services, such as fisheries, tourism, coastal protection, and cultural heritage, and identifying strategies to enhance resilience and adaptive capacity (Anthony et al., 2020).

Developing Innovative Technologies:

Developing and deploying innovative technologies for coral reef monitoring, assessment, and management is essential for improving our understanding of reef dynamics and facilitating timely intervention strategies. This includes advancing remote sensing techniques, underwater robotics, genetic tools, and bioinformatics approaches to enhance data collection, analysis, and decision support systems (McClanahan et al., 2012).

Promoting Social-Ecological Resilience:

Integrating social and ecological perspectives to promote resilience and adaptive capacity in coral reef-dependent communities is essential for sustainable development. This includes incorporating traditional ecological knowledge, indigenous governance systems, and participatory approaches into conservation planning and decision-making processes, as well as fostering community-based adaptive management strategies that empower local stakeholders (Weeks & Adams, 2018).

Enhancing Policy Effectiveness:

Evaluating the effectiveness of policy interventions and governance mechanisms for coral reef conservation is essential for identifying best practices and guiding future policy development. This includes assessing the impact of marine protected areas, fisheries regulations, coastal zoning policies, and incentive-based mechanisms on reef health, biodiversity, and socioeconomic outcomes, as well as exploring innovative policy instruments and governance models that promote stakeholder participation, accountability, and equity (Cumming et al., 2023).

Conclusion:

In conclusion, securing coral reefs in the Anthropocene requires a multifaceted approach that integrates Sustainable Development Goals (SDGs) into management strategies. Through the preceding discussion, it becomes evident that the health and resilience of coral reef ecosystems are intrinsically linked to socio-economic factors, climate change impacts, and local communities' livelihoods. Efforts to safeguard coral reefs must prioritize collaborative partnerships among stakeholders, including governments, NGOs, local communities, and the private sector. These partnerships should leverage scientific research, traditional knowledge, and innovative technologies to inform adaptive management practices.

Furthermore, the integration of SDGs provides a framework for holistic and inclusive conservation efforts. By addressing poverty alleviation, food security, climate action, and sustainable livelihoods, SDGs offer a pathway towards achieving long-term resilience for coral reefs and the communities dependent on them. However, effective implementation requires robust governance mechanisms, capacity building, and financial resources. Governments and international organizations must commit to policy coherence and resource mobilization to support coral reef conservation efforts effectively. In essence, securing coral reefs in the Anthropocene necessitates a paradigm shift towards sustainable development that balances ecological integrity with human well-being. By embracing the principles of the SDGs, we can strive towards a future where coral reefs thrive amidst the challenges of the Anthropocene.

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Chapter- 31

Utilizing Climate Physics: Advancing SDG 13 with Integrated Low Carbon Energy from Diverse Sources – A Glimpse Ahead

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Keywords: Climate physics, Sustainable development goal, Climate patterns, Ocean-atmosphere interaction, Paleoclimate Physics, Computational simulations.

Abstract:

This study examines the crucial role of climate physics in advancing Sustainable Development Goal (SDG) 13, "Climate Action," through the incorporation of low-carbon emission energy derived from both traditional and unconventional sources. As the international community grapples with the urgent imperative to address climate change, a profound understanding of the intricate dynamics of climate physics is essential for formulating effective solutions. This research delves into the intricacies of climate physics, exploring how they can be utilized to facilitate the shift towards sustainable energy systems. The investigation draws insights from a spectrum of energy sources, encompassing conventional options like solar, wind, and hydroelectric power, alongside nonconventional sources such as geothermal and tidal energy. The primary objective of this study is to showcase the viability and effectiveness of integrating a diverse range of energy resources to mitigate carbon emissions. Through a thorough examination of existing literature and case studies, this project aims to provide a glimpse into the prospective future of energy systems marked by diminished environmental impact and heightened resilience to climate change. By elucidating the synergies between climate physics and sustainable energy technologies, this research endeavours to furnish practical insights for policymakers, energy professionals, and stakeholders engaged in the pursuit of SDG 13. Ultimately, harnessing climate physics as a catalyst for integrating sustainable energy holds substantial potential to propel global initiatives toward a more resilient, low-carbon future.

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Introduction:

Embarking on the study of climate physics opens doors to a fascinating realm where the intricate dance of Earth's atmosphere, oceans, land, and ice unfolds. At its core, climate physics is the key to unravelling the mysteries of our planet's climate system — a puzzle that holds crucial insights into our past, present, and future. Delving into radiative transfer, thermodynamics, and ocean-atmosphere interactions, you will uncover the fundamental principles governing climate patterns and long-term changes (Stamnes et al., 2017; Webster, 1994; Banwell et al., 2023). From scrutinizing the impact of solar radiation to simulating climate behaviour through cutting-edge numerical models, climate physics equips you with the tools to predict, understand, and address the challenges of a changing climate (Lean & Rind, 1998). As you explore cryo-spheric and paleoclimate physics, you'll witness the profound influence of ice and snow dynamics and decipher the Earth's climatic history hidden in proxy data (Hoffmann & Spekat, 2021). Your journey into climate physics isn't just an academic pursuit — it's an essential step toward comprehending the forces steering climate change and shaping a sustainable future (Mathevet et al., 2018; Nwankwo et al., 2020).

SDG 13:

SDG 13, part of the Sustainable Development Goals, addresses climate action, emphasizing the need to address anthropogenic activities that contribute to climate change and the resulting threats to human life. It is divided into specific targets aimed at empowering countries to tackle climate-related hazards (13.1), integrating climate change data into national policies and strategies (13.2), and raising awareness about climate change (13.3) (Coscieme et al., 2020; Fraisl et al., 2020). Target 13.1 is crucial for identifying affected populations and deaths per 100,000 individuals, as well as assessing the adoption of strategies to mitigate national disasters by countries and local governments. Target 13.2 focuses on developing long-term strategies to reduce the impact of climate change and monitoring annual greenhouse gas emissions. Furthermore, Target 13.3 underscores the importance of education in promoting sustainable development and increasing awareness of climate change, advocating for its incorporation into national education policies 2020 (Hwang et al., 2021). Climate physics serves as a vital tool in achieving SDG 13 objectives.

Various approaches leveraging climate physics can contribute significantly to achieving SDG 13. Climate physics, being a powerful tool, can be utilized in several ways:

Global Impact:

Climate change is one of the most critical global challenges of our time. By studying climate physics, you have the opportunity to contribute to understanding and addressing the factors driving climate change, ultimately working towards solutions that benefit the entire planet (Cundill et al., 2019).

Environmental Stewardship:

If you are passionate about the environment and sustainability, studying climate physics allows you to actively contribute to the responsible management of Earth's resources. Your knowledge can be applied to finding sustainable solutions and mitigating the impacts of climate change on ecosystems.

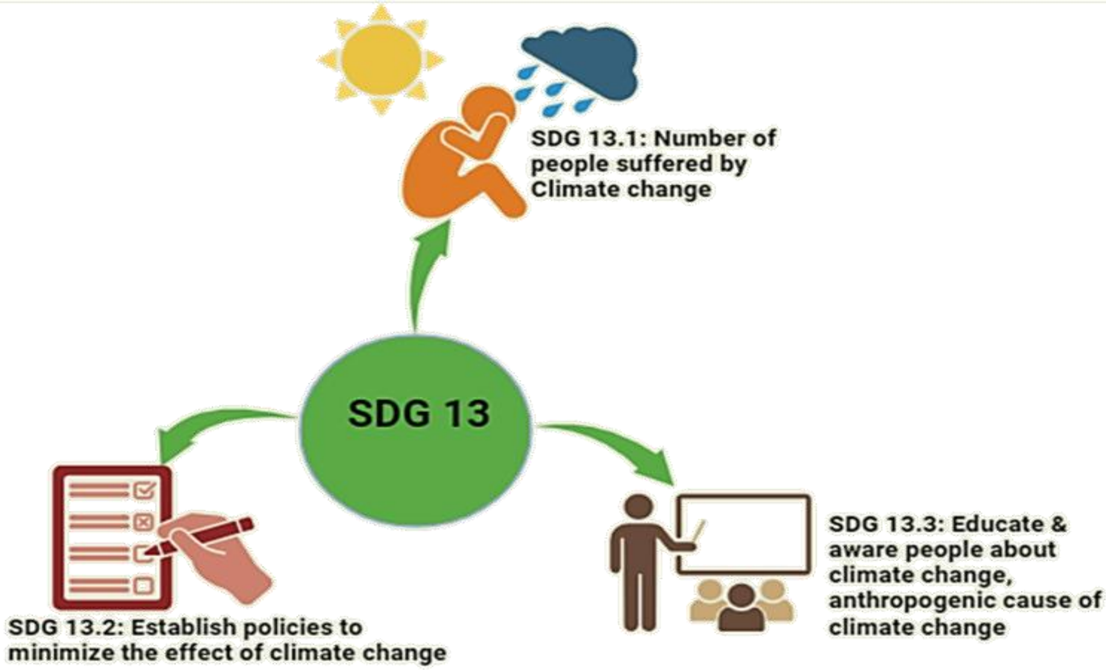

Figure 1. Summary of Sustainable Development Goal 13.

Interdisciplinary Nature:

Climate physics is inherently interdisciplinary, involving elements of physics, meteorology, oceanography, atmospheric science, and more. This interdisciplinary approach provides a holistic understanding of the Earth's climate system and allows you to collaborate with experts from various fields (Peixóto & Oort, 1984).

Innovation and Technology:

Climate physics research often involves the development and application of cutting-edge technologies and computational models. This field offers opportunities to work on innovative solutions, such as advanced climate models, remote sensing technologies, and sustainable energy technologies.

Policy and Advocacy:

Understanding the physics of climate change equips you with the knowledge needed to engage in policy discussions and advocate for evidence-based decision-making (Hussain et al., 2017). Many climate physicists actively contribute to shaping policies that address climate change on local, national, and global levels.

Global Collaboration:

Climate change is a global challenge that requires international collaboration. Studying climate physics provides the opportunity to work with scientists, researchers, and policymakers from around the world, fostering a sense of global community and shared responsibility.

Career Opportunities:

There is a growing demand for experts in climate physics across various sectors, including academia, research institutions, government agencies, and private industries. Pursuing a career in this field can lead to impactful and fulfilling professional opportunities.

Personal Fulfilment:

Contributing to the understanding of climate science and working towards solutions for a sustainable future can bring a deep sense of personal fulfilment. Knowing that your work has the potential to positively impact the well-being of current and future generations can be a powerful motivator.

In summary (Rotberg & Rabb, 1981; Bierly, 1988), studying climate physics offers the chance to make a meaningful contribution to global challenges, work at the forefront of scientific innovation, and play a role in shaping a sustainable and resilient future for our planet.

Recent Scopes:

Recent challenges in climate physics encompass a range of critical issues with profound implications for environmental sustainability (Stott, 2016). A comprehensive understanding and advancements in climate physics are essential for addressing the intricate dynamics of these challenges.

Extreme weather events, such as hurricanes, floods, droughts, and heat waves, pose formidable challenges (Roberts et al., 2012; Hossain & Mahmud, 2014). Unravelling the underlying physics of these events enhances prediction models, fortifying disaster preparedness and response capabilities. The physics of melting ice sheets and glaciers is crucial for predicting and mitigating future sea level rise. Insights from climate physics research are indispensable for formulating adaptation strategies to safeguard coastal communities from rising sea levels. Carbon Capture and Storage (CCS) is a key facet of climate physics research, informing strategies for capturing and storing carbon dioxide emissions (Abdmouleh et al., 2015; Boeker & Van Grondelle, 2011; Boccard, 2022). This knowledge contributes significantly to developing more efficient CCS technologies vital for mitigating climate change. Renewable energy integration into the grid, linked to climate physics, involves optimizing energy storage, grid stability, and efficient use of renewable resources. Research in this area is fundamental for transitioning to sustainable, low-carbon energy systems. Investigating the physics of climate mitigation strategies, such as afforestation and carbon sequestration, is integral to gauging their effectiveness. Climate physics provides essential insights, guiding their implementation for maximum impact. Ocean acidification, a consequence of increased carbon dioxide absorption by oceans, is critical in climate physics (Hossain et al., 2016; Sarkar et al., 2021; Sarkar et al., 2020; Iqbal et al., 2014). Understanding the underlying physics is essential for predicting and comprehending its impacts on marine ecosystems. Climate physics research contributes to understanding changing precipitation patterns and their impact on agriculture. Farmers can adapt to climate variability and mitigate climate change impacts on crops with insights from climate physics. Investigating the physics of urban heat islands is crucial for developing strategies to cool urban areas, rooted in a sound understanding of climate physics. Studying the physics of Arctic feedback mechanisms, including permafrost thawing, is crucial for predicting the rate of Arctic warming and its global consequences, informing our understanding of processes driving climate change in polar regions. Climate physics contributes to discussions on the unequal distribution of climate impacts, informing policies that prioritize vulnerable communities and fostering climate justice and equity. Understanding how climate physics influences ecosystems, biodiversity, and migration patterns is essential for developing conservation strategies (Gurunathan et al., 1999; Zohuri, 2018; Skoglund et al., 2010). This interdisciplinary approach is crucial for addressing the complex and interconnected challenges associated with climate change. It is imperative to acknowledge that climate physics is a dynamic field, and ongoing research continues to unveil new insights and solutions. Staying abreast of the latest literature and advancements is vital for navigating the intricate and evolving landscape of climate change and environmental sustainability

In the context of renewable energy integration, we delve into the intricate relationship between renewable energy adoption and the principles of climate physics. This integration involves a thorough examination of the carbon footprints linked to diverse activities, processes, and systems. The analysis encompasses both direct and indirect emissions of greenhouse gases, predominantly carbon dioxide, associated with the life cycle of individuals, organizations, events, products, or services. Quantifying these emissions, usually expressed in equivalent tons of CO_2, serves as a metric to assess environmental impact.

Within the purview of climate physics, concerted efforts are aimed at comprehending, mitigating, and strategically addressing these carbon footprints. This endeavour entails a rigorous exploration of sustainable practices, the embrace of renewable energy sources, and the improvement of overall energy efficiency. Through systematic assessment and reduction of carbon footprints, our objective is to make a meaningful contribution to the broader imperative of climate change mitigation and the pursuit of a sustainable future.

Renewable energy integration:

The integration of renewable energy sources into existing energy systems is a critical aspect of addressing climate change and achieving sustainability goals (Gernaat et al., 2021). Climate physics plays a significant role in understanding and optimizing the integration of renewable energy.

Here are several key considerations in the study of renewable energy integration within the context of climate physics:

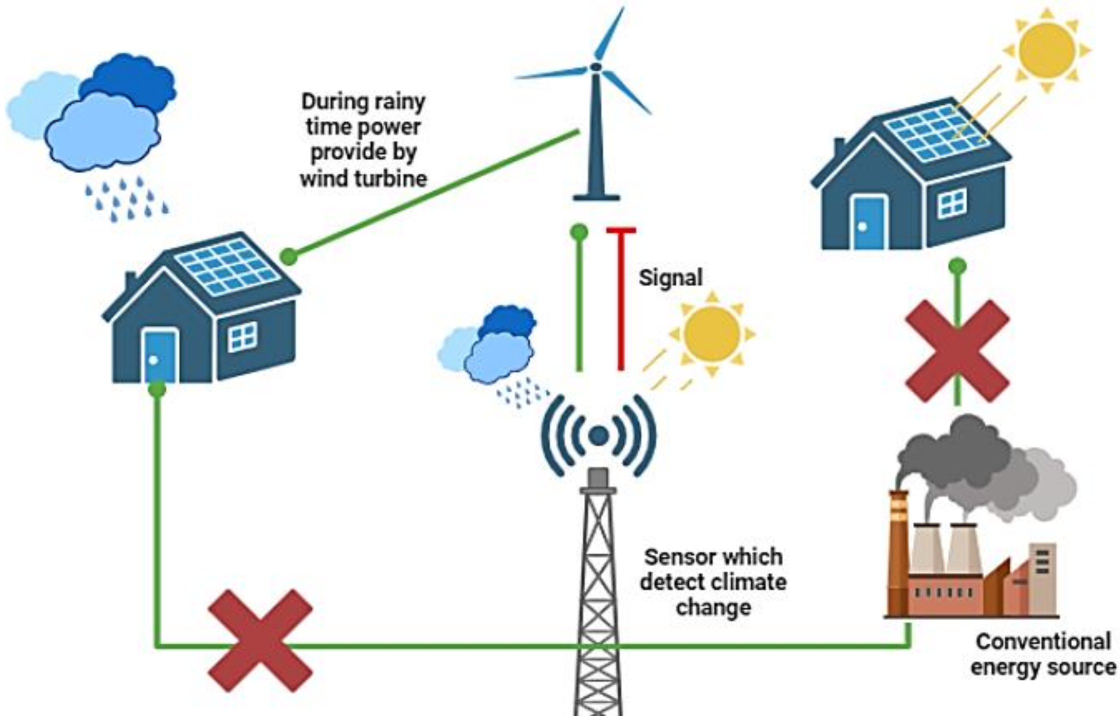

Figure 2. In a hypothetical model, a sensor is designed to detect rain and promptly signal the nearby wind turbine to harness energy during such weather conditions. When sunlight is present, the sensor triggers the wind turbine to turn off, allowing solar panels to efficiently capture and generate energy. This dynamic system ensures optimal energy utilization based on weather conditions. Moreover, if conventional energy sources prove insufficient in any climatic situation, the sensor is programmed to activate nonconventional energy sources. This proactive approach enhances the overall resilience and reliability of the energy supply system, seamlessly transitioning between wind, solar, and nonconventional sources to meet energy demands under varying environmental circumstances. This integrated model not only optimizes energy production but also emphasizes sustainability and adaptability in response to changing climatic conditions.

Variability and Intermittency:

Climate physics helps in understanding the variability and intermittency of renewable energy sources, such as solar and wind. Research focuses on developing models that predict renewable energy generation patterns based on climate conditions, including seasonal variations and short-term fluctuations.

Energy Storage:

Climate physics contributes to the study of energy storage technologies, such as batteries and pumped hydro storage. Understanding the physics of energy storage systems is essential for optimizing their performance and efficiency in storing excess energy generated by renewables for use during periods of low generation.

Grid Integration:

The physics of power grid systems is crucial for integrating renewable energy into existing grids. Climate physicists work on developing models that consider the spatial and temporal distribution of renewable resources, transmission losses, and the overall stability and reliability of the power grid.

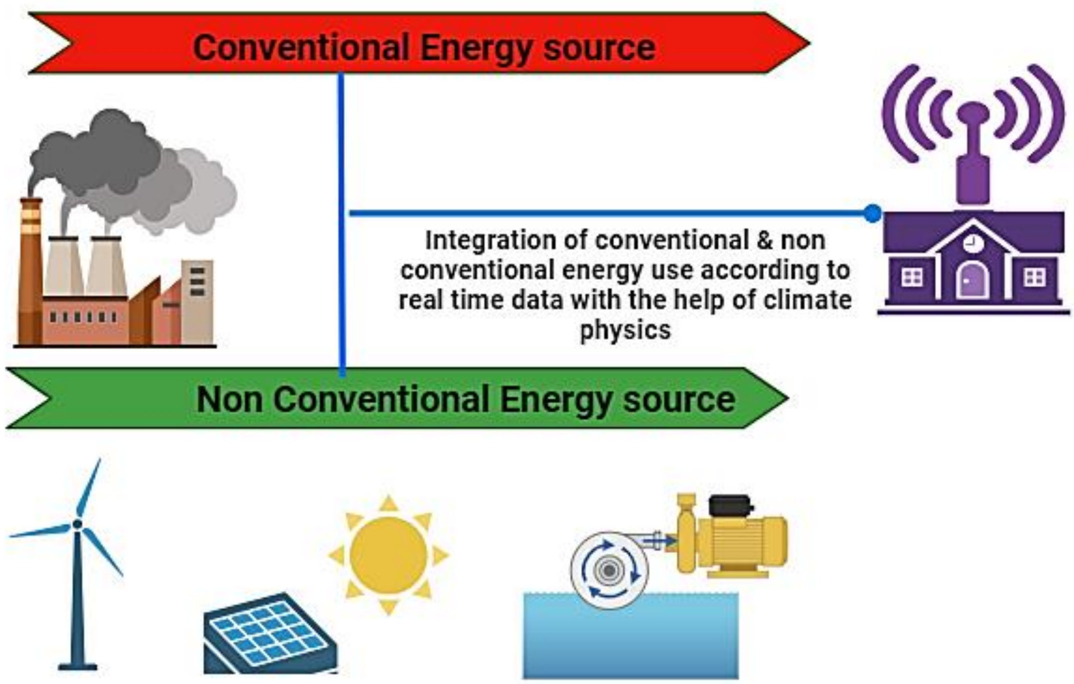

Figure 3. Integration of conventional and nonconventional energy can optimize the power grid.

Smart Grids:

Climate physics research supports the development of smart grid technologies. These technologies use real-time data and advanced communication systems to optimize the distribution and consumption of electricity, enhancing the integration of renewable energy into the grid.

Hybrid Systems:

Hybrid energy systems, combining multiple renewable sources or integrating renewables with conventional sources, are an area of study. Climate physics helps in understanding the synergies and challenges associated with hybrid systems.

Demand Response:

Climate physics contributes to the study of demand response strategies, where energy consumption is adjusted based on the availability of renewable energy. This involves understanding how climate conditions influence energy demand patterns and developing models for responsive energy consumption.

Climate-Resilient Energy Infrastructure:

Climate physics informs the design and development of climate-resilient energy infrastructure. This includes assessing the vulnerability of renewable energy installations to extreme weather events and climate-related changes.

Optimizing Renewable Resource Deployment:

Climate physics research helps in identifying optimal locations for deploying renewable energy resources. Understanding regional climate patterns and variability is essential for maximizing the efficiency of solar, wind, and other renewable technologies.

Climate Change Impact on Renewable Resources:

Studying the impact of climate change on renewable resources is crucial for assessing the long-term sustainability of these energy sources. Changes in climate patterns, such as shifts in wind or sunlight availability, can affect the reliability of renewable energy generation.

Life Cycle Assessments:

Climate physics is involved in conducting life cycle assessments of renewable energy technologies. This involves analyzing the environmental impact of renewable energy systems from raw material extraction to end-of-life disposal.

By integrating climate physics into the study of renewable energy, researchers can develop more accurate models, optimize energy systems, and contribute to the transition to a sustainable and low-carbon energy future (Zohuri, 2018; Skoglund et al., 2010). This interdisciplinary approach is essential for addressing the complex and interconnected challenges associated with climate change and renewable energy integration.

A low-carbon energy future is pivotal for achieving sustainable environmental development. This transition offers multifaceted benefits that extend beyond the immediate reduction of carbon emissions (Skoglund et al., 2010; Gernaat et al., 2021). Several interrelated ways in which the shift to low-carbon energy sources contributes to environmental sustainability can be elucidated. Mitigation of Climate Change stands as a primary impetus for the adoption of low-carbon energy sources. Traditional fossil fuels contribute significantly to greenhouse gas emissions, exacerbating climate change. In contrast, renewables (solar, wind, hydropower) and nuclear energy exhibit minimal or no carbon emissions during operation, thus diminishing the overall carbon footprint of energy production. Air Quality Improvement emerges as a consequential outcome of this transition. Conventional energy sources like coal and oil not only drive climate change but also release pollutants detrimental to air quality and human health. Embracing low-carbon energy sources results in diminished air pollution, fostering cleaner environments that benefit both human well-being and ecosystems.

Reduced Dependence on Finite Resources is another significant advantage. Fossil fuels, finite resources with associated environmental risks, contribute to environmental degradation. Low-carbon energy sources, being renewable and sustainable, alleviate dependence on finite resources, mitigating the negative impacts of resource extraction. Biodiversity Conservation is facilitated through the deployment of low-carbon energy technologies. Traditional energy extraction and use can disrupt ecosystems, causing habitat loss and biodiversity decline. Low-carbon technologies, when implemented with due consideration for environmental impact, help mitigate harm to ecosystems, thereby contributing to biodiversity conservation. Water Conservation is addressed through the adoption of certain low-carbon technologies. Conventional energy production often demands substantial water for cooling processes. Low-carbon alternatives like solar and wind power exhibit lower water requirements, contributing to the conservation of water resources, which is particularly crucial in regions facing water scarcity. Improved Land Use Practices are inherent in the footprint of renewable energy installations. Generally smaller compared to traditional power plants, especially when sited on already disturbed lands or in ways that support coexistence with existing land uses, these installations promote more sustainable land use practices. Enhanced Energy Efficiency constitutes a core attribute of low-carbon technologies. Energy-efficient appliances and smart grid systems, integral to this transition, reduce overall energy demand. This not only lowers environmental impact but also alleviates strain on resource availability. Resilience to Climate Change Impacts is bolstered by a low-carbon energy future. The reduction in greenhouse gas emissions contributes to mitigating the severity of climate-related events, including extreme weather, sea-level rise, and disruptions to ecosystems. Community Empowerment materializes through localized renewable energy projects. Initiatives such as community solar or wind endeavors empower communities by providing sustainable and decentralized energy sources, enhancing energy security and resilience at the local level. Economic Opportunities and Job Creation are inherent in the transition to a low-carbon energy future. The development and deployment of new technologies in renewable energy sectors create job opportunities, fostering sustainable economic development while concurrently addressing environmental challenges.

In summary, a low-carbon energy future represents a pivotal pillar of sustainable environmental development. Its implications extend across diverse realms, encompassing climate change mitigation, pollution reduction, biodiversity conservation, and the cultivation of a more balanced and resilient coexistence between human activities and the natural world.

Drawbacks:

While a low-carbon energy future (Cai et al., 2012) is generally considered a positive goal for addressing climate change and reducing environmental impact, there are some potential drawbacks and challenges associated with the transition.

Here are a few,

Intermittency and Reliability Issues:

Many low-carbon energy sources, such as solar and wind power, are intermittent and dependent on weather conditions. This can lead to variability in energy production and challenges in maintaining a reliable power supply, especially during periods of low renewable energy generation.

Energy Storage Challenges:

To address the intermittency of renewable energy sources, effective energy storage solutions are needed. Current energy storage technologies, such as batteries, are improving but may not yet be fully capable of handling the demands of large-scale energy storage required for a low-carbon future.

Resource Constraints:

The production of certain low-carbon technologies, such as batteries and solar panels, relies on the availability of specific raw materials. There could be concerns about the environmental impact of mining these resources, as well as potential geopolitical issues related to the control of these resources.

Land Use and Habitat Impact:

Large-scale deployment of renewable energy infrastructure, such as solar and wind farms, can require significant land areas. This may lead to habitat disruption, land-use conflicts, and potential impacts on biodiversity.

Transition Costs:

The upfront costs of transitioning to a low-carbon energy system can be substantial. Governments, businesses, and individuals may face financial challenges in adopting and investing in new technologies and infrastructure.

Job Displacement:

The shift away from traditional fossil fuel industries may lead to job displacement for workers in those sectors. A successful transition would need to include measures to retrain and support workers in affected industries.

Infrastructure Challenges:

Building the necessary infrastructure for a low-carbon energy future, including an updated power grid and charging infrastructure for electric vehicles, requires significant investment and planning. Upgrading existing infrastructure can be logistically challenging.

Social Equity Concerns:

The benefits and burdens of transitioning to a low-carbon energy future may not be distributed evenly across communities. There is a risk of exacerbating social and economic inequalities if certain groups are disproportionately affected or excluded from the benefits.

Global Cooperation:

Achieving a truly low-carbon energy future requires global cooperation, as climate change is a global challenge. However, reaching consensus on international agreements and actions can be challenging due to differing priorities and interests among nations.

Technological Risks:

The rapid deployment of new technologies may pose unforeseen risks and challenges. For example, issues related to the disposal and recycling of new technologies could emerge, leading to unintended environmental consequences.

Addressing these drawbacks requires careful planning, investment in research and development, and ongoing efforts to mitigate potential negative impacts as we transition to a low-carbon energy future.

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Chapter- 32

How Plastics Affect the Marine Environment: Its Sources, Threats, and Consequences, Potential Countermeasures for a Healthy Ocean Environment

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Keywords: Plastic pollution, Marine environment, Environmental threats, Ocean health, Sustainable Solutions.

Abstract:

The vast majority of modern consumer goods are made of plastic. They play a significant role in practically every product category and are widely incorporated into modern living. But nowadays, plastic makes up a significant portion of litter and is widely documented in the context of the marine environment. Globally, plastic pollution is acknowledged as a serious problem for marine and coastal ecosystems. A major worldwide concern that affects the marine industry, tourism, marine life, and human health is the unusual and ongoing build-up of growing plastic contaminants into aquatic ecosystems. These pollutants have the potential to directly or indirectly impair ecological processes. Even though plastic has numerous advantages, it is obvious that society's dependence on plastics has to be addressed. On the other hand, substitute materials for plastic products or ways to reduce the release of plastic also need to be evaluated to ensure that their qualities and effects on the environment are more favorable.

Introduction:

Materials made of plastic are relatively new. Large manufacturing of plastics did not start until the conclusion of World War II, and by the 1950s, yearly production was only around 5 million tons (Andrady & Neal, 2009). Due to their strong, lightweight, affordable, long-lasting, and corrosion-resistant qualities, plastics soon proved to have many advantages. Adhesives,

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foams, fibers, and a variety of rigid and flexible goods may all be made from plastics, which are incredibly versatile materials (Andrady & Neal, 2009; Bandyopadhyay et al., 2023). Natural or semi-natural organic polymers make up plastic. Long, chain-like molecules composed of recurrent chemical structural units give these polymers their distinctive molecular structure (Law, 2017). A very productive zone, the marine and coastal environment is home to a variety of ecosystems, including seagrass beds and coral reefs. From different primordial to the most evolved animals, it is a complex habitat with abundant biodiversity. For the benefit of humanity, every ocean basin serves as a crucial ecological and economic system (George, 2020). Lagoons and estuaries are examples of distinct, transitional ecosystems formed by the connection of freshwater lotic systems with oceans and seas (Reddy et al., 2018). Numerous single-use, handy, and throwaway plastic items are utilized by individuals daily. Consequently, plastics constitute a significant portion of garbage, and large amounts are already building up as litter in the marine environment (Jambeck et al., 2015).

As a result of unsustainable development and building operations, debris or litter buildup poses a serious hazard to marine and coastal systems. Due to inappropriate trash disposal, five trillion pieces of plastic garbage, weighing approximately 260,000 tons, are drifting across the world's ocean surface (Eriksen et al., 2014). Physical, chemical, and biological processes worldwide have led to plastic pollution being a major hazard over nearly all ocean basins, developed or underdeveloped (Browne et al., 2010; Wang et al., 2018). Plastic pollution accumulation has several negative consequences for ecological elements, such as biodiversity, economic activity, and human health (Wang et al., 2018; IFREMER et al., 2010).

Sources of Plastic Buildup:

Numerous sources both directly and indirectly contribute to the accumulation of plastic debris in aquatic habitats. Plastic contamination in coastal and marine ecosystems mostly originates from land-based and ocean-based sources (Figure 1). The main causes of plastic pollution on land include freshwater intake, home and residential activities, tourism, and other commercial activities, such as harbor operations. More than 75% of the plastic debris found in the ocean comes from land-based sources (Andrady, 2011). An extremely residential, urbanized, and industrialized area is the coastal zone as well. Depending on size differences, plastic may be classified as megaplastic (>1 m), macroplastic (<1 m), mesoplastic (<2.5 cm), and microplastic (<5 mm) (Wang et al., 2018). Numerous sources, often classified as marine or land-based, can release macroplastics into the environment. Fishing, boating, and shipping are examples of oceanic sources, as is the slow deterioration of rope and paints made of polymers. Primary industries, trash, sewage, and stormwater are examples of land-based sources (Cunningham & Wilson, 2003; Sheavly & Register, 2007; Luo et al., 2019; Verlis & Wilson, 2020; Madhu et al., 2022). Macroplastics can break down into microplastics by a variety of mechanisms, including photo-degradation, mechanical degradation, hydrolysis, and degradation, which alters the plastic's state. Understanding plastics' biodegradability is equally crucial to understanding their ultimate destiny and location in the relevant environment (Hartmann et al., 2019).

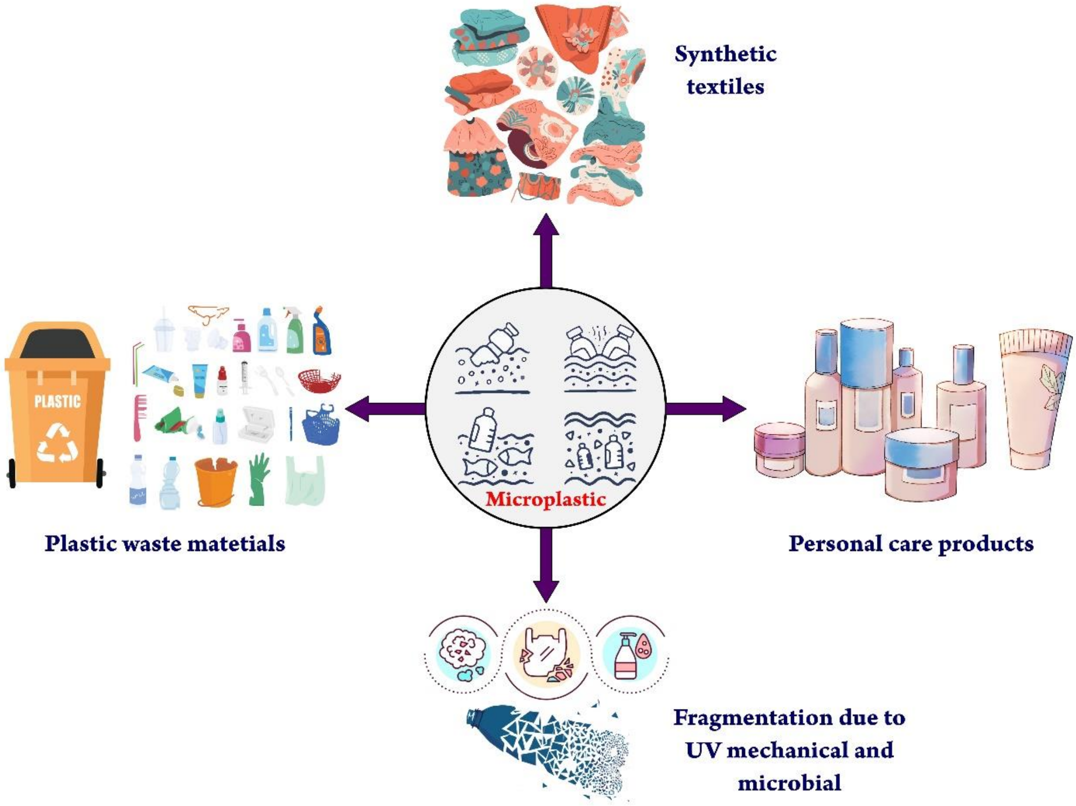

Figure 1. Varied sources behind plastic accumulation in the marine environment.

The two main categories of microplastics are primary and secondary types. Primary microplastic directly comes into the environment in the microplastic size (<5 mm in diameter). They are produced by extrusion or grinding and are used as air-blasting media (Gregory, 1996), cleaning products (Cole et al., 2011; Derraik, 2002), microbeads in cosmetics (Zitko & Hanlon, 1991; Napper & Thompson, 2019), as a feedstock for product manufacturing or for direct use (Turner & Holmes, 2015; Bergmann et al., 2015). Secondary microplastics are those that are created when other plastic objects or parts break apart. This can also include microplastics that are produced when products are used, such as textile fibers or tire wear (Cole et al., 2011; Law & Thompson, 2014; Browne et al., 2011). According to predictions, even if emissions of bigger plastic items into the environment were to cease immediately, there is a good chance that the fragmentation of larger plastic objects currently present in the environment would cause an increase in the amount of microplastic (Bergmann et al., 2015). Although they make up a minor part of the total amount of plastic in the water, microplastics much outweigh big plastic objects in marine systems (Cózar et al., 2014; Browne et al., 2010). Still, human waste in freshwater and marine habitats includes microplastics on a large scale (Obbard et al., 2014; Browne et al., 2011; Imhof et al., 2013; Mani et al., 2015; Driedger et al., 2015).

The total amount of plastic garbage that can reach the marine environment from land might rise by around three times over the ten years leading up to 2025 if no changes are made to the waste management system (Jambeck et al., 2015). This estimate may be further supported by the extremely high amounts of microplastics that have been found in rivers and lakes around the world (Auta et al., 2017; Free et al., 2014; McCormick et al., 2016). It is estimated that tire wear contributes 28% of secondary microplastics to the world's seas annually, or 40,000 tons, making it another significant source of microplastic emissions into the environment (Boucher & Friot, 2017). These several sources of microplastics can get into the marine environment by evading storm drains, wastewater treatment plants, or even by being transported by the wind and ending up at sea (Dris et al., 2015; Bergmann et al., 2019).

Moreover, ocean-based activities like shipping and aquaculture might leak plastic (Andrady, 2011). The majority of fishing gear is constructed of plastic since it is inexpensive and long-lasting. Synthetic rope has a very strong framework, but the plastic substance that makes it up is prone to breaking, embrittlement, and loss of mechanical qualities. As a result, secondary microplastics are created and fragmentation occurs (Koehler et al., 2015; Arthur et al., 2009). Consequently, there's a chance that the fragmentation may cause a significant amount of microplastic particles to be released into the marine ecosystem (Welden & Cowie, 2017). Plastics break down into smaller and smaller bits over time, eventually becoming microplastic and then most likely nanoplastic particles. This process of deterioration is continuous (Cole et al., 2011). The chemistry of the polymer and the environment to which it was exposed determine how quickly it degrades (Andrady, 2011; Andrady, 2003). Most of this plastic enters the ocean through rivers or coasts after coming from inland sources (Jambeck et al., 2015). According to predictions, rivers represent a significant conduit for the movement of marine plastics, carrying somewhere between 1.15 and 2.41 million tons of garbage into the ocean annually (Lebreton et al., 2017). Plastic's buoyancy and durability allow it to be moved widely once it enters the maritime environment (Thushari & Senevirathna, 2020).

How Plastics Affect the Marine Environment:

Plastic pollution is one of the biggest dangers to biota and has a significant negative influence on biodiversity, especially in marine systems (Figure 2) (Gray, 1997). Plastic can potentially have a wide range of effects on the marine environment. It has been claimed that over 700 different kinds of marine creatures come into contact with plastic trash. This can have extreme physical consequences, such as bodily injury or death, or more subtle effects on behavior and ecological interactions, such as the capacity to migrate or escape from predators (Gall & Thompson, 2015; Bergmann et al., 2015).

Entanglements of marine life in marine debris, including lost or abandoned fishing nets and ropes, are the most obvious result of plastic pollution on marine life (Coe & Rogers, 1997; Baulch & Perry, 2014). Movement, feeding, and breathing can all be hampered in entangled creatures. Moreover, a large number of marine creatures consume garbage after mistaking it for food. The first records of seabirds and turtles consuming plastics date back to the 1960s

(Shomura & Yoshida, 1985; Harper & Fowler, 1987). Ten species of marine animals that were stranded along the British coast were found to have microplastics in their digestive systems (Nelms et al., 2019). Laboratory experiments have shown that ingested plastics may accumulate in the stomach of organisms and affect individual fitness, with potential consequences for reproduction and growth (Avio et al., 2015; Wright et al., 2013). Plastics may transfer contaminants absorbed from surrounding water, such as endocrine disruptors and persistent organic pollutants (Browne et al., 2011). Additive chemicals can be present in high concentrations and it is considered their release could provide an important pathway for chemical transfer to biota (Tanaka et al., 2013; Oehlmann et al., 2009). The durability and buoyancy of plastics present the possibility of transporting species horizontally to ecosystems where they are not native or vertically from the sea surface through the water column to the seafloor (Bergmann et al., 2015; Ioakeimidis et al., 2015).

According to lab tests, swallowed plastics may build up in an organism's stomach and have an impact on its fitness, which might have an impact on growth and reproduction (Avio et al., 2015; Wright et al., 2013). Endocrine disruptors and persistent organic pollutants are among the toxins that plastics may carry after being absorbed from nearby water (Browne et al., 2011). As additive chemicals are known to exist in high quantities, it is thought that their release might offer a crucial route for chemical transfer to the biota (Tanaka et al., 2013; Oehlmann et al., 2009). Plastics are durable and buoyant, which means that organisms may be transported vertically from the sea surface to the bottom or horizontally to environments where they are not native (Bergmann et al., 2015; Ioakeimidis et al., 2015; Mondal et al., 2022).

It has been demonstrated that microorganisms belonging to the Vibrio family may raft on plastics and microplastics (Zettler et al., 2013). Plastic may also provide habitats; for example, it has been shown that the insect *Halobates micans* uses plastic trash as oviposition sites (Goldstein et al., 2012). Nonbuoyant plastic debris has also overtaken sediments, influencing gaseous exchange and changing the species makeup of assemblages (Mordecai et al., 2011; Green et al., 2015). Because marine plastics disrupt the ecosystems that regulate the exchange and circulation of marine CO_2, they may also result in increased greenhouse gas emissions (Shen et al., 2020). The significant amounts of plastics that are regularly entering aquatic environments can have several detrimental effects on the ecology and economy (Newman et al., 2015; Jambeck et al., 2015). The economic effects of plastic waste on fisheries, aquaculture, tourism, and navigation might be detrimental. Plastic debris that has been stranded along beaches is an aesthetic problem that hurts tourism (Jang et al., 2014). Plastic waste has the potential to harm or decrease fisheries yield and vessel integrity. Additionally, there's growing evidence that even tiny amounts of trash on beaches might be detrimental to people's health (Wyles et al., 2016). Environmental plastic waste can have significant financial consequences.

Consuming or being entangled in macroplastic waste can have fatal or non-lethal consequences. The immediate outcome of entanglement or ingestion is the death or fatal injury of coastal and marine biotic species. Reduced ability to capture and swallow food particles, impaired ability to reproduce, loss of sensitivity, incapacity to flee from predators, loss of movement, stunted development, and altered bodily condition are all consequences of sub-lethal impacts. In contrast, marine animals, seabirds of all kinds, and sea turtles are more likely to become entangled in or consume plastic waste. The following species have been seen to be adversely impacted by the aforementioned consequence: Hawksbill turtle, Green sea turtle, Fulmar, Seals, Puffin, Sea Lions, Right whales, Albatross, and Greater Shearwater (Gall & Thompson, 2015). Among the more ingestible plastic waste kinds that birds consume are fishing hooks (Hong et al., 2013). The buildup of microplastics has complex effects on ecosystems and individual species. Every ocean on the planet is becoming more dense with microplastic (Thompson et al., 2009). High-density particles sink into the bottom sediments of the benthic system, whereas lightweight, low-density plastics float in the water. Microplastic pieces are comparable in size to suspended particles and plankton, which are examples of feeding matter (Wright et al., 2013). Because of this unique quality, invertebrates can consume these artificial microparticles. In the gastrointestinal system, plastic particles larger than 80 μm accumulate in the epithelial cells of digestive tubules, leading to negative consequences for invertebrates, including inflammation (Von Moos et al., 2012).

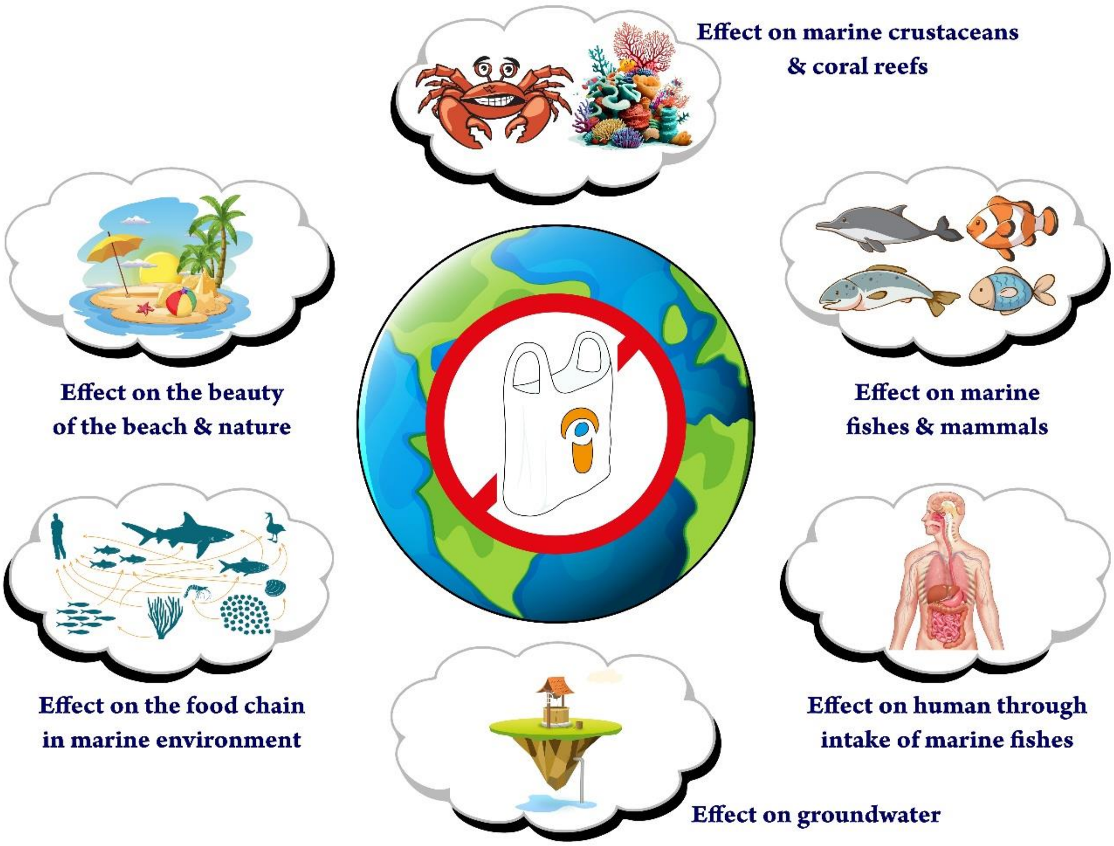

Figure 2. Plastics' impact on the marine environment.

Plastics include toxic ingredients such as metal ions, oligomers, flame retardants, BPA, monomers, and antibiotics. When marine species inadvertently consume plastics, these toxins can build up in their bodies (Lithner et al., 2011). The presence of phthalates and flame retardants in plastics may have harmful consequences on fish, mollusks, and mammals (Teuten et al., 2009; Oehlmann et al., 2009). Significant effects on organism development, genetic mutations, and reproduction are caused by BPA and phthalates found in plastic (Oehlmann et al., 2009). Similar to artificial populations, natural populations suffer significant negative effects from the above-mentioned harmful compounds in their food or surroundings.

Conversely, materials made of plastic can absorb harmful chemicals that have the potential to bioaccumulate over time. The potential for contaminated plastic debris containing these kinds of chemicals to introduce persistent pollutants into marine creatures through feeding is quite considerable (Miller et al., 2020). Consuming seafood tainted with plastics, persistent pollutants, heavy metals, and pharmaceutical substances can lead to the accumulation of toxic chemical compounds in species at higher trophic levels. Therefore, these chemicals may enter human bodies through food webs and cause health problems (Smith et al., 2018).

Plastics and other types of marine trash are beneficial to aquatic life as habitats. Coastal and marine organisms assemble and colonize on those man-made, hard substrates as a new surface. The majority of taxa that use the substrate of litter and debris as habitats are invertebrate species, which include bivalves, crustaceans, gastropods, coelenterates, bryozoans, insects, echinoderms, sponges, polychaetes, seagrasses, and seaweeds (Gall & Thompson, 2015). Micro and megaplastics also have the ecological consequence of dispersing via plastic litter. Debris is made of plastic floats and offers a steady surface for the rafting and movement of sessile and mobile creatures. Invasive organisms are introduced into a new ecosystem through this process. The fight between native and non-native species for resources (such as food, habitat, and space) in such systems completely changes the composition, structure, and balance of the ecosystem (García-Gómez et al., 2021).

The presence of plastic trash on the seawater's surface lowers the habitats' ability to absorb light and the amount of dissolved oxygen (DO). As a result, alterations in the physical and chemical parameters of the water quality hurt the water's tropic relationship and primary production. Food availability and DO level are thought to be the primary determinants (habitat factors) controlling biodiversity, and when these conditions are absent from the habitats and niches, biodiversity steadily decreases. Additionally, the behavioral alterations of marine and coastal species are adversely affected by the presence of plastic trash in their particular habitats (Thevenon et al., 2015). When plastic waste is present, the intertidal mollusk *Nassarius pullus*'s ability to forage decreases quickly (Aloy et al., 2011).

Plastic pollution has diverse socio-economic effects on human health, shipping, tourism, commercial fishing, and other areas. It also has a detrimental influence on the national economy of the country in question by increasing the cost of garbage disposal. Overabundance of plastic pollution in coastal areas and ocean basins has a direct impact on aquaculture, tourism, and commercial fishing. Debris clearance in Scotland, which includes plastic waste like fishing gear and PVC pipes, results in lost fishing time and increased cleaning costs (Ten Brink et al., 2009).

Human Health Implications:

Plastic pollution in the marine environment poses significant threats not only to marine life but also to human health. As plastics break down into smaller particles through processes such as photodegradation and mechanical abrasion, they release a variety of harmful chemicals and toxins into the water. These chemicals can accumulate in the tissues of marine organisms, eventually entering the human food chain through seafood consumption (Yuan et al., 2022). Bisphenol A (BPA), phthalates, polychlorinated biphenyls (PCBs), and polybrominated diphenyl ethers (PBDEs) are among the most commonly detected chemicals associated with plastics in marine environments. These substances have been linked to a range of adverse health effects in humans, including reproductive problems, hormonal imbalances, developmental disorders, and increased risk of cancer (Montano et al., 2022).

One of the primary concerns regarding human health impacts is the ingestion of microplastics, which are tiny plastic particles less than 5mm in size. Microplastics can be ingested by marine organisms such as fish, shellfish, and crustaceans, which may mistake them for food. These particles can then accumulate in the tissues of these animals, concentrating toxic chemicals and serving as vectors for their transfer to higher trophic levels (Lee et al., 2023). When humans consume seafood contaminated with microplastics, they may unknowingly ingest these particles along with associated toxins, leading to potential health risks (Bhuyan et al., 2022). Studies have found microplastics present in various seafood products consumed by humans, including fish, mussels, and shrimp, raising concerns about the potential health impacts of plastic pollution on seafood consumers (Cáceres-Farias et al., 2023).

Furthermore, the presence of plastic additives such as plasticizers, flame retardants, and antimicrobial agents adds another layer of concern for human health. These additives can leach from plastics into the marine environment, posing additional risks to human health through direct exposure or consumption of contaminated seafood. For example, plasticizers like phthalates, commonly used in plastics to increase flexibility, have been associated with endocrine disruption and reproductive abnormalities in humans. The implications of plastic pollution on human health extend beyond direct exposure through seafood consumption (Maddela et al., 2023; Campanale et al., 2020). Inhalation of airborne microplastics, ingestion of drinking water contaminated with microplastics, and dermal exposure to microplastics in beach sands are emerging concerns that warrant further investigation. Additionally, the role of plastics as carriers of pathogens and harmful algae in the marine environment raises concerns about the potential transmission of diseases to humans through contact with contaminated water or seafood (Enyoh et al., 2020). So, plastic pollution in the marine environment presents significant implications for human health due to the release of toxic chemicals, ingestion of microplastics through seafood consumption, and potential exposure through other pathways

(Smith et al., 2018). Addressing this issue requires comprehensive strategies to reduce plastic waste and mitigate its impacts on both marine ecosystems and human populations.

Current Legislation and Policies:

The proliferation of plastic pollution in marine ecosystems has prompted governments and international bodies to enact legislation and policies aimed at mitigating its adverse effects. This regulatory framework encompasses a range of measures addressing plastic production, use, disposal, and cleanup efforts. At the national level, countries worldwide have implemented various laws and regulations targeting single-use plastics, marine litter, and pollution prevention (Thushari & Senevirathna, 2020).

In the European Union (EU), for instance, the Single-Use Plastics Directive, adopted in 2019, seeks to curb the consumption of certain disposable plastic products, such as straws, cutlery, and plates, which are among the most prevalent items found in marine litter (Kiessling et al., 2023). Additionally, the directive mandates extended producer responsibility schemes, compelling manufacturers to cover the costs of waste management and cleanup efforts. The EU's Circular Economy Action Plan further reinforces these measures by promoting the sustainable production and consumption of plastics, as well as enhancing recycling infrastructure to reduce plastic leakage into marine environments (Kasznik & Łapniewska, 2023).

Similarly, in the United States, several legislative initiatives and policies have been introduced to address plastic pollution in oceans and waterways. The Save Our Seas Act signed into law in 2018, aims to improve domestic and international efforts to combat marine debris by enhancing waste management infrastructure, supporting research on plastic pollution, and fostering partnerships with other nations to address the global nature of the issue. Additionally, individual states have enacted their measures, such as bans on single-use plastic bags and microbeads, to reduce plastic waste and its impact on marine ecosystems (Leah, 2013).

Internationally, the United Nations Environment Assembly (UNEA) has played a crucial role in advancing global efforts to combat marine plastic pollution. The UNEA Resolution on Marine Litter and Microplastics, adopted in 2019, calls for coordinated action by member states to prevent and reduce marine litter, including plastics, through enhanced waste management, sustainable consumption patterns, and public awareness campaigns (Carlini & Kleine, 2018). Moreover, multilateral agreements like the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal have been expanded to include plastic waste, thereby facilitating international cooperation in managing plastic pollution and preventing its transboundary movement (Carlini & Kleine, 2018).

Despite these legislative and policy efforts, challenges persist in effectively addressing plastic pollution in marine environments. Implementation gaps, inadequate enforcement mechanisms, and limited resources hinder the full realization of regulatory measures (Da Costa et al., 2020). Furthermore, the complex nature of plastic pollution requires a holistic approach that integrates policy interventions with public engagement, technological innovation, and stakeholder collaboration to achieve lasting solutions.

Possible solutions and challenges to overcome:

A variety of approaches have been found to deal with the problem of plastic pollution. Institutions at the international, regional, and national levels play a critical role in managing and halting the buildup of plastic waste in marine and coastal ecosystems. Product disposal routes should be taken into account from the very beginning of design, with an industrial focus. A more circular economy must replace the linear economy to achieve long-term sustainable solutions (Bergmann et al., 2015; MacArthur et al., 2016; Saha, 2023). Reducing waste may be accomplished through more circular material usage combined with sustainable patterns of production and consumption. On a local, national, regional, and worldwide scale, several actions have already been implemented (Hartley et al., 2018). To reduce the amount of plastic that ends up in the environment, governments play a crucial role. Policies that demand a fee on non-recyclable goods or offer incentives for new product designers to use recycled materials to promote reuse and/or recyclability can help bring about systemic improvements. Increasing awareness, education, and outreach are useful strategies for addressing marine trash (Napper & Thompson, 2019). This is because raising public knowledge of the issues caused by plastic waste is a crucial first step in influencing people's purchasing habits. Frameworks for waste management are usually created to reduce environmental damage. Recycling may be utilized to improve material flows and circularity (Kibria et al., 2023).

In the quest to mitigate the detrimental effects of plastic pollution on marine environments, significant strides have been made in developing innovative technologies and conducting cutting-edge research. These endeavors span a wide spectrum, encompassing novel cleanup methods, sustainable materials development, and advanced monitoring techniques (Oliveira et al., 2020). Recent advancements in plastic formulation technology have led to claims that these materials degrade more quickly and/or have less environmental effects due to their shorter persistence, offering a potential solution to the world's mounting plastic waste problem. However, any possible advantages should be carefully weighed against any potential drawbacks when substituting traditional plastic with other materials (Webb et al., 2012).

One area of innovation lies in the development of cleanup technologies designed to remove existing plastic debris from marine ecosystems. Traditional cleanup methods often face challenges due to the vastness of oceanic environments and the persistence of microplastics. However, emerging technologies such as ocean cleanup arrays, autonomous surface vessels, and aerial drones equipped with sensors and collection devices show promise in enhancing efficiency and effectiveness in plastic removal efforts (Schmaltz et al., 2020). Furthermore, exploring biological solutions, such as employing marine microorganisms capable of degrading plastics, offers a potential eco-friendly approach to remediation (Wu et al., 2023). In parallel, significant efforts are directed towards developing sustainable alternatives to conventional plastics. Biodegradable polymers derived from renewable resources, such as plant-based materials or bio-based plastics, represent a promising avenue for reducing plastic pollution. Research in this field focuses on enhancing the biodegradability and functional properties of alternative materials to ensure compatibility with diverse applications while minimizing environmental impact (Samir et al., 2022).

Advanced monitoring and detection techniques also play a crucial role in tracking and assessing the extent of plastic pollution in marine environments. Remote sensing technologies, including satellite imagery and aerial surveys, enable large-scale monitoring of oceanic plastic accumulation, providing valuable data for policy-making and conservation efforts (Almeida et al., 2022). Additionally, the integration of artificial intelligence and machine learning algorithms facilitates the automated analysis of vast datasets, enhancing our understanding of plastic distribution patterns and informing targeted interventions (Kamyab et al., 2023).

Community engagement and education play pivotal roles in combating plastic pollution in marine environments. Public awareness campaigns, educational programs, and community-led initiatives are essential for fostering behavioral changes that reduce plastic consumption and promote responsible waste management practices. These efforts not only increase awareness about the detrimental impacts of plastic pollution on marine ecosystems but also empower individuals to take action in their daily lives (Mathis et al., 2022). By involving local communities in cleanup activities, recycling programs, and beach conservation projects, a sense of ownership and stewardship for the marine environment is cultivated. Furthermore, educational outreach efforts aimed at schools, businesses, and civic organizations can instill a deeper understanding of the interconnectedness between human actions and environmental health. Ultimately, community engagement and education serve as catalysts for collective action, driving momentum toward a more sustainable future for our oceans (Uneputty et al., 1998).

Conclusions & Future Directions:

In conclusion, addressing the pervasive issue of plastic pollution in marine environments requires a multifaceted approach that combines regulatory measures, technological innovations, and widespread public engagement. The insights gained from this review underscore the urgent need for coordinated efforts on a global scale. While current legislation and policies represent crucial steps forward, continual evaluation and refinement are necessary to adapt to evolving challenges. Future research endeavors should prioritize the development of sustainable alternatives to traditional plastics, considering their life cycle and environmental impact. Investigating the socio-economic ramifications of plastic pollution on coastal communities will further inform comprehensive mitigation strategies. Additionally, monitoring and assessing the effectiveness of existing cleanup technologies and exploring new, innovative methods are imperative. Community engagement remains a linchpin in fostering behavioral changes essential for reducing plastic consumption. Education initiatives, coupled with collaborations between governments, NGOs, industries, and local communities, will be instrumental in achieving meaningful, lasting results. Collaborative research efforts should also delve into the long-term trends of marine plastic pollution, aiming to identify emerging threats and refine mitigation strategies. In navigating the future direction of marine plastic pollution research, a holistic and interdisciplinary approach will be pivotal, fostering a collective commitment to preserving the health and sustainability of our oceans for generations to come.

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Chapter- 33

Campus Ecosystems: Nurturing Biodiversity and Sustainability for a Greener Future

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Keywords: Diversity, Sustainable practice, Acharya Prafulla Chandra College, urbanization, local ecosystem.

Abstract:

The book chapter inquires into the importance of Acharya Prafulla Chandra College (APC) campus in the fight to conserve and improve the environment by taking care of biodiversity on their grounds. The abstract provides criteria for the college in terms of programs and techniques concerning biodiversity and conservation such as employing sustainable landscaping methods, conserving native species, and tree plantation. It thus gives an important message that it is much more desirable to provide environmental learning and public awareness to stimulate the involvement of the whole community and the kids, especially in conservation efforts. The abstract focuses on the platforms the campus environment can evolve into. It can be utilized for providing the training ground using which environmental stewardship can be enhanced and people can learn to make sustainable choices. The unique ecosystems within educational institutions can serve to foster a healthy environment and provide practical or hands-on learning opportunities. Sustainable practices including water conservation, efficient energy/resource utilization, and waste disposal are very important for us to demonstrate ethical environmental stewardship. The abstract reports that Acharya Prafulla Chandra College has shown its diversified floral and faunal biodiversity and the involved sustainable practices for the awakening of environmental knowledge and conservation.

Introduction:

In this modern era, urbanization is leading to the destruction of biodiversity as natural habitats are continuously replaced by concrete structures, disrupting ecosystems and displacing

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diverse plant and animal species (Nagendra et al., 2013). Addressing the challenges of increased development and the threat of pollution posed by urbanization requires sustainable urban planning, eco-friendly infrastructure, and effective waste management practices (Rana, 2011). Implementing green spaces within urban areas can help mitigate the negative environmental impacts associated with rapid urbanization. Human-influenced cultural landscaping such as botanical gardens, parks, church-symmetry, suburban forests, and greenways can preserve biodiversity, and act as green space. College campuses are also included in the cultural landscapes that serve as green spaces, incorporating areas with trees, lawns, and gardens (Wheeler Jr, 2008; Modi & Dudani, 2013; De et al., 2019). These environments not only enhance the aesthetic appeal but also provide students and the community with greenery, recreational spaces, and opportunities for nature appreciation, contributing to overall well-being and ecological balance. The variety and variability of different life forms within an educational institution represent a unique and localized ecosystem shaped by human activities, landscaping choices, and conservation efforts. Each campus reveals a distinct biodiversity with its own set of ecological characteristics and challenges (Bouma et al., 2014; Gogoi et al., 2023). Nurturing biodiversity in college campuses ensures a healthy environment, with a variety of plants, animals, and ecosystems working together. A rich and diversified campus creates opportunities for students to study and understand local ecosystems, contributing to broader scientific knowledge (Martusewicz, et al., 2014).

Implementing sustainable practices ensures the responsible use of resources, reduces environmental degradation, and contributes to a resilient, equitable, and economically viable future. Recognizing the interconnectedness of these concepts is vital for addressing global challenges and fostering a harmonious relationship between humanity and the natural world (Colding & Barthel, 2017). If there are spaces, educational institutions need to prioritize environmental conservation and employ sustainable resource management practices. Furthermore, when institution authorities utilize resources efficiently and implement proper waste management practices, they can serve as models for demonstrating ethical management of the environment. This article discusses the Acharya Prafulla Chandra College campus and its biodiversity along with significant sustainable practices to promote environmental awareness and safeguard of campus environment as contributors to biodiversity conservation within urban landscapes.

Campus Biodiversity:

Acharya Prafulla Chandra College located near New Barrackpore, a developing science and arts degree college in Kolkata is a productive habitat. Apart from the infrastructural building structures, the campus area has green lawns, flowering gardens, medicinal herbs, shrubs, grass fields, and a pond. These limited but diverse zonal spaces harbor a wide variety of flora and fauna that contribute to the distinct identity of the campus, influence the surroundings, and promote community involvement.

Figure 1. College campus location (obtained from Google Maps).

Flora:

Acharya Prafulla Chandra College is situated in a semi-urban area where huge varieties of diversity are found in plant species because the college premises are enriched with fertile, Clayey loam with deep humus soil, adequate precipitation, temperature, and adequate sunlight and has a good drainage system which influences the diversification among the plant group. The diverse vegetation plays a vital role in the ecological balance of the college campus. Diversity is further reflected in the different types of ecosystems available here like freshwater ecosystems and grassland ecosystems on college campuses.

There are 550 different kinds of plants belonging to different families, various seasonal ornamental plants, vegetables, and 114 medicinal plants present on the college premises. A few of them are endangered, vulnerable, and threatened species also conserved in the college premises.

Table 1: List of plants on college premises.

Sl	Scientific name	Common name	Family	No. of plant
1	*Peltophorum pterocarpum* (DC.) K.Heyne	Radhachura	Fabaceae	1
2	*Casuarina equisetifolia* L.	Jhau	Casuarinaceae	5
3	*Lagerstroemia speciosa* (L.) Pers.	Jarul	Lythraceae	4
4	*Samanea saman* (Jacq.) Merr.	Shirish	Fabaceae	2
5	*Swietenia mahagoni* (L.) Jacq.	Mehagoni	Meliaceae	8
6	*Bauhinia purpurea* L.	Rakta Kanchan	Fabaceae	2
7	*Alstonia scholaris* L.R.Br.	Chhatim	Apocynaceae	1
8	*Polyalthia lingifolia* (Sonn.) Thwaites	Debdaru	Annonaceae	13

9	*Tectona grandis* L.f.	Segun	Verbanaceae	1
10	*Areca catechu* L.	Supari	Arecaceae	4
11	*Terminalia arjuna* (Roxb)Wight& Arn	Arjun	Combretaceae	10
12	*Acacia auriculiformis* A.Cunn.ex.Benth	Sonajhuri	Fabaceae	7
13	*Ficus religiosa* L.	Ashwattha	Moraceae	1
14	*Psidium guajava* L.	Peyara	Myrtaceae	7
15	*Mangifera indica* L.	Aam	Anacardiaceae	42
16	*Syzygium cumini* (L.) Skeels	Jam	Myrtaceae	4
17	*Mimusops elengi* L.	Bakul	Sapotaceae	2
18	*Neolamarckia cadamba* (Roxb.) Bosser	Kadam	Rubiaceae	2
19	*Syzygium samarangense* (Blume) Merr. & L.M.Perry	Jamrul	Myrtaceae	9
20	*Carissa carandas* L.	Karamcha	Apocynaceae	2
21	*Citrus limetta* Risso	Lebu	Rutaceae	5
22	*Ziziphus mauritiana* Lam.	Kul	Rhamnaceae	4
23	*Tecoma stans* (L.) Juss. ex Kunth	Chandra prava	Bignoniaceae	1
24	*Nerium oleander* L.	Karabi	Apocynaceae	1
25	*Pterocarpus santalinus* Linn.	Rakta Chandan	Fabaceae	1
26	*Terminalia chebula* Retz.	Haritaki	Combretaceae	1
27	*Hibiscus rosa-sinensis*	Joba	Malvaceae	2
28	*Thuja occidentalis* L.	Jhau	Cupressaceae	244
29	*Roystonea regia*	Palm	Arecaceae	96
30	*Euphorbia milii* Des Moul.	Kata mukut	Euphorbiaceae	29
31	*Azadirachta indica* A.Juss.	Neem	Meliaceae	2
32	*Phyllanthus emblica* L.	Amlaki	Phyllanthaceae	4
33	*Carica papaya* L.	Pepe	Caricaceae	3
34	*Averrhoa carambola* L.	Kamranga	Oxalidaceae	1
35	*Punica granatum* L.	Dalim	Lythraceae	2
36	*Artocarpus heterophyllus* Lam.	Kathal	Moraceae	1
37	*Khaya anthotheca* (Welw.) C.DC	Lambu	Meliaceae	26

On the college campus is a medicinal garden, which serves as a vital resource for education, research, environmental protection, conservation, and outreach to the local population (Sarkar, 2017). It does this by bridging the gap between theory and practice, promoting a greater understanding of medicinal plants and their role in medical care. Colleges that demonstrate their dedication to holistic education, environmental responsibility, and the progress of natural medicine by maintaining a medicinal garden exemplify this devotion.

Some important medicinal plants at the premises of Acharya Prafulla Chandra College are-

Table 2: List of wild types of medicinal plants at the premises of Acharya Prafulla Chandra College.

1	Binomial name: *Syzygium aromaticum* (L) Merril & Perry Family: Mytraceae Common name: Labanga	2	Binomial name: *Barleria prionitis* L. Family: Acanthaceae Common name: Bazradanti
3	Binomial name: *Glycosmis pentaphyla* (Retz) Correa Family: Rutaceae Common name: Ash shaowra	4	Binomial name: *Trema orcientalis* (L) Blume Family: Cannabaceae Common name: Jibanti
5	Binomial name: *Blumea lacera* (Burm. F.) Dc. Family: Asteraceae Common name: Bara cooksina	6	Binomial name: *Clitoria ternatea* L. Family: Fabaceae Common name: Aporajita
7	Binomial name: *Aegel marmelos* (L) correa Family: Rutaceae Common name: Bel	8	Binomial name: *Elaeocarpus serratus* L. Family: Elaeocarpaceae Common name: Jalpai
9	Binomial name : *Pogostemon cablin* (Blanco) Benth Family: Lamiaceae Common name: Pachouri	10	Binomial name: *Cympogon citrus* (L.) Spreng Family: Poaceae Common name: Lebughash
11	Binomial name: *Ocimum tenuiflorum* L. Family: Lamiaceae Common name: Krishna Tulsi	12	Binomial name: *Stephania japonica* (Thumb). Micrs Family: Menispermaceae Common name: Nimukha
13	Binomial name: *Mikania scandense* B. L. Rob. Family: Asteraceae Common name: Jarman lata	14	Binomial name: *Aerva lantana* L. Family: Amaranthaceae Common name: Chaya
15	Binomial name: *Desmodium gangeticum* (L.) Dc. Family: Fabaceae Common name: Shalparni	16	Binomial name: *Costus specious* (J. Koning.) C. Specht. Family: Zingiberaceae Common name: Keu
17	Binomial name: *Uraria picta* (Jack) Dc. Family: Fabaceae Common name: Prishiparni	18	Binomial name: *Iresine herbstii* Hook. ex Lindl. Family: Amaranthaceae Common name: Lal vishyalikarani
19	Binomial name: *Ruellia prostrata* L. Family: Acanthaceae Common name: Patpati	20	Binomial name: *Barringtonia acutangula* (L) Gaertn. Family: Lecythidaceae Common name: Hijol
21	Binomial name: *Madhuca longifollia* (J. Konig) J. F. Macbr Family: Sapotaceae	22	Binomial name: *Cephalandra indica* (W. and A.) Naud Family: Cucurbitaceae

	Common name: Mahua		Common name: Talakuch
23	Scientific name: *Hemidesmus indicus* R. Br. Family: Asclepedaceae Common name: Ananta mul	24	Scientific name: *Syzazium jambos* L. (Aloston) Family: Mytraceae Common name: Jam
25	Scientific name: *Artemisia vulguris* L. Family: Asteraceae Common name: Nagdola	26	Scientific name: *Ocimum gratissimum* L. Family: Lamiaceae Common name: Chandan Tulsi
27	Scientific name: *Morinda critifolia* L. Family: Rubiaceae Common name: Noni	28	Scientific name: *Saraca asoca* (Roxb.) Willd. Family: Fabaceae Common name: Ashok
29	Scientific name: *Vitex negundo* Linn. Family: Verbaneceae Common name: Nishinda	30	Scientific name: *Murraya koenigii* (L.) Spreng. Family: Rutaceae Common name: Kari Pata
31	Scientific name: *Withania somnifera* (L.) Kuntze Family: Solanaceae Common name: Awshagandha	32	Scientific name: *Cissus quadrangularis* L. Family: Vitaceae Common name: Harjora
33	Scientific name: *Amomum aromaticum* Roxb. Family: Zingiberaceae Common name: Alach	34	Scientific name: *Clerodendrum indicum* L. Family: Verbenaceae Common name: Bamunhati
35	Scientific name: *Psidium guajava* Linn. Family: Mytraceae Common name: Payara	36	Scientific name: *Adhatoda vasica* Nees Family: Acanthaceae Common name: Vashak
37	Scientific name: *Wedelia calendula* (L.) Less. Family: Asteraceae Common name: Bhringaraj	38	Scientific name: *Terminalia chebula* Retz. Family: Combrataceae Common name: Haritaki
39	Scientific name: *Asparagus racemosus* Willd Family: Asparagaceae Common name: Satamuli	40	Scientific name: *Euphorbia tirucalli* L. Family: Euphorbiaceae Common name: Lankaseji
41	Scientific name: *Justicia gendarusa* Burm. f. Family: Acanthaceae Common name: Bishahari	42	Scientific name: *Stachytarpheta jamaicensis* L. Family: Verbenaceae Common name: Jerbo
43	Scientific name: *Coleus aromaticus* Benth. Family: Lamiaceae	44	Scientific name: *Centella asiatica* L. Family: Apiaceae

	Common name: Aijawan		Common name: Thankuni
45	Scientific name: *Hygrophyla spinosa* T. Anderson Family: Acanthaceae Common name: Kulekhara	46	Scientific name: *Abutilon indicum* (L.) Sweet Family: Malvaceae Common name: Atibol
47	Scientific name: *Alstonia scholaris* R. Br. Family: Apocynaceae Common name: Chatim	48	Scientific name: *Anacardium occidentali* L. Family: Anacardiaceae
49	Scientific name: *Acacia auriculiformis* A. Cunn. ex Benth. Family: Mimosaceae	50	Scientific name: *Bauhinia purpuria* L. Family: Caesalpinaceae Common name: Rakta kanchan
51	Scientific name: *Gardenia latifolia* G. Don Family: Rubiaceae Common name: Gandharaj	52	Scientific name: *Mimosa pudica* L. Family: Mimosaceae Common name: Lajjabati
53	Scientific name: *Sanscvieria roxburghiana* Schult & Schult. f. Family: Asperagaceae Common name: Murga	54	Scientific name: *Bryophyllum pinnatum* (Lam.) Oken Family: Crassulaceae Common name: Pasan veda
55	Scientific name: *Kalanchoe pinnata*. Lamm Family: Crassulaceae Common name: Patharkuchi	56	Scientific name: *Azadirachta indica* A. Juss. Family: Meliaceae Common name: Neem
57	Scientific name: *Nyctanthus arbortristis* Linn. Family: Oleaceae Common name: Sheuli	58	Scientific name: *Termelia arjuna* (Roxb) Wight & Ara. Family: Combretaceae Common name: Arjun
59	Scientific name: *Ocimum sanctum* L. Family: Lamiaceae Common name: Tulshi	60	Scientific name: *Crotalaria juncea* L. Family: Fabaceae Common name: Atashi
61	Scientific name: *Swietentia mahagoni* (L) Jacq Family: Meliaceae Common name: Mehogani	62	Scientific name: *Mentha arvenensis* Linn. Family: Lamiaceae Common name: Pudina
63	Scientific name: *Duranta erecta* L. Family: Verbenaceae Common name: Duranta	64	Scientific name: *Ziziphus jujube* Mill. Family: Rhamnaceae Common name: Kul
65	Scientific name: *Emblica officinalis* L. Family: Euphorbiaceae	66	Scientific name: *Mimusops enlengi* L.

	Common name: Amlaki		Family: Sapotaceae Common name: Bakul
67	Scientific name: *Aerva aspera* L. Family: Amaranthaceae Common name: Apang	68	Scientific name: *Crenum asiaticum* L. Family: Amaryllidaceae Common name: Sukha darshan
69	Scientific name: *Aloe berberadensis* Mill. Family: Liliaceae Common name: Ghrita kumari	70	Scientific name: *Rauvolfia serpentine* (wall.) Benth. ex. Hook. f. Family: Apocynaceae Common name: Sarphagandha
71	Scientific name: *Gomphrena globosa* Family: Amaranthaceae Common name: Botam phul	72	Scientific name: *Euphorbia ayapana* Vent. Family: Euphorbiaceae Common name: Ayapon
73	Scientific name: *Amaranthus spinosus* L. Family: Amaranthaceae Common name: Kata Notey	74	Scientific name: *Andrographis paniculata* (Brum. f.) Wall. ex. Nees Family: Acanthaceae Common name: Kal Megh
75	Scientific name: *Amaranthus viridis* L. Family: Amaranthaceae Common name: Bon Notey	76	Scientific name: *Cassia tora* L. Family: Caselpinaceae Common name: Chakwar
77	Scientific name: *Carrica papya* Family: Caricaceae Common name: Pepe	78	Scientific name: *Curcuma longa* L. Family: Zingiberaceae Common name: Halud
79	Scientific name: *Paederia foetida* L. Family: Rubiaceae Common name: Gadal	80	Scientific name: *Tridax procumbens*. Family: Asteraceae Common name: Tridakha
81	Scientific name: *Pouzolzia indica*. Family: Uitriaceae Common name: Tuici	82	Scientific name: *Commelina benghalensis*. Family: Comelinaceae Common name: Kansira
83	Scientific name: *Agaratum conyzoids* Family: Asteraceae Common name: Uchunti	84	Scientific name: *Sida cordifolia* Linn. Family: Malvaceae Common name: Bala
85	Scientific name: *Sonchus arvensis* Linn. Family: Asteraceae Common name: Dudhi	86	Scientific name: *Piper longum L.* Family: Piperaceae Common name: Pipul
87	Scientific name: *Ricinus communis* Linn.	88	Scientific name: *Phyllanthus niruri* Auct.

	Family: Euphorbiaceae Common name: Varenda		Family: Phyllanthaceae Common name: Bhui amla
89	Scientific name: *Oxalis corniculata* Linn. Family:- Oxalidaceae Common name: Amrul	90	Scientific name: *Heliotropium indicum* Linn. Family: Boraginaceae Common name: Hatisur
91	Scientific name: *Ocimum basilicum* Linn. Family: Lamiaceae Common name: Babui tulsi	92	Scientific name: *Nicotiana plumbaginifolia* Viv. Family: Solanaceae Common name: Bon tamak
93	Scientific name: *Nerium olenader* Linn. Family: Apocynaceae Common name: Rakta karabi	94	Scientific name: *Cajanus cajan* (Lin) Mill Family: Papilionaceae Common name: Arahar
95	Scientific name: *Nymphaea stellata* Wild. Family: Nymphaeaceae Common name: Saluk	96	Scientific name: *Lawsonia inermis* Lin. Family: Lythraceae Common name: Mehendi
97	Scientific name: *Mimosa pudica* Linn. Family: Mimosaceae Common name: Lajjabati	98	Scientific name: *Boerhaavia repens* L. Family: Nyctaginaceae Common name: Punarnava
99	Scientific name: *Euphorbia hirta* Linn. Family: Euphorbiacea Common name: Dudurli	100	Scientific name: *Acalypha indica* Linn. Family: Euphorbiacea Common name: Muktojhuri
101	Scientific name: *Croton bonplandianum* L. Family: Euphorbiacea Common name: Bontulsi	102	Scientific name: *Solanum nigram* Linn. Family: Solanaceae Common name: Kakamachi
103	Scientific name: *Physalis minima* Family: Solanaceae Common name: Bantepari or patka	104	Scientific name: *Vernonia cinerea* Linn. Family: Asteraceae Common name: Kukasim
105	Scientific name: *Eclipta alba* Family: Asteraceae Common name: Keshuth	106	Scientific name: *Scoparia dulcis* Family: Plantaginaceae Common name: Bon dhone

107	Scientific name: *Cassia occidentalis* L. Family: Caesalpiniaceae Common name: Chakor	108	Scientific name: *Cassia alata* L. Family: Caesalpiniaceae Common name: Dadmari
109	Scientific name: *Cyperous rotundus* L. Family: Cyperaceae Common name: Muthaghas	110	Scientific name: *Cassia alata* (L.) Roxb. Family: Fabaceae Common name: Dadmari
111	Scientific name: *Euphorbia meriifolia* Family: Euphorbiaceae Common name: Manasa Gach	112	Scientific name: *Barleria lupulina* Lindl. Family: Acanthaceae Common name: Kata Bishalya Karani
113	Scientific name: *Stephania japonica* (Thumb) Miers Family: Meninspermaceae Common name: Nemuwa	114	Scientific name: *Jatropha gossypifolia* Linn. Family: Euphorbiaceae Common name: Lal Vanda

Figure 2. Medicinal Garden on Acharya Prafulla Chandra College premises.

Iresine herbstii **Hook. ex Lindl.**

Barleria lupulina **Lindl.**

Amomum aromaticum **Roxb.**

Rauvolfia serpentine **(wall.) Benth. ex. Hook. f.**

Wedelia calendula **(L.) Less.**

Stachytarpheta jamaicensis **L.**

Figure 3. Some medicinal plants on college premises.

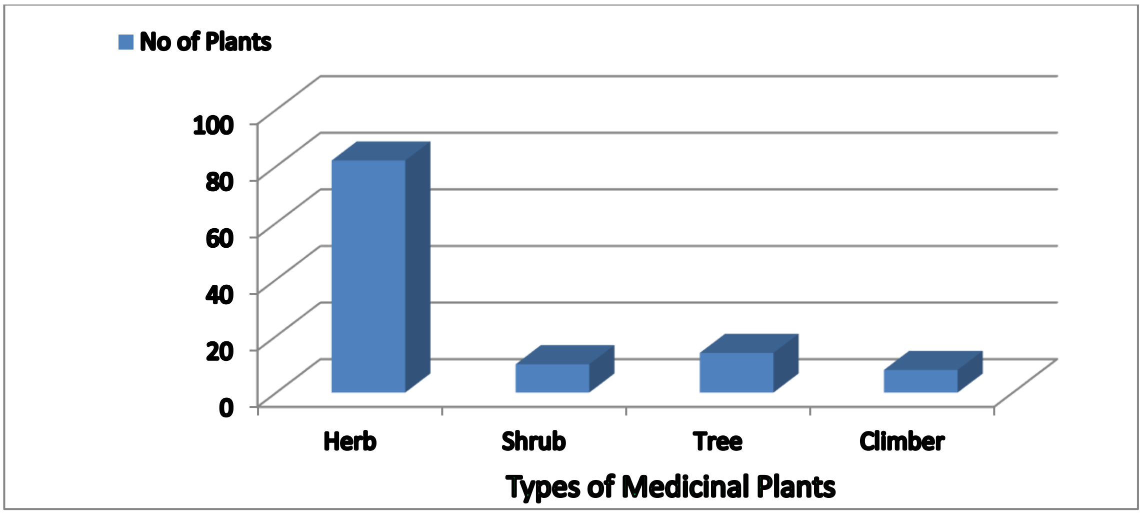

Figure 4. Types of medicinal plants in the medicinal garden.

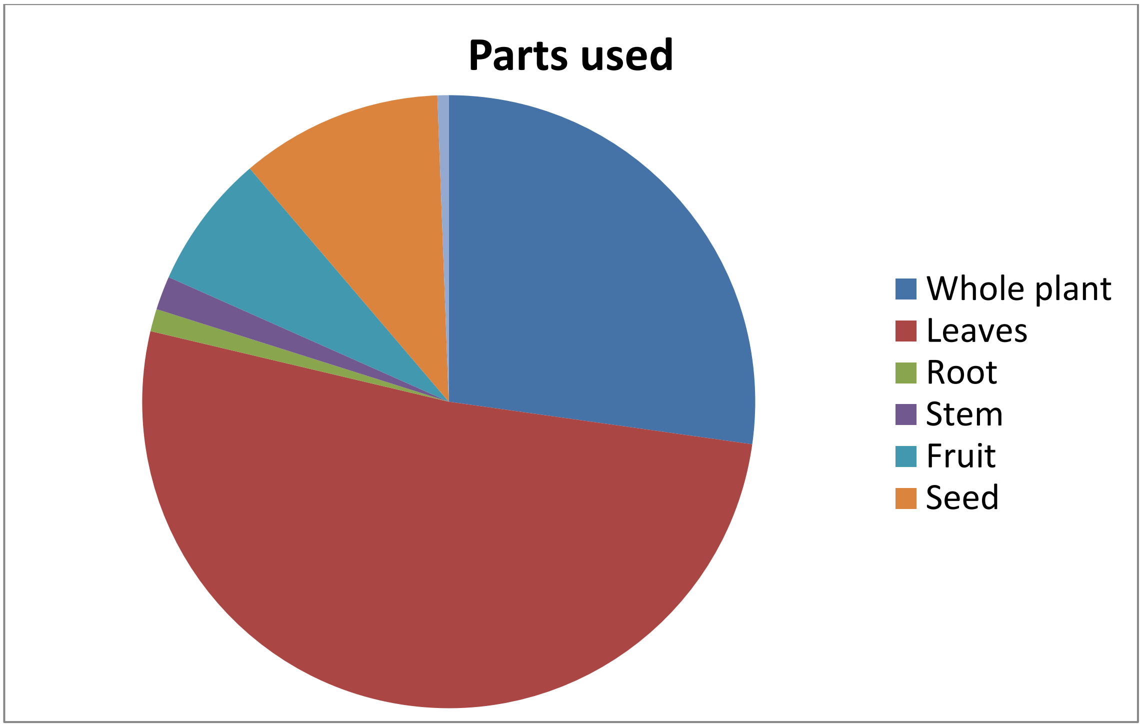

Figure 5. Graph showing percentages of plant parts used as medicine by men/women/ local peoples of semi-urban areas.

Figure 6. A grassland is a good waiting place for lots of characteristics such as the different plants and animals that are found on campus and thus contributing greatly to ecosystem continuity. Grasslands have a very unique ability to remove carbon dioxide from the air and store it in their soil. Furthermore, the carbon that is captured in soil acts as a greenhouse gas so it reduces the overall levels of those gases in the atmosphere. This way grasslands help the fight against climate change and reduce greenhouse gas emissions.



Figure 7. Ornamental plants on college premises.

Fauna:

The diversity of various plant and animal species in campus greenery significantly improves the overall college environment. In addition to the aesthetic appeal, the campus provides opportunities for hands-on learning and serves as a living laboratory.

The Pond harbors a rich diversity of zooplankton that play pivotal roles in shaping the ecosystem's dynamics. Within this small water body, numerous zooplankton, ranging from rotifers to copepods, thrive and contribute to nutrient cycling, energy transfer, and the overall functioning of the pond's food web. Among the rotifer *Brachionus* sp., *Keratella* sp., *Filinia* sp., *Asplancha* sp. and *Euchlanis* sp. are very common in the pond while in the cladoceran group *Daphnia* sp., *Bosmina* sp., *Ceriodaphnia* sp. also prevail in the water. In copepod, a variety of *Cyclops* sp., *Mesocyclops* sp., and very few *Diaptomus* sp. are present in the habitat and serve as voracious phytoplankton consumers. Protozoans such as *Paramecium* sp., and *Euglena* sp., are commonly observed in sampling whereas a few crustaceans *Cypris* sp., *Moina* sp. are occasionally found.

Pollinators, including bees, and butterflies play a pivotal role in maintaining ecological balance within campus ecosystems. Their unique interactions with flowering plants contribute to biodiversity, ecosystem resilience, and the production of food resources. The college campus, in particular, is a haven for butterflies (Table 2). These lepidopterans are sensitive to environmental changes, including shifts in climate, and habitat quality their presence and diversity serve as indicators of the good health of the ecosystem (Saha, 2017).

Table 3: Checklist of Some butterflies observed on campus.

Name	Scientific Name	Group	Category
Common spotted flat	*Celeonorrhinus leucocera*	Skipper	Regular
Dark palm dart	*Telicota ancilla*	Skipper	Regular
Common red eye	*Matapa aria*	Skipper	Rare
Tailed jay	*Graphium agamemnon*	Swallowtails	Rare
Common mime	*Chilasa clytia*	Swallowtails	Abundant

Common mormon	*Papilio polytes*	Swallowtails	Regular
Lime butterfly	*Papilio demoleus*	Swallowtails	Rare
Common rose	*Atrophaneura hector*	Swallowtails	Rare
Common grass yellow	*Eurema hecabe*	White and Yellow	Abundant
Striped albatross	*Appias libythea*	White and Yellow	Regular
Common jezebel	*Delias eucharis*	White and Yellow	Abundant
Common pierrot	*Castalius rosimon*	Blues	Rare
Common lineblue	*Prosotas nora*	Blues	Regular
Pale grass blue	*Pseudozizeeria maha*	Blues	Regular
Forget me not	*Catochrysops strabo*	Blues	Rare
Lime blue	*Chailades lajus*	Blues	Abundant
Blue tiger	*Tirumala limniace*	Nymphalids	Regular
Striped tiger	*Danaus genutia*	Nymphalids	Abundant
Plain tiger	*Danaus chrysippus*	Nymphalids	Abundant
Common crow	*Euploea core*	Nymphalids	Abundant
Common evening brown	*Melanitis leda*	Nymphalids	Abundant
Common bush brown	*Mycalesis perseus*	Nymphalids	Rare
Common four ring	*Ypthima huebneri*	Nymphalids	Abundant
Palm fly	*Elymnias hypermnestrs*	Nymphalids	Abundant
Tawny coaster	*Acraea violae*	Nymphalids	Abundant
Common leopard	*Pathalanta phalantha*	Nymphalids	Rare
Common sailor	*Neptis hylas*	Nymphalids	Regular
Common castor	*Ariadne merione*	Nymphalids	Regular
Chocolate pansy	*Junonia iphita*	Nymphalids	Abundant
Grey pansy	*Junonia atlites*	Nymphalids	Regular
Lemon pansy	*Junonia lemonias*	Nymphalids	Regular
Peacock pansy	*Junonia almana*	Nymphalids	Abundant
Danaid egg fly	*Hypolimnas misippus*	Nymphalids	Rare
Commander	*Moduza procis*	Nymphalids	Rare

Due to the presence of the pond and the adjacent Sajirhat Jheel dragonflies and damselflies are abundant in the campus area. The diversity and abundance of dragonflies and damselflies act as reliable indicators, reflecting the health of aquatic ecosystems by sensitively responding to changes in water quality, pollution levels, and habitat conditions. A study by Baidya, 2017 revealed the presence of 19 species of these odontate insects on the campus Table 3.

Figure 8. A) Common Pierrot, B) Red eye, C) Tailed jay, D) Common castor, E) Dannid egg fly, F) Common jezebel, G) Common Mormon, H) Lemon pansy, I) Grass yellow, J) Four rings, K) Commander, L) Lime butterfly, M) Palm fly, N) Oriental forget me not, O) Grey pansy.

Table 4: Checklist of recorded dragonflies and damselflies on campus.

Suborder	Family	Scientific Name	Common Name
Anisoptera	Libellulidae	*Crocothemis servilla*	Scarlet skimmer, Ruddy marsh skimmer.
		Brachythemis contaminate	Ditch jewel.
		Diplacodes trivialis	Blue percher, Chalky percher, Ground skimmer.
		Orthetrum Sabina	Slender skimmer, Green marsh hawk.
		Rhyothemis variegate	Common picture wing, Variegated flutterer.
		Trithemis pallidinervis	Long legged marsh glider, Dancing dropwing.
		Tramea basilaris	Keyhole glider, Red marsh trotter.
		Bradinopyga geminate	Granite ghost
		Orthetrum pruinosum	Crimson-tailed marsh hawk.
	Gomphidae	*Ictinogomphus rapax*	Common Clubtail
		Paragomphus lineatus	Common Hooktail
	Aeshnidae	*Anax immaculifrons*	Blue Darner
Zygoptera	Coenagrionnidae	*Pseudagrion microcephalaum*	Blue riverdamsel, Blue sprite, Blue grass dart.
		Ceriagrion coramandelianum	Coromandel marsh dart, yellow waxtail.
		Pseudagrion rubriceps	Saffron faced blue dart.
		Agriocnemis femina	Variable wisp, Pinheaded

			wisp.
		Agriocnemis pygmaea	Pygmy wisp, Wandering midget, Pygmy dartlet, Wandering wisp.
		Ischneura seneghalensis	Common bluetail, Marsh bluetail, African Bluetail.
		Onychargia atrocyana	Marsh dancer, Black marsh dart.
		Ischneura aurora	Golden dartlet, Aurora bluetail.

Ants are a successful group of social insects belonging to the order Hymenoptera, family Formicidae, characterized by their organized colonies, diverse species, and complex social structures. By scavenging and decomposing organic matter and other debris they play a crucial role in recycling nutrients in the ecosystems (Del Toro et al., 2012). Most prevailed species on the campus are *Solenopsis geminata* (Tropical fire ant), *Paratrechina longicornis* (Longhorn crazy ant), *Oecophylla smaragdina* (Weaver ant), *Tetraponera rufonigra* (African twig ant), *Tetramorium* sp. (Pavement ant*)*, *Diacamma rugosum* (Velvet ant), *Pheidole roberti* (Big-headed ant), *Camponotus compressus* (Carpenter ant).

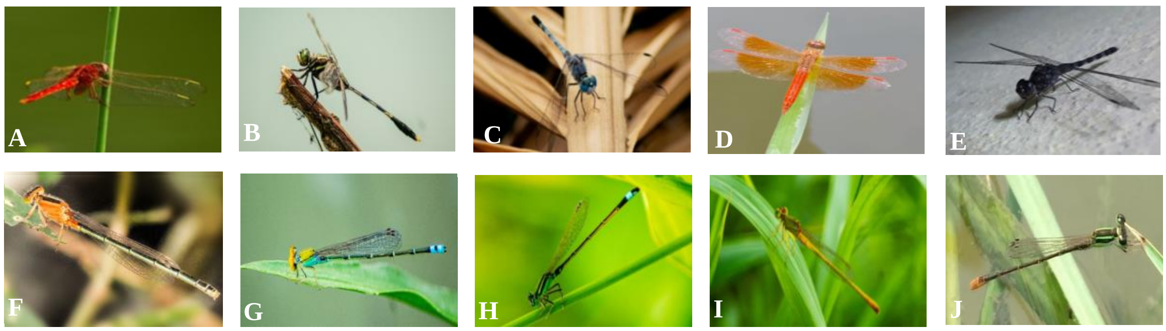

Figure 9. A) Scarlet skimmer, B) Slender skimmer, C) Ground skimmer, D) Ditch jewel, E) Granite ghost, F) Senegal golden dartlet, G) Blue river damsel, H) Common bluetail, I) Yellow waxtail, J) Variable whisp.

The campus harbors a few gastropod mollusks, with their presence evident in both the garden and aquatic habitats. Species like *Bellamya bengalensis* (Bengal Snail), *Melanoides tuberculata* (Red-rimmed Melania), *Indoplanorbis exustus* (Lymnaeid Snail), Lymnaea acuminate (Pond snail), *Pila globosa* (Apple Snail), *Achatina fulica* (land snail). Overall, the presence and activities of freshwater and land mollusks contribute to the ecological balance and functioning of aquatic ecosystems, making them integral components of the campus area.

Fishes play a vital role in maintaining a healthy and sustaining aquatic ecosystem (Dey, 2019).

Due to the lack of proper maintenance and water conditions, temperature and other environmental factors, only certain types of fish, species namely blue panchax or white spot

(*Aplocheilus panchax*) Tilapia (*Oreochromis niloticus*), Rohu (*Labeo rohita*), and Bata (*Labeo bata*), Catla (*Catla catla*) were seen in the pond. These fishes help in nutrient cycling and algae control.

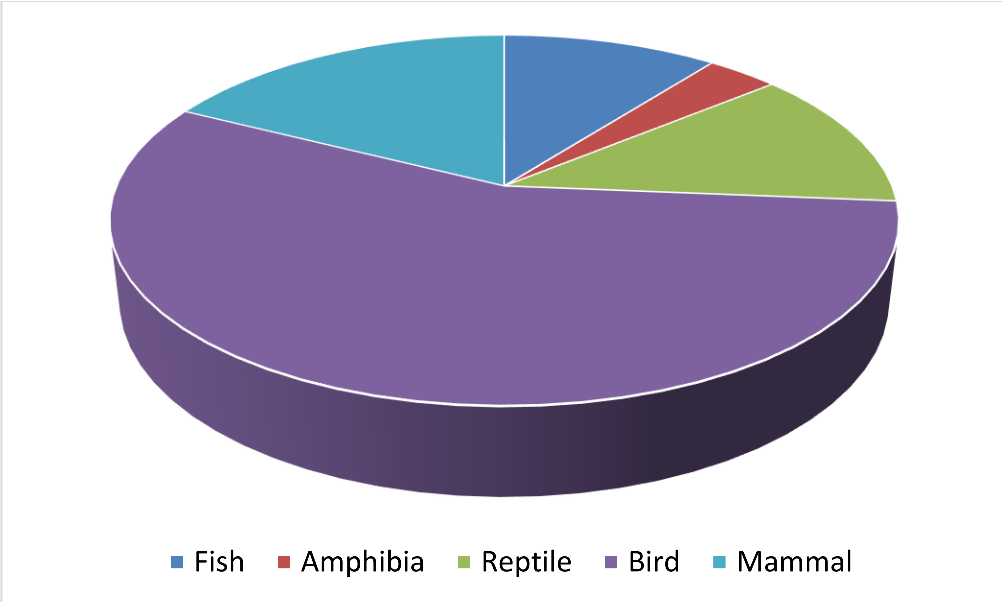

Figure 10. Percentage of different vertebrates on the campus.

The college campus is home to a few amphibians and reptiles. Common Indian Toad (*Duttaphrynus melanostictus*) and common Indian bullfrog (*Hoplobatrachus tigerinus*) are two occasionally found amphibians on the campus. Nonvenomous snakes are frequently seen on the campus namely checkered Keelback (*Xenochrophis* sp.) and striped Keelback (*Amphiesma* sp.), common wolf snake (*Lycodon aulicus*). Rat Snakes (*Ptyas mucosa*) are also encountered on the campus. Garden lizards (*Calotes* sp.) and skinks (*Mabuya* sp.) are often spotted basking in the sun. Meanwhile, the House Lizard (*Hemidactylus* sp.) thrives in various habitats, from classroom walls to outer spaces.

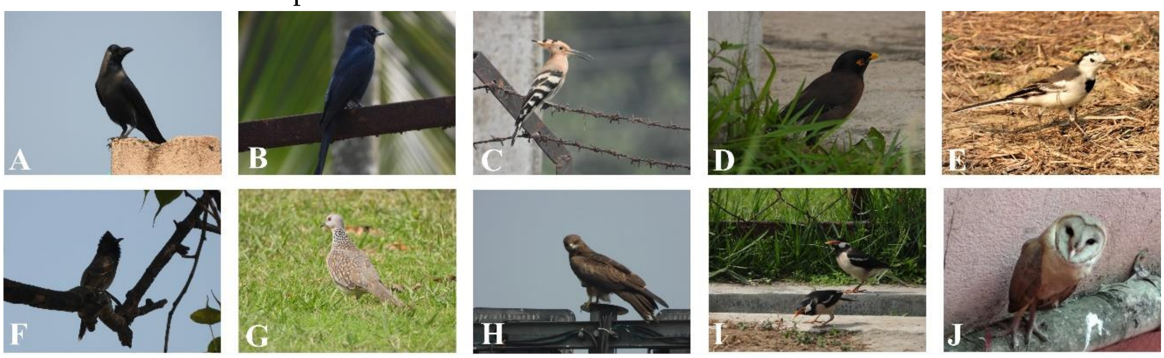

Figure 11. A) Common crow, B) Black Drongo, C) Hoppoe, D) Common Myna, E) White Wagtail, F) Red-vented Bulbul, G) Spotted Dove, H) Common Kite, I) Pied Mayna, J) Barn Owl.

The college campus has several avian visitors, some of which are occasional and rare whereas others are regular establishing a balancing environment. Depending on the sighting and feeding habits they are listed in Table 4.

Table 5: Checklist of recorded avian species on campus.

Common Name	Scientific Name	Feeding Habit	Category
Rufous Treepie	*Dendrocitta vagabunda*	Omnivorous	Regular
Blue-throated Barbet	*Megalaima asiatica*	Frugivorous	Rare
Red-vented Bulbul	*Pycnonotus cafer*	Omnivorous	Abundant
Asian Koel	*Eudynamys scolopaceus*	Omnivorous	Rare(seasonal)
Hawk Cuckoo	*Hierococcyx varius*	Carnivorous	Rare
Grater coucal	*Centropus sinensis*	Carnivorous	Rare
Rose-ringed Parakeet	*Psittacula krameri*	Frugivorous	Rare
Green Bee-eater	*Merops persicus*	Carnivorous	Regular
Common Myna	*Acridotheres tristis*	Omnivorous	Abundant
Pied Myna	*Gracupica contra*	Omnivorous	Abundant
Jungle Myna	*Acridotheres fuscus*	Omnivorous	Rare
Black Drongo	*Dicrurus macrocercus*	Carnivorous	Abundant
Jungle Babbler	*Turdoides striata*	Omnivorous	Abundant
Flame-backed woodpecker	*Dinopium benghalense*	Carnivorous	Regular
White-breasted Kingfisher	*Halcyon smyrnensis*	Carnivorous	Abundant
Brown Shrike	*Lanius cristatus*	Carnivorous	Rare
Greater Coucal	*Centropus sinensis*	Carnivorous	Regular
Stork-billed Kingfisher	*Pelargopsis capensis*	Carnivorous	Rare
Purple Sunbird	*Cinnyris asiaticus*	Nectar feeder	Regular
White Wagtail	*Motacilla cinerea*	Carnivorous	Rare
Tailor Bird	*Orthotomus sutorius*	Carnivorous	Regular
Sparrow	*Passer domesticus*	Omnivorous	Abundant
Common Crow	*Corvus splendens*	Omnivorous	Abundant
Black Kite	*Milvus migrans*	Carnivorous	Regular
Little Cormorant	*Phalacrocorax niger*	Carnivorous (Fish eater)	Regular
Spotted Dove	*Stigmatopelia chinensis*	Grain eater	Abundant
Black Headed Golden Oriole	*Oriolus xanthornus*	Carnivorous (Insect-eater)	Regular (Season specific variation)
Pond Heron	*Ardeola grayii*	Carnivorous	Regular
Cattle Egret	*Bubulcus ibis*	Carnivorous	Abundant
Red-Whiskered	*Pycnonotus jocosus*	Omnivorous	Regular

Bulbul			
Yellow-footed Green Pigeon	*Treron phoenicoptera*	Frugivorous and grain eater	Rare
Hoopoe	*Upupa epops*	Carnivorous (occasional seed eater	Rare
Oriental Magpie Robin	*Copsychus saularis*	Carnivorous	Regular
Barn owl	*Tyto alba*	Carnivorous	Rare
Barn swallow	*Hirundo rustica*	Insectivorous	Regular

Alongside some domesticated cats (*Felis* sp.) and dogs (*Canis* sp.), several mammals are being observed on the campus creating a dynamic and balanced environment.

Table 6: Checklist of the Mammalian species on campus.

Common Name	Scientific Name	Category	Feeding Habit
Mongoose	*Herpestidae* sp.	Regular	Carnivorous
Asian Palm Civet	*Paradoxurus hermaphroditus*	Regular	Omnivorous
House Shrew	*Suncus murinus*	Abundant	Omnivorous
Five Striped Palm Squirrel	*Funambulus pennantii*	Abundant	Frugivorous and grain eater
Lessor Bandicoot Rat	*Bandicota bengalensis*	Rare	Omnivorous
House Mice	*Mus musculus*	Abundant	Omnivorous
Indian Flying Fox	*Pteropus giganteus*	Regular	Frugivorous
Indian Pygmy Pipistrelle	*Pipistrellus mimus*	Regular	Carnivorous

Sustainable Practices:

Maintaining natural habitats on college campuses is crucial for conserving biodiversity, providing educational and research opportunities, and offering aesthetic, and recreational services. These green spaces contribute to climate resilience, support local fauna, and connect the campus community to nature, fostering environmental awareness and a sustainable campus culture (Li et al., 2019).

In APC College, sustainable development practices are seamlessly integrated into various aspects of campus life, promoting a well-rounded approach to environmental, social, and economic responsibility. The college has thoughtfully designed green spaces, and sustainable landscaping creating an environmentally friendly and aesthetically pleasing campus. Key initiatives at the College involve collaboration with local agencies and NGOs to enhance sustainable projects like e-waste management, tree plantation, floriculture, vermicomposting, and different events focused on sustainable development such as workshops, and seminars.

These efforts help to maintain the greeneries on campus, providing habitats for various plant and animal species. Additionally, the college's emphasis on responsible waste reduction, and education for sustainable development fosters an awareness of biodiversity conservation among students and the local community, promoting a harmonious coexistence between the campus and its natural surroundings.

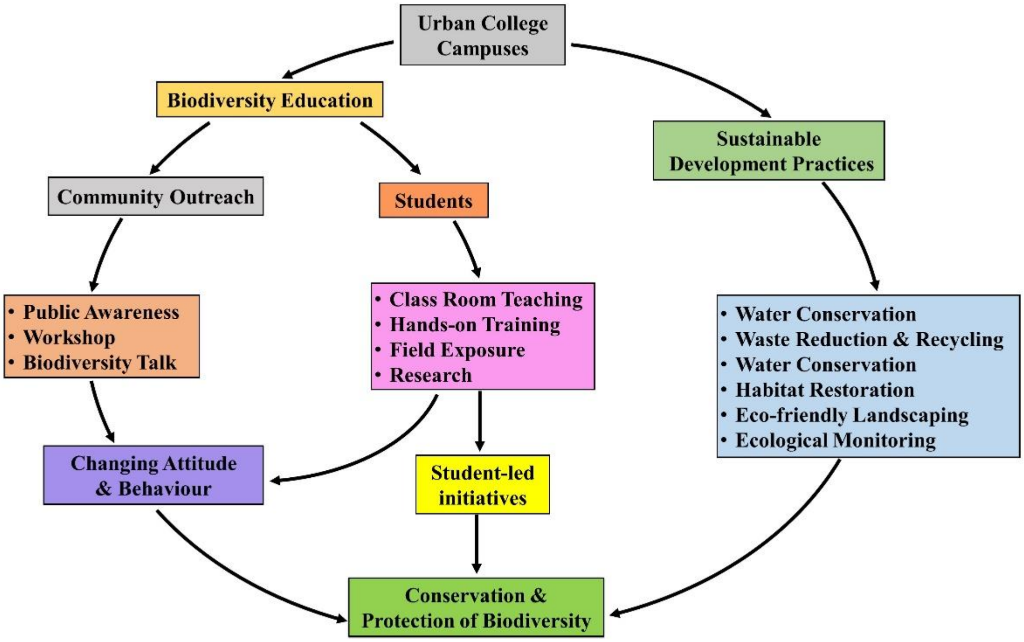

Figure 12. Strategies College can adopt to promote biodiversity conservation.

Future Prospects:

The college authority employs sustainable development initiatives that hold promising prospects, encompassing environmental stewardship, biodiversity enhancement, conservation of natural biota, innovation, and research opportunities. The institution is likely to continue its role as a community collaborator in sustainable practice and education with a focus on resilience to climate change and a commitment to continuous improvement in its different environment-centric approaches for the greater future.

Conclusion:

Among the different human-influenced landscapes, college campuses are unique and can serve as vital patches of biodiversity. In the face of urbanization surroundings, the small area of the Acharya Prafulla Chandra College campus holds diverse habitats that contribute to a rich diversity of plant and animal species. Implementation of sustainable practices on college campuses helps to reduce environmental impact and promotes efficient use of resources. As the institution continues to evolve, it is likely to play a vital role in the conservation of local ecosystems and serve as a model for how educational institutions can harmonize with nature while promoting sustainability.

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Chapter- 34

Light Pollution in Urban Life: Effects on Environment and Human Health

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Keywords: Light pollution, Urban ecology, Sustainable development.

Abstract:

Artificial lighting is indispensable for human activity. One thing that is not emphasized is the fact that it is the one that is responsible for the creation of light pollution. On the other hand, a significant amount of energy is wasted, and this pollution is clearly visible and thus, it has a disruptive effect on the nocturnal sky. Since numerous of these disastrous effects may be experienced, among these well-known are the death of birds flying over buildings illuminated by lights and the disorientation of hatchling sea turtles on natal beaches, the latter caused by light pollution. Little is understood about the severe consequences of these brightening levels on species behavior and even community ecology. Along with being to address the conservation issues, this is a novice area of ecology research. However, all of the risk factors are time-urgent and thus, there are feasible solutions to each of those risks.

Introduction:

Nature habitat recovery is now increasingly happening everywhere, near or in the natural areas, than ever before. It is the case that our natural environments are more and more exposed to the phenomenon of light fighting at night. When keeping the natural cycles of the sun, moon and stars, over-illumination or misuse of light and also their interference are all causes of light pollution. The side-effect of progress and civilization is the increased light pollution. It will also come from external building lighting, advertising, landscape lighting, offices, factories, street lamps, stadiums and other brightly illuminated areas. This matter, at last, has become a global issue, which leads to the slow fading of the clarity in our sky to look for the stars (Longcore and Rich, 2004). In support of good night lighting, it helps a lot in the completion of several commercial, industrial and leisure activities in different regions. Illegal installation or usage of light accessories leads to the death of various species and the pollution of nature. As per the Light pollution monitoring done by the International Dark Sky Association (ISDS, 2013), it has a lot of negative impacts on plant and animal species. Birds leave urban areas for the large distance between the night sky which is bright due to electricity and which is necessary for them to sleep. By artificial lighting, the situation of photosynthesis as a process of plants is also

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influenced, and so as the oxygen we inhale gets affected. The possibility, then, that the nightlight could lead to the disruption of homeostatic as well as behavioral control systems could portray a scary picture. Both national and local administrations, in equal measure, should be implementing the right action plan that will eliminate the negative effects of artificial lighting.

Astronomical and Ecological Light Pollution: Scale and Extent:

The fact that the brightness and its amount, which is artificial in nature, act as a first indicator for the size and development of modern human societies, providing that nighttime illumination has had an imperative role in the present civilizations (Hocker et al., 2010). It is important to note that, in this context, illumination refers to 'astronomical light pollution' in which stars and celestial bodies are glazed by forwarded or reflected light towards the point of the sky. The natural light-dark patterns that occur in the ecosystems are the ones disrupted by artificial light. Hence, ecologists refer to this as a case of persisting light pollution. Artificial light emissions can be seen as a phenomenon with probable consequences exhibiting a range of the GS+QS+ grade, including spatial and temporal scales, and its planetary reach can be observed from the first atlas of astronomical light pollution, which reports on light pollution on every continent where people inhabit (Cinzano, 2001). As regards wildlife, nocturnal lighting influences a lot of species, from plants.

Measurements and Units:

Building the denominator of ecological light pollution is the pathway of illumination determination. The illumination could be defined as the total quantity of light (be it sun light or manmade) that falls on a specific unit of area (Verheijen 1985). Measuring light usually depends on two properties of light: (i) spatial resolution, (ii) spectral resolution, and (iii) wavelength. Taken in day-to-day life, Lux (also known as foot candles - non-SI unit) is the most often applied unit to measure light in connection with the human notion of objective light characteristics. The illuminance coefficient, which is central to the lux measure, defines wavelengths of light that are the most visible to the human eye (Verheijen 1985). The human eye has been proven to adjust to different colors of light, and LUX is the standard that is commonly used by lighting designers, lighting engineers and environmental regulators. The elementary unit for observations and reporting in communications is the unit. Then, moths are used for a high-pressure sodium light but not for a low-tension sodium light. These lamps, which have the same Lux value, can only be compared to high-pressure sodium lamps since these are the only ones that are capable of emitting ultraviolet radiation. The moths are attracted to the presence of this particular type of radiation (Rydell and Baagøe, 1996).

Sources of Light Pollution:

Excessive lighting is a complex word that sums up a combination of issues, all of which are the result of ineffective, unattractive, or unnecessary use of artificial illumination. Sources of light pollution include urban sky glow, light trespass, glare and light clutter, of which the last two are mostly observed within urban areas.

Urban Sky Glow:

As a result of direct and indirect reflection, the night sky is brightening in urban areas in the context of scattering of light from the various components of the atmosphere (molecules, aerosols and particulates) (The Institution of Lighting Engineers, 2002). The very fact that we cannot even see stars, planets and the galaxy due to light pollution stands as enough to imply the magnitude of the problem at hand. The 'globe lanterns', often fixed to the facades or standing alone themselves, act as the base cause of the radiant glow that emerges from the sky. The astronomy stars get offended when the sky glow is high because they even fail to brighten the sky to the extent that they can only see the most visible stars. Almost all outstanding optical astronomical observatories are located within the area, the background of which are rules obligatory for observance. Luminous emissions, according to these rules, shall be strictly limited and be solely defined. Visualize ‘sky glow’ by employing luminaires that cast light only within 90 degrees measured from the horizon and above the horizon. It is especially a challenging ‘indirect’ way of sky glow that is produced by reflections from external vertical and horizontal surfaces. For that reason, the effective solution would be in its prevention with the minimization of over-illumination.

Light Trespass:

City lighting sometimes causes a problem known as Light Trespass, when the lights go into odd places. Just as the light bleeds into the wrong place when the lamp is not shielded. The election results are not the ones the voters would like to see. If a rule for this was approved, it would be set to control how much light spills over into the property line. The LEED protocol gives the allowance with the level set at, between lines, and 10 - 15 ft distant from the property perimeter or exceeding 0.01 foot-candles. Nevertheless, the beloved thing is the light trespass, but when it interacts with the eyes of people, we are not sure how much light enters in the eyes. This problem is in the way the cities solve it by enacting by-laws regarding how high a light pole can stand. Thus, controlling light is necessary. This implies the use of light that orients to the business purposes, putting them in the right places and paying attention to the overall level of light.

Over – illumination:

Over illumination, also known as the overuse of light, refers to situations where light is used beyond the recommended limits. Energy audits of existing buildings reveal lighting as the dominant ratio of its consumption, representing about 30 to 60 % at residential, commercial and industrial levels across the USA, which varies by area of use (Fotios and Gibbons, 2018). Over-lighting can be explained via various reasons among which the most common is decorative. Unlike the others, the act of switching off lights when there is not anyone using them is all that is not done. Lighting layout mistakes can also be classified as picking the wrong faucets or light globes that do not illuminate where it is needed. One case that uses more energy for doing lighting work is selected hardware most of the time. This way is also tempting as building managers as well as occupants, do not get security education on the proper handling of lighting systems. Fortunately, the majority of these hindrances can be averted without expensive technology available. The problem needs to have immense particular attention being focused on them, especially from the developed nations, which will help in knowing the advantages of lessening over-illumination. The light can be filtered or other solutions can be used, reducing the direct effect of bright lights, although they will lead to less bright devices (Fotios and Gibbons, 2018).

Glare:

Glare is a visual sensation where there is a feeling of discomfort, decreased ability to recognize objects or eye irritation. It can be caused by improper distribution or range of luminance or excessive contrast. Even good-quality lighting fixtures can become problematic and cause Glare. The use of Unshielded or poorly located and directed luminaries near the line of sight may cause this phenomenon. The most effective ways to reduce Glare rely on the proper selection of lighting fixtures tailored to the project (Ibid et al., 1993).

Glare can be several types like-

Blinding Glare:

Blinding Glare describes effects such as that caused by staring into the sun. It is completely blinding and leaves temporary or permanent vision deficiencies.

Disability Glare:

Disability Glare describes effects such as being blinded by oncoming cars' light or light scattering in frogs or in the eye, reducing contrast as well as reflections from print and other dark areas that render them bright with a significant reduction in sight capabilities.

Discomfort Glare:

Discomfort Glare does not typically cause a dangerous situation in itself and is irritating at best. It can potentially cause fatigue if experienced over extended periods.

Light Clutter:

The clutter of light can be viewed as light clutter, which implies a profuse scattering of lights. Placements of light, be they non-consecutive or in sequence, may create disorientation, take eye attention away from obstacles and lead to falls as a result. The presence of clutter could also suggest a potential risk in the activation zone if aviation lighting must provide proper conditions for the pilots' sighting and not be overlooked by the pilots. For example, these might happen with runways confusing commercial lights with suburban lighting or with aircraft collision avoidance lights having ground lights as a misperception (Fotios and Gibbons, 2018).

Effects

Impacts on Ecosystem and Wildlife:

Those ads are automatically put on silent, while those that are tagged "mute" are always on mute. Light pollution significantly disturbs their familiar night-time environment by providing night-time environment with the taste of the day. Nighttime light can also cause luminescence that tampers amphibian habitats, including frogs and toads, where the chorus of croaking at night time is part of the reproduction ritual. The presence of artificial lights meanwhile confuses this nocturnal event, which results in incomplete reproduction and decreases in the populations of animals involved. A lot of insects dazzle towards lights, but being artificial lights leads to a lethal crush. Some insects are also averse to some other species of plants depended for pollination or food or pollens. This includes herbivores attracted to beautiful plants that, other than acting as a visual treat to the eyes, become a source of nutrition to some predators who may, through such, exploit the situation in unanticipated ways, thereby affecting the food webs.

Impacts on Plants:

Functioning of plants includes but is not limited to managing their metabolism, their growth and development and their life cycle. What it can do to some plants is dramatic - to make them unable to blossom and bear colours ever if they are missing darkness for some time. Plant captures and reactions to light intensities influence the formation of plant foods, stem increases, leaf colour and flowering stipulations. Just like the above-mentioned example of two plants grown in very bright light, they end up being shorter, they have good branches, and their leaves are larger and dark green. The study finds that the ambient lights at night time may act in the same way as the photochrome hormone and high-going light levels avoid the release of the hormone and as a result, the plants are wiped out. Bidwell establishes that short-wave sodium lights affect the photoperiodic cycle and the growth pattern of plants (2003).

Impacts on Animals:

Periodic light and shadow structures have been here since the day the life existed, so aberrations to the patterns naturally affect various animal behavioural traits. Light pollution can directly stress the physiology of animals. Navigation, competitive behaviour, prey to predator relationship, and migration can be affected adversely due to the light pollution because of its specific effect on the creatures. Another critical aspect is that not only animals but also many insects are attracted by or repelled from the same lights. The overwhelming majority of animals have developed an eye remuneration involving diurnal or nocturnal light, which is disturbed if the world is flooded with light. With this came a chance that an entire species could go towards extinction. It's the animals that really alter depending on the headway in the habitat where mainly they live. Over lighting may also attract pests to human areas. Pests may move by themselves when light is diminished in areas that are less polluted by light.

Threats to Birds:

Exhibit a vast repertoire of activity in response to the glare from artificial light in birds. Our studies revealed that bird behaviour is impacted by extremely bright lamps that are normally installed on oil rigs. This attracts them and forces them to move away from their migratory routes. Besides, these lights were capable of catching and killing more seabird fledglings with a high death rate. A correlation exists among birds whereby during nighttime illumination, they alter their behaviour at rest. This sunlight can make a bird awake sooner, which may lead to a loss of sleep episodes or they will be inactive for long. In Lighthouses, it was pointed out that whether there would be a lot of deaths is determined by the sort of light being used. People would be more inclined to employ white lights that are mounted in the usual manner than flashing or colored lights. Along the flight path, the beam of the laser could decrease the pilot's ability to steer as much as three meters per second and also alter its flying direction by up to 15%. The lamps on the platform attract birds, which can be lifelong injured or even die of heat scalding or oil collision indeed. Finally, flares on the windmills can be used to divert birds as well. The statistics show that there has been an increase from graph to graph in the number of total collisions between wild birds and broadcasting and telecommunication systems' towers, both in terms of concerned towers number and height. On other hand, songbirds could bear on their wings as well instead of the highway that has divided their path of migration. The continuous growth of cities and thus the ever-increasing number of artificial lights, for example, street lights and buildings illuminated, change the environment of migratory birds and may cause birds deaths as a result.

Threats to sea turtles:

Concerning the effect of artificial light on female turtles in terms of nesting, and on the hatchlings under the water after their arrival, we can summarize that there are a number of effects. The fact that the females choose to lay at more dimly lit beaches means that their nests become scattered around these places and not lighted areas with more light. Turtles can be drawn to the sources of urban lighting, such as car parks, roads, and houses. It follows that their movements will be in the opposite direction of the light in such situations. This light effect can not only influence the sea turtles' hatch but also the illumination direction. The bizarre light is more often than not misread as a signal to the wildly hatched sea turtles to go to water for the purpose of their endeavours. As a consequence of this, the hatchlings will crawl in a way that is contrary to what safe and the right connections are, hence risking getting dehydrated actually getting preyed, and high day temperatures after the break of day (Salmon, 2003). Compasses point them towards the sea but can do so only if specific strength and light intensity regulations are met. Thus, hatchlings may lose their bearings and head inland, where they will never reach the sea and, inevitably, die.

Threats to Fish:

The artificial lighting in input to fish farms and deep sea fish has an impact on visibility, and the reaction to the natural light by fish is very specific while the species difference exists. The fish are nonchalantly attracted to the light in the dark by anglers, so light attraction is a usual method for them. This method poses a high risk of seething in infant silver cyprinid fish Mukene (*Rastrineobola argentea*), Nile perch, and Tilapia hence killing their nursery grounds. The white light application represented as the primary obstacle that altered fish behavior in natural dialects when studied in depth-sea fish lighting machinery. The depth of the aquaculture and the number of activities of swimming are dependent on how much light is used in the farms whether it is too less or too much. Salmon hold their schooling behavior firmly just as they are said to take the graded position near the artificial light just as Parido et al. (2001) did reveals.

Threats to Molluscan Species:

In addition to molluscs light seems to have a role in their behavior - that is, they substantially avoid predators and that in turn it 'light' is responsible for snails to be attracted. Through launching deep into one's whole body the immune response that *L. stagnalis* uses, it manages to live after the exposure to predators. Also in mollusks' reproductivity could be affected by interference created by pollution or their growth and development. In the freshwater pulmonate *L. stagnalis*, the organism is able to achieve a rapid rate of growth together with increased energy storage when it is exposed to a source of light on a regular basis. Salmon and Wyneken (2003) found that the quantity of energy being saved by medium-day snails was more than that being used by long-day snails and vice versa.

There is mention of the varieties of mollusca species too as they are light sensitive. *Aplysia californica* sea slug breeding is somewhat insensitive to shifts in daytime/nighttime proportions unlike to the snails that live in the freshwater. The development and growth of gonads which is the another reproductive parameter is also by the light considerably affected. Earlier Sokolove and McCone (1978) found that the gonads and the oocytes of native *Limax valentianus* slugs which had been placed under short photoperiod were heavier than those of slugs that had been placed under a long photoperiod. This being the unique situation was the first time it was seen. Write an appropriate response to this post question. Instructions: Humanize the given sentence. The distinct difference evolved as a re-emergence of it exactly after hatching the egg and gaining the cycle up to 90 days, and it would seemingly disappear once reaching 120 days, whereas the latter one underwent the same way, short photoperiod slugs, of reaching the final stage of spermatogenesis (Jess and Marks, 1998).

Effects on Human-health and psychology:

It is interesting to see the conclusions from the recent medical research on how excess light affects human bodies, as it seems that light pollution may cause a range of sicknesses and disorders that are injurious to the health of human beings. Medical professionals can diagnose an increase in the number of headaches, tiredness, and stress, as well as an act of decreasing sexual function and an increase in anxiety as the result of excessive artificial lighting considering the wrong spectrum of light. To be exact, for those who have to attend night shifts, in addition to the light what is in the atmosphere during the night also changes your mood and impacts you significantly.

Glaring in the eyes:

A type of disability is called visual impairment that leads to crosslights which is not due to intentional design of the street lighting. The conceiving truth is that the glare emitted by disability is blinding dark like an oncoming vehicle leaving you to open your eyes in the haze of sunlight currently being scattered all over your retina. The levels of light in such a situation, with the sole exclusion of the source of the light, are inclined to when the rest of the objects fail to become visible. The fact that our eyes already have problems with adjusting to varying levels of illumination and in older age especially the condition worsens even more with glare vision disability being the end result. Drivers are exposed to a relatively lesser amount of hazard with protected illumination that is accomplished by this occurrence and driving becomes safer and more enjoyable as such. The light projection will be done more expansively and the light will eventually be directed to the road rather than the eyes of the drivers.

Changes in the circadian rhythm:

This is a 24-hour cycle of day to night, which is popularly known as, the circadian clock, that has a significant effect on the physiological processes in every organism including human beings. The brain is a complex organ that works in conjunction with the patterns of brain waves, the generation of hormones, the control of cell activity and other biochemical as well as physiological functions. This disruption in rhythm could result in the appearance of different health issues such as cardiovascular disease, sleeplessness, cancer and depression. It appears that, in particular, women taking on night shifts, have an increased possibility occurs developing breast cancer. The cells were exposed to intensive night lights and this was linked to the growth of breast tumors in the test, as shown by the laboratory experiment. To the extent of being a direct link between the intensity of the light coming from the room which has shorter wavelength (less than 46nm), the risk of breast cancer is almost entirely dependent on its intensity. This, hence, it establishes that those women at home are as vulnerable as the ones in the active fields of life to the potential risk of breast cancer. The use of contraceptives with quartz stones was particularly to blame for this. In industrialized nations (such as Canada and United States), the risk of breast cancer was up to five times higher than in poor nations.

Changes of Melatonin Level:

Melatonin is an endocrine hormone responsible for the regulation of the maintaining the state of sleepiness and darkness is its major triggering factor. Teams producing melatonin is the case of hormones available to us. Melatonin is an agent in the body responsible for various biological reactions which all have an effect of decreasing estrogen levels throughout the night. Melatonin is often formed by the body at night, and the level of melatonin diminishes to almost zero due to the fact that the body is exposed to external light (artificial or natural) (Madhu and Manna, 2010; Madhu et al., 2010; Madhu and Manna, 2011; Madhu and Manna, 2021 Melatonin which is mostly produced at the night time has been linked with the studies that may be indicative of the population going to be more vulnerable to cancer if the melatonin levels are reduced. However, response to melatonin treatment was also dramatically decreased in a patient after the influence of breast cancer. Though this wasn't the obvious causal event, there was a clear correlation between the quantity of melatonin in the body and the development of cancers in the colon, larynx, liver, and lungs. According to a research report, communities with whom high-levels of exposure to artificial light during the nighttime hours were more likely to develop prostate cancer in contrast to those with low levels of exposure. We placed these two groups of participants under conditions of similar sleep routines with a low level of exposure to light pollution. Melatonin is mainly hydrolyzed in men with 6-oxo hydroxy melatonin-sulfate (6-SOHMS), a degradation product, having a lower risk of developing 75% prostate cancer according to the investigation conducted in Iceland (Sigurdardottir et al., 2015). In relation to this, it is obvious that the experiment had proven the prediction previously made by the researchers.

Sleep Disorder:

Although adequate sleep is fundamental for mental and physical states, most of us realise that the bed soothing conditions in the darkness are conducive to that. Disruption of proper sleep rhythm is one of the most severe challenges that suffer from these people. It may happen that chip of a chip as people can have trouble sleeping underneath their new solar-like surroundings. As a result, it may have a bad impact on their health which can be the reason for a lot of diseases. An abrogation of our inside rhythm of time lessens our motor and cognitive capacity even in the most effortless tasks for us and also makes it difficult to go to bed and wake up at the usual time, declares NIH. The association of the factors with better sleep is decreased risks of depression, stress, weight gain, and diabetes. It is likely that the very obvious link that exists between switch-on to artificial light and different sleep problems would definitely exist. Numerous sleep disorders may result from the clock's circadian function troubles. Thus, desynchronization of the circadian rhythm, e.g., shift-work sleep disorder, which is experienced by professionals who are active at night or whose duty times are unconventional. In turn, the delayed sleep-phase syndrome is characterized by people who fall asleep late and have problems waking up on the dot for class, a social event, or work

(International Agency for Research on Cancer, 201 Temperature oscillations, desynchronizing of the biological clock that is measured by 24-hour periods conforming to sunlight, resetting the hypothalamic pacemaker, exhibiting repeated headaches, fatigue at work, stress-related symptoms (according to the criteria of a doctor), lowering the sexual function, and increased anxiety as well are some of the possible health effects of improper spectral proportion of lighting.

Effects on Astronomy:

Light pollution greatly affects astronomy. Because the sky glow makes it harder to see fainter objects, it makes it harder to distinguish between the sky and celestial objects like galaxies. This is one reason why newer telescopes are being constructed in more and more inaccessible locations. The Bortle scale measures the likelihood of spotting an item in the night sky. Light pollution has a greater impact on the sight of diffuse sky objects like nebulae and galaxies than on stars, because of their lower surface brightness. Finding the Milky Way is a quick and easy way to gauge the amount of darkness in a given area. In addition to sky glow, light trespass occurs when non-optical surfaces reflect artificial light into the telescope tube, which in turn affects observations (National Geographic, 2008).

Effects on Economy:

A waste of resources is the massive illumination of pointless spaces by artificial lighting. The environmental and economic costs of energy waste are high. According to Ashe et al. (2010), a staggering 35 billion kilowatt hours of electricity are wasted each year for outdoor lighting, amounting to USD 35 billion. This is because 30% of outdoor lighting is not adequately lighted. Compared to low-pressure sodium lamps, incandescent lights use five times as much energy, while fluorescent lights use one and a half times as much energy. This proves beyond a reasonable doubt that light pollution is a major economic sustainability risk element in addition to a danger to public health, ecological balance, and astronomical study.

Ways to Reduce Light Pollution:

Bringing down the amount of light pollution involves a number of different elements, including lowering the amount of sky glow, glare, light trespass, and clutter. One potential remedy is to reduce the amount of harm that is caused to the environment, as well as to the flora, wildlife, and people. It is essential to regulate the total level of lighting in accordance with the number of people present and the time of day. Therefore, it is essential to make use of light sources that have the least amount of intensity in order to achieve the objective of the light. The utilization of a lighting control system that is both flexible and equipped with an astronomical time clock facility as a means of ensuring that the appropriate illumination is provided at the appropriate location and at the appropriate time is recommended. Improving lighting fixtures so that they focus their light more effectively towards where it is needed and with fewer side effects; turning off lights manually or using a timer or occupancy sensor when they are not needed; Improving lighting fixtures.

Lighting Control:

It is vital to adjust the general amount of illumination according to occupancy and the time of day in order to limit the harmful impact that it has on the environment, as well as on flora, wildlife, and people. It is recommended to utilize a lighting control system that is both flexible and equipped with an astronomical time clock facility. This system should be able to ensure that the appropriate amount of illumination is provided at the appropriate time and location. Not only does this make use of location data like latitude and longitude, but it also features a mechanism that allows the date and time of the year to be updated. Additionally, it activates and disables the external illumination based on the information that it receives. The degree of light intensity should be reduced or turned to "0" after the peak activity period, which is around midnight or another time that has been specified. This will allow for a significant reduction in the potential adverse effects that could be caused to the urban environment. In addition, daylight sensors should be utilized in buildings that are made of glass in order to maximize the amount of natural light that is produced for as long as possible while simultaneously reducing the amount of energy that is required for electrical lighting (Burkett, 2013).

Conclusion:

Having finished the investigation of the lighting master plans practiced by the cities and by the author for the practical design experience, it is clear that the only possible way to overcome the drawbacks of light pollution for the cities will be to call upon professional independent lighting designers and city representatives that will define the lighting level in the city at the macro level for the lighting master plan that will make it possible. Light pollution is a severe problem carrying with it repercussions for the animal kingdom, human well-being, scientific study, energy consumption, climate change as well as a youthful activity that goes far back to the dawn of time; that is, to watch the night sky. Light pollution is a threat not only to astronomy across the world and public health ecosystem balance but also to the economy, which makes the danger exerted on the concept of sustainability quite urgent. Installing documents of the type a set of guidelines turns out to be helpful for those people who are responsible for the illumination of the cities at night and would give them an idea on how to solve challenging issues.

In order to achieve success at the macro-lighting level, it is necessary to have electrical light sources that have a long lifespan, in addition to having a suitable color temperature, luminaries that have optics that match the requirements, easy maintenance, installation, and a high mounting position. The utilization of an ecological and holistic approach, in conjunction with the replacement of lighting sources that are inefficient and ineffective, reduces the amount of light spill and energy waste, assures the protection and strength of the environment, maintains biodiversity, reduces air pollution, and conserves resources. Creating an effective luminaire to light up indoors requires a great development process. The critical issue here is not only choosing the optimal place of the light source by taking into account both its quality and quantity but also balancing it with the conflicting criteria. Clarification studies still need to investigate the relationship between self-reported subjective everyday levels of light at night and actually assessed objectively in order to reproduce the current findings precisely and to incorporate additional factors into the multifactorial equation.

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