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Chapter- 4

Role of Nutrition in Combating Air Pollution for Sustainable Development

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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°C to 0.5°C. 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).

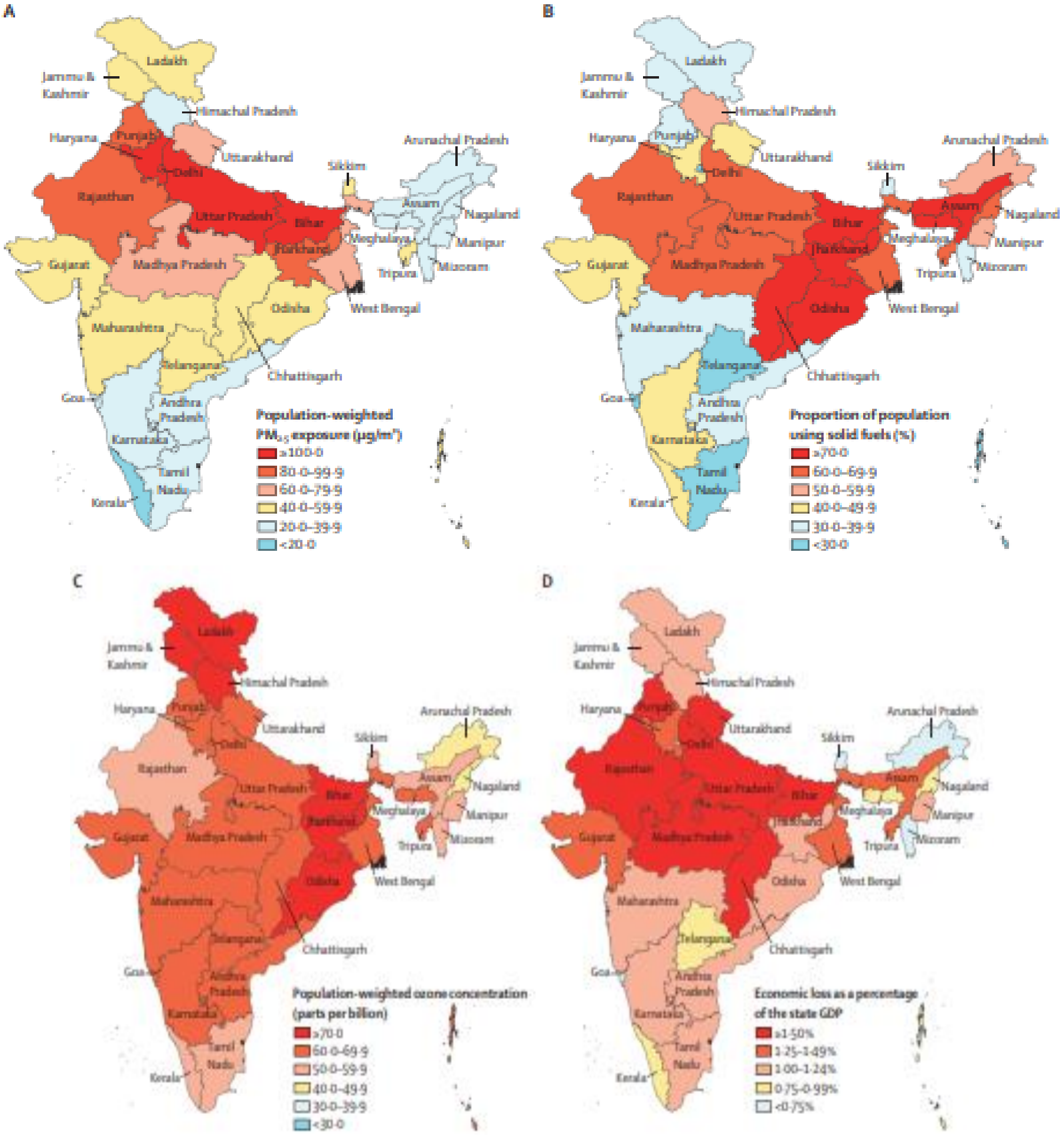

Figure 1: Exposure to atmospheric contamination and financial detriment arising from untimely fatalities and illness linked to atmospheric contamination in the Indian states, 2019 (A) Mean atmospheric concentration of $PM_{2·5}$, weighted by population. (B) Percentage of the populace utilizing solid 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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