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Chapter- 22

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

Indrani Banerjee, Hiya Roy, Sumana Saha*

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

Indrani Banerjee
PG Department of Zoology, Barasat Government College, Barasat, India
E-mail: indranibiozoo@gmail.com; Orcid iD: https://orcid.org/0009-0009-2237-3223
Hiya Roy
PG Department of Zoology, Barasat Government College, Barasat, India
E-mail: hiya2017dtk@gmail.com
Sumana Saha*
PG Department of Zoology, Barasat Government College, Barasat, India
E-mail: sahasumana2010@gmail.com
***Corresponding Author**: sahasumana2010@gmail.com

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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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