

Seasonal Assessment of Heavy Metal Concentration in Edaphodon kawai Fish of River Yamuna, Uttar Pradesh

POONAM VERMA, SHALINI YADAV, DHIRENDRA YADAV and VINOD KUMAR*

Department of Chemistry, Agra College, Dr. B.R.A. University, Agra, India.

Abstract

The levels of eight heavy metals zinc, iron, nickel, chromium, copper, manganese, cadmium, and lead, were determined in the fish samples collected from four selected study sites along the Yamuna River in Uttar Pradesh—Mathura, Agra, Firozabad, and Etawah. Sampling was conducted across two seasons i.e. before and after monsoon, from June to December 2023. Concentrations of heavy metals were recorded at all four sampling sites. These metals enter the environment in different ways, like industrial activities, increased population growth, technological progress, etc. The results indicate that the toxicity of heavy metals (HMs) in fish of the Yamuna River is greater than the permissible limit of drinking water, as declared by BIS and WHO. Despite the fish being contaminated, people are used to eating it on a regular basis. The finding raises significant public health concerns, as the eating tainted fish may lead to serious health issues over time. It is crucial for authorities to raise awareness and implement measures to mitigate the pollution levels in the river and protect the health of the community. Furthermore, it is essential to train farmers in pollution mitigation practices, encouraging the judicious use of pesticides to minimize wastewater leaching and promoting cultivation in areas away from industrial zones and other contaminations prone regions.



Article History

Received: 07 August 2025
Accepted: 29 September 2025

Keywords

Fish;
Heavy Metals;
Toxicity;
Seasonal Variations;
Yamuna River.

Introduction

Aquatic food contains essential amino acids, proteins, fatty acids, carbohydrates, minerals, and vitamins. Fish are a popular seafood and a conduit for harmful heavy metals into the human beings. Heavy metals tend to accumulate in various organs of water animals, particularly fish, and can be transmitted to human via the food chain, posing serious health risks.¹ Many studies have examined

metal contamination in various edible fish species because fish constitute a large portion of the human diet. Ecotoxicologists and environmental scientists define "heavy metals" as those metals that are linked to environmental issues.² Heavy metals are among the most dangerous substances that are introduced into the environment via industrial and agricultural activities. They are difficult to decompose or decay easily.³ Heavy metals enter biological systems

CONTACT Vinod Kumar ✉ vinodkchem@gmail.com 📍 Department of Chemistry, Agra College, Dr. B.R.A. University, Agra, India.



© 2025 The Author(s). Published by Enviro Research Publishers.

This is an  Open Access article licensed under a Creative Commons license: Attribution 4.0 International (CC-BY).

Doi: <http://dx.doi.org/10.12944/CWE.20.3.20>

through the food web, eventually accumulating at higher trophic levels. Humans, being at the apex of the food chain, are particularly prone to bioaccumulation of these metals via food and water consumption. Although certain heavy metals act as essential trace elements necessary for human metabolic processes, their elevated concentrations may result in toxic and detrimental health effects. Heavy metals from the polluted Yamuna River are entering the food web and food chain,⁴ leading to their accumulation across various trophic levels.

Edaphodon kawai is an omnivorous fish and its primary food source include various aquatic plants available in the Yamuna River. The accumulation of heavy metals in *Edaphodon kawai* can provide valuable knowledge into public health concerns. Consuming polluted fish can lead to the build-up of metals in the human body and adverse health effects. The distribution of these metals among water, fish, and sediment may offer helpful information about effective water quality management. Since fish are a major source of dietary protein, their contamination levels have important implications for human health.

Fish constitute a vital component of the human diet as they are abundant sources of superior-quality proteins and Omega-3 polyunsaturated fatty acids, especially Eicosapentaenoic acid (EPA) and Docosahexaenoic acid (DHA). These long-chain fatty acids are indispensable for proper growth and physiological development and are widely recognized for their therapeutic value. Their intake has been linked to lowering serum cholesterol, reducing the incidence of cardiovascular disorders, and diminishing the probability of premature deliveries.

Fish are a good source of vitamins and minerals that are vital for human health.⁵ However, because fish constitute a key component of the human diet, their contamination may serve as a primary pathway for heavy metal exposure. Evidence suggests that the consumption of polluted fish poses a significant health risk due to the presence of toxic metals.

“Minamata disease was first identified in 1952 near the fishing harbor of Minamata, Japan, and was later found to be caused by methylmercury pollution from industrial wastewater. Similarly, Itai-Itai disease emerged in Toyama Prefecture, Japan, due to cadmium

contamination, primarily from mining operations. Both cases represent significant examples of heavy metal pollution and its severe impacts on human health.⁶

The overarching purpose of this research was to critically examine the adequacy of existing datasets on Yamuna River pollution to facilitate a comprehensive interpretation of the scale and severity of its degradation.

The present research is designed with the following objectives:

- To determine the concentration of HMs in aquatic organisms collected from the Yamuna River.
- To identify potential sources contributing to HMs contamination in the river ecosystem.
- To assess the impact of seasonal variations on the status of HMs pollution.
- To analyze the correlation between anthropogenic pressures and the degree of HMs bioaccumulation in aquatic ecosystems.

Materials and Methods

Collection of Research Samples

Between June and December 2023, samples were obtained from designated locations along the Yamuna River with the support of skilled fishers. The specimens were promptly sealed in labeled polyethylene bags, and preserved in an insulated polystyrene icebox container. Sampling was conducted twice during the study period once before and once after the monsoon season. The sample locations were Mathura (M1), Agra (A2), Firozabad (F3), and Etawah (E4).

Types and Origin of Fish

Scientific Name of *Edaphodon Kawai*

Edaphodon kawai

Etymology: Its scientific name, *kawai*, means "fish" in the language of the Moriori, a Pacific tribe that inhabited the islands. *Edaphodon* is a genus of extinct chimaeriform fish, also known as rabbitfish, a type of cartilaginous fish related to sharks and rays.

Identification

The species exhibits a robust, silvery physique with a stiff body structure, frequently adorned with black speckles or undulating patterns. Juveniles,

attaining lengths of up to 25 cm, present vertical series of spots beneath the lateral line. They can be differentiated from other similarly sized kingfish by a prominent, elongated dorsal fin that is seamlessly connected to the soft, reddish posterior portion of the fin.⁷

Local fishermen collected specimen of *Edaphodon kawai* from various study sites along the Yamuna River. This species was found to be prevalent in the Yamuna River and is widely consumed as a food source. Following measurements and species identification, the specimens were rinsed with deionized water, placed into labeled polyethylene bags, and preserved in a freezer icebox until chemical analysis.

Reagents and Chemicals

All chemicals and reagents employed in the analytical procedures were of analytical grade or equivalent purity and were obtained from Merck (Germany). The glassware used during samples preparation and analysis, including digestion flasks, volumetric flasks, beakers, was manufactured by Borosil and Polylab. All the aqueous solutions were prepared using de-ionized water. Every piece of glassware and plastic was cleaned and left to soak overnight in 10% (v/v) HNO₃. Prior to use, all laboratory apparatus and glassware were meticulously cleaned with de-ionized water and dried to ensure contamination free analysis. All acids used in the study, including Nitric acid, Perchloric acid, Sulfuric acid, Hydrochloric acid,

and oxidants Hydrogen peroxide were of standard pure quality.

Sample Preparation Digestion of Fish Samples

In this study, varying concentrations and amounts of acids were utilized in the wet digestion method. Prior to analysis, the fish were defrosted and dissected. The muscle tissue was meticulously extracted from each specimen and preserved for further study. 4 grams of the fish flesh were placed in porcelain basin and heated over a water bath for 15 minutes to remove moisture. Once the emission of vapors had ceased and the solution attained clarity, the samples were taken out of the water bath and allowed to equilibrate to room temperature. Thereafter, filtration was performed with Whatman No. 42 filter paper, and the filtrates were diluted with deionized water to make up a final volume of 50 mL.⁸

Result

The concentrations of Cr, Mn, Fe, Ni, Cu, Zn, Pb, and Cd were determined fish samples from all selected locations along the Yamuna River. Higher concentration of heavy metals were consistently observed at sites where the river receives effluents from multiple industrial and municipal sources. This result suggests a direct correlation between industrial discharge and the bioaccumulation of heavy metals in aquatic organism. The observed regional difference in heavy metal concentrations be attributed to a combination of anthropogenic inputs, lithological factors, and hydrological conditions.

Table 1: Evaluation of Heavy Metal Accumulation in Aquatic Fauna of the Yamuna River during Pre-Monsoon 2023.

S. No.	Heavy Metals	M-1	A-2	F-3	E-4
T-1	Cr	0.98	1.69	1.38	1.42
T-2	Mn	1.14	1.36	2.32	1.89
T-3	Fe	74.5	22.6	181.5	113.6
T-4	Ni	0.35	0.19	0.46	0.31
T-5	Cu	0.75	0.52	0.51	1.14
T-6	Zn	1.93	1.45	2.17	3.12
T-7	Pb	0.53	1.26	0.37	1.89
T-8	Cd	0.02	0.03	0.01	0.09

Table 2: Evaluation of Heavy Metal Accumulation in Aquatic Fauna of the Yamuna River during Post-Monsoon 2023.

S. No.	Heavy Metals	M-1	A-2	F-3	E-4
T-1	Cr	0.85	1.55	1.2	1.13
T-2	Mn	1.03	1.13	2.17	1.63
T-3	Fe	73.42	19.9	173.2	109.05
T-4	Ni	0.14	0.22	0.37	0.21
T-5	Cu	0.86	0.69	0.62	1.32
T-6	Zn	1.56	1.36	1.61	2.42
T-7	Pb	0.42	1.03	0.23	1.7
T-8	Cd	0.01	0.02	0.01	0.07

Discussion

Chromium

Cr, is considered as a specific pollutant, and is commonly used as an indicator of contamination from industry and domestic waste.⁹ The current study identified elevated concentrations of chromium (Cr) in fish of the Yamuna River, ranging from 0.98 to 1.69 mg/kg during the before monsoon and from 0.85 to 1.55 mg/kg in the after monsoon period. These concentrations varied considerably across the four sampling sites. The findings demonstrated that the levels of Cr were higher than the permissible limits. Higher levels of Cr in fish can damage their intestines, liver, kidneys, and gills.¹⁰ They can also cause changes in breathing rate, gallbladder cancer, loss of balance, and decreased survival and growth. These toxicological effects pose serious concerns not only for aquatic ecosystems but also for human population consuming contaminated fish.¹¹ Therefore, it is crucial to monitor and manage chromium pollution to protect both ecosystems and public health.

Manganese

The concentration of manganese is attributed to municipal discharges from small and commercial businesses, tannery effluents, and various industries. In this study, Mn concentration varied between 1.14 to 2.32 mg/kg in the post-monsoon period and between 1.03 to 2.17 mg/kg in the pre- monsoon period. These concentrations exceeded the permissible limits for safe consumption. Elevated Mn levels are known to induce oxidative stress and activate cell death pathways. This can result in immunosuppression and heightened vulnerability to infections. Manganese poisoning can cause a chronic neurological condition.¹²

Hallucinations, aggression, and milder signs like irritability frequently precede these symptoms. These neurological effects not only impact individual organisms but can also disrupt entire ecosystems.¹³ The growing impact of Mn toxicity on fish and other aquatic organisms poses a significant threat to ecological stability, potentially disrupting the intricate balance of the food web and resulting in wider ecological ramifications.

Iron

The current research indicates that Fe concentrations in fish surpassed the acceptable limit set by BIS across all samples. During the pre-monsoon period, Fe concentration ranged from 22.6 to 181.5 mg/kg, while in the post-monsoon period, they varied between 19.9 to 173.2 mg/kg. These elevated levels are likely attributable to anthropogenic sources, particularly effluents from industries such as metal pipes and steel production.¹⁴ Excessive iron accumulation in fish can lead to several physiological biochemical disturbances, including gill damage, respiratory dysfunction, oxidative stress, reduced growth, and development, and asphyxiation.¹⁵ As a result, these health impacts could severely affect fish population and disrupt the aquatic ecosystem. Furthermore, the presence of elevated Fe levels in edible fish raises public health concerns, underscoring the importance of consistent monitoring and regulating industrial discharges into the river.

Nickel

The concentration of nickel was observed to range between 0.19 to 0.46 milligrams per kilogram before monsoon and from 0.14 to 0.37 milligrams per

kilogram after monsoon. These values exceed the permissible limits which is set by BIS. The elevated levels of Ni are likely attributed to wastewater from industrial discharge, urban runoff and municipal discharges.¹⁶ Higher concentrations of Ni in fish have been associated with both chronic and acute toxicity, as well as hyperplasia and hypertrophy.¹⁷ Moreover, the potential nickel bioaccumulation in the food chain raises serious concerns for ecosystem stability and human health through the consumption of contaminated fish. Due to these finding, it is essential to implement stricter regulations and monitoring practices to safeguard both environmental and public health.

Copper

The concentration of copper exhibited significant variability. The elevated levels of Cu observed are likely due to persistent inputs from pesticides and fungicides, along with continuous wastewater discharge from local industries including footwear manufacturing, petha production and bangles making units.¹⁸ The studies revealed that Cu fluctuating from 0.51 to 1.14 milligrams per kilogram during the pre-monsoon period and from 0.62 to 1.32 milligrams per kilogram during the post-monsoon period. These levels exceeded the permissible limits established by BIS. While copper is an essential trace element required by almost all living organisms, its excessive accumulation is considered toxic. Elevated Cu concentrations can result in a range of harmful effects in fish, including external lesions such as discoloration and necrosis on livers, alterations in gills and testes, reduced egg production, decreased survival rates of juveniles, impaired growth, weakened immune response, shortened lifespan, reproductive dysfunction, reduced fertility, and notable changes in appearance and behavior.¹⁹ Therefore, continuous monitoring and strict regulation of these pollutants are crucial to safeguard aquatic organisms and ensure the overall health of the ecosystem.

Zinc

Zn level measured in fish samples from various sites ranged from 1.45 to 3.12 mg/kg before the monsoon and 1.36 to 2.42 mg/kg after the monsoon, exceeding the permissible limits set by the BIS. Elevated Zn levels in aquatic organisms are often linked to effluents from industries such

as electroplating, brass manufacturing, and agrochemical industries, including fertilizers and pesticides.²⁰ The findings showed that it causes gill damage,²¹ growth and development issues, hypoxic conditions, and teratogenic effects. These detrimental effects demonstrate the importance of monitoring and managing of Zn concentrations in aquatic environments to safeguard both fish populations and the broader ecosystem.²² Furthermore, sustained exposure to high concentrations of zinc threatens aquatic organisms and may also adversely affect human health through the intake of contaminated fish. Accumulation of heavy metals in fish can threaten human health and disrupt entire aquatic ecosystems. As a result, it is essential to monitor and regulate these contaminants to ensure both environmental sustainability and public safety.

Lead

Lead concentration across the study sites ranges from 0.37 to 1.89 mg/kg during the pre-monsoon period and from 0.23 to 1.03 mg/kg during the post-monsoon period, which is above the BIS acceptable limits. The high percentage of Pb can be attributed to runoff from lead battery manufacturing units, tannery waste, and various businesses in the region, including pharmacies, footwear production, and diesel engine manufacturing.²³ The observed Pb concentration in fish surpass both WHO and BIS standards, raising serious public health concerns, particularly for health sensitive cohorts such as young children and pregnant woman. In aquatic species, elevated Pb levels have been associated with reduced fertility, abnormal sperm and egg development, damage CNS.²⁴ and impaired growth among young fish.²⁵ Therefore, continuous monitoring and stringent regulation of industrial effluents are imperative to mitigate lead pollution and safeguard both ecological and human health.

Cadmium

Cadmium, an inherently present but non-essential trace metal, demonstrates a marked propensity for bioaccumulation in aquatic organisms, potentially attaining levels that are toxic and environmentally concerning. In the present investigation, cadmium levels in fish were observed to range between 0.01 and 0.09 mg/kg during the pre-monsoon season, while values between 0.01 and 0.07 mg/kg were recorded in the post-monsoon season. Among

the studied locations the arid region of Etawah exhibited the highest concentration of cadmium likely due to localized industrial activities and waste disposal practices, Cadmium can enter aquatic ecosystems through industrial effluents, improper waste management and domestic sewage. Once accumulated in aquatic organism, Cd may cause testicular degeneration and damages the proximal

tubules in renal units, reproductivity loss, hepatic dysfunctions, development of cancer,²⁶ tumour production and hypertension in fishes. Low level of Cd can cellular stress.²⁷ and trigger DNA damage.²⁸ Consequently, monitoring and managing industrial discharges into the Yamuna River is crucial to safeguard aquatic life and ensure a balanced ecosystem.

Graphically Representation of Concentration of Heavy Metals in Fish of the Yamuna River.

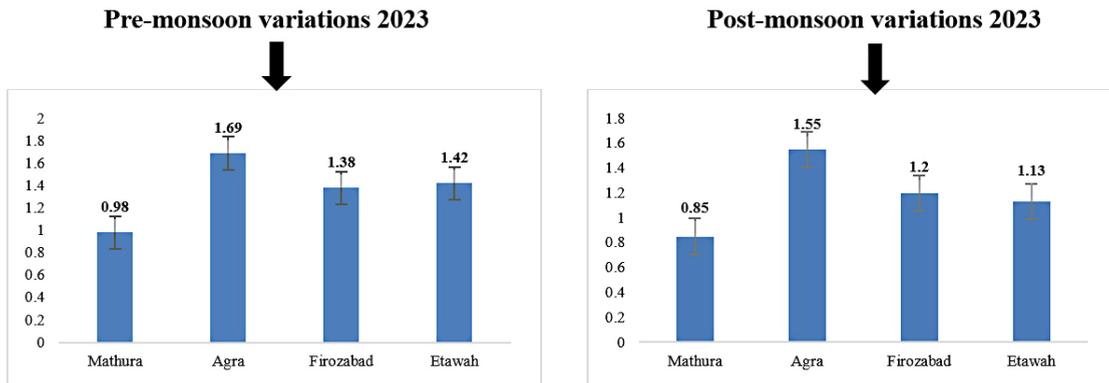


Fig. 1: variations of Cr (mg/kg) in fish of the Yamuna River at the sites of samples

variations of Cr (mg/kg) in fish of the Yamuna River at the sites of samples.

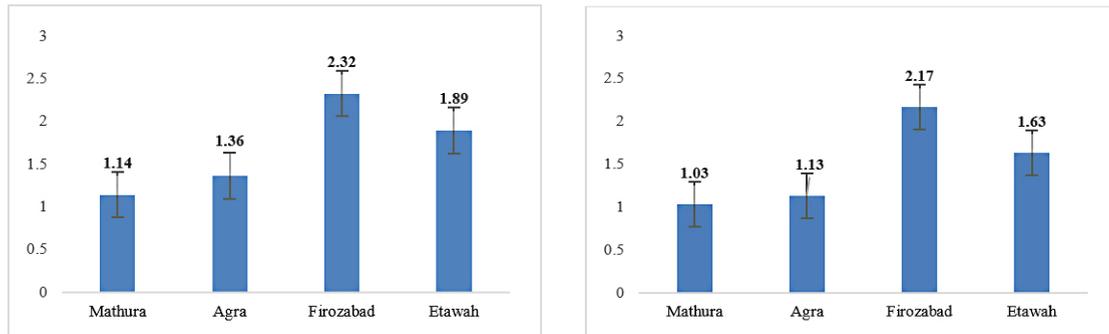


Fig. 2: variations of Mn (mg/kg) in fish of the Yamuna River at the sites of samples.

variations of Mn (mg/kg) in fish of the Yamuna River at the sites of sample.

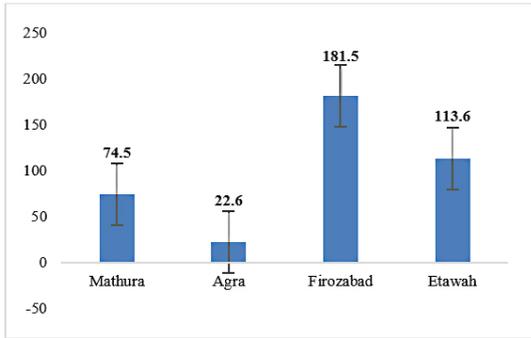
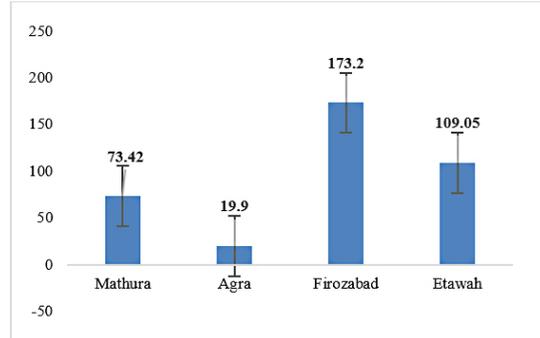


Fig. 3: variations of Fe (mg/kg) in fish of the Yamuna River at the sites of samples.



variations of Fe (mg/kg) in fish of the Yamuna River at the sites of sample.

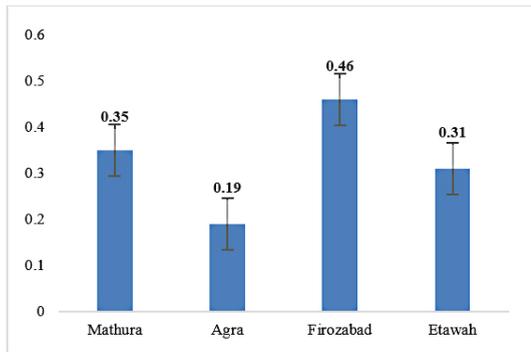
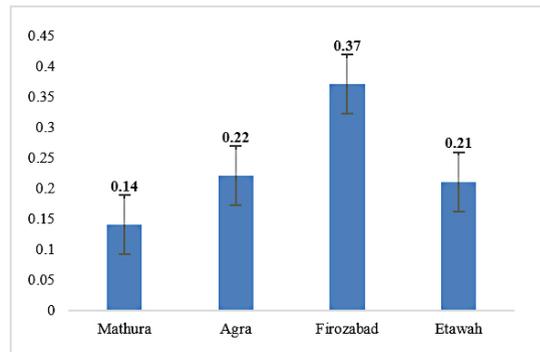


Fig. 4: variations of Ni (mg/kg) in fish of the Yamuna River at the sites of samples.



variations of Ni (mg/kg) in fish of the Yamuna River at the sites of samples.

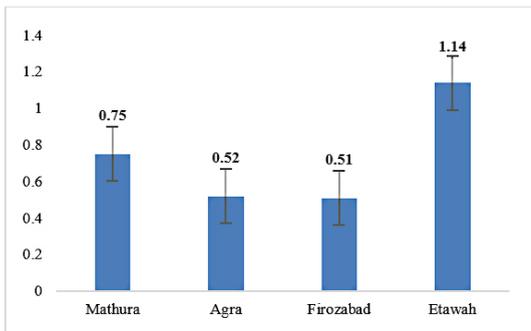
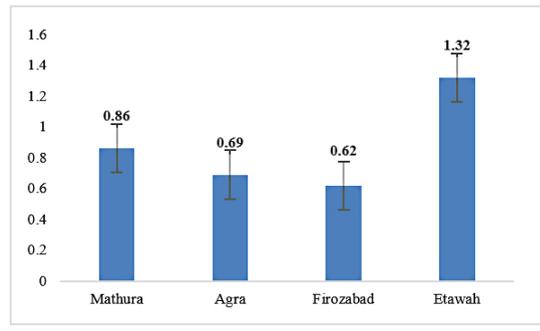


Fig. 5: variations of Cu (mg/kg) in fish of the Yamuna River at the sites of samples.



variations of Cu (mg/kg) in fish of the Yamuna River at the sites of sample.

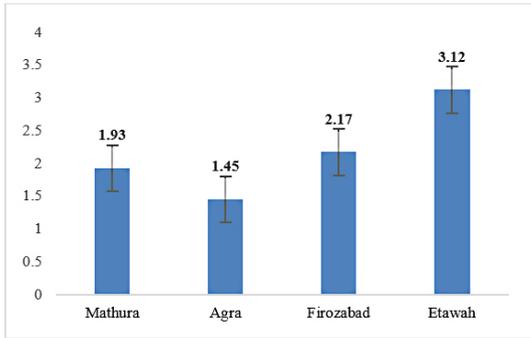
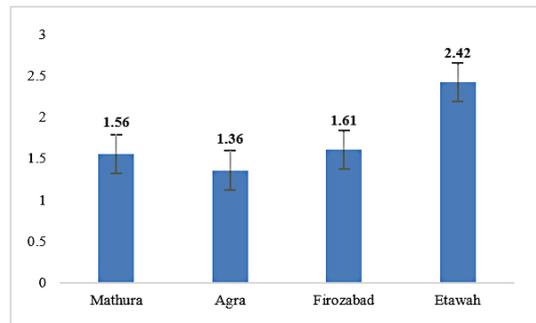


Fig. 6: variations of Zn (mg/kg) in fish of the Yamuna River at the sites of samples.



variations of Zn (mg/kg) in fish of the Yamuna River at the sites of sample.

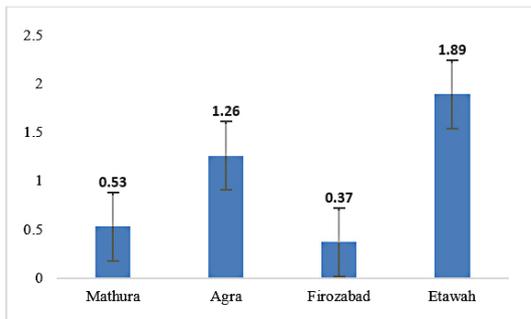
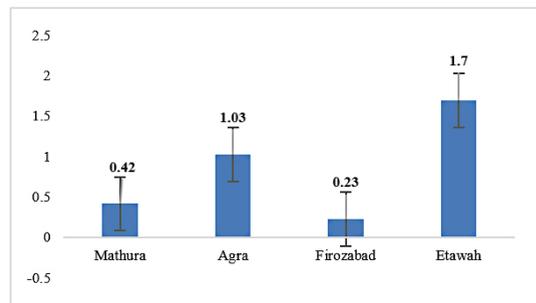


Fig. 7: variations of Pb (mg/kg) in fish of the Yamuna River at the sites of samples.



variations of Pb (mg/kg) in fish of the Yamuna River at the sites of sample.

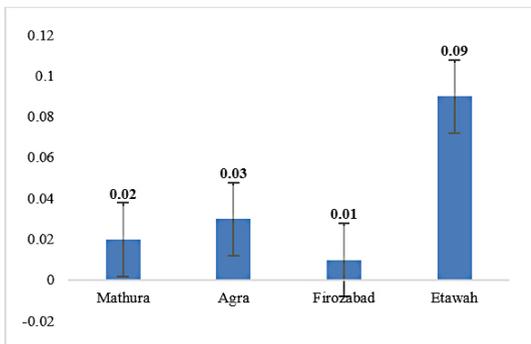
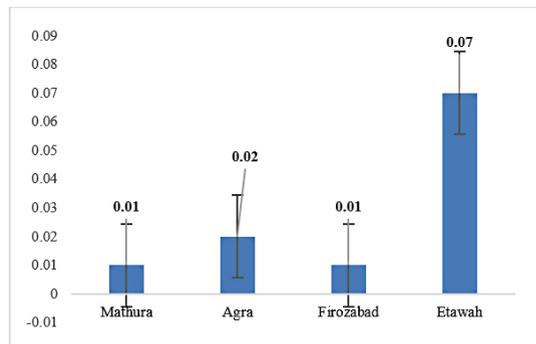


Fig. 8: variations of Cd (mg/kg) in fish of the Yamuna River at the sites of samples.



variations of Cd (mg/kg) in fish of the Yamuna River at the sites of sample.

Conclusion

The segment of the Yamuna River between Mathura and Etawah has emerged as an area of growing environmental concern due to increasing levels of heavy metal contamination. This stretch of the river is impacted by a combination of pollutants

originating from upstream sources, persistent effluents discharges from localized industries, untreated domestic sewage, municipal solid and liquid waste and the extensive application of chemical fertilizers and pesticides in surrounding areas. These contaminants enter the river through

direct discharge or via surface runoff. All these factors contribute significantly to the accumulation of toxic metals in river water. These pollutant including iron, copper, zinc, manganese, lead, nickel, cadmium, and chromium are often released without adequate treatment leading to bioaccumulation in aquatic organisms. The unregulated release of industrial effluents and domestic waste into the river not only degrades water quality but also poses a severe threat to the health of communities that depend on the river for drinking water, agriculture, and fishing. The present study conducted in response to increasing levels of HMs level in edible *Edaphodon Kawai* fish from Yamuna River. Finding from these studies revealed that the concentration of heavy metals in the fish samples exceeded the allowable limits for drinking water set by different regulatory authorities. This growing contamination requires urgent intervention through stringent regulatory frameworks, regular monitoring, and public awareness campaigns to mitigate the harmful effects and restore the ecological balance of Yamuna River.

Acknowledgement

The author gratefully acknowledges the Indian Institute of Technology, Delhi, for providing the necessary instrumentation facilities. I extend my sincere gratitude to all who contributed to this research, including colleagues and friends for their valuable discussions, the study participants for their contributions, and everyone who supported me throughout this research journey.

Funding Sources

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Conflict of Interest

The authors do not have any conflict of interest.

Data Availability Statement

The datasets generated and analyzed during this study are available from the corresponding author on reasonable request.

Ethics Statement

This study was conducted in accordance with internationally accepted guidelines for the ethical use of animals in research, including the ARRIVE guidelines and the OECD principles for good laboratory practice. Ethical approval was not required for this study, as it involved the collection of fish samples from natural water bodies for heavy metals analysis in compliance with the fisheries regulations of Uttar Pradesh.

All necessary precautions were taken to ensure animal welfare. Fish were captured using standard non-destructive fishing methods, handled carefully to minimize stress, and humanely euthanized prior to flash testing for heavy metals. No endangered or protected species were collected during the course of this research.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Permission to Reproduce Material

Not Applicable

Author Contributions

- **Poonam Verma:** Conceptualization, Methodology, Data Collection, Analysis, Writing – Review & Editing.
- **Shalini Yadav:** Visualization, Conceptualization, Provided valuable instruction to frame the work.
- **Dhirendra Yadav:** Conceptualization.
- **Vinod Kumar:** Supervision and Over all editing.

References

1. Kumar R, Tripathi R. M. Gupta A. K, Seasonal Variation of Heavy Metal Concentration in *Labeo Rohita* and *Edaphodon Kawai* Fishes of River Yamuna, Allahabad, Uttar Pradesh, India. *J Environ Sci Toxicol Food Technol* 2014; 8(6): 27–34
2. Sen I, Shandil A, Shrivastava V. S. Study for Determination of Heavy Metals in Fish Species of the River Yamuna (Delhi) by Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES). *Adv Appl Sci Res* 2011; 2(2): 161-166

3. Mohanta V. L, Singh S, Kumar Mishra B. Human Health Risk Assessment of Fluoride Rich Groundwater using Fuzzy Analytical Process over the Conventional Technique, *Groundw Sustain Dev* 2020;10(1):1-31
4. Ali H, Khan E. Bioaccumulation of non-essential hazardous heavy metals and metalloids in freshwater fish, *Risk to human health*, 2018;16(3):903-917
5. Burger J. Gochfeld M. Heavy Metals in Commercial Fish in New Jersey. *Environ Res*, 2005;99(3):403-412
6. Paudel P. N, Pokhrel B, Kafle B. K, Gyawali R. Analysis of Heavy Metals in Some Commercially Important Fishes of Kathmandu Valley, Nepal. *Int Food Res J* 2016;23(3):1005-1011
7. Ghosh R, Upadhyay A. D, Roy A. K, Tiwari A. Structural and Functional Analysis of Cytochrome-b Protein of Indian Major Carps Labeo Rohita. *J Entomol Zool Stud* 2020;8(2):540-550
8. Rohan Y, Khan I, Pandit J. U. Heavy Metals Analysis in Water, Fish and Veg- etative amples of Lakha-Banjara Lake, Sagar, Madhya Pradesh, India, *J Environ Res Develop* 2014;8(3):1-6
9. Singh R, Gautam N, Mishra A, Gupta R. Heavy Metals and Living Systems: An Overview. *Indian J Pharmacol* 2011;43(3):246-253
10. Sharma J, Pant G, Hossain K, Ahmad A, Bakht M. A, Tripathi R, Setapar S. H. M. Chromium Toxicity in the Yamuna River Ecosystem at Brij Region–Uttar Pradesh, India. *Desalin Water Treat* 2022;267(1):13-25
11. Sankhla M. S, Kumar R, Prasad L. Distribution and Contamination Assessment of Potentially Harmful Element Chromium in Water. *Int'l Legal study J* 2019;2(3):1-6
12. Rahman M. S, Molla A. H, Saha N, Rahman A. Study on Heavy Metals Levels and Its Risk Assessment in Some Edible Fishes from Bangshi River, Savar, Dhaka, Bangladesh, *Food Chem* 2012;134(4):1847-1854
13. Ahmad Z. Biomonitoring of Heavy Metal in Selected Biomarkers of Clarias Gariepinus, A Comparative Study of River Galma, River Kubani and Fish Farms in Zaria, Nigeria. *Adv Appl Sci Res* 2014;5(6):198-206
14. Sarkar A, Shekhar S. Iron Contamination in the Waters of Upper Yamuna basin, *Groundw Sustain Dev* 2018;7(1):421-429
15. Sankhla M. S, Sharma K, Kumar R. Heavy Metal Causing Neurotoxicity in Human Health., *Int. J Innov Res Sci Eng Technol* 2017;6(5):7721-7726
16. Bhardwaj R, Gupta A, Garg J. K. Evaluation of Heavy Metal Contamination using environmetrics and Indexing Approach for River Yamuna, Delhi Stretch, India. *Water Sci* 2017;31(1):52-66
17. Sankhla M. S, Kumar R, Prasad L. Seasonal Variation of Nickel and Zinc Concentration in Water of River Yamuna, Delhi, India, *J Punjab Acad Forensic Med Toxicol* 2021;21(2):190-193
18. Pal R, Dubey R. K, Dubey S. K, Singh A. K. Assessment of Heavy Metal Pollution Through Index Analysis for Yamuna Water in Agra Region, India. *IJCMAS* 2017;6(12):1491-1498
19. Agbugui M. O, Abe G. O. Heavy Metals in Fish: Bioaccumulation and Health. *BJESR* 2022;10(1):47-66
20. Authman M. M, Zaki M. S, Khallaf E. A, Abbas H. H. Use of Fish as Biondicator of the Effects of Heavy Metals Pollution. *J Aquac Res Dev* 2015;6(4):1-13
21. Khedr A. I, Ghannam H. E. Evaluation of some heavy metals in water and health implications for fish consumers of the Great Cairo Sector of the Nile River. *Sci Reports*. 2025;15(1):1-20
22. Zeitoun M. M, Mehana E. E. Impact of Water Pollution with Heavy Metals on Fish Health. *Glob Vet* 2014;12(2):219-23
23. Sfakianakis D. G, Renieri E, Kentouri M, Tsatsakis A. M. Effect of Heavy Metals on Fish Larvae Deformities: A Review. *Environ Res* 2015;137(1):246-255
24. Sharma M, Rawat S, Kumar D, Awasthi A, Sarkar A, Sidola A, Choudhury T, Kotecha K. The state of the Yamuna River: a detailed review of water quality assessment across the entire course in India. *App Water Sci* 2024;14(8):1-24
25. Sonone S. S, Jadhav S, Sankhla M. S, Kumar R. Water Contamination by Heavy Metals and

- Their Toxic Effect on Aquaculture and Human Health Through Food Chain. *Appl Nano Bio Sci* 2020;10(2):2148-2166
26. Kanojia R, Khurana N, Jaiswal AK, Bhagat S. Assessment and Analysis of Heavy Metals Present in Vegetables Grown Near Yamuna River Region: A Review. *IJFSC* 2024; 17;9(3):1-8
27. Zhang H, Reynolds M. Cadmium Exposure in Living Organisms: A Short Review. *Sci Total Environ* 2019;678(15):761-767
28. Afshan S, Ali S, Ameen U. S, Farid M, Bharwana S. A, Hannan F, Ahmad R, Effect of Different Heavy Metal Pollution on Fish. *Res J Chem Environ Sci* 2014;2(1):74-79