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Seasonal and Spatial Variations of Heavy Metals in the Kollidam River: Implications for Water Quality and Aquatic Health

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Heavy metal pollution in aquatic ecosystems is a growing global concern, especially given the severe health and environmental risks posed by these contaminants of Rivers, as crucial water resources, are highly susceptible to heavy metal contamination from both natural sources and anthropogenic activities, including industrial and agricultural runoff. The Kollidam River in Tamil Nadu, India, which supports agriculture, drinking water, and diverse aquatic life, faces mounting pollution pressures due to rapid industrialization and urbanization, leading to the accumulation of metals like copper (Cu), manganese (Mn), zinc (Zn), and iron (Fe). These metals can persist in river ecosystems and bioaccumulate in aquatic organisms, impacting the food web and consequently

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human health. This study utilizes Atomic Absorption Spectroscopy (AAS) to quantitatively assess the concentration of Cu, Mn, Zn, and Fe in Kollidam River water, with a focus on understanding the ecological risks posed by these metals. Findings from this study provide critical insights into pollution sources seasonal variations and the potential health risks associated with heavy metal contamination.

Keywords: Heavy metal; Kollidam River; aquatic health; ecosystems; environmental pollution.

1. INTRODUCTION

Water is the most precious gift nature has given to mankind. Unlike other resources, water has no substitute in its main uses and cannot be replaced. Virtually, no activity in the environment would be possible in the absence of water bodies. Not only do we need water for our food, power generation and industrial processes, but we also need it as a requirement in our lives and our bodies need to ingest water every day to continue its functioning. Lack of good- quality of water is found to be one of the important causes of human distress, disease, and early death, either directly or indirectly. Because of the intimate association between water and life, water is woven into the fabric of all cultures, religions and societies. Water as a resource is not evenly distributed spatially or temporally around the world and its declination and deterioration affects every sphere of life. Many parts of the world are affected by water scarcity and water quality problems to a greater extent.

The Kollidam River is a prominent tributary of the Cauvery River in Tamil Nadu India. Heavy metal contamination in aquatic ecosystems is a pervasive environmental concern, with widespread effects on biodiversity, ecosystem health, and human populations (Ali & Khan, 2018). Rivers in particularly vulnerable to heavy metal pollution due to their critical role in supplying water for agriculture, drinking, and industrial purposes. It is necessary to provide the Heavy metals, including copper Cu, manganese Mn, zinc Zn and iron Fe are of significant concern due to their persistence in the environment and potential for bioaccumulation which can disrupt aquatic ecosystems and human health (Mandel, 2017). Rapid industrialization and urban development in the surrounding regions have escalated the risks of heavy metal contamination through industrial discharges, agricultural runoff, before and untreated wastewater, threatening both ecological health and human (Khan et al*.,* 2020). Heavy metals are a pressing concern in terms of their pollution in aquatic ecosystems because of their persistence, environmental toxicity, bioaccumulation, etc. (Jordanova et al., 2018).

The growing concern over heavy metal contamination in rivers, especially in developing regions like Tamil Nadu, has prompted several studies focusing on assessing the extent of pollution and its implications for both aquatic life and human health. The Kollidam River, which plays a crucial role in the livelihoods of thousands of people, is increasingly impacted by anthropogenic activities such as industrial effluents, agricultural runoff, and urban wastewater discharge (Praveena et al., 2018). Industrial discharges, in particular, are a significant source of heavy metals such as (Cu),Mn), (Zn), and (Fe), which, if not adequately managed, can lead to the contamination of water bodies and pose risks to aquatic organisms and human populations who rely on the river for drinking, irrigation, and fishing (Dutta et al*.,* 2017).

Heavy metals like Cu, Mn, Zn, and Fe have been shown to persist in aquatic environments and accumulate in the food chain, leading to adverse health effects in both aquatic organisms and humans, Water contamination by heavy metals is one of the serious threats to the health of mankind (Saha and Paul, 2019). Heavy metals enter into the ecosystem as highly stable and somewhat non-degradable contaminants (Burgess, 2015), For instance, high concentrations of Cu and Zn can cause toxicity in fish, impairing their growth and reproduction (Wang et al*.,* 2005). Similarly, excessive levels of Mn and Fe can lead to water quality degradation, affecting the overall health of aquatic ecosystems (Li et al*.,* 2017). Consequently, the monitoring and assessment of these metals in water bodies like the Kollidam River are essential for formulating effective water management strategies aimed at minimizing pollution and mitigating its harmful effects.

Which are influenced by factors such as rainfall, runoff, and water flow dynamics (Kumari et al., 2017). The findings will provide critical insights into the extent of heavy metal pollution in the Kollidam River and its potential ecological and health impacts. Overall, this research seeks to contribute to the growing body of knowledge on water quality in southern India, emphasizing the importance of continuous monitoring and implementing effective pollution control measures to protect both aquatic biodiversity and human health (Zhang et al., 2020). Through this work, we aim to inform policy decisions and support sustainable water management practices that ensure the longterm health of the Kollidam River ecosystem.

In addition to the industrial and urban pressures, agricultural runoff is another significant source of heavy metal pollution in the Kollidam River. The use of fertilizers and pesticides, which often contain trace amounts of metals like copper and manganese, contributes to the accumulation of these metals in river systems (Singh et al., 2017). This problem is further exacerbated during the monsoon season, when rainfall increases surface runoff, carrying pollutants from the land into the river. As a result, the Kollidam River experiences seasonal variations in the concentration of heavy metals, with higher levels typically observed during the monsoon season due to increased runoff from agricultural fields and surrounding areas (Tiwari et al., 2013). The ongoing discharge of untreated wastewater from industries and domestic sources has also led to the contamination of the river with high levels of heavy metals, which can have long term detrimental effects on aquatic organisms and the surrounding ecosystem Results indicated that the nature of water is reasonable in storm, which at that point changed to medium in winter and poor in summer (Rattan et al.,2002).

To address these concerns, this study conducts a detailed assessment of Cu, Mn, Zn, and Fe concentrations in Kollidam River water. Employing Atomic Absorption Spectroscopy (AAS), a reliable method for quantifying trace metals, this research evaluates both the seasonal variability of metal concentrations and their potential ecological impacts. Insights from this study are expected to inform mitigation strategies for heavy metal contamination and support sustainable water management efforts, emphasizing the importance of routine monitoring to protect this valuable water resource. As an important component in riverine ecosystems, sediment serves as both a sink and a source of heavy metals (Huang et al., 2009).

Through the findings of this study, we aim to contribute to the growing body of knowledge regarding the pollution levels in the Kollidam River and provide a scientific basis for the implementation of effective water quality management strategies. These strategies could include improved waste treatment processes better agricultural practices and stricter regulations on industrial discharges. In doing so, the study will help ensure the sustainability of the Kollidam River as a vital resource for both human populations and aquatic ecosystems, while mitigating the longterm impacts of heavy metal contamination.

2. MATERIALS AND METHODS

2.1 Study Area

The Kollidam River, a significant tributary of the Cauvery River, flows through the picturesque landscapes of Tamil Nadu, India, and was selected as the focal point of this study. The river plays a crucial role in supporting local agriculture, drinking water supply and aquatic biodiversity. To ensure a comprehensive assessment of the river's water quality four strategic sampling sites were chosen from the Thirumanur to Anaikarai stretch of the river. These locations were selected based on varying land use practices and potential pollution sources to capture the diverse impacts on water quality across different stretches. The selection of these sites aimed to reflect the variability of the river's environmental conditions, providing a holistic view of the heavy metal contamination levels in the region (WHO, 2017).

1. **Station-1:** Thirumanur (10°55'34.7"N, 79°06'15.2"E)
2. **Station-2:** Vazhkai (10°59'00.1"N, 79°16'05.4"E)
3. **Station-3:** Kollidam Bridge, Madhanadhur (11°02'56.3"N, 79°21'35.4"E)
4. **Station-4:** Ukkarai, Anaikarai Bridge (11°08'08.9"N, 79°27'12.8"E)

2.2 Sample Collection

Water samples were meticulously collected from a precise depth of one meter at each of the four designated sampling sites along the Kollidam River, spanning across the seasons of summer and monsoon, in 2022 to 2023. (Fig. 1) The sampling locations were chosen to represent a range of land use patterns and potential pollution sources. The samples were collected using acid washed polyethylene bottles to avoid contamination and preserve sample purity. To maintain the integrity of the metal content, each sample was treated with nitric acid, ensuring preservation of the original composition of the water and preventing metal precipitation (APHA, 2017). Water samples were collected at a depth of one meter from the surface using precleaned, acid washed polyethylene bottles. To minimize contamination and maintain sample integrity all sampling equipment was thoroughly cleaned and prepared according to standard protocols (APHA, 2017). Sampling was conducted during the summer and monsoon seasons of 2022 to 2023 account for seasonal variations in water quality.

To preserve the metal content and prevent precipitation, the samples were acidified with concentrated nitric acid to adjust the pH to 2. This acidification process ensures that the metals remained in a dissolved state for subsequent analysis. After collection, the samples were carefully transported to the laboratory under cold storage conditions to minimize any alteration in their chemical composition. These methods ensured that the samples remained unaltered facilitating accurate and reliable subsequent analysis of the heavy metal concentrations.

2.3 Data Preparation

In the preparation phase, to eliminate any potential interference from suspended particulate matter each sample was filtered using a 0.45 µm membrane filter. This filtration process removed fine particulate matter and ensured that the resulting filtrate was suitable for metal analysis. Following filtration, the acidified samples were stored in clean labeled containers and kept at a controlled temperature to maintain their stability until the analysis could be performed. The use of these stringent sample preparation protocols ensured that the collected data would provide an accurate representation of the heavy metal contamination levels in the Kollidam River.

2.4 Heavy Metal Analysis Using AAS

For the determination of heavy metals, namely Copper (Cu), Manganese (Mn), Zinc (Zn), and Iron (Fe), the Atomic Absorption Spectroscopy (AAS) technique was employed (Tiwari et al*.,* 2013). The AAS method was selected due to its sensitivity, accuracy, and ability to detect trace levels of metals in water samples. Prior to analysis, calibration standards were prepared using certified stock solutions and blank samples were run to account for any potential contamination or interference during the analytical process (Swaileh and Sansur, 2004).

2.5 Quality Control and Assurance

To ensure the accuracy and reliability, stringent quality control measures were followed. These included running procedural blanks, duplicate samples, and certified reference materials at regular intervals to validate the instrument's calibration and precision. All analysis were conducted under standardized conditions to maintain consistency and minimize errors. The standards used in the analysis were traceable to international standards to ensure the robustness of the data (Rattan et al., 2002).

A

B

Fig. 1. Photographs of some studied area A. water samples collecting. B. stream from agriculture land that mixed with river

2.6 Statistical Analysis

Data obtained from the AAS analysis was subjected to statistical analysis to evaluate the spatial and seasonal distribution of the heavy metals in the river water. Descriptive statistics such as mean, standard deviation, and range were calculated to summarize the data (Wang et al., 2005). The data were also subjected to analysis of variance (ANOVA) to assess significant seasonal variations and the impact of different sampling locations on metal concentrations. Statistical software such as SPSS (Statistical Package for the Social Sciences) was used for these analyses, ensuring the robustness and validity of the results (Singh et al., 2020).

3. RESULTS AND DISCUSSION

The present study determined the mean Copper concentrations heavy metal analysis of water at four different sites and two seasons of Kollidam River from 2022–2023 are reported in Tables 1 & 2. The present study shows the maximum level of Cu station 1 and minimum level of Cu was observed in the station 4 of Kollidam River. The average level of Cu was observed in the station 1 and 2 of Kollidam River in Summer and Monsoon season. The clarity of natural body of water is an important determinant of its condition and productivity. This difference suggests that summer conditions possibly due to evaporation or increased agricultural activity, may elevate Cu levels in the river water the range was observed seasons of heavy metal at sites S1>S3>S2>S4, while dilution from rainfall in the monsoon season S1>S3>S2>S4 could reduce the overall heavy metal concentration. Similar trends have been reported in studies where Cu levels were affected by seasonal variation, often tied to both anthropogenic activities and natural processes (Bhosle & Patil, 2001). This pattern may be due to increased agricultural runoff during the dry season, where concentrated fertilizers and pesticides elevate metal levels in surface waters. The observed seasonal fluctuations align with other studies that report lower Cu concentrations during periods of high rainfall due to dilution effects (Lu, et al., 2009). This is critical as elevated Cu concentrations can disrupt aquatic ecosystems by affecting fish health and altering species composition in polluted areas (Mandal et al., 2017).

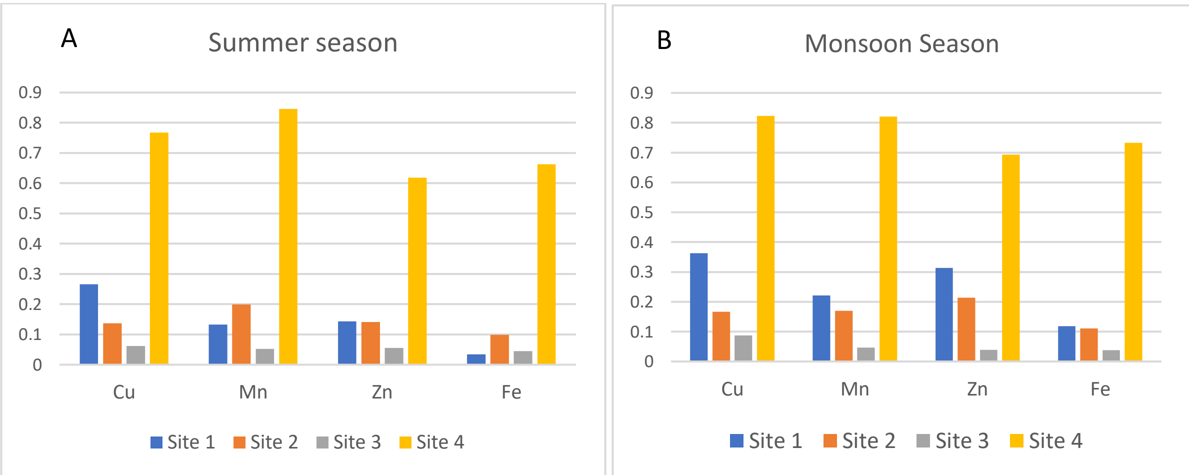

Fig. 2. Heavy metal concentration in the Water collected at the various sampling stations of Kollidam River. (A) Summer seasons and (B) Monsoon seasons

Table 1. The mean ± standard deviation (SD) for heavy metal concentrations of water (mg/l) in various sampling stations summer seasons of Kollidam River

Season	Stations	Heavy Metal mg/l			
		Cu	**Mn**	**Zn**	**Fe**
Summer	S1	0.2661±0,02	0.1365±0.43	0.0613±0.29	0.7675±1.42
	S2	0.1323±0.14	0.1997±1.37	0.0528±2.08	0.8464±0.28
	S3	0.1434±0.67	0.1416±0.04	0.0558±0.75	0.6180±2.07
	S4	0.0347±0.32	0.0990±2.01	0.0448±1.07	0.6628±3.64

Table 2. The mean ± standard deviation (SD) for heavy metal concentrations of water (mg/l) in various sampling stations of monsoon seasons of Kollidam River

Season	Stations	Heavy metal mg/l			
		Cu	Mn	Zn	Fe
Monsoon	S1	0.3630±0.03	0.1667±0.42	0.0867±1.7	0.8224±0,41
	S2	0.2213±0.21	0.1703±1.06	0.0465±0.04	0.8203±3.02
	S3	0.3130±1.08	0.2133±0.14	0.0390±1.37	0.6931±027
	S4	0.1178±0.65	0.1107±1.18	0.0375±1.03	0.7325±2.06

The present study determined the mean Manganese levels concentrations heavy metal analysis of water at four different sites and two different seasons of Kollidam River from 2022–2023 are recorded in Tables 1 & 2. Manganese levels were notably higher during the monsoon (0.2133 mg/l) compared to summer (0.1997 mg/l), with the highest standard deviation also recorded in the monsoon. The increase in Mn during the monsoon could be attributed to agricultural runoff and soil erosion, both of which are intensified by rainfall. This is consistent with other findings that have linked seasonal rain patterns to elevated Mn levels in river systems (Ramesh et al., 2020). Manganese displayed a contrasting trend, with lowest levels recorded in the monsoon (0.1107 mg/l) than in summer (0.0990 mg/l). The range was observed Summer season of heavy metal at sites S2>S3>S1>S4, while dilution from rainfall in the monsoon season S3>S2>S1>S4 could be reduce the overall heavy metal concentration.

The monsoon increase can likely be attributed to the enhanced runoff of Mn rich soil and leaching of minerals into the river, a common occurrence in regions with significant agricultural and industrial activities Heavy metals are subjective to surface runoff groundwater dissolution from sediment, atmospheric depositions and anthropogenic sources such as agricultural runoff wastewater irrigation excess fertilizers–pesticide application on agro-lands, municipal and industrial wastes, mining, smelting, traffic emission and combustion of fossil fuels apart from natural geological origin by weathering and erosion and thus are sensitive markers for any alterations in aquatic system (Kullar, et al., 2019). Excessive Mn can pose a risk to aquatic life affecting enzymatic functions in fish and accumulating in sediment thereby posing long term ecological concerns (Shankar, et al., 2014).

The concentration of Zinc exhibited a distinct seasonal variation, with a mean of heavy metal concentration high in 0.0613 mg/l in summer on high 0.0867 mg/l in monsoon Tables 1 and 2. This sharp decrease in monsoon may result from dilution effects due to rainfall, which has been noted in previous studies that observed lower Zn levels in water bodies during high rainfall seasons (Chatterjee, et al., 2017). The may elevate Zn levels in the river water the range was observed seasons of heavy metal at sites S1>S3>S2>S4, while dilution from rainfall in the monsoon season S1>S2>S4>S3 could reduce the overall heavy metal level also suggests significant site to site variation, possibly due to localized sources such as industrial discharge or urban runoff. The observed Zn concentration peaked in the summer and decreased notably during the monsoon possibly due to dilution effects from heavy rainfall, as reported in similar studies (Lu, et al., 2009). Zinc is essential in trace amounts for aquatic organisms but higher concentrations can cause toxicity impacting reproductive health and growth in fish species (Singh et al*.,* 2017 and Patel, et al., 2001). This seasonal fluctuation in Zn concentration highlights the importance of periodic monitoring especially during dry seasons when pollutant levels tend to accumulate.

The present study determined the mean Fe levels concentrations heavy metal analysis of water at four different sites and two different seasons of Kollidam River from 2022–2023 are recorded in Tables 1 & 2. In the Fe levels were highest in the summer (0.8464 mg/l) to the monsoon seasons (0.8224 mg/l). The may elevate Fe levels in the river water the range was observed summer seasons of heavy metal at sites S2>S1>S4>S3, while dilution from rainfall in the monsoon season S1>S2>S4>S3 could reduce the overall heavy metal level also suggests significant site to site variation. Iron concentrations may rise during drier seasons due to reduced water flow and increased leaching from river water which aligns with research indicating that sediment and water interactions can substantially impact Fe levels in river systems (Das, et al*.,* 2008). The higher variability in Fe levels during summer also implies that specific sites along the river might have localized

Fe inputs, possibly from industrial or agricultural sources. Iron concentrations were highest in the summer and lower in the monsoon with significant variation likely due to site specific inputs and reduced water flow during dry periods. Iron, while not acutely toxic, can affect water quality by altering the pH and impacting species diversity in sediment heavy areas (Singh, et al., 2010). The summer's elevated levels may stem from decreased water flow which increases Fe accumulation through sedimentation and oxidation processes. Dissolution of granite and ferruginous shales of parent rock and indiscriminate direct discharge of domestic sewage effluents in the river result in the enrichment of iron in the basin. Organic matter present in domestic sewage acts as reducing agent which converts iron mineral into its soluble form as shown below (Raju, et al., 2011). These patterns underscore the need for targeted interventions during dry seasons when metal concentrations peak.

The seasonal fluctuation in heavy metal concentrations highlights the influence of rainfall on pollutant levels in river systems. Elevated concentrations in summer for certain metals like Cu and Fe may indicate that these pollutants are partially retained in the river during dry periods, whereas the monsoon's dilution effect is more pronounced for metals like Zn. These findings underscore the need for seasonal monitoring to better understand pollutant dynamics and mitigate health risks for communities relying on river water (Senesi, et al.,1999). The study of heavy metal concentrations in the Kollidam River across summer and monsoon seasons reveals distinct seasonal trends and provides insights into potential environmental impacts and pollution sources (Khan, et al.,2020). The focus on metals such as Cu, Mn, Zn and Fe is especially relevant due to their ecological significance and possible health implications for both aquatic organisms and human populations.

3.1 Environmental Implications and Risk Assessment

The findings demonstrate that metal concentrations vary considerably between seasons, with summer generally exhibiting higher levels for Cu, Zn, and Fe, whereas Mn peaks in the monsoon. These variations underscore the impact of seasonal dynamics on water quality in river systems, which is consistent with patterns observed in other Indian rivers (Rattan, et al.,2002). Elevated heavy metal concentrations pose risks to both aquatic life and human communities, as they may bioaccumulate in fish and other organisms, entering the human food chain (Raju, 2006). Seasonal monitoring and preventive measures are recommended to mitigate these impacts.

3.2 Seasonal Variability in Metal Concentrations

The observed seasonal differences in heavy metal concentrations are likely driven by varying hydrological conditions between summer and monsoon. During the summer season, lower river flow rates and increased evaporation contribute to higher concentrations of metals like Cu, Zn, and Fe due to limited dilution. The mean Cu concentration was highest in the summer possibly due to industrial runoff or agricultural activities contributing residual copper to the river. Conversely Zn and Fe also showed higher mean concentrations in the summer, which could be attributed to increased leaching from nearby agricultural lands and soil erosion. These elevated concentrations in summer high light the impact of anthropogenic activities coupled with natural conditions that limit metal dispersion.

During the monsoon, heavy rainfall and increased flow rates lead to a dilution effect, resulting in generally lower mean concentrations for most metals. However, Mn exhibited a reverse trend, with its mean concentration peaking in the monsoon season. The increase in Mn during the monsoon may be due to the washing of surface soils enriched with manganese and runoff from agricultural areas. This trend underscores the need to consider seasonal variations in evaluating water quality as monsoon flows may carry different contaminants into the river compared to the dry season. Specifically, iron and manganese are essential trace elements for organisms but can become toxic at elevated levels. Copper and zinc, though similarly essential in small quantities, can interfere with enzyme activity and metabolic processes when present at high concentrations. These findings underscore the importance of regular monitoring to identify trends and prevent levels from reaching ecologically and biologically harmful thresholds.

4. CONCLUSION

This study's findings on heavy metal fluctuations in the Cauvery on the Kollidam River added to the growing body of evidence regarding the impact of seasonal changes on riverine ecosystems. By identifying high risk periods on the area's stakeholders can prioritize interventions that protect both biodiversity and water quality. This research not only reinforces the need for consistent environmental surveillance but also underscores the relevance of localized pollution control measures to ensure sustainable use of river resources. A study highlights the significance of monitoring heavy metal concentrations in river systems, emphasizing the need to consider both seasonal and spatial variations in assessing water quality. The findings underscore the impact of human activities and natural processes on heavy metal distribution within the Kollidam River informing the development of effective water quality management strategies. Ensuring the health and sustainability of the Kollidam River requires continued monitoring, targeted pollution control measures, and collaboration among stakeholders to mitigate potential environmental and health risks associated with heavy metal contamination.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Ali, H., & Khan, E. (2019). Trophic transfer, bioaccumulation, and biomagnification of nonessential hazardous heavy metals and metalloids in food chains/webs – Concepts and implications for wildlife and human health. *Human and Ecological Risk Assessment, 25*(6), 1353–1376.

American Public Health Association. (2017). *Standard methods for the examination of water and wastewater* (23rd ed.). Baltimore, Maryland.

Bhosle, A. B., & Patil, P. M. (2001). Seasonal variation in the copper content of river water Godavari at Nandod, Maharashtra. *Journal of Ecotoxicology and Environmental Monitoring, 11*(1), 61–64.

Burgess, G. L. (2015). *Effects of heavy metals on benthic macroinvertebrates in the Cordillera Blanca, Peru* (WWU Master Thesis Collection, p. 414).

Chatterjee, S., Datta, S., & Gupta, D. K. (2017). Studies on arsenic and human health. In *Arsenic contamination in the environment* (pp. 37–66). Springer.

Das, N., Vimala, R., & Karthika, P. (2008). Biosorption of heavy metals—An overview. *Indian Journal of Biotechnology, 7*, 159–169.

Dutta, J., Chowdhury, G. R., & Mitra, A. (2017). Bioaccumulation of toxic heavy metals in the edible fishes of eastern Kolkata wetlands (EKW), the designated Ramsar Site of West Bengal, India. *International Journal of Aquaculture and Fishery Sciences, 3*(1), 018–021.

Huang, T. K., Lin, K. W., Tung, S. P., Cheng, T. M., Chang, I. C., Hsieh, Y. Z., ... & Chiu, H. T. (2009). Glucose sensing by electrochemically grown copper nanobelt electrode. *Journal of Electroanalytical Chemistry, 636*(1–2), 123–127.

Jordanova, M., Hristovski, S., Musai, M., Boškovska, V., Rebok, K., Dinevska-Ḱovkarovska, S., & Melovski, L. (2018). Accumulation of heavy metals in some organs in barbel and chub from Crn Drim River in the Republic of Macedonia. *Bulletin of Environmental Contamination and Toxicology, 101*, 392–397.

Khan, W. R., Zulkifli, S. Z., bin Mohamad Kasim, M. R., Zimmer, M., Pazi, A. M., Kamrudin, N. A., ... & Nazre, M. (2020). Risk assessment of heavy metal concentrations in sediments of Matang mangrove forest reserve. *Tropical Conservation Science, 13*, 1940082920933122.

Kullar, S. S., Shao, K., Surette, C., Foucher, D., Mergler, D., Cormier, P., ... & Zayed, J. (2019). A benchmark concentration analysis for manganese in drinking water and IQ deficits in children. *Environmental International, 130*, 104746.

Kumari, B., Kumar, V., Sinha, A. K., Ahsan, J., Ghosh, A. K., Wang, H., & De Boeck, G. (2017). Toxicology of arsenic in fish and aquatic systems. *Environmental Chemistry Letters, 15*, 43–64.

Li, N., Tian, Y., Zhang, J., Zuo, W., Zhan, W., & Zhang, J. (2017). Heavy metal contamination status and source apportionment in sediments of Songhua River Harbin region, Northeast China. *Environmental Science and Pollution Research, 24*(4), 3214–3225.

Lu, X., Wang, L., Lei, K., Huang, J., & Zhai, Y. (2009). Contamination assessment of copper, lead, zinc, manganese, and nickel in street dust of Baoji, NW China. *Journal of Hazardous Materials, 161*(2–3), 1058–1062.

Mandal, P. (2017). An insight into environmental contamination of arsenic on animal health. *Emerging Contaminants, 3*(1), 17–22.

Patel, K. S., Shukla, A., Tripathi, A. N., & Hoffmann, P. (2001). Heavy metal concentrations of precipitation in east Madhya Pradesh of India. *Water, Air, and Soil Pollution, 130*, 463–468.

Praveena, S. M., Ahmed, A., & Radojevic, M. (2018). Heavy metal contamination in the east coast of Peninsular Malaysia: A review. *Environmental Science and Pollution Research, 28*(14), 17325–17335.

Raju, N. J. (2006). Seasonal evaluation of hydro-geochemical parameters using correlation and regression analysis. *Current Science, 91*(6), 820–826.

Raju, N. J., Shukla, U. K., & Ram, P. (2011). Hydrogeochemistry for the assessment of groundwater quality in Varanasi: A fast-urbanizing center in Uttar Pradesh, India. *Environmental Monitoring and Assessment, 173*, 279–300.

Ramesh, P., Jayaprakash, M., & Gopal, V. (2020). The seasonal variation of physic-chemical parameters in surface water of Kollidam Estuary, Nagapattinam, SE Coast of India. *Journal of Xi'an University of Architecture & Technology, 7*(3), 5761–5768.

Rattan, R. K., Datta, S. P., Chandra, S., & Saharan, N. (2002). Heavy metals and environmental quality: Indian scenario. *Fertilizer News, 47*, 21–40.

Saha, P., & Paul, B. (2019). Assessment of heavy metal toxicity related with human health risk in the surface water of an industrialized area by a novel technique. *Human and Ecological Risk Assessment: An International Journal, 25*(4), 966–987.

Senesi, G. S., Baldassarre, G., Senesi, N., & Radina, B. (1999). Trace element inputs into soils by anthropogenic activities and implications for human health. *Chemosphere, 39*(2), 343–377.

Shankar, S., Shiv, U., & Shikha. (2014). Arsenic contamination of groundwater: A review of sources, prevalence, health risks, and strategies for mitigation. *Science World Journal, 2014*, Article 304524.

Singh, A., Sharma, R. K., Agrawal, M., & Marshall, F. M. (2010). Health risk assessment of heavy metals via dietary intake of foodstuffs from the wastewater irrigated site of a dry tropical area of India. *Food Chemistry and Toxicology, 48*(2), 611–619.

Singh, A., Singh, D., & Yadav, H. (2017). Impact and assessment of heavy metal toxicity on water quality, edible fishes, and sediments in lakes: A review. *Trends in Biosciences, 10*, 1551–1560.

Singh, J., Yadav, P., Pal, A. K., & Mishra, V. (2020). Water pollutants: Origin and status. In P. D., Kumar, P., Singh, P., & Patil, S. (Eds.), *Sensors in water pollutants monitoring: Role of material* (pp. 17–36). Springer. https://doi.org/10.1007/978-981-15-0671-0_2

Swaileh, K. M., & Sansur, R. (2004). Monitoring urban heavy metal pollution using the sparrow. *Journal of Environmental Monitoring, 8*, 209–213.

Tiwari, A. K., & Singh, A. K. (2014). Hydrogeochemical investigation and groundwater quality assessment of Pratapgarh district, Uttar Pradesh. *Journal of Geological Society of India, 83*(3), 329–343.

Tiwari, K., Sharma, A., & Goyal, R. (2013). Impact of climate change on water resource systems of Rajasthan state. In D. T. Shete (Ed.), *Proceedings of National Seminar on Water Resource System* (pp. 27–29). Parul Institute of Engineering and Technology.

Wang, X., Sato, T., Xing, B., & Tao, S. (2005). Health risks of heavy metals to the general public in Tianjin, China via consumption of vegetables and fish. *Science of the Total Environment, 350*(1–3), 28–37.

World Health Organization. (2017). *Guidelines for drinking-water quality* (4th ed.). Geneva: WHO Press.

Zhang, Z., Xiao, C., Adeyeye, O., Yang, W., & Liang, X. (2020). Source and mobilization mechanism of iron, manganese, and arsenic in groundwater of Shuangliao City, Northeast China. *Water (Switzerland), 12*(2).

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