International Research Journal of Environmental Sciences ISSN 2319–1414
Vol. **15(1),** 14-22, January **(2026)** *Int. Res. J. Environmental Sci.*

Comparative Spatiotemporal assessment and bioaccumulation strategies of Heavy Metals Across Protected, Pilgrimage and Urbanized Zones of the Pamba River Basin, Kerala, South India

Vidhya Vasudevan* and R. Aruna Devy
[1]Department of Zoology, Catholicate College, Pathanamthita, Kerala, India
[2]Department of Zoology, St. Thomas College, Ranni, Kerala, India
vidhyamalu1998@gmail.com

Available online at: www.isca.in, www.isca.me
Received 12th December 2025, revised 30th December 2025, accepted 20th January 2025

Abstract

The Pamba River is one of the major freshwater systems in Kerala, India. It plays a crucial ecological and socio-cultural role, particularly due to the annual Sabarimala pilgrimage that significantly increases human influence on the river basin. The present study provides a comparative spatiotemporal assessment of heavy metal concentrations across protected, pilgrimage, and urbanised zones of the Pamba River. It evaluates the bioaccumulation patterns in selected fish species from selected sites, also using water and sediment samples collected from Kakki Reservoir, Pamba, Chengannur and Punnamada regions. Heavy metals, including Al, Cr, Zn, Cd, and Pb, were quantified using standard analytical protocols. Results indicated substantially higher concentrations of Al and Cr in pilgrimage and urban regions, while protected upstream sites showed lower contamination. Sediments exhibited strong metal accumulation, especially for Al, Zn and Cr, reflecting combined geogenic and human-derived inputs. Bioaccumulation analysis in Anabas testudineus and Etroplussuratensis revealed elevated uptake of Al and Cr, indicating their sensitivity to fluctuating environmental metal loads. Seasonal comparison further showed increased metal concentrations during the pilgrimage period, highlighting the impact of large-scale human presence. Overall, the findings demonstrate progressive but spatially variable metal enrichment in the Pamba River system and emphasise the need for continuous monitoring, improved waste management during peak pilgrimage seasons and targeted conservation measures to safeguard this culturally and ecologically important river. Overall, the integrated dataset indicates that the Pamba River is undergoing uneven but progressive heavy metal enrichment driven by natural weathering, pilgrimage-associated disturbances and urban effluents in downstream sections. These findings highlight the need for sustained monitoring, improved waste management strategies during peak pilgrim seasons and targeted ecological restoration to preserve the river's health and long-term sustainability.

Keywords: Heavy metals, Freshwater ecosystems, Pamba River, Metal contamination, *Etroplussuratensis*, Anabas testudines, River pollution.

Introduction

Rivers are the dynamic and most vital freshwater ecosystem which supports the ecological stability, human livelihoods and the socio-cultural activities[1,2]. India is endowed with one of the world's most extensive riverine systems, supporting diverse ecological habitats and sustaining millions of people across the subcontinent[3]. Indian rivers play a vital role in agriculture, drinking water supply, transportation, hydropower generation, and cultural practices, making them central to the nation's socio-economic development[4]. These river basins, originating from the Himalayas and the Peninsular highlands, exhibit significant seasonal and spatial variations in flow, influencing water quality and ecosystem dynamics[5]. In recent decades, increasing anthropogenic pressures such as urbanization, industrial discharge, pilgrimage activities, and agricultural runoff have contributed to the degradation of many river systems[6,7]. Understanding the physicochemical characteristics and contaminant levels in Indian rivers is essential for effective water resource management and conservation[8]. Rivers hold immense ecological and spiritual significance, acting as major sources of drinking water, agricultural, inland fisheries, and cultural identity[1].

In India, riverine ecosystems hold immense ecological and spiritual significance, acting as major sources of drinking water, agriculture, inland fisheries, and cultural identity[4]. However, increasing anthropogenic pressures have led to a gradual decline in river health, particularly due to pollution from industrial discharge, domestic wastewater, urban runoff, and seasonal human activities[9]. Heavy metal contamination has emerged as one of the most persistent environmental problems in freshwater systems because of their non-biodegradable nature, long-term persistence, and ability to bioaccumulate in aquatic organisms[10,11]. These pollutants pose threats not only to aquatic ecosystems but also to the communities that depend on them for drinking water, fishing, and religious activities[12].

The Pamba River, the third-longest river in Kerala, represents a unique combination of ecological importance and religious relevance[13]. Originating from the Western Ghats (Pulachimalai, Idukki), the river traverses forested highlands, rural villages, and urban settlements before draining into the Vembanad Lake[14]. It covers four districts in Kerala, namely Idukki, Kottayam, Pathanamthitta and Alappuzha[13]. Its importance lies in its role in supporting the Sabarimala pilgrimage, one of the largest annual religious gatherings in the world[15]. Every year, millions of pilgrims visit Sabarimala, and the Pamba River becomes a central site for ritual bathing, transportation, and temporary settlements[7]. This massive seasonal influx of people significantly alters the river's physical, chemical, and biological characteristics[15]. The pilgrimage season (Mandala–Makaravilakku) is associated with increased waste generation, open defecation, plastic discharge, food waste disposal, and high organic loading, all of which have potential implications for heavy metal entry into the river system[7,9].

In addition to pilgrimage-related stress, the Pamba Basin is also influenced by urbanisation and land-use changes, particularly in downstream regions[13]. Urban centres, agricultural fields, resorts, and local markets contribute to the continuous discharge of untreated sewage, metal-laden runoff, pesticides, and household effluents[4]. In contrast, the upper catchment area, being protected forest land, experiences minimal anthropogenic interference and serves as an ecological reference zone[14]. These three distinct zones—protected, pilgrimage, and urbanized—therefore provide a natural gradient for studying the spatial and temporal variability of heavy metal contamination[8].

Heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), zinc (Zn) etc. can enter freshwater systems through both natural weathering and human activities[11]. Once introduced, they can accumulate in sediments, water, and most importantly, in aquatic organisms[10]. Fish and benthic organisms are excellent indicators of metal contamination because heavy metals tend to bioaccumulate in their tissues over time [16]. Bioaccumulation not only affects the physiology and survival of aquatic species but also introduces potential human health risks through food-chain transfer[12]. Understanding these bioaccumulation strategies across zones with different levels of human influence is crucial for environmental risk assessment[17].

Despite rising concerns, comprehensive studies integrating spatiotemporal assessment and bioaccumulation patterns in the Pamba River Basin remain limited[15]. Most existing research focuses on water pollution during the pilgrimage season alone, while comparative data across protected, pilgrimage, and urbanized zones throughout different seasons are scarce[7]. There is also an inadequate understanding of how heavy metal concentrations vary between normal (non-pilgrimage) periods and peak pilgrimage months[8]. Such information is essential for identifying contamination hotspots, evaluating ecological risks, and developing targeted river management policies[5]. Given this background, the present study aims to conduct a detailed spatiotemporal assessment of heavy metals and to examine bioaccumulation trends in aquatic organisms across different ecological settings of the Pamba River Basin. By comparing protected forest regions, pilgrimage-dominated zones, and urbanized stretches of the river, this research provides a holistic understanding of how human activities shape heavy metal distribution. The findings of this study will serve as valuable baseline data for policymakers, environmental scientists, and conservationists, helping to strengthen river restoration strategies, regulate waste management during pilgrimage, and ensure the long-term ecological health of the Pamba River.

Materials and Methods

Study area: The Pamba River is also known as *Dakshin Ganga* in flows through four districts in Kerala, south India. It is the third largest river in Kerala, about 176 km long. It is originated from *Pulachimalai* hill in the *Peerumedu* plateau of Idukki district, Kerala. The river is significant because of its religious importance, as it flows through the famous pilgrimage center Sabarimala. The Sabarimala is one of the overcrowded pilgrimage stations in South India, yearly around 32.5 lakh people visiting here during the pilgrimage season.

The river (latitude 9.414599 and longitude 77.06802) is divided into three distinct zones based on the topographical and physiographical analysis. The first one is the highland region (above 75 MSL-Mean Sea Level), the second is the midland region (between 75 and 15 MSL), and the last one is the lowland region (below 15 MSL). The river is highly dependable by a huge population for various purposes, in the aspect of certain religion concepts, agricultural purposes, drinking water, through riverine fishes etc.

The present study focuses on the first sampling site, located at the Kakki reservoir, which falls within a protected forest zone and is designated as S1. The second site (S2) is situated along the Pamba River near Sabarimala, a major pilgrimage centre. Both S1 and S2 lie within the highland region of the Pamba basin. Among the urbanised zones, the third site (S3) corresponds to the municipal region of Chengannur. The final sampling location, Punnamada, represents the lowland region where the river converges before entering the larger agricultural landscape. The lowland zone is characterised by extensive agricultural activity, particularly paddy cultivation, and depends heavily on the river for freshwater supply. The river is also utilised for multiple domestic and livelihood needs, including fisheries, with several riverine fish species commonly harvested for human consumption.

Sample collection: Water, sediment, and fish species were collected during the dry season (Months of January- May moths of 2025).

Water sample collection: The surface water samples were collected from the selected sites by using pre-cleaned polyethene bottles of a size of 1 litre. Totally 5 different samples were collected within a minimum distance of 200 m from each collection site (S1, S2, S3, S4 and S5). For sample preservation,1-2 ml of concentrated nitric acid (HNO_3) is added to the sample to lower the pH. This step is for stabilising the sample and preventing the heavy metals from adhering to the container wall or precipitating. Then samples were stored in an ice box to maintain the temperature. By following the EPA method 1669- sampling ambient water for trace metals.

Sediment Collections: The sediment samples were collected by using a grab samples from five different stations (around 200-meter distance) of each specific site (S1, S2, S3, S4 and S5). The collected samples were stored in pre-cleaned polythene bags and stored in an icebox at 4°C to prevent microbial activity.

Fish Species Collection: The fish species were selected based on the abundance, and those that are especially used for human consumption. The *Anabas testuidens* were collected near the sabarmila region with the help of some local fishermen. Additionally, *Etroplus suratensis* was selected from the last site, which s Punnamda, for the heavy metal analysis. The fish were stored in an icebox in a frozen condition to prevent their decomposition. In total, 5-6 fish of each species were collected, and the muscle samples were used for heavy metal detection, because the most consumed part in a fish is the muscles.

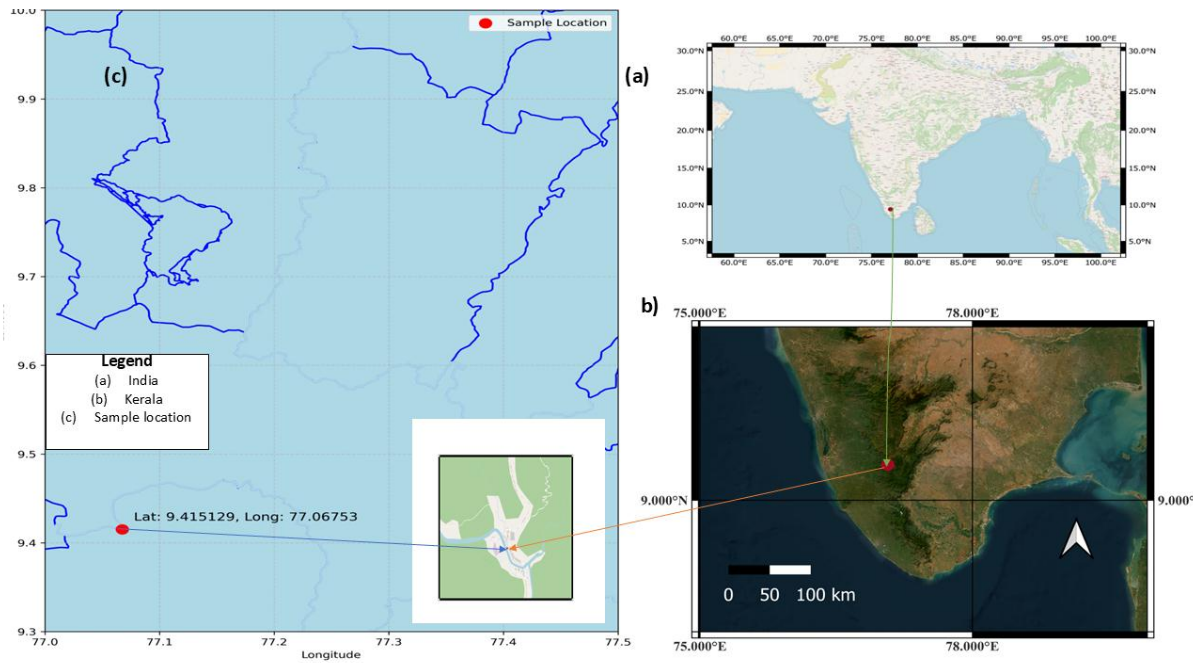
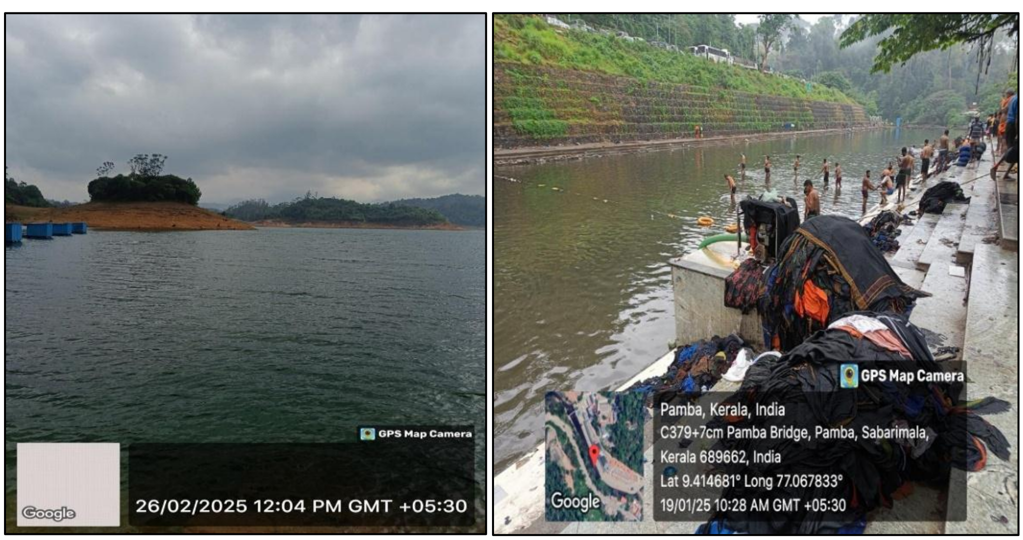
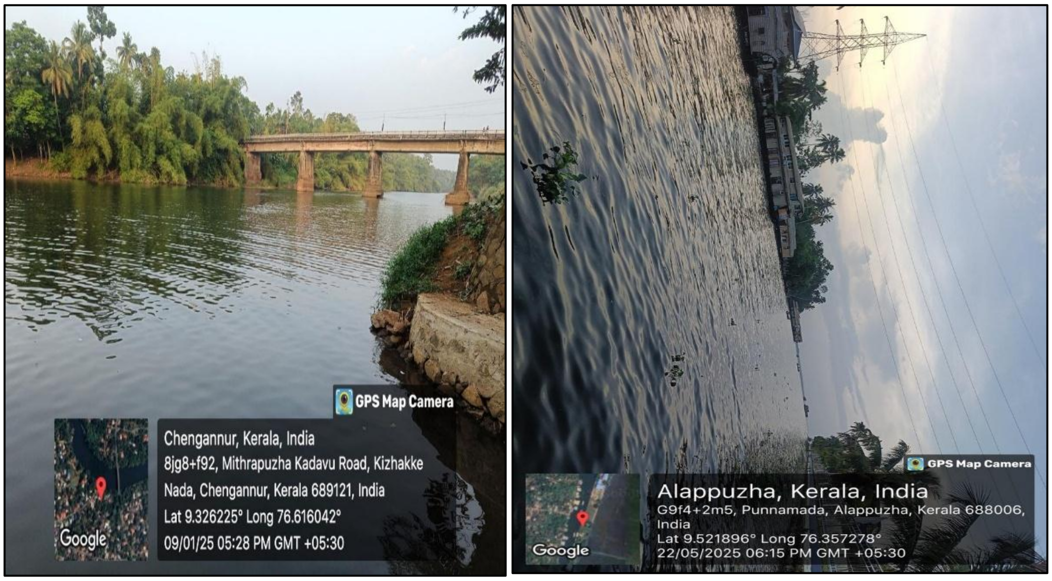


Figure-1: Map showing the sampling sites of Pamba River.



(A) (B)



(C) (D)

Figure-2: Study areas (A- Kakki Reservoir (S 1), B- Pamba (S 2), C- Chengannur (S 3), D- Punnamada (S 4).

Figure-2: Image of fish species *Etroplus suratensis* (from Punnamda the converging point).

Laboratory Analysis: Sample Preparation: The water samples were acidified with concentrated HNO_3 solution. The sediment samples were first dried to remove the moisture content and then oven dried. After that powder them as fine structures then after sieving them using 230 mesh (600 µ). This sample is used for heavy metal detection. After analysing the morphometric parameters of fish species, the muscles were dissected carefully from each fish. The dissected parts were oven dried and make it into fine powder and used for heavy metal analysis.

Figure-3: Image of fish sample *Anabas testudineus* (Collected near Sabarimala region).

Analysis for Heavy metals: This analysis was conducted by digesting the samples using a Microwave digester. The microwave digestion procedure was conducted using the methods described by researchers[18,19]. A sample weighing approximately 0.1g was combined with 8 ml of nitric acid (Trace Metal TM Grade) and 2ml of sulphuric acid (Trace Metal TM Grade) in a Teflon tube. Following a 30-minute open digestion, the closed digestion was performed using a microwave digestion device. The sample took around 2 hours to fully digest. After completing the digestion process, the digestion containers were cooled briefly in the microwave and then on the bench or in a water bath as advised. Following the cooling process, the digested liquid underwent filtration using What man no. 42 filters. The filtered liquid was thereafter poured into a 25-ml standard flask and filled using deionized distilled water. This process was carried out under identical conditions as the calibration standards. A blank digest was prepared using the same methodology.

Measurement of the metal content: Heavy metal and other mineral content were analysed by Inductively Coupled Plasma-Mass Spectrometry, ICP-MS, (iCAP Q, Thermo Fisher). The ICP-MS working conditions are provided in Table-1. Standardization was done with the ICP multielement standard VI made by Merk.

Results and Discussion

Heavy Metals in Water samples: The concentration of heavy metals across the four sampling sites—Kakki Reservoir, Pamba, Chengannur, and Punnamada—exhibited marked spatial variation, reflecting both geogenic influences and varying degrees of anthropogenic pressure. Aluminium showed the highest level in Kakki Reservoir (910.99 mg/L), followed by Punnamada and Chengannur, while Pamba recorded the lowest concentration, indicating minimal disturbance. Chromium was most elevated at Chengannur (103.76 mg/L), suggesting significant industrial or urban inputs, whereas Pamba again showed the lowest value. Zinc displayed a similar pattern with maximum levels in Chengannur (70.43 mg/L) and the lowest at Pamba (1.57 mg/L), falling below the detection limit, indicating negligible contamination at this site. Cadmium concentrations remained relatively low across all sites but peaked at Punnamada (5.24 mg/L), likely due to agricultural runoff and domestic wastewater discharge, while Pamba showed values near the detection limit. Lead concentrations were also highest at Chengannur (53.36 mg/L), followed by Kakki Reservoir and Punnamada, with Pamba again showing minimal contamination. Overall, the data indicate that urban and semi-urban sites such as Chengannur and Punnamada exhibit pronounced heavy metal enrichment due to anthropogenic activities, whereas Pamba remains the least impacted, and Kakki Reservoir reflects primarily natural geogenic contributions. The spatial distribution of heavy metals in the Pamba River basin showed pronounced variability across the four sampling locations, highlighting distinct environmental pressures shaping local water quality. Aluminium exhibited exceptionally high concentrations at Kakki Reservoir, reflecting natural geological inputs, while all other metals were significantly elevated at Chengannur, indicating strong anthropogenic influence from urban, industrial, and domestic sources. Punnamada demonstrated moderate enrichment, particularly for cadmium, suggesting contributions from agricultural runoff and wastewater intrusion. In contrast, Pamba consistently recorded the lowest values for all metals, with several concentrations approaching their respective detection limits, confirming its relatively undisturbed condition. The overall pattern clearly demonstrates that urbanized stretches of the river experience notable heavy-metal loading, whereas protected upstream regions remain largely unaffected. These findings emphasize the need for targeted management strategies in high-impact zones, with priority interventions in Chengannur and Punnamada to mitigate contaminant influx and preserve downstream ecological integrity.

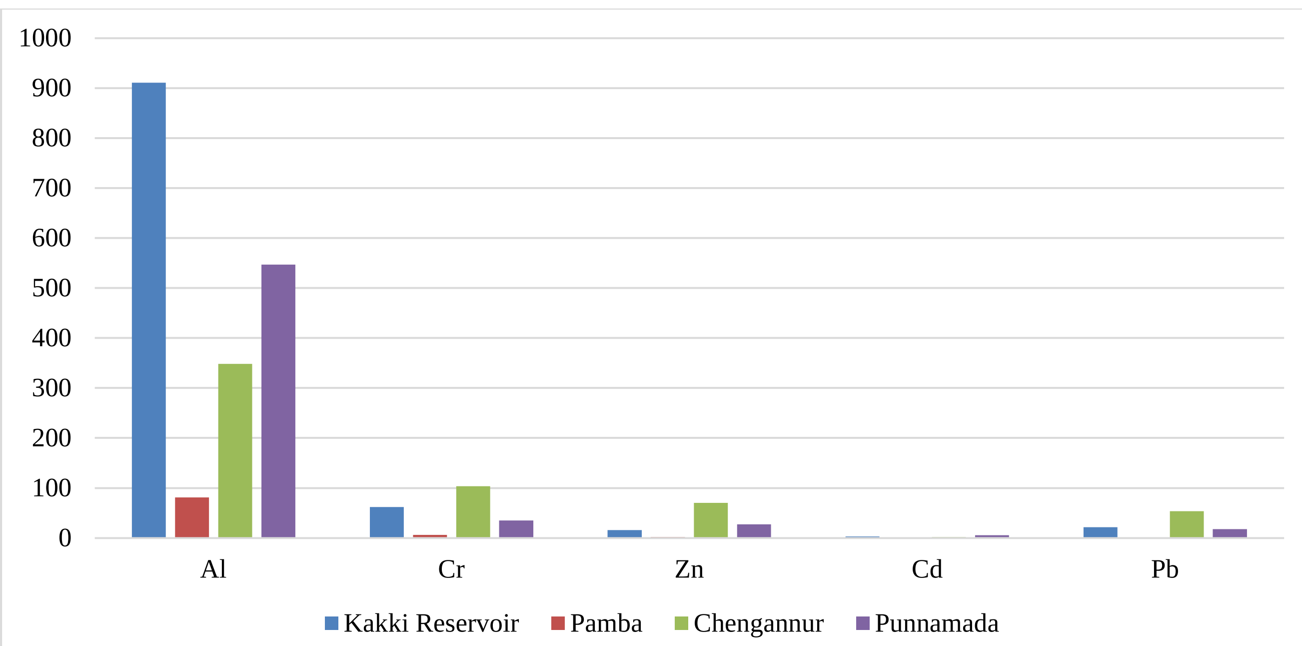


Figure-4: Heavy metals in water sample.

Table-1: Heavy Metal concentration in water samples.

Site	Al	Cr	Zn	Cd	Pb
Kakki Reservoir	910.9884	62.11656	15.52699	2.7349009	21.42486
Pamba	81.33349	6.143344	1.57134	0.0226021	1.098867
Chengannur	348.1177	103.7564	70.42729	1.5595632	53.36075
Punnamada	546.585	34.81242	27.08431	5.2438466	17.51269
Detection Limit (mg/l)	3.3	12	2.9	0.2	0.2

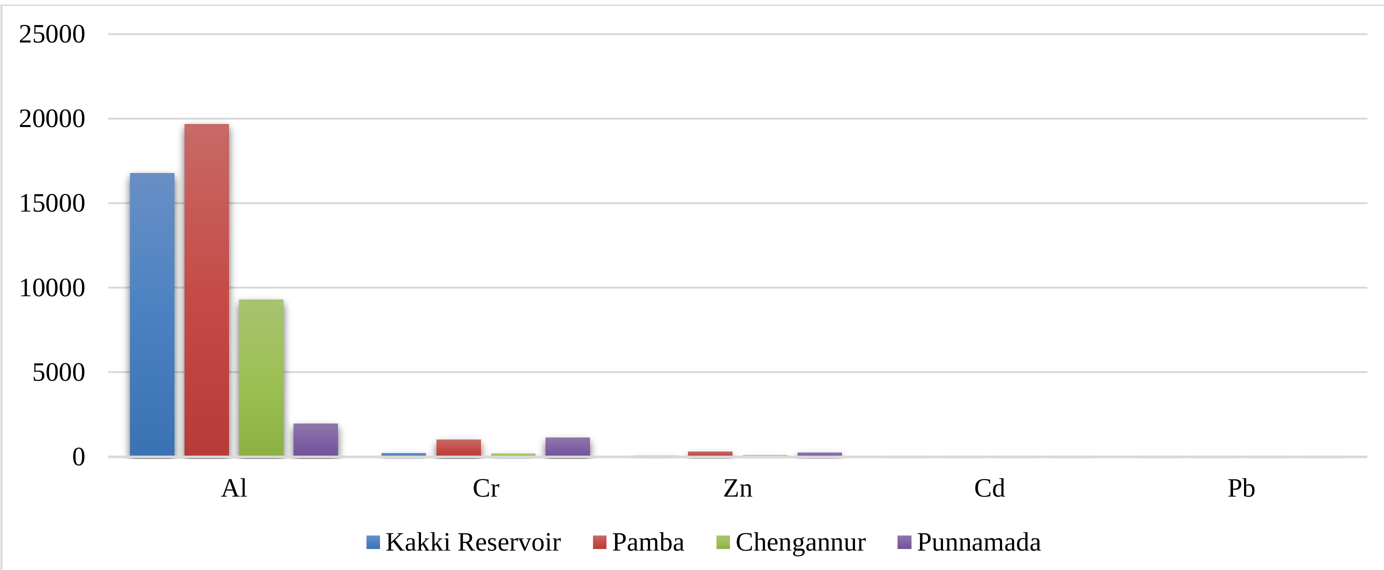


Figure-5: Heavy Metals in Sediment Samples.

Table-2: Heavy Metals in Sediment samples.

Site	Al	Cr	Zn	Cd	Pb
Kakki Reservoir16784.56		216.367	75.498	5.687	36.245
Pamba	19688.2	1018.006	307.7936	1.6497	30.678
Chengannur	9290.021	186.2159	89.73928	0.6459405	10.56457
Punnamada	1965.5	1134.92	242.68	26.46	21.49
Detection Limit (mg/kg)	165	600	40	4	4

Heavy metals in sediment samples: The sediment samples exhibited pronounced spatial variability in heavy-metal accumulation across the four sites, reflecting differences in watershed characteristics, anthropogenic inputs and hydrodynamic conditions. Aluminium (Al) concentrations were exceptionally elevated at Pamba (19,688.2 mg/kg) and Kakki Reservoir (16,784.56 mg/kg), indicating the predominance of aluminosilicate minerals and possible catchment-derived erosional inputs, whereas Chengannur (9,290.021 mg/kg) and Punnamada (1,965.5 mg/kg) showed comparatively lower levels, suggesting reduced mineralogenic loading downstream. Chromium (Cr) displayed a marked gradient, with Pamba showing the highest value (1,018.006 mg/kg), far exceeding that of Kakki (216.367 mg/kg), Chengannur (186.2159 mg/kg) and Punnamada (1,134.92 mg/kg), highlighting the influence of domestic wastewater, religious activities and increased industrial discharge in midstream and urban stretches. Zinc (Zn) accumulation followed a similar pattern, peaking at Pamba (307.7936 mg/kg) and decreasing downstream, but remaining above detection limits across all stations, signifying the widespread distribution of Zn-bearing particulates from household, boating and surface-runoff sources. Cadmium (Cd) concentrations remained relatively low at Chengannur (0.6459 mg/kg) and Pamba (1.6497 mg/kg) but were substantially higher at Punnamada (26.46 mg/kg), implying site-specific contamination likely linked to localized urban waste inputs and canal-connected backwater dynamics. Lead (Pb) concentrations showed notable enrichment at Kakki (36.245 mg/kg) and Pamba (30.678 mg/kg), whereas Chengannur (10.56457 mg/kg) and Punnamada (21.49 mg/kg) presented moderate levels, reflecting differences in sediment retention capacity, vehicular emissions, and atmospheric deposition patterns. Overall, the elevated concentrations of several metals, particularly at Pamba and Kakki, exceed their respective detection limits and point towards significant geogenic–anthropogenic interactions influencing sediment quality in the Pamba River system, underlining the need for continuous monitoring and targeted mitigation strategies.

Heavy metals in fish species: *Anabas testudineus:* The heavy-metal profile of *Anabas testudineus* revealed moderate accumulation of Al (236.52 mg/kg), while Cr (16.002 mg/kg) and Zn (16.152 mg/kg) were present at comparatively lower yet detectable levels, indicating differential metal uptake reflecting both environmental exposure and species-specific bioaccumulation physiology. Aluminium, though not typically associated with strong bioaccumulation in fish tissues, appeared at concentrations far above its detection limit (3.3 mg/kg), suggesting substantial geogenic or sediment-derived inputs within the habitat. Chromium concentrations exceeded the detection threshold (12 mg/kg), highlighting possible contamination from industrial effluents, run-off, or religious activity-associated waste along the riverine stretch. Zinc, an essential micronutrient but toxic at elevated levels, also remained above the detection limit (8 mg/kg), implying continuous exposure from domestic wastewater, feed sources, or particulate suspension within the aquatic system. Cadmium, a non-essential toxic metal, was detected only at trace levels (0.1226 mg/kg), remaining well below its detection limit (20 mg/kg), indicating minimal Cd bioavailability in the fish environment during sampling. Lead accumulation (1.6702 mg/kg), though higher than Cd, remained below the detection limit (2 mg/kg), signifying relatively low Pb contamination in this species at the sampling site. Overall, the metal burden in E. *suratensis* suggests moderate bioaccumulation primarily driven by Al, with other metals occurring at low to moderate levels, reflecting a combination of natural background inputs and limited anthropogenic influence in the studied segment of the Pamba River system.

Etroplussuratensis: The heavy metal analysis of the muscle tissue of *Etroplussuratensis* showed a clear variation in the extent of metal accumulation. Aluminium recorded the highest concentration (345.55 mg/kg) in the muscle, indicating strong bioaccumulation from the surrounding environment. Chromium (86.67 mg/kg) and zinc (27.54 mg/kg) were also present at elevated levels, both exceeding their analytical detection limits, suggesting active uptake and retention of these metals by the fish. In contrast, cadmium was detected only at a very low concentration (1.78 mg/kg), remaining far below its detection limit, which indicates minimal Cd accumulation in the muscle tissue. Lead (Pb) was BDL, suggesting that *E. suratensis* muscle does not accumulate Pb to detectable quantities. Overall, the results reveal that the muscle tissue of *Etroplussuratensis* accumulates aluminium, chromium, and zinc more prominently than cadmium and lead, reflecting both the environmental availability of these metals and species-specific bioaccumulation behaviour.

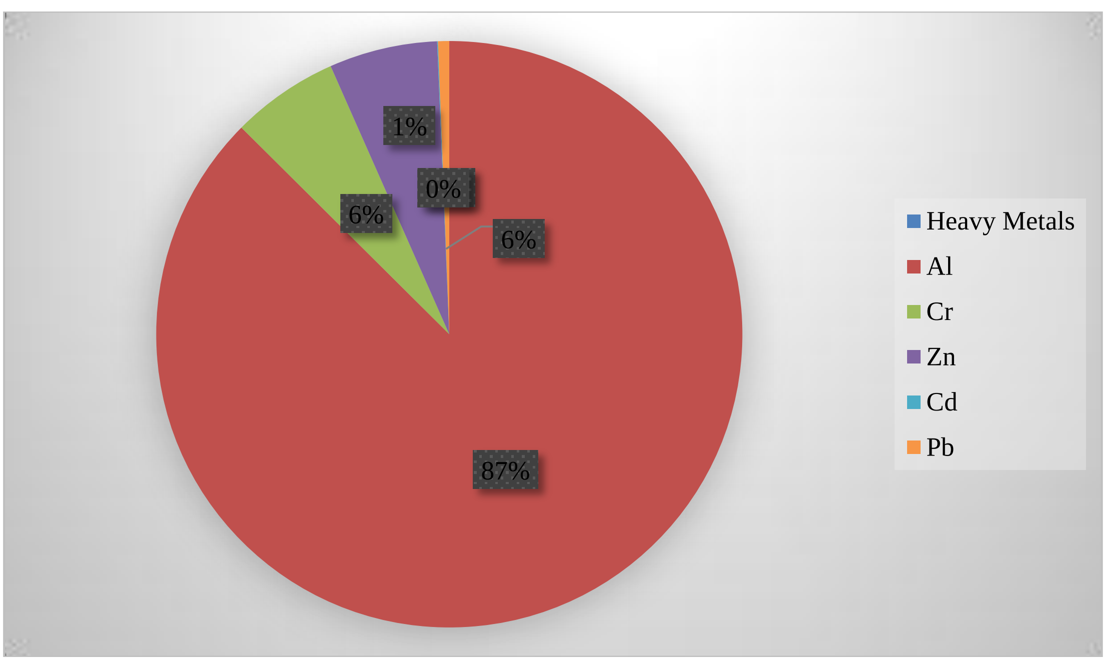


Figure-6: Heavy Metals in muscle tissue of *A. testudineus.*

Table-3: Heavy Metals in muscle tissue of A. testudineus.

Heavy Metals	Al	Cr	Zn	Cd	Pb
Concentration in samples (mg/kg)	236.52	16.002	16.152	0.1226	1.6702
Detection Limit (mg/kg)	3.3	12	8	20	2

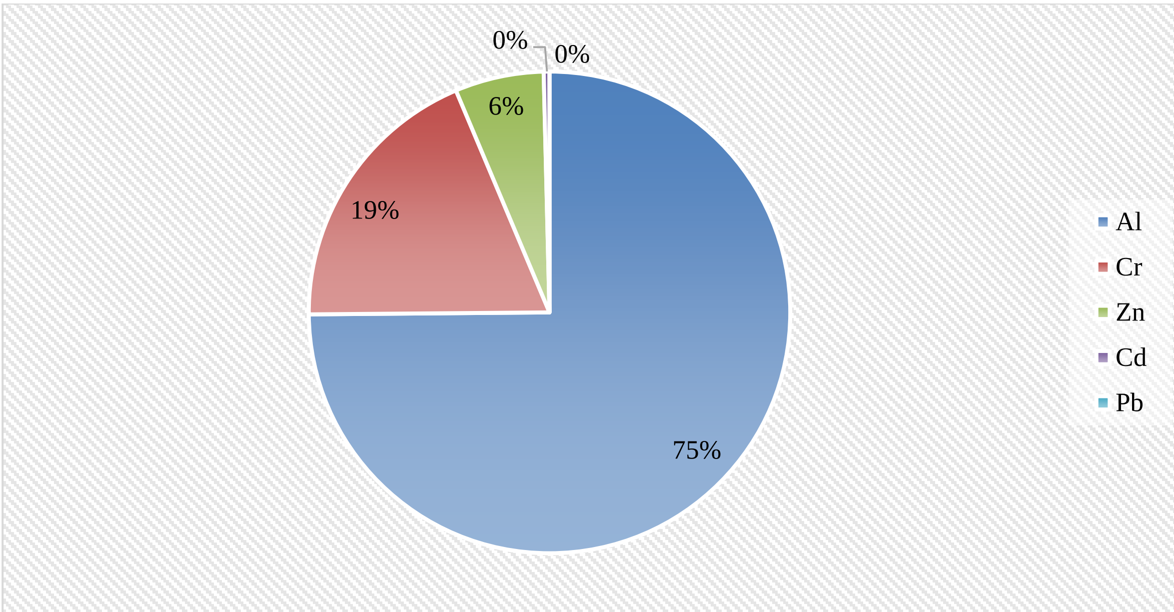


Figure-7: Heavy Metal concentration in *Etroplussuratensis.*

Table-5: Heavy Metal concentration in *Etroplussuratensis.*

Heavy Metals	Al	Cr	Zn	Cd	Pb
Concentration in samples (mg/kg)	345.55	86.67	27.54	1.78	BDL
Detection Limit (mg/kg)	3.3	12	8	20	2

Conclusion

The present investigation provides a comprehensive spatiotemporal assessment of heavy-metal contamination and bioaccumulation patterns across the protected, pilgrimage-influenced, and urbanized zones of the Pamba River basin. The findings clearly demonstrate that both water and sediment compartments exhibit substantial spatial variability in metal concentrations, with the midstream pilgrimage zone (Pamba) and the upstream reservoir region (Kakki) showing the highest levels of Al, Cr and Pb, reflecting the combined influence of natural geological weathering, intense anthropogenic pressure, and seasonal influx of pilgrims. In contrast, downstream locations such as Chengannur and the urban-backwater interface at Punnamada displayed elevated concentrations of Zn and Cd in specific matrices, indicating site-specific contamination potentially linked to municipal effluents, agricultural runoff and stagnation-induced metal retention.

Bioaccumulation analysis in *Etroplussuratensis* further confirmed that the riverine organism responds sensitively to ambient metal loads, with Al and Zn demonstrating the greatest uptake, whereas Cd and Pb remained comparatively low, signifying lower bioavailability during the sampling period. Nevertheless, the presence of Cr and Pb above permissible limits in several environmental samples highlights a potential risk to the trophic system and raises concerns regarding long-term ecological and human-health impacts.

Collectively, the study underscores the urgent need for continuous biomonitoring, stricter pollution-control measures during pilgrimage seasons, and improved wastewater management in downstream settlements. The integrated evaluation of water, sediment, and fish tissues provides a holistic understanding of metal dynamics in the Pamba River and reaffirms that the basin is undergoing progressive, but uneven contamination driven by both natural and anthropogenic factors. Sustained management interventions, supported by regular scientific surveillance, are essential to safeguard the ecological integrity of this culturally significant river system.

Acknowledgement

I sincerely acknowledge the institutional support and research facilities provided by the Environmental Science Department of Mahatma Gandhi University, which were indispensable for the successful execution of this study. I am grateful to the technical and laboratory staff for their invaluable assistance in sample preparation, and analysis. I extend my appreciation to my friend Nidhin and the local communities along the Pamba River basin for their cooperation and support during field investigations, which made data collection feasible and effective. Finally, I acknowledge the broader academic and research community whose prior studies and publications provided the essential foundation for this research.

References

1. Gopal, B. (2005). Does inland aquatic biodiversity have a future in Asian developing countries?. *Hydrobiologia*, 542, 69–75. https://doi.org/10.1007/s10750-004-5529-3

2. Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., et al. (2010). Global threats to human water security and river biodiversity. *Nature*, 467, 555–561. https://doi.org/10. 1038/nature09440

3. Central Water Commission (CWC) (2019). *Water and related statistics.* Ministry of Jal Shakti, Government of India.

4. Kumar, V., Sharma, A., Kumar, R., Bhardwaj, R., Thukral, A. K., & Rodrigo-Comino, J. (2017). Assessment of heavy metal pollution in river water: A review. *Environmental Monitoring and Assessment*, 189, 540. https://doi.org/10. 1007/s10661-017-6284-z

5. Chapman, D. (1996). *Water quality assessments: A guide to the use of biota, sediments and water in environmental monitoring* (2nd ed.). E & FN Spon, WHO/UNEP.

6. Garg, R. K., Rao, R. J., & Uchchariya, D. (2010). Seasonal variations in water quality and major threats to Ramsagar reservoir, India. *Environmental Monitoring and Assessment*, 168, 1–14. https://doi.org/10.1007/s10661-009-1091-8

7. Sharma, D., Kansal, A., & Pelto, J. (2015). Water quality changes due to religious mass bathing events. *Environmental Monitoring and Assessment*, 187, 237. https://doi.org/10.1007/s10661-015-4464-x

8. Varol, M., & Şen, B. (2012). Assessment of nutrient and heavy metal contamination in surface water using multivariate statistical techniques. *Environmental Research*, 118, 164–175. https://doi.org/10.1016/j.envres. 2012.08.004

9. Dwivedi, S., Mishra, S., & Tripathi, R. D. (2018). Ganga water pollution: A potential health threat to inhabitants of Ganga basin. *Journal of Environmental Biology*, 39, 707–714.

10. Ali, H., Khan, E., & Ilahi, I. (2019). Environmental chemistry and ecotoxicology of hazardous heavy metals: Environmental persistence, toxicity, and bioaccumulation. *Journal of Chemistry*, 2019(1), Article ID 6730305. https://doi.org/10.1155/2019/6730305

11. Förstner, U., & Wittmann, G. T. W. (2012). *Metal pollution in the aquatic environment*. Springer-Verlag

12. Singh, A., Sharma, R. K., Agrawal, M., & Marshall, F. M. (2010). Health risk assessment of heavy metals via dietary intake of foodstuffs from wastewater irrigated sites. *Food and Chemical Toxicology*, 48, 611–619. https://doi.org/10.1016/j.fct.2009.11.04

13. Nair, S. M., & Balchand, A. N. (2015). Water quality assessment of rivers in Kerala, India. *Journal of Aquatic Biology & Fisheries*, 3, 51–58.

14. Harikumar, P. S., Nasir, U. P., & Rahman, M. P. M. (2009). Distribution of heavy metals in the core sediments of a tropical wetland system. *International Journal of Environmental Research*, 3(3), 361–372.

15. Sreejith, M. P., Mohan, M., &Muraleedharan, K. R. (2013). Impact of pilgrimage activities on water quality of Pamba River, Kerala, India. *Journal of Environmental Biology*, 34, 341–347.

16. Authman, M. M. N., Zaki, M. S., Khallaf, E. A., & Abbas, H. H. (2015). Use of fish as a bio-indicator of the effects of heavy metal pollution. *Journal of Aquatic Research and Development*, 6(4), 1–13.

17. Dural, M., Göksu, M. Z. L., & Özak, A. A. (2007). Investigation of heavy metal levels in economically important fish species captured from the Tuzla Lagoon. *Environmental Monitoring and Assessment*, 130, 411–423. https://doi.org/10.1007/s10661-006-9403-9

18. Chen, M., & Ma, L. Q. (2001). Comparison of three aqua regia digestion methods for twenty Florida soils. *Soil Science Society of America Journal*, 65(2), 491–499. https://doi.org/10.2136/sssaj2001.652491x

19. Sreenivasa, R. B., Prathima, B., Rajesh, N. M., & Shashikumar, N. S. (2014). Assessment of heavy metal contamination in soil and groundwater at automobile waste disposal sites in Davangere City, Karnataka, India. *International Journal of Current Microbiology and Applied Sciences*, *3*(9), 533–542. https://www.ijcmas.com