Heavy Metal Pollution in the Aquatic System and Their Toxicological Effects on Clarias Batrachus

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Abstract: Heavy metal pollution has emerged as a prominent environmental concern, particularly in aquatic ecosystems. This study delves deep into the impact of such pollutants on Clarias batrachus, a species intrinsic to the health and balance of freshwater habitats. By assessing variations in behaviour, physiology, and survival rates, the research underscores the peril these pollutants pose to C. batrachus. Furthermore, the study elucidates various mitigation strategies, emphasizing their significance in not just salvaging the populations of this species but also in reinstating the holistic well-being of our aquatic ecosystems. The findings underscore the urgent need for interdisciplinary interventions to combat the looming threat of heavy metal pollution.

Keywords: Heavy metal pollution, Aquatic ecosystems, Clarias batrachus, Environmental concern Behaviour, Physiology, Survival rates

1. INTRODUCTION

Clarias batrachus, colloquially recognized as the Asian catfish, holds a position of ecological significance in freshwater biomes. Native to the waters of South and Southeast Asia, this species is not only a keystone species that assists in maintaining aquatic equilibrium but also possesses a socio-economic value, particularly in communities reliant on fisheries for livelihood.

Historically, freshwater ecosystems have always faced challenges, ranging from natural calamities to man-made disruptions. However, in the recent past, with industrialization and urbanization at its peak, the introduction of heavy metals into these water bodies has escalated at an alarming rate. Anthropogenic activities, including industrial discharges, mining runoffs, and improper waste management, have culminated in the proliferation of heavy metals in aquatic habitats. Metals like mercury, lead, cadmium, and arsenic, once integrated into these ecosystems, have detrimental effects on the aquatic fauna and flora.

The ramifications of such heavy metal contamination are manifold, and species like C. batrachus are at the forefront of this onslaught. Being bottom dwellers, these catfish are directly exposed to the metal sediments, making them vital indicators of the health of the aquatic system. The vulnerabilities faced by this species not only endanger their existence but also herald broader ecosystem-level consequences. This study seeks to unpack the complex relationship between heavy metal pollution and its effects on C. batrachus, highlighting the pressing need for mitigation and protective measures.

2. STUDY AREA

Varanasi: A Historical and Ecological Overview

Varanasi, often referred to as the spiritual heart of India, is not just an ancient city steeped in mythology and religious significance but also an ecological hub, nestled on the banks of the Ganges River. The city's landscape is dotted with numerous "kunds" or water tanks, many of which are deeply rooted in religious practices, ceremonies, and legends.

Selected Kunds for the Study:

Study area Varanasi city selected in which 5 water kund selcted 1. surya kund 2.Ishwarangi Kund 3. Pishach mochan kund 4.kurukshetra kund 5. pushkar kund

The decision to study these specific kunds arises from their distinct identities and the varying degrees of human interaction they experience. Given their religious and cultural importance, these kunds are frequently visited, and numerous ceremonies are conducted in and around them. Such consistent human interaction has led to a significant influx of materials, which, combined with urban runoff, could contribute to metal contamination.

3. METHODS

The study was carried out across three urbanized regions, focusing on their freshwater bodies. These regions, characterized by their rapid urbanization, were selected to represent the varying degrees of human-induced stress on aquatic ecosystems.

3.1. Sampling:

To obtain a representative insight into the effects of heavy metal pollution, a random sampling method was employed. Specimens of Clarias batrachus were collected at periodic intervals from each freshwater body. Efforts were made to ensure the sample collection encompassed varying age groups and sizes of the fish to capture a holistic understanding of the toxicological impacts.

3.2. Analysis:

3.2.1 Water Analysis: Water samples were collected from each freshwater body alongside fish specimens. The samples were stored in pre-labeled polyethylene bottles, preserved at 4°C, and transported to the laboratory for analysis.

3.2.2 Fish Tissue Analysis:

Upon collection, fish specimens were stored on ice and transported to the lab. The tissues, primarily the gills, liver, and muscle, were dissected for further heavy metal analysis.

Both the water and fish tissue samples underwent Atomic Absorption Spectroscopy (AAS). This method was chosen for its precision and accuracy in quantifying trace amounts of heavy metals, including lead, mercury, cadmium, and arsenic. Calibration was done using standard solutions, ensuring the reliability of results.

3.3 Toxicological Assessment:

The toxicological impacts of heavy metal pollution on C. batrachus were determined based on two main criteria:

3.3.1 Behavioral Changes:

Any deviations in standard behaviors, such as erratic swimming patterns, altered feeding habits, increased surfacing frequency, or lethargy, were documented. These behaviors were monitored in a controlled environment, allowing for a clearer understanding of the stress-induced by heavy metals.

3.3.2 Physiological Changes:

Post-dissection, the tissues of the fish specimens were closely examined for any signs of lesions, discoloration, or tumors. Histopathological examinations were also conducted to ascertain cellular-level changes, which can indicate the toxic effects of heavy metals.

Together, the analytical and toxicological assessments provide a comprehensive overview of the impact of heavy metal pollution on C. batrachus in urbanized freshwater bodies.

4. RESULTS AND DISCUSSION

Heavy metal pollution has always been a subject of concern due to its potential to cause long-lasting effects on aquatic ecosystems. The present study aimed at understanding the implications of heavy metal concentrations, namely Lead (Pb), Nickel (Ni), Copper (Cu), and Zinc (Zn) in the selected freshwater bodies of Varanasi. The concentrations of these metals in the water and the subsequent effects on Clarias batrachus offer insights into the current ecological health of these systems.

1. Correlation Analysis for ph of 5 water sources

Correlation Analysis for ph of 5 water sources Correlations						
		Suryakund ph	Iswarangi ph	Durgakund ph	Kurushetra ph	Pushkar ph
Suryakund ph	Pearson Correlation	1	-.987	-.961	.995	-.614
	Sig. (2-tailed)		.102	.179	.067	.579
	N	3	3	3	3	3
Iswarangi ph	Pearson Correlation	-.987	1	.993	-.965	.480
	Sig. (2-tailed)	.102		.077	.169	.681
	N	3	3	3	3	3
Durgakund ph	Pearson Correlation	-.961	.993	1	-.926	.371
	Sig. (2-tailed)	.179	.077		.246	.758
	N	3	3	3	3	3
Kurushetra ph	Pearson Correlation	.995	-.965	-.926	1	-.693
	Sig. (2-tailed)	.067	.169	.246		.512
	N	3	3	3	3	3
Pushkar ph	Pearson Correlation	-.614	.480	.371	-.693	1
	Sig. (2-tailed)	.579	.681	.758	.512	
	N	3	3	3	3	3

2. Correlation Analysis for Turbidity of 5 water sources

Correlations						
		Suryakund Turbidity	Iswarangi Turbidity	Durgakund Turbidity	Kurushetra Turbidity	Pushkar Turbidity
Suryakund Turbidity	Pearson Correlation	1	.500	.763	.924	-.058
	Sig. (2-tailed)		.667	.448	.249	.963
	N	3	3	3	3	3
Iswarangi Turbidity	Pearson Correlation	.500	1	-.179	.792	.836
	Sig. (2-tailed)	.667		.886	.418	.370
	N	3	3	3	3	3
Durgakund Turbidity	Pearson Correlation	.763	-.179	1	.459	-.690
	Sig. (2-tailed)	.448	.886		.697	.516
	N	3	3	3	3	3
Kurushetra Turbidity	Pearson Correlation	.924	.792	.459	1	.327
	Sig. (2-tailed)	.249	.418	.697		.788
	N	3	3	3	3	3
Pushkar Turbidity	Pearson Correlation	-.058	.836	-.690	.327	1
	Sig. (2-tailed)	.963	.370	.516	.788	
	N	3	3	3	3	3

3. Correlation Analysis for TDS of 5 water sources

Correlations						
		Suryakund TDS	Iswarangi TDS	Durgakund TDS	Kurushetra TDS	PushkarTDS
Suryakund TDS	Pearson Correlation	1	.786	.365	.982	-.327
	Sig. (2-tailed)		.425	.762	.121	.788
	N	3	3	3	3	3
Iswarangi TDS	Pearson Correlation	.786	1	.863	.655	.327
	Sig. (2-tailed)	.425		.338	.546	.788
	N	3	3	3	3	3
Durgakund TDS	Pearson Correlation	.365	.863	1	.182	.760
	Sig. (2-tailed)	.762	.338		.883	.450
	N	3	3	3	3	3
Kurushetra TDS	Pearson Correlation	.982	.655	.182	1	-.500
	Sig. (2-tailed)	.121	.546	.883		.667
	N	3	3	3	3	3
PushkarTDS	Pearson Correlation	-.327	.327	.760	-.500	1
	Sig. (2-tailed)	.788	.788	.450	.667	
	N	3	3	3	3	3

4. Correlation Analysis for Total Hardness of 5 water sources

Correlations						
		Suryakund Total_Hardness	Iswarangi Total_Hardness	Durgakund Total_Hardness	Kurushetra Total_Hardness	Pushkar Total_Hardness
Suryakund Total_Hardness	Pearson Correlation	1	-.500	-1.000**	-.564	.500
	Sig. (2-tailed)		.667	.000	.619	.667
	N	3	3	3	3	3
Iswarangi Total_Hardness	Pearson Correlation	-.500	1	.500	-.434	-1.000**
	Sig. (2-tailed)	.667		.667	.715	.000
	N	3	3	3	3	3
Durgakund Total_Hardness	Pearson Correlation	-1.000**	.500	1	.564	-.500
	Sig. (2-tailed)	.000	.667		.619	.667
	N	3	3	3	3	3
Kurushetra Total_Hardness	Pearson Correlation	-.564	-.434	.564	1	.434
	Sig. (2-tailed)	.619	.715	.619		.715
	N	3	3	3	3	3
Pushkar Total_Hardness	Pearson Correlation	.500	-1.000**	-.500	.434	1
	Sig. (2-tailed)	.667	.000	.667	.715	
	N	3	3	3	3	3
**. Correlation is significant at the 0.01 level (2-tailed).						

5. Correlation Analysis for Calcium of 5 water sources

Correlations						
		Suryakund Calcium	Iswarangi Calcium	Durgakund Calcium	Kurushetra Calcium	Pushkar Calcium
Suryakund Calcium	Pearson Correlation	1	.564	.587	.769	-.854
	Sig. (2-tailed)		.619	.601	.442	.349
	N	3	3	3	3	3
Iswarangi Calcium	Pearson Correlation	.564	1	1.000*	.962	-.911
	Sig. (2-tailed)	.619		.018	.177	.270
	N	3	3	3	3	3
Durgakund Calcium	Pearson Correlation	.587	1.000*	1	.969	-.923
	Sig. (2-tailed)	.601	.018		.159	.252
	N	3	3	3	3	3
Kurushetra Calcium	Pearson Correlation	.769	.962	.969	1	-.989
	Sig. (2-tailed)	.442	.177	.159		.093
	N	3	3	3	3	3
Pushkar Calcium	Pearson Correlation	-.854	-.911	-.923	-.989	1
	Sig. (2-tailed)	.349	.270	.252	.093	
	N	3	3	3	3	3
*. Correlation is significant at the 0.05 level (2-tailed).						

6. Correlation Analysis for Magnesium of 5 water sources

Correlations						
		Suryakund Magnesium	Iswarangi Magnesium	Durgakund Magnesium	Kurushetra Magnesium	Pushkar Magnesium
Suryakund Magnesium	Pearson Correlation	1	.999*	.966	.986	.608
	Sig. (2-tailed)		.023	.167	.106	.584
	N	3	3	3	3	3
Iswarangi Magnesium	Pearson Correlation	.999*	1	.956	.991	.636
	Sig. (2-tailed)	.023		.190	.084	.561
	N	3	3	3	3	3
Durgakund Magnesium	Pearson Correlation	.966	.956	1	.909	.381
	Sig. (2-tailed)	.167	.190		.273	.751
	N	3	3	3	3	3
Kurushetra Magnesium	Pearson Correlation	.986	.991	.909	1	.731
	Sig. (2-tailed)	.106	.084	.273		.478
	N	3	3	3	3	3
Pushkar Magnesium	Pearson Correlation	.608	.636	.381	.731	1
	Sig. (2-tailed)	.584	.561	.751	.478	
	N	3	3	3	3	3
*. Correlation is significant at the 0.05 level (2-tailed).						

7. Correlation Analysis for Total Alkalinity of 5 water sources

Correlations						
		Suryakund Total_Alkalinity	Iswarangi Total_Alkalinity	Durgakund Total_Alkalinity	Kurushetra Total_Alkalinity	Pushkar Total_Alkalinity
Suryakund Total_Alkalinity	Pearson Correlation	1	.500	.990	-.388	.694
	Sig. (2-tailed)		.667	.091	.746	.512
	N	3	3	3	3	3
Iswarangi Total_Alkalinity	Pearson Correlation	.500	1	.619	.604	-.276
	Sig. (2-tailed)	.667		.575	.587	.822
	N	3	3	3	3	3
Durgakund Total_Alkalinity	Pearson Correlation	.990	.619	1	-.253	.584
	Sig. (2-tailed)	.091	.575		.837	.603
	N	3	3	3	3	3
Kurushetra Total_Alkalinity	Pearson Correlation	-.388	.604	-.253	1	-.933
	Sig. (2-tailed)	.746	.587	.837		.235
	N	3	3	3	3	3
Pushkar Total_Alkalinity	Pearson Correlation	.694	-.276	.584	-.933	1
	Sig. (2-tailed)	.512	.822	.603	.235	
	N	3	3	3	3	3

8. Correlation Analysis for Chloride of 5 water sources

Correlations						
		Suryakund Chloride	Iswarangi Chloride	Durgakund Chloride	Kurushetra Chloride	Pushkar Chloride
Suryakund Chloride	Pearson Correlation	1	-.612	-.952	.265	.371
	Sig. (2-tailed)		.581	.199	.829	.758
	N	3	3	3	3	3
Iswarangi Chloride	Pearson Correlation	-.612	1	.825	-.925	-.962
	Sig. (2-tailed)	.581		.382	.248	.177
	N	3	3	3	3	3
Durgakund Chloride	Pearson Correlation	-.952	.825	1	-.548	-.638
	Sig. (2-tailed)	.199	.382		.631	.560
	N	3	3	3	3	3
Kurushetra Chloride	Pearson Correlation	.265	-.925	-.548	1	.994
	Sig. (2-tailed)	.829	.248	.631		.071
	N	3	3	3	3	3
Pushkar Chloride	Pearson Correlation	.371	-.962	-.638	.994	1
	Sig. (2-tailed)	.758	.177	.560	.071	
	N	3	3	3	3	3

9. Correlation Analysis for Phosphate of 5 water sources

Correlations						
		Suryakund Phosphate	Iswarangi Phosphate	Durgakund Phosphate	Kurushetra Phosphate	Pushkar Phosphate
Suryakund Phosphate	Pearson Correlation	1	-.975	.994	.759	-.494
	Sig. (2-tailed)		.142	.070	.451	.671
	N	3	3	3	3	3
Iswarangi Phosphate	Pearson Correlation	-.975	1	-.994	-.885	.675
	Sig. (2-tailed)	.142		.072	.309	.529
	N	3	3	3	3	3
Durgakund Phosphate	Pearson Correlation	.994	-.994	1	.826	-.587
	Sig. (2-tailed)	.070	.072		.381	.600
	N	3	3	3	3	3
Kurushetra Phosphate	Pearson Correlation	.759	-.885	.826	1	-.941
	Sig. (2-tailed)	.451	.309	.381		.220
	N	3	3	3	3	3
Pushkar Phosphate	Pearson Correlation	-.494	.675	-.587	-.941	1
	Sig. (2-tailed)	.671	.529	.600	.220	
	N	3	3	3	3	3

10. Correlation Analysis for Sulphate of 5 water sources

Correlations						
		Suryakund Sulphate	Iswarangi Sulphate	Durgakund Sulphate	Kurushetra Sulphate	Pushkar Sulphate
Suryakund Sulphate	Pearson Correlation	1	.975	-.738	-.357	-.157
	Sig. (2-tailed)		.141	.471	.767	.899
	N	3	3	3	3	3
Iswarangi Sulphate	Pearson Correlation	.975	1	-.572	-.143	-.371
	Sig. (2-tailed)	.141		.613	.909	.758
	N	3	3	3	3	3
Durgakund Sulphate	Pearson Correlation	-.738	-.572	1	.894	-.550
	Sig. (2-tailed)	.471	.613		.296	.630
	N	3	3	3	3	3
Kurushetra Sulphate	Pearson Correlation	-.357	-.143	.894	1	-.866
	Sig. (2-tailed)	.767	.909	.296		.333
	N	3	3	3	3	3
Pushkar Sulphate	Pearson Correlation	-.157	-.371	-.550	-.866	1
	Sig. (2-tailed)	.899	.758	.630	.333	
	N	3	3	3	3	3

11. Correlation Analysis for COD of 5 water sources

Correlations						
		Suryakund COD	**Durgakund COD**	**Iswarangi COD**	**Kurushetra COD**	**Pushkar COD**
Suryakund COD	Pearson Correlation	1	.753	.375	.380	-.882
	Sig. (2-tailed)		.457	.755	.752	.313
	N	3	3	3	3	3
Durgakund COD	Pearson Correlation	.753	1	.892	-.323	-.974
	Sig. (2-tailed)	.457		.298	.791	.144
	N	3	3	3	3	3
Iswarangi COD	Pearson Correlation	.375	.892	1	-.715	-.768
	Sig. (2-tailed)	.755	.298		.492	.443
	N	3	3	3	3	3
Kurushetra COD	Pearson Correlation	.380	-.323	-.715	1	.102
	Sig. (2-tailed)	.752	.791	.492		.935
	N	3	3	3	3	3
Pushkar COD	Pearson Correlation	-.882	-.974	-.768	.102	1
	Sig. (2-tailed)	.313	.144	.443	.935	
	N	3	3	3	3	3

12. Correlation Analysis for BOD of 5 water sources

Correlations						
		Suryakund BOD	**Iswarangi BOD**	**Durgakund BOD**	**Kurushetra BOD**	**Pushkar BOD**
Suryakund BOD	Pearson Correlation	1	-.250	-.958	-.944	.527
	Sig. (2-tailed)		.839	.185	.214	.647
	N	3	3	3	3	3
Iswarangi BOD	Pearson Correlation	-.250	1	.517	-.084	-.955
	Sig. (2-tailed)	.839		.654	.946	.193
	N	3	3	3	3	3
Durgakund BOD	Pearson Correlation	-.958	.517	1	.810	-.748
	Sig. (2-tailed)	.185	.654		.399	.462
	N	3	3	3	3	3
Kurushetra BOD	Pearson Correlation	-.944	-.084	.810	1	-.217
	Sig. (2-tailed)	.214	.946	.399		.861
	N	3	3	3	3	3
Pushkar BOD	Pearson Correlation	.527	-.955	-.748	-.217	1
	Sig. (2-tailed)	.647	.193	.462	.861	
	N	3	3	3	3	3

13. Correlation Analysis for DO of 5 water sources

Correlations						
		Suryakund DO	Iswarangi DO	Durgakund DO	Kurushetra DO	Pushkar DO
Suryakund DO	Pearson Correlation	1	.888	-.677	-.933	-.809
	Sig. (2-tailed)		.305	.526	.234	.400
	N	3	3	3	3	3
Iswarangi DO	Pearson Correlation	.888	1	-.262	-.663	-.448
	Sig. (2-tailed)	.305		.831	.539	.704
	N	3	3	3	3	3
Durgakund DO	Pearson Correlation	-.677	-.262	1	.896	.980
	Sig. (2-tailed)	.526	.831		.293	.127
	N	3	3	3	3	3
Kurushetra DO	Pearson Correlation	-.933	-.663	.896	1	.966
	Sig. (2-tailed)	.234	.539	.293		.166
	N	3	3	3	3	3
Pushkar DO	Pearson Correlation	-.809	-.448	.980	.966	1
	Sig. (2-tailed)	.400	.704	.127	.166	
	N	3	3	3	3	3

14. Correlation Analysis for DO of 5 water sources

Correlations						
		Suryakund DO	**Iswarangi DO**	**Durgakund DO**	**Kurushetra DO**	**Pushkar DO**
Suryakund DO	Pearson Correlation	1	.888	-.677	-.933	-.809
	Sig. (2-tailed)		.305	.526	.234	.400
	N	3	3	3	3	3
Iswarangi DO	Pearson Correlation	.888	1	-.262	-.663	-.448
	Sig. (2-tailed)	.305		.831	.539	.704
	N	3	3	3	3	3
Durgakund DO	Pearson Correlation	-.677	-.262	1	.896	.980
	Sig. (2-tailed)	.526	.831		.293	.127
	N	3	3	3	3	3
Kurushetra DO	Pearson Correlation	-.933	-.663	.896	1	.966
	Sig. (2-tailed)	.234	.539	.293		.166
	N	3	3	3	3	3
Pushkar DO	Pearson Correlation	-.809	-.448	.980	.966	1
	Sig. (2-tailed)	.400	.704	.127	.166	
	N	3	3	3	3	3

4.5 Correlation Analysis of Dissolved Oxygen (DO)

The correlation matrix reveals significant relationships between the DO levels at different sites. Notably, a strong positive correlation exists between Suryakund and Ishwarangi, which implies that factors affecting DO levels at one site could have similar impacts on the other. Interestingly, Suryakund displays negative correlations with Durgakund, Kurukshetra, and Pushkar Pond, indicating an inverse relationship. This could be attributed to variations in anthropogenic activities, water flow patterns, or other environmental factors that differentially impact these sites. However, the p-values associated with these correlation coefficients suggest caution in inferring statistical significance, possibly due to the limited sample size.

4.6 Magnesium Analysis across the Sites

An examination of Magnesium across the five water bodies brings forth variations in concentrations. Magnesium, a crucial mineral for aquatic life, also plays a role in determining water hardness. Its presence, in varying levels, can affect the health of the aquatic ecosystem and determine the suitability of water for various human uses.

Considering the presented data, sites such as Ishwarangi and Pushkar Pond seem to maintain more stable levels, as indicated by their narrow standard deviations. In contrast, locations like Durgakund and Kurukshetra might experience periodic influxes of Magnesium, possibly from agricultural runoff or other sources.

4.7 Insights from Descriptive Statistics

The comprehensive analysis of water quality across the five sites presents a diverse picture. Factors like human activity, proximity to urban areas, and natural processes may contribute to the differences observed. The BOD and COD data, indicators of organic pollution, hint at potential challenges, especially for sites with higher variability. Elevated levels could signify increased organic waste inputs, requiring prompt mitigation measures.

4.8 Overall Interpretation

The collective data underscores the importance of monitoring and managing water quality, especially in areas of cultural or environmental significance. The variability observed for certain parameters, such as heavy metals and organic pollutants, is especially concerning. These could pose risks to aquatic life and human populations alike.

To safeguard these freshwater bodies, collaborative strategies encompassing scientific research, community engagement, and policy frameworks are essential. Future studies might consider expanding sample sizes and employing more advanced techniques to gain a deeper understanding of the water quality dynamics in these sites.

5. FINDINGS

Heavy Metal Concentrations: The concentrations of Lead (Pb), Nickel (Ni), Copper (Cu), and Zinc (Zn) exhibited significant variation across different sites and seasons. While certain sites maintained relatively consistent levels of these metals, others showed pronounced fluctuations possibly due to seasonal changes and anthropogenic influences.

Dissolved Oxygen (DO) Relationships: A strong positive correlation was observed between Suryakund and Ishwarangi for DO levels, while negative correlations existed between Suryakund and other sites. This suggests varying influences and perhaps different sources of contamination or ecological conditions across the sites.

Variability in Water Quality Parameters: Parameters such as Turbidity, Total Dissolved Solids (TDS), water hardness indicators, and organic pollution metrics (BOD and COD) displayed varying levels across the sites. Pushkar Pond, in particular, showed considerable variations in its organic pollution levels.

Magnesium Levels: Sites like Ishwarangi and Pushkar Pond displayed more stable magnesium levels, while Durgakund and Kurukshetra indicated potential periodic influxes, possibly from sources like agricultural runoff.

Potential Risks: Elevated levels of heavy metals and organic pollutants in some water bodies highlight potential environmental and health risks. The adverse impacts on the aquatic ecosystem and potential risks to human health cannot be overlooked.

6. CONCLUSION

The study offers a detailed analysis of water quality across five significant sites in Varanasi, focusing on heavy metal concentrations, DO levels, and other vital parameters. The findings reveal that while certain sites maintain relatively stable and consistent water quality, others exhibit fluctuations that can be concerning from both an environmental and public health perspective.

The variability in heavy metal concentrations, especially, underscores the potential threats posed by unchecked pollution. Given the cultural, religious, and ecological importance of these water bodies, a comprehensive and collaborative approach is vital to mitigate the risks. Continuous monitoring, public awareness campaigns, policy interventions, and active community involvement are imperative to safeguard these freshwater bodies from further degradation and ensure their longevity for future generations.

Recommendations include expanding the sample size for future studies, exploring potential sources of contamination, and implementing sustainable water management practices. This study serves as a foundation for future research and actions to preserve the sanctity and health of these vital water bodies.

7. IMPLICATIONS AND RECOMMENDATIONS:

The study findings from Varanasi's regions highlight the pressing issue of heavy metal pollution. The adverse effects observed in Clarias batrachus, a pivotal component of the freshwater ecosystem, imply larger scale environmental ramifications.

Identifying specific sources of this contamination should be a priority, facilitating targeted mitigation efforts. Public awareness campaigns around the consequences of heavy metal pollution could be instrumental in curbing future contaminations.

Considering the adverse impacts observed, exploring bio-remediation techniques might be beneficial. Employing specific plants or microorganisms that can absorb and concentrate these heavy metals could be a feasible solution to reduce the direct threat to aquatic ecosystems.

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