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DISTRIBUTION AND BIOACCUMULATION OF POLYCHLORINATED BIPHENYL (PCB) RESIDUES IN WATER, SEDIMENT AND *Clarias gariepinus* FROM ZOBE RESERVOIR, KATSINA STATE, NIGERIA

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ABSTRACT

Polychlorinated biphenyls (PCBs) are persistent organic pollutants of global concern due to their toxicity, environmental persistence, and bioaccumulation in aquatic organisms. This study assessed physicochemical characteristics and concentrations of selected PCB congeners (PCB-28, PCB-52, PCB-101, PCB-138, PCB-153, and PCB-180) in water, sediment, and tissues (muscle, liver, and gills) of Clarias gariepinus from Zobe Reservoir, Katsina State, Nigeria. Physicochemical parameters indicated moderate organic pollution with spatial variation. Turbidity ranged from 27–51 NTU, exceeding NESREA limits, while dissolved oxygen showed negative correlations with turbidity ($r = –0.39$) and biological oxygen demand ($r = –0.45$). Conductivity correlated strongly with nitrate ($r = 0.77$, $p < 0.05$), suggesting runoff influence. PCB concentrations followed the pattern: sediment > liver > muscle > gills > water. Water concentrations were low (0.012–0.060 µg/L) with no significant variation. Higher concentrations were observed in sediment (up to 0.320 mg/kg) and fish tissues, particularly liver (up to 0.302 mg/kg), indicating bioaccumulation. PCB-101 showed the highest levels across all matrices. Significant differences occurred among sample types ($p < 0.001$), but not across stations or months, suggesting widespread contamination. Sediments act as the primary sink, while the liver is the major site of accumulation. Despite low concentrations in water, elevated levels in fish tissues indicate ecological and potential public health risks. Continuous monitoring of PCB contamination in the reservoir is recommended.

Keywords: Polychlorinated Biphenyls (PCBs), *Clarias gariepinus,* Zobe, Sediments, Reservoir

INTRODUCTION

Polychlorinated biphenyls (PCBs) are mixtures containing up to 209 different chlorinated compounds, known as congeners (Davies and Anwuri, 2020). These chemicals are artificially manufactured and do not occur naturally. They typically appear as colorless to light yellow oily liquids or waxy solids and have no detectable taste. The chlorine atoms attach to specific positions on the benzene rings, with each position numbered according to the carbon atoms. PCBs have been used as coolants and lubricants in transformers, capacitors, and other electrical equipment because they are fire-resistant and excellent insulators (Davies and Anwuri, 2020). They were also employed in the production of plasticizers for rubber and polyvinyl chloride (PVC) materials. Originally manufactured in the United States and Europe, PCBs were banned in the U.S. in 1977 due to their highly toxic effects (Ololade *et al.,* 2025). The occurrence of PCB congeners in the environment has attracted scientific concerns because of their toxic characteristics, persistence, and bioaccumulation in biota, including fish (Byrne *et al.,* 2015). Hence, they are of global interest, from both an environmental and a human health stand point (Adeogun *et al*., 2016). Exposure to PCBs may enhance the genotoxic activity of similar compounds to cause more severe toxic effects which are explained by the binding of planar (non-ortho) PCBs and PCDD/Fs to the aryl hydrocarbon (Ah) receptor (Boalt *et al.,* 2014. Their lipophilic characteristics are responsible for their ability to bioaccumulate particularly in tissues and organs rich in lipids which leads to their consequent possible connection with carcinogenesis in living organisms. They are rapidly accumulated by aquatic organisms and bioaccumulated through the aquatic food chain. Greater relative amounts of PCBs are usually found in the liver, adipose tissue, skin, and breast milk. It has been shown that absorption by nursing infants of tetra and higher chlorinated congeners from breast milk ranges from 90% to 100% of the dose (Wang and Zhong, 2011). Therefore, this study investigated the levels of PCBs in the water, sediment and some aquatic fauna found in and around samples locations as well as assessed the ecological risk posed to the organisms by PCBs contamination.

MATERIALS AND METHODS

Study Area

The Zobe Reservoir (Figure 1), which served as Study Area 1**,** is an earth-fill dam constructed in 1983**.** It is located at 12°23′18″ N latitude and 7°28′29″ E longitude in Dutsin-Ma Local Government Area of Katsina State, Nigeria. The dam has a height of 48 m, a length of 360 m, and a base width of 2,750 m**.** The reservoir has a storage capacity of approximately 179 million cubic meters (MCM) and is primarily fed by two major rivers, Karaduwa River and Gada River**,** which supply water to the reservoir. Zobe Reservoir serves important functions including irrigation, domestic water supply, fisheries, and flood control within the surrounding communities (Adeogun *et al*., 2016; Sadauki, *et al.,* 2024).

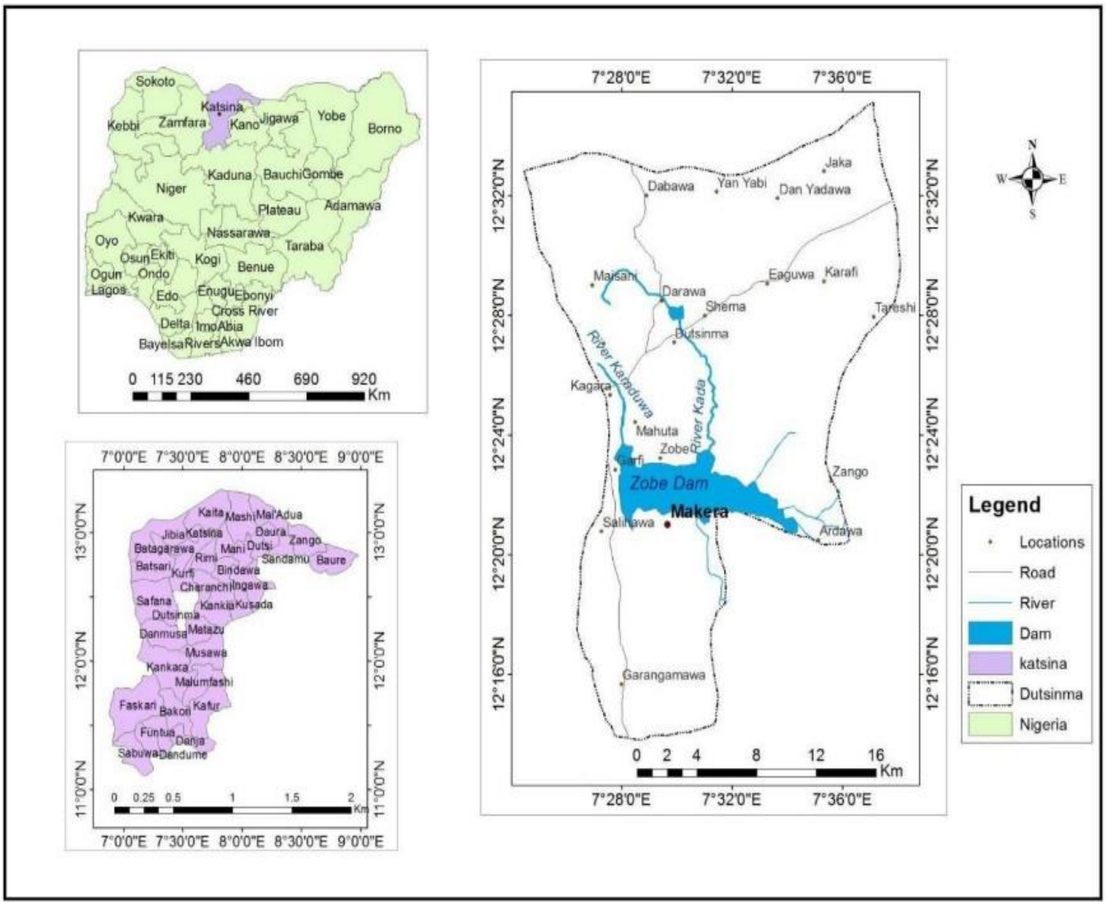

Figure 1: Map of Zobe Reservoir (Source: Global Information System Laboratory, Federal University Dutsin-Ma, 2024)

Collection of Water, Sediment and Fish Samples

Water Sample

Plastic containers were rinsed three times before filling up at a depth of one meter below the surface. The water samples were collected from three (3) sampling points denoted as S1 to S3 by dipping the plastic bottles in the water according to (Adeogun *et al*., 2016). Six (6) samples were collected monthly. A calibrated measuring rod, weight at one end were used to measure the average water depth at each station.

Sediment Samples

The sediment samples were collected at different points in the reservoir under study. These points were denoted as S1 to S3, at varying distances from each other. Six samples were collected monthly in polythene containers (1 kg), carefully closed to avoid any contact with air. The samples were stored, where necessary, at a temperature of 4°C to prevent bacterial activity that could modify their properties. The samples were dried in an electric furnace at a temperature of 40°C until the mass becomes constant. The samples were then be sieved through sieves of stainless steel 2mm mesh size. (Adeogun *et al*., 2016).

Fish Samples

A total of 24 fish samples (at least 8 from each station) of different sizes were collected from local fishermen at the dam's landing sites in Zobe Reservoir. The collected were spread over the four (4) months of the study Samples were collected and transported to the laboratory in clean iced containers. The African catfish (*Clarias gariepinus*) was selected due to its abundance in the reservoir, benthic feeding habit, and high consumption rate by the local population, which makes it a good bioindicator of PCB contamination. *Clarias gariepinus* specimens were captured using baited cast nets. Specimens were selected based on size uniformity to ensure comparability. Digestion of fish tissue samples was carried out using enzymatic digestion with proteinase K to break down organic matter (Ogbeibu *et al.,* 2017).

Physicochemical Analysis of Water Samples

Temperature

Water temperature was measured in situ at each sampling location using a calibrated digital thermometer. The readings were recorded immediately to avoid changes due to environmental exposure.

pH

The pH of the water samples was determined using a standard digital pH meter. The instrument was calibrated using buffer solutions (pH 4, 7, and 10) before measurement.

Dissolved Oxygen (DO)

Dissolved oxygen was measured using a dissolved oxygen meter based on the membrane electrode method. Measurements were taken on-site to prevent oxygen fluctuation.

Electrical Conductivity (EC)

Electrical conductivity was determined using a conductivity meter, which measures the ability of water to conduct electric current, indicating the presence of dissolved ions.

Turbidity
Turbidity was measured using a nephelometric turbidity meter and expressed in Nephelometric Turbidity Units (NTU), indicating the level of suspended particles in the water.

Total Dissolved Solids (TDS)
Total dissolved solids were measured using a TDS meter, which estimates the concentration of dissolved substances in the water sample.

Biological Oxygen Demand (BOD)
BOD was determined using the 5-day incubation method (BOD_5). Water samples were incubated at 20°C for five days, and the difference in dissolved oxygen before and after incubation was recorded.

Chemical Oxygen Demand (COD)
COD was analyzed using the dichromate reflux method, where the amount of oxygen required to oxidize organic matter in the sample was determined.

Nitrate
Nitrate concentration was determined using spectrophotometric methods after appropriate reagent treatment, and absorbance was measured at a specific wavelength.
All analyses were carried out in accordance with standard methods described by the American Public Health Association (2012).

Determination of PCBs
PCBs determination was done on water, sediments and fish samples with the help of Hewlett-Packard 7890 Gas chromatograph coupled with a Hewlett Packard Model 5975 mass analyzer: quadrupole and automatic sampler. The column made up of fused silica capillary was a 30 m DB – 1 ms (100% dimethylsiloxane) (Cj & W Scientific, CA, USA) (0.25 mm i.d. x 0.25 µm of the thickness of film). The temperature of the oven was initially programmed at 100^0C (standing for 1 min) – 325^0C at the ratio of 15^0C/min for 5 min. The conditions under which the gas chromatograph was carried out were 250◦C injection temperature and 280◦C transfer line temperature. Helium was used as a carrier gas through a steady flow count of 1.2 mL/min, with an elevated oven temperature. The running conditions of the mass spectrometer were 250◦C used for transfer line and ionization source temperature, 70eV was used as ionization voltage, the time used for scanning was 0.3s with 0.5s scanning delay and 5 minutes delay solvent.

Quality Assurance and Quality Control Procedures
To ensure accuracy and reliability of results, strict quality assurance and quality control measures were observed throughout the study. All glassware were thoroughly cleaned and solvent-rinsed prior to use. Reagent blanks and procedural blanks were analyzed alongside samples to detect possible contamination.

Data Analysis
Data was statistically analyzed to determine mean concentrations, standard deviations, and ranges of PCB residues in water, sediment, and fish tissue. One-way analysis of variance (ANOVA) was conducted to assess the significance of differences among sampling sites and matrices ($p < 0.001$). Results were compared against WHO, 2017 EPA, 2019 and FAO, 2016 guidelines to evaluate environmental and public health risks.

RESULTS AND DISCUSSION
Table 1 presents the summary statistics of selected physicochemical parameters of water from Zobe Reservoir during the study period. The mean water temperature was 28.38 ± 0.38 °C, indicating relatively warm conditions typical of tropical reservoirs and within the desirable upper limit for surface waters. The pH values ranged from 6.60 to 7.10 with a mean of 6.88 ± 0.16, reflecting slightly neutral conditions and falling within the WHO and NESREA recommended range for surface water. Dissolved oxygen concentrations showed moderate variation, with a mean value of 5.69 ± 0.63 mg/L, slightly below the recommended minimum of 6.0 mg/L, suggesting occasional reduced oxygen availability. Biological oxygen demand recorded a mean value of 3.10 ± 0.34 mg/L, which is within permissible limits and indicates low to moderate organic pollution. Electrical conductivity and total dissolved solids were low, with mean values of 72.15 ± 3.63 µS/cm and 34.85 ± 1.78 mg/L respectively, both well below regulatory limits, reflecting low ionic and dissolved solid content in the reservoir. Turbidity values were relatively high, with a mean of 36.75 ± 8.83 NTU, exceeding recommended limits and indicating elevated suspended particles, likely from runoff and sediment suspension. Nutrient levels were generally low, as evidenced by mean nitrate and organophosphate concentrations of 0.70 ± 0.13 mg/L and 0.037 ± 0.015 mg/L respectively, both within acceptable limits, suggesting minimal nutrient enrichment of the reservoir water.

Table 1: Physicochemical Parameters of Water Samples from Zobe Reservoir

Parameter	Mean ± SD	Minimum	Maximum	NESREA/WHO Limit
Temperature (°C)	28.38 ± 0.38	27.8	29.0	12–25°C (typical), < 30°C desirable
Ph	6.88 ± 0.16	6.60	7.10	6.5–8.5
DO (mg/L)	5.69 ± 0.63	4.75	6.85	≥ 6.0 mg/L
BOD (mg/L)	3.10 ± 0.34	2.55	3.90	≤ 6 mg/L
Conductivity (µS/cm)	72.15 ± 3.63	68	80	≤ 1000 µS/cm
TDS (mg/L)	34.85 ± 1.78	32	38	≤ 1000 mg/L
Turbidity (NTU)	36.75 ± 8.83	27	51	≤ 10 NTU above natural
Nitrate (mg/L	0.70 ± 0.13	0.52	0.92	≤ 50 mg/
Organophosphate (mg/L)	0.037 ± 0.015	0.015	0.060	pesticide-specific (<0.1 mg/L typical)

Table 2 shows that the spatial variation of physicochemical parameters across the three sampling stations showed moderate differences. Temperature ranged from 27.9°C to 29.0°C**,** with the highest value recorded at Station 3. pH values were slightly acidic to neutral across all stations, ranging from 6.7 to 7.1**.** Dissolved Oxygen (DO) increased progressively from 4.9 mg/L at Station 1 to 6.6 mg/L at Station 3**,** suggesting better oxygenation conditions downstream. Similarly**,** Biological Oxygen Demand (BOD) increased slightly from 2.8 mg/L at Station 1 to 3.5 mg/L at

Station 3, although all values remained within acceptable environmental limits. Electrical conductivity and total dissolved solids showed a gradual increase across the stations, indicating a slight rise in dissolved ionic substances along the sampling gradient. Turbidity values were highest at Station 3 (46 NTU), suggesting higher suspended particulate matter at that location. Nitrate concentrations increased slightly from 0.55 mg/L at Station 1 to 0.85 mg/L at Station 3, but remained far below the recommended limit. Organophosphate concentrations also showed a gradual increase across the stations, with the highest value recorded at Station 3 (0.05 mg/L), although levels remained within typical environmental safety guidelines.

Table 2: Physicochemical Parameters Across Three Sampling Stations

Parameter	Station 1 (S1)	Station 2 (S2)	Station 3 (S3)
Temperature (°C)	28.2 ± 0.4	27.9 ± 0.3	29.0 ± 0.5
pH	6.7 ± 0.2	6.9 ± 0.1	7.1 ± 0.2
DO (mg/L)	4.9 ± 0.5	5.6 ± 0.6	6.6 ± 0.4
BOD (mg/L)	2.8 ± 0.3	3.1 ± 0.2	3.5 ± 0.4
Conductivity (µS/cm)	70 ± 3	72 ± 4	75 ± 5
TDS (mg/L)	33 ± 2	35 ± 1	37 ± 2
Turbidity (NTU)	28 ± 6	36 ± 7	46 ± 9
Nitrate (mg/L	0.55 ± 0.1	0.70 ± 0.1	0.85 ± 0.1
Organophosphate (mg/L)	0.02 ± 0.01	0.04 ± 0.01	0.05 ± 0.02

Table 3 shows the mean concentrations (± standard deviation) of selected PCB congeners in water, sediment and tissues (muscle, liver and gills) of *Clarias gariepinus* from Zobe Reservoir. PCB levels in water were generally low, ranging from 0.012 ± 0.002 µg/L for PCB-180 to 0.060 ± 0.006 µg/L for PCB-101, indicating limited persistence of PCBs in the aqueous phase. In contrast, sediment recorded higher concentrations (0.106 ± 0.011–0.293 ± 0.023 mg/kg), confirming its role as a major sink for PCBs. Accumulation in fish tissues followed the order liver > gills ≈ muscle, with liver showing the highest PCB burdens (0.110 ± 0.008–0.302 ± 0.018 mg/kg), reflecting its detoxification and storage function. Across all matrices, PCB-101 consistently exhibited the highest mean concentration, while PCB-180 recorded the lowest, suggesting a predominance of lower-chlorinated congeners in the reservoir. Overall, the distribution pattern observed was sediment > liver > gills ≥ muscle > water, demonstrating preferential partitioning of PCBs into sediments and biological tissues rather than remaining in the water column.

Table 3: Selected Polychlorinated Biphenyl (PCB) Congeners in Water, Sediment and Tissues of *Clarias gariepinus* from Zobe Reservoir, Dutsin-Ma, Katsina State

PCB Congener	Water (µg/L)	Sediment (mg/kg)	Muscle (mg/kg)	Liver (mg/kg)	Gills (mg/kg)
PCB-28	0.034 ± 0.005 (0.027–0.042)	0.157 ± 0.018 (0.135–0.185)	0.082±0.006 (0.0730.092)	0.160±0.011 (0.1450.178)	0.093±0.006 (0.0850.104)
PCB-52	0.046 ± 0.006 (0.038–0.054)	0.218 ± 0.020 (0.190–0.248)	0.115±0.007 (0.1040.126)	0.212±0.014 (0.1950.238)	0.129±0.007 (0.1200.140)
PCB-101	0.060 ± 0.006 (0.051–0.072)	0.293 ± 0.023 (0.255–0.320)	0.150±0.009 (0.1350.165)	0.302±0.018 (0.2700.320)	0.169±0.008 (0.1550.185)
PCB-138	0.028 ± 0.003 (0.022–0.032)	0.201 ± 0.019 (0.175–0.230)	0.103±0.008 (0.0940.118)	0.203±0.014 (0.1850.225)	0.122±0.006 (0.1120.135)
PCB-153	0.019 ± 0.002 (0.016–0.023)	0.157 ± 0.012 (0.140–0.178)	0.085±0.006 (0.076-095)	0.162±0.011 (0.1450.175)	0.094±0.005 (0.0850.102)
PCB-180	0.012 ± 0.002 (0.009–0.014)	0.106 ± 0.011 (0.092–0.122)	0.064±0.005 (0.0560.072)	0.110±0.008 (0.0980.122)	0.071±0.005 (0.0630.078)

The distribution of PCB congeners across the three sampling stations showed a gradual increase in concentration from Station 1 to Station 3 (table 4.4). PCB-101 recorded the highest concentration among all congeners at each station, with values of 0.055 µg/L, 0.060 µg/L, and 0.065 µg/L at Stations 1, 2, and 3 respectively. Similarly, other congeners such as PCB-28, PCB-52, PCB-138, PCB-153, and PCB-180 followed the same increasing trend across the sampling stations. The lowest concentrations were consistently observed at Station 1, while Station 3 recorded the highest levels, suggesting a possible increase in contamination sources or pollutant accumulation downstream.

Table 4: Distribution of PCB Congeners Across Three Sampling Stations

PCB Congener	Station 1 (S1)	Station 2 (S2)	Station 3 (S3)
PCB-28	0.030 ± 0.004	0.034 ± 0.005	0.038 ± 0.006
PCB-52	0.042 ± 0.005	0.046 ± 0.006	0.050 ± 0.007
PCB-101	0.055 ± 0.006	0.060 ± 0.006	0.065 ± 0.007
PCB-138	0.025 ± 0.003	0.028 ± 0.003	0.031 ± 0.004
PCB-153	0.017 ± 0.002	0.019 ± 0.002	0.021 ± 0.003
PCB-180	0.010 ± 0.002	0.012 ± 0.002	0.014 ± 0.002

Discussion

The physicochemical characteristics of the Zobe Reservoir demonstrated clear spatial and temporal variations that reveal the ecological condition and potential stressors acting on the water system. Across the three sampling stations (S1–S3), water temperature showed slight but meaningful differences, ranging from 27.8°C to 29.0°C, with Station S1 having the highest mean temperature. This result is similar to the findings of previous research (Kinta *et al.,* 2021). In this study, the transparency variations fell below the permissible limit of 20-80cm recommended by WHO, (2017/2022) and below the values reported by (Sadauki *et al.,* 2022, Auta *et al.,* 2024). The pH condition of the reservoir suggests a stable and suitable environment for aquatic life, indicating the absence of significant acidification or alkalinity stress. The relatively low BOD levels imply minimal organic pollution and good water quality capable of supporting fish survival and growth. In addition, the low nitrate levels indicate limited nutrient enrichment, reducing the risk of eutrophication. Overall, these observations reflect a relatively healthy aquatic system, despite minor spatial variations across sampling locations. This result agrees with the work reported by previous researchers (Kinta *et al.,* 2021). The results obtained in this study also revealed measurable concentrations of polychlorinated biphenyls (PCBs) across water, sediment, and fish samples collected from Zobe Reservoir, indicating the persistence of these contaminants within the aquatic ecosystem. The observed distribution pattern agrees with findings reported by Ololade *et al.* (2025), which demonstrated that aquatic environments in Nigeria continue to serve as sinks for PCB contamination due to their environmental stability and resistance to degradation. The accumulation of PCBs in *Clarias gariepinus* tissue further demonstrates bioaccumulation along the aquatic food chain. The higher concentrations detected in fish relative to water support the bioaccumulative potential of PCBs due to their lipid solubility. Aina *et al.* (2016) similarly reported significant PCB burdens in fish tissues, attributing the accumulation to prolonged exposure and trophic transfer. The presence of PCBs in edible fish tissue raises public health concerns, particularly for communities that depend on the reservoir as a major protein source.

CONCLUSION

The physicochemical assessment of the Zobe Reservoir revealed spatial and temporal variations indicative of both natural processes and anthropogenic influences. Temperature, turbidity, DO, TDS, and organophosphate concentrations differed significantly across stations, with S1 and S2 showing the most elevated stress indicators. Several parameters including turbidity**,** reduced DO at S2, and measurable pesticide residues point to episodes of organic loading, sediment disturbance, and agricultural runoff. Despite these variations, most measured values remained within WHO/NESREA limits for potable water, except turbidity, which consistently exceeded recommended thresholds. The significant monthly shifts in pH, BOD, conductivity, and nitrate reflect seasonal dynamics tied to rainfall and runoff patterns. Collectively, this study demonstrates extensive PCB contamination in the Zobe Reservoir, with concentrations following the Sediment had higher concentrations than Liver, followed by Muscle/Gills and Water. Sediments contained the highest levels, confirming their role as the sink for hydrophobic contaminants. Liver tissues accumulated PCBs to levels nearly identical to sediment, indicating active and ongoing bioaccumulation. Muscle tissues, with PCB-101 concentrations as high as present a potential risk pathway for human consumers.

RECOMMENDATION

There should be increased research on effective methods for recycling and utilizing industrial wastes, rather than allowing them to become environmental nuisances. Industries should maintain clean and hygienic environments and strictly adhere to proper waste treatment processes before discharging waste into aquatic ecosystems, regardless of the associated costs.

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