



Physicochemical Parameters and Ecological Implications of Heavy Metal Contamination in *Tympanotonus fuscatus* from Woji–Eledenwo Creek, Rivers State, Nigeria

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Abstract

This study aimed to analyze the physicochemical parameters of surface water and evaluate the ecological implications of heavy metals using *Tympanotonus fuscatus* from the Woji–Eledenwo Creek, Rivers State, Nigeria. Samples of surface water, sediments, and *T. fuscatus* were collected from four stations: Station 1 (Eledenwo Slaughter), Station 2 (Company Woji), Station 3 (ABEC Woji), and Station 4 (Okpoko), following standard procedures. Physicochemical parameters were determined in situ using a Hanna multi-parameter model HI 9829 water kit, while solid samples were transported to the laboratory for analysis. Metal concentrations (Pb, Mn, Cr, Cd, Fe, Zn, and Ni) were determined using Atomic Absorption Spectrophotometry (AAS) and expressed in mg/kg. Ecological implications were assessed using the Pollution Load Index (PLI) and Enrichment Factor (EF), with Fe serving as the reference element. Statistical analysis revealed no significant differences ($p > 0.05$) in the mean values of physicochemical parameters across the sampling stations. All measured parameters were within the Federal Ministry of Environment (FMEnv, 2002) permissible limits, except for electrical conductivity. Enrichment factors ranged from depletion to significant enrichment ($5.66E+00$) in the order: Ni < Cr < Cd = Zn < Fe < Mn = Pb ($0, 3.69E-01, 8.23E-01 = 8.23E-01, 9.04E-01, 5.14E+00 = 5.14E+00$). Pb had the highest PLI value ($5.14E+00$), followed by Mn ($1.44E+00$), while Fe, Mn, Cr, Zn, and Ni had PLI values < 1. Overall, the study area exhibited moderate metal enrichment, with notable increases in Pb and Mn indices. Both positive and negative correlations were observed between metal concentrations in *T. fuscatus* and sediment, indicating direct uptake of metals from the environment by the organism. The elevated concentrations of metals and electrical conductivity suggest significant anthropogenic influence in the creek. Therefore, periodic assessment and monitoring of the aquatic environment are recommended, particularly for edible organisms, to ensure ecological and public health safety.

Keywords: Heavy Metals, *Tympanotonus fuscatus*, Ecological Implication, Enrichment Factor, Pollution Load Index

Introduction

Aquatic pollution has various sources, domestic, mining, municipal waste disposal, modern agriculture practices, marine dumping, radioactive, oil spill, underground storage leakage, and industrial effluent. Industries are identified to be the greatest pollutants of water resources among them Akar and Tunali (2006). Water bodies are polluted by indiscriminate discharges of toxic chemicals brought about by effluents released by industries like textiles, steel, oil refineries, tanneries, canneries, fertilizer plants, detergent factories, electroplating, and sugar mills, which cause dangerous impacts on aquatic flora and fauna (Gavrilescu, 2005; Iqbal and Edyve, 2004). Water is among the most important natural resources, which is used in various ways including domestic and industrial, irrigation, transportation, recreation, fisheries, power generation, and waste disposal. It is therefore important to manage the water bodies

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effectively to address these competing needs. With the world moving towards a fast industrialization and modernization, water and water management continue to play a key role in sustainable development and health of the environment (WHO, 2008). Water is an essential factor in the development of the society and in the ecological balance (UNESCO, 2003). Although water pollution is not a new phenomenon, the increasing rate of industrialization and urbanization has greatly exacerbated its effects on the environment. Urbanization affects the hydrological process by changing the erosion rates, pollutant loads, runoff properties and other significant parameters (Efe, 2000). The main issues which have been identified in the world as problems of water resources are scarcity, excess and pollution (UNESCO, 2003b). In Nigeria, especially in the Niger Delta region, the issue is mostly good-quality (drinkable) water because of the prevalent degradation and pollution of the environment (Efe, 2005). This leads to wastage of a considerable amount of time and resources in the procurement of questionable quality water. Research has indicated that the anthropogenic activities are easy to contaminate the Nigerian water resources (Orisakwe et al., 2001; Nduka et al., 2009). The pollution of heavy metal in water bodies poses a problem in water since it is not easily detectable and involves special sampling and analysis techniques (Biney et al., 1991). In Nigeria, decades of bioaccumulation of heavy metals in fish and other aquatic organisms have been reported (Egborge, 2000). Every freshwater body has its characteristic physical and chemical properties that depend mostly on climatic, geomorphological and physicochemical factors including total dissolved solids (TDS), conductivity and redox potential. These parameters give an idea of the quality and ecological condition of water bodies (Klic, 2002). The mineral content measured by TDS is an important measure of water quality, which is based on the dynamic interaction between the processes of dissolution and precipitation.

Materials and Methods

The study area is the Coastal Plain of the Niger Delta region, Rivers State, Nigeria, and geographically located between longitudes 7°02'00" and the longitudes 7°04'10" E, and latitudes 4°49'00" and 4°50'00" N of the Equator (Figure 1). The region receives a lot of rainfall nearly all the year round and humidity and temperature are very high in a wet tropical climate. There were four sampling stations picked along the Woji/Eleenwo Creek according to the severity of the human activities and potential sources of contamination. The coordinates and descriptions of the sampling stations are as follows:

Station 1 - Elelenwo Abattoir / MTN Computer Village Waterfront latitude 4°51'2.94"N and longitude 7° 3'35.84"E. Station 2 – Oil Servicing Company Waterfront latitude 4°50'2.16" N and longitude 7° 3'40.55"E. Station 3 - ABEC International Secondary School Waterfront latitude 4°49'28.17"N and longitude 7° 4'9.43"E. Station 4 – Elelenwo by Akpajo Waterfront latitude 4°48'12.53"N and longitude 7° 4'10.84"E. These stations represent varying degrees of anthropogenic influence, including abattoir activities, industrial discharges, and domestic waste inputs, all of which potentially contribute to the physicochemical and heavy metal composition of the creek.

Sample Collection and Preparation

Physicochemical analysis of surface water samples was done in four sampling stations by taking samples at depth of 15-25 cm in pre-rinsed one liter plastic containers. Contamination was also minimized by thoroughly rinsing all containers with the sample water. A 0.1 m² quadrant was used to collect sediment samples at each station as recommended by Ekweozor (1985). A clean plastic shovel was used to sample to a depth of 0.1 m on the mudflat. Sediment samples were put in zip-lock bags and labelled accordingly and taken to the laboratory. They were also dried at room temperature in the laboratory after four days and then analyzed. *Tympanotonus fuscatus* samples were selected by hand in the sampling points, in collaboration with local fishermen. Sampling was done, and the samples were washed using river water, then put in labeled aluminum foil plates, wrapped in black polyethylene bags, and taken to the laboratory. To prevent decay, all biological samples were frozen until analysis.

Laboratory Analysis of PhysicoChemical Parameters

In-situ, surface water temperatures were recorded at the respective sampling stations with a hand-held OAKTON Acorn series digital thermometer. Mercury in glass thermometer was used in order to measure the readings in centigrade (°C). The procedure was done by inserting the thermometer with a long stainless probe into the surface water, the thermometer remained $\frac{3}{4}$ immersed for 5 minutes to stabilize and the thermometric reading were then recorded. The water pH was determined in-situ by dipping a hand-held battery-operated electrometer (Hanna multi-parameter model HI 9829) water kit in the surface water and the value was recorded for each station. Turbidity was also measured, in-situ, with the use of (Hanna multi-parameter model HI 9829) model with sensitivity of 0-1000NTU

and the reading was taken at each sampling stations. The alkalinity was estimated by titration of 50ml sample 5 drops of methyl orange indicator with 0.02N H₂SO₄ solution. The limit of detection was 1.0mg/l CaCO₃. The Electrical Conductivity was determined by immersing the conductivity probe of (Hanna multi-parameter water kit model HI 9829) in the water samples and left to equilibrate and the reading was recorded. The level of salinity in the water samples was determined by immersing the Salinity probe of the Hanna multi-parameter model of HI 9829 into the water samples and recording the reading.

Analysis of Heavy Metals in Sediment

The air-drying and grinding of each sediment sample to fine powder was done using agate mortar and pestle. The homogenized sample (1.0 g) was weighed in a clean Teflon beaker with 5 mL of concentrated HF and 20 mL of HNO₃ being carefully added. The solution was swirled lightly to achieve the maximum dissolution and then heated up in a fume hood until an appropriate digestion was reached. One hour or so later heating was terminated, and the digest allowed to cool. This was then filtered and brought to volume in a 25 mL standard flask with distilled water and the filtrate refrigerated until analysis by Atomic Absorption Spectrophotometry (AAS).

Analysis of Heavy Metals in *T. fuscatus*

Tympanotonus fuscatus were de-shelled and the soft tissues (including intestines) dried in the oven at 45oc until a constant weight was attained. The tissues were dried and then a fine powder was made using a clean mortar and pestle. A 0.5 g sample of the powdered tissue was put into a borosilicate beaker and 25 mL of freshly prepared aqua regia (HCl: HNO₃, 3:1) was added. The mixture was heated to a near dryness and left to cool. The sample was cooled, followed by the addition of 20 mL of distilled water, then the sample was heated again (3-5 minutes) and filtered. The flask containing the filtrate was volumetrically brought up to 25 mL and kept under refrigeration until metal analysis was performed through AAS.

Enrichment Factor (EF)

The Enrichment Factor (EF) is a convenient measure to determine the level of anthropogenic impact on concentration of heavy metals in environmental samples. It can be used to differentiate between metals of natural (lithogenic) and anthropogenic (human-induced) origin. The EF of each metal in the sediment samples was computed in this study, as a ratio of the background abundance of the element in the continental crust, using iron (Fe) as the reference element. The reason why iron is usually chosen is due to its comparatively constant concentration and crustal derivation (Sutherland, 2000). Table 1. is identified in terms of enrichment factor. The higher the values of the enrichment factors, the higher are the contributions of the anthropogenic origins (Sutherland, 2000; Lukuku et al., 2013). In the current study, the EF was determined as follows.

$$EF = (C_m/C_{ref})/B_m/B_{ref} \dots\dots\dots (1)$$

Where

EF= Enrichment Factor

C_m= Contamination of examined metal in the sediment of study area

C_{ref} = background levels of metals in sediment

B_m = concentration of reference in the sediment of the study area

B_{ref} = Background concentration of the reference metal in sediment (Budzinski, et al., 1979).

Table 1: Five Contamination Categories of Enrichment Factor

1. Enrichment Factor	< 2	Deficiency to minimal enrichment
2. Enrichment Factor	2 – 5	Moderate enrichment
3. Enrichment factor	5 – 20	Significant enrichment
4. Enrichment factor	20 – 40	Very high enrichment
5. Enrichment factor	> 40	Extremely high enrichment

Sutherland, 2000.

Pollution Load Index (PLI)

The PLI provides simple but comparative means for accessing the quality of a location. Where a value of $PLI < 1$ denote perfection, whereas $PLI = 1$ means that only baseline levels of pollutant are present, and the $PLI > 1$ indicates pollution of sediment. The PLI was computed according to Mmolawa et al. (2011).

The PLI for each sampling site was calculated using the following equation:

$$CF = C_{\text{Metal}} / C_{\text{Background value}} \dots\dots\dots(3)$$

$$PLI = \sqrt[n]{(CF_1 \times CF_2 \times CF_3 \dots CF_n)} \dots\dots\dots(4)$$

Where CF is the contamination factor, which is the quotient of the heavy metal in biota and the concentration in the sediment. $CF = \text{concentration of heavy metal in biota} / \text{concentration of heavy metal in sediment}$.

Results

Physicochemical Parameters of Surface Water

The temperature of surface water was observed in the four sampling sites during a period of twelve months. The recorded temperature values ranged from 28.00 to 29.65°C, with a mean of $28.92 \pm 0.76^\circ\text{C}$. This marginal difference shows that there were comparatively constant thermal conditions in the creek during the study period. The pH of surface water, which indicates the level of acidity or alkalinity, was between 6.30 and 7.89 with an average value of 7.32. The maximum pH (7.89) was recorded in December and the minimum (6.60) was recorded in April. The mean pH was the largest in Station 1 (7.47 ± 0.50) and the smallest in Station 2 (7.26 ± 0.44). The slightly alkaline to near neutral values measured are characteristic of brackish water systems that are affected by freshwater and tidal water sources. The surface water salinity was highly variable between 0.40 and 13.00‰ throughout the sampling period with a total mean of $5.46 \pm 2.00\%$. Majority of the mean salinity was recorded during the dry season of 9.45 to 10.57 with the highest salinity of 9.45 being in the month of February and the lowest salinity of 2.68 was recorded in the month of June (during the rainy season). Among the stations, Station 3 exhibited the highest mean salinity ($7.16 \pm 2.23\%$), and Station 1 the lowest ($1.49 \pm 0.85\%$) (Table2). The effect of tidal influx, freshwater discharge and seasonal precipitation on the ionic composition of the creek water explains the observed variation.

Table:2 Descriptive Analysis of Physicochemical Parameters in Surface Water

Parameter	Mean	Range	Standard Dev.	Standard Limit	Reference
Salinity ‰	5.46	0.40 – 13.00	2.12	600	FMEnv, 2001;
Temp ° C	28.92	27.50-30.40	0.758	Ambient ±2	FMEnv, 2001
Ph	7.32	6.30 – 8.23	0.38	6.5 – 8.5	DPR, 2018
Electric Conductivity (µs/cm)	22260.83	12000– 26900	1573.09	8,000	DPR, 2018

Table:3 Mean and Standard deviation value of Surface Water by Stations.

Parameter	Station 1	Station 2	Station 3	Station 4
Temp ° C	28.56 ± 0.66^a	28.74 ± 0.73^a	29.14 ± 0.9^a	29.23 ± 0.84^a
Salinity ‰	1.49 ± 0.85^a	6.47 ± 3.14^b	7.16 ± 2.35^b	6.72 ± 2.53^b
Ph	7.47 ± 0.5^a	7.26 ± 0.44^a	7.29 ± 0.3^a	7.27 ± 0.32^a
Electric Conductivity (µs/cm)	17993.33 ± 48264^a	23316.67 ± 1614.43^b	25308 ± 1484.06^b	22425 ± 736.12^b

Pollution Load Index (PLI)

The **Pollution Load Index (PLI)** of the heavy metals in the study area was determined using *Tympanotonus fuscatus* as the bioindicator species. The calculated PLI values are presented in Table 4. Among the analyzed metals, **lead (Pb)** exhibited the highest pollution index value of 5.14×10^0 , which is greater than 1, indicating a significant level of contamination. This was followed by manganese (Mn) with a PLI value of 1.44×10^0 , also above 1, suggesting moderate pollution.

In contrast, iron (Fe), chromium (Cr), zinc (Zn), and nickel (Ni) all recorded PLI values < 1 , signifying that these metals were within baseline or non-polluted levels in *T. fuscatus*. According to the interpretation of the PLI index (Mmolawa et al., 2011), values greater than 1 denote deterioration of sediment or biotic quality due to metal contamination, whereas values equal to 1 represent baseline conditions, and values less than 1 indicate absence of pollution. The elevated PLI values for Pb and Mn therefore suggest that these metals pose the greatest ecological concern in the study area, likely reflecting anthropogenic inputs such as industrial effluents, abattoir discharges, and surface runoff from surrounding urban activities.

Table:4 Pollution Load Index of Heavy Metals in Sediment and Periwinkle of the Study Area

Heavy Metals	Sediment vs Periwinkle
Pb	5.14E+00
Mn	5.14E+00
Cr	3.69E-01
Ni	0
Fe	9.04E-01
Zn	8.23E-01
Cd	8.23E-01

Enrichment Factor

Table 5 presents the enrichment factors (EF) of heavy metals in sediment samples, using **iron (Fe)** as the reference element. The results show that lead (Pb) had the highest enrichment factor value of 5.66×10^0 , indicating significant enrichment in the study area. This suggests that Pb input may largely originate from anthropogenic sources such as industrial discharge, vehicular emissions, and urban runoff. The EF values of the other metals were all less than 2, signifying depletion to minimal enrichment (Table 5). This implies that these metals are primarily of natural (lithogenic) origin, reflecting minimal external influence from human activities. According to the classification by Sutherland (2000), EF values < 2 indicate minimal enrichment, 2–5 moderate enrichment, 5–20 significant enrichment, 20–40 very high enrichment, and > 40 extremely high enrichment. Based on this scale, only Pb showed evidence of significant anthropogenic contribution, while the other metals remained within natural background levels.

Table:5 Enrichment Factor using Fe as Reference Element

Heavy Metals	Heavy Metal Conc. (mg/kg)	Enrichment Factor	Implication
Pb	2.81E-02	5.66E+00	Significantly enriched
Mn	5.06E-02	1.61E+00	Depletion to minimal enrichment
Cr	3.32E-01	4.18E-01	Depletion to minimal enrichment
Cd	5.22E-02	9.09E-01	Depletion to minimal enrichment
Ni	3.70E-01	0.00E+00	Depletion to minimal enrichment
Fe	6.24E-02	1	Depletion to minimal enrichment
Zn	6.89E-02	1.05E+00	Depletion to minimal enrichment

EF < 2 (Depletion to minimal enrichment), EF $2 \leq 5$ (Moderate enrichment), $5 \leq EF < 20$ (Significantly enrichment), $20 \leq EF < 40$ (Very high enrichment), EF > 40 (Extreme enrichment).

Correlation Matrix of Heavy Metals in Periwinkle and Sediment

Table 6 presents the correlation coefficients between heavy metal concentrations in *Tympanotonus fuscatus* (periwinkle) and those in sediment. The results revealed varying degrees of association among the metals, indicating possible differences in their sources, geochemical behavior, and bioavailability.

Chromium (Cr) exhibited a significant negative correlation with cadmium (Cd) in sediment ($r = -0.4850$), suggesting an inverse relationship, possibly due to differing uptake or geochemical pathways. Zinc (Zn) showed a significant negative correlation with iron (Fe) in sediment ($r = -0.5059$), implying that higher Fe concentrations in sediment may limit Zn bioavailability to periwinkle. Conversely, Zn displayed a significant positive correlation with Zn in sediment ($r = 0.4885$), indicating that sediment Zn concentration influences its accumulation in periwinkle tissue.

Manganese (Mn) had a significant negative correlation with Fe in sediment ($r = -0.4885$), while it exhibited a significant positive correlation with Zn in sediment ($r = 0.4569^*$), suggesting potential co-mobilization or shared anthropogenic sources for Mn and Zn.

These correlations indicate that certain metals (e.g., Zn and Mn) in *T. fuscatus* reflect the corresponding sediment concentrations, implying bioavailability and possible trophic transfer, whereas others (e.g., Cr and Cd) show inverse relationships, possibly influenced by environmental or physiological factors.

Table:6 Correlation of Heavy Metals in Periwinkle and Heavy Metals in Sediment

	Pb_sed	Cd_sed	Cr_sed	Ni_sed	Fe_sed	Zn_sed	Mn_sed
Pb_peri	0.1632						
Cd_peri	-0.0402	0.1462					
Cr_peri	-0.2125	-0.4850*	-0.1998				
Ni_peri	0.0000	0.0000	0.0000	0.0000			
Fe_peri	0.0872	-0.1913	-0.1125	-0.3431	-0.2503		
Zn_peri	-0.0374	-0.0707	-0.2784	-0.2923	-0.5059*	0.4885*	
Mn_peri	-0.1282	0.0192	-0.1811	-0.4021	-0.4997*	0.4569*	0.0127

*Correlation is significant at $p < 0.05$

Discussion

Temperature is a key parameter influencing biological activity and growth in aquatic environments. All aquatic organisms have specific temperature ranges for optimal survival, and temperature affects both water chemistry and the rate of biochemical reactions (Efe, 2000). In this study, water temperature ranged from 28.00 – 29.65°C. Station 4 recorded the highest mean temperature ($29.23 \pm 0.84^\circ\text{C}$), while Station 1 recorded the lowest ($28.56 \pm 0.66^\circ\text{C}$). Although there was no significant difference in mean temperature across stations, the observed range was lower than the 30.5–39.0°C reported by Akaninwor et al. (2007). However, the results were comparable to those of Otene (2014) in Amadiama Creek ($27.4\text{--}31.22^\circ\text{C}$) and higher than the 19.5–21.0°C range recorded by Asonye et al. (2007) for Nigerian rivers and streams. Overall, temperature values in this study were within the recommended limit of 30°C for surface water (USEPA, 2018; WHO, 2008).

The pH of a water body is critical to the survival of aquatic organisms, as it influences metal solubility, nutrient availability, and overall water chemistry. The pH values recorded ranged from 6.30–7.89 with a mean of 7.32 ± 0.38 ,

which falls within the permissible limits for surface water set by the Department of Petroleum Resources (DPR, 2002). No significant spatial variation was observed in pH across the sampling stations, which aligns with findings by Makinde et al., 2018 for Elechi Creek and Buguma. The slightly higher pH value at Station 1 may be attributed to its freshwater nature, which differs from the brackish conditions of the other stations.

Electrical Conductivity (EC) reflects the ionic concentration of a water body and serves as an indicator of salinity and dissolved solids. In this study, EC ranged from 12,000–26,900 $\mu\text{S}/\text{cm}$, with a mean of 22,260.83 $\mu\text{S}/\text{cm}$, which is significantly higher than the 8,000 $\mu\text{S}/\text{cm}$ limit set by DPR (2018). Station 1 exhibited a statistically significant difference from the other stations, likely due to its freshwater composition. The pattern observed is consistent with that reported by Makinde et al. (2018), who recorded variations in EC between wet and dry seasons in Buguma and Ekerekana Creeks.

Salinity values ranged from 0.4–13.0 with a mean of 5.46 ± 2.00 , which falls within the DPR (2018) guideline limits. Station 1 differed significantly from the other stations, again reflecting its freshwater characteristics. Similar patterns have been reported by Olu et al. (2019) in the Soku Oil Field area of the Niger Delta.

The Pollution Load Index (PLI) of metals in *Tympanotonus fuscatus* showed that Pb had the highest value (5.14×10^0), followed by Mn (1.44×10^0), while other metals (Fe, Cr, Zn, and Ni) had PLI values < 1 . These results indicate that Pb is the most prominent pollutant in the area. This finding agrees with Adepoju and Adekoya (2014), who reported high Pb PLI values in the Orle River, Southwestern Nigeria, and with Bababtunde et al. (2013), who recorded elevated Pb concentrations in the Bonny/New Calabar River Estuary, Niger Delta.

The Enrichment Factor (EF) results revealed depletion to minimal enrichment for most metals, except Pb, which exhibited significant enrichment. This suggests a strong anthropogenic input of Pb, likely from industrial effluents, urban runoff, and other human activities. The result aligns with Moslen et al. (2018), who reported moderate metal enrichment in tidal creeks of the Niger Delta, and contrasts with Orlu et al. (2019), who observed extremely high Cd enrichment in the Soku Oil Field area.

The correlation analysis revealed both positive and negative associations among heavy metals in *T. fuscatus* and sediments. Positive correlations indicate that certain metals (e.g., Zn, Mn) are bioavailable and may be absorbed directly or through food sources, while negative correlations suggest differences in uptake mechanisms or geochemical partitioning. These patterns are consistent with the findings of Bassey and Chukwu (2019), who observed similar correlations among heavy metals in fish species.

Conclusion

This study demonstrates that physicochemical parameters of surface water across the sampling stations showed no significant variations, except in salinity and conductivity, where Station 1 differed due to its freshwater character. Conductivity values exceeded the permissible limits set by FMEnv (2001) and DPR (2018), indicating anthropogenic influence within the study area. The positive and negative correlations between metals in sediments and *T. fuscatus* reflect the complex interaction between metal availability, environmental factors, and biological uptake. The ecological risk assessment, based on PLI and EF values, indicates that Pb poses the most significant pollution concern. *Tympanotonus fuscatus* proved to be an effective bioindicator species due to its high metal accumulation potential, making it suitable for continuous monitoring of aquatic pollution in the Niger Delta Region of Nigeria.

Recommendations

Based on the findings of this study, the following recommendations are proposed:

1. Regular environmental monitoring and systematic monitoring of physicochemical parameters and heavy metal concentrations in both water and sediments should be carried out to detect early signs of pollution and guide mitigation efforts.
2. Periodic public health and risk assessments of edible aquatic organisms, particularly *Tympanotonus fuscatus* should be conducted to evaluate potential human exposure to toxic metals through consumption.

3. **Pollution** source control **regulatory** agencies such as FMEnv and DPR should strengthen enforcement of effluent discharge standards to minimize anthropogenic inputs, especially from industrial, domestic, and oil-related activities around the Woji–Eledenwo Creek.
4. Community, stakeholders, local communities and Industries should be educated and encouraged to adopt environmentally responsible practices to reduce pollution load and protect aquatic life

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