

Physicochemical Parameters and Heavy Metal Contamination of Surface Water of Mgbuodahia River, Niger Delta, Nigeria

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Abstract

This study assessed the physicochemical parameters and heavy metal (Pb, Cd, Cr, Ni, Cu, Zn) concentrations in surface water of Mgbuodahia River, Niger Delta, Nigeria, for six months (May–October 2025) across four stations (ST1–ST4). Physicochemical parameters were measured in situ, heavy metals were quantified by atomic absorption spectrophotometry, and data were evaluated using a General Linear Model ANOVA with Tukey's pairwise comparison. Dissolved oxygen was low (0.62 ± 0.12 mg/L) and biochemical oxygen demand elevated (8.41 ± 4.20 mg/L), indicating organic pollution. Lead (0.33 ± 0.10 mg/L) and cadmium (0.10 ± 0.06 mg/L) exceeded WHO permissible limits (0.01 and 0.003 mg/L respectively) at every station and month. ANOVA showed significant monthly variation for pH, conductivity, temperature and most heavy metals, while chromium showed no significant station or month effect, suggesting a diffuse rather than point-source origin. Nickel showed a pronounced June peak roughly double every other month's mean, indicating an episodic input event. These concentrations are higher than values reported for several other Niger Delta water bodies, indicating that Mgbuodahia River is affected by lead and cadmium inputs. The study concludes that Mgbuodahia River is impacted by organic and heavy metal pollution and recommends continuous monitoring and regulation of discharge into the river.

Keywords: Physicochemical parameters; heavy metals; surface water; Mgbuodahia River; Niger Delta

Introduction

Heavy metals are persistent environmental pollutants that accumulate in aquatic systems and are transferred through food chains, posing risks to ecosystem and human health (Hou et al., 2024; Dan et al., 2022; Moslen et al., 2017). Anthropogenic sources, including industrial discharge, artisanal oil refining, and domestic waste, are now the dominant drivers of heavy metal loading in Niger Delta rivers, many of which are used directly by riverine communities for fishing and domestic water use (Dixit et al., 2015; Bob-Manuel et al., 2015). Physicochemical parameters such as pH, dissolved oxygen, and biochemical oxygen demand determine the solubility, mobility, and toxicity of heavy metals in the water column, making their joint assessment essential for interpreting contamination risk (Ahmed et al., 2015). Despite its continued use for fishing, domestic water use, and seafood harvesting, Mgbuodahia River is used directly by neighboring communities for fishing, domestic water supply and seafood harvesting, in the same way that

Azuabie Creek, Okujagu Creek, Ekerekana Creek, Okochiri Creek and the Choba and Iwofe axes of the New Calabar River have each been shown, in this research group's earlier work, to be under sustained anthropogenic pressure from industrial effluent, oil bunkering, dredging and domestic waste (Moslen et al., 2006; Daka et al., 2007; Moslen and Daka, 2013, 2014, 2016; Moslen and Ekweozor, 2017; Aigberua and Moslen, 2017; Moslen and Aigberua, 2018; Wosu et al., 2022). Given that Mgbuodahia River shares its receiving water connection to the Bonny River system with several of these previously studied creeks, and that construction, mining, and oil and gas activity have been observed along its banks, it is reasonable to expect comparable or greater contamination pressure. Updating this baseline, and situating it explicitly against the wider series of Bonny estuary assessments produced by this research group, is therefore both a scientific and a regulatory priority. This study therefore aimed to determine the physicochemical parameters and heavy metal (Pb, Cd, Cr, Ni, Cu, Zn) concentrations in the surface water of Mgbuodahia River, and to evaluate the resulting water quality and pollution status by comparison with published values from comparable Niger Delta systems.

Materials and Methods

Study Area and Sampling: The study was conducted along Mgbuodahia River, a tidal water body located in Port Harcourt Local Government Area, Rivers State, Nigeria, lying at approximately latitude 4.8188°N and longitude 6.9664°E (Figure 1). The river is a mangrove intertidal wetland receiving inputs from the Bonny River system and effluents from neighbouring oil and gas, construction, and mining activities. Four sampling stations (ST1-ST4) were established along the river channel. Surface water samples were collected monthly from each station over six months (May–October 2025). Water pH, temperature, electrical conductivity, salinity, turbidity, dissolved oxygen were measured *in situ* while biochemical oxygen demand was determined in the laboratory after 5 days of incubation using standard methods. The selected heavy metals; lead, cadmium, chromium, nickel, copper and zinc were analysed using Atomic Absorption Spectrophotometry (AAS). Data were analysed using a General Linear Model (Location x Time) analysis of variance with Tukey's pairwise comparison at 95% confidence to identify significant differences between stations and months.

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Results and Discussion

Physicochemical parameters by station are presented in Figure 2. Surface water pH ranged from slightly acidic to alkaline, with significant monthly variation ($p=0.003$) but no significant difference between stations ($p=0.519$). Dissolved oxygen was consistently low across all stations, with no significant station ($p=0.591$) or month ($p=0.957$) effect, while biochemical oxygen demand was correspondingly high (highest at Station 2), together indicating organic pollution consistent with domestic waste input, though neither station ($p=0.753$) nor month ($p=0.746$) reached statistical significance for BOD. Conductivity showed significant monthly variation ($p=0.010$) but no station effect ($p=0.776$), with a declining trend from May ($30.20 \mu\text{S/cm}$) to June ($23.18 \mu\text{S/cm}$) consistent with dilution by rainfall. Temperature varied significantly by month ($p=0.069$) but not station ($p=0.251$), turbidity showed no significant differences in stations ($p=0.331$) and monthly effects ($p=0.116$), salinity showed no significant differences in stations ($p=0.554$) and monthly effects ($p=0.294$), turbidity and salinity showed no significant differences indicating these two parameters are governed more by tidal mixing than by systematic spatial or seasonal trends.

Physicochemical Parameters

Physicochemical parameters by station are presented in Figure 2, and the significance pattern for each parameter is summarised in Table 1.

Surface water pH ranged from slightly acidic to alkaline across the study period, with significant monthly variation ($p=0.003$) but no significant station effect ($p=0.519$). This near-neutral, temporally-driven pH pattern is broadly consistent with the pH ranges reported for other Niger Delta tidal systems by this research group, including Ekerekana and Okochiri creeks (Moslen and Daka, 2016) and the Choba and Iwofe axes of the New Calabar River, where pH likewise did not differ significantly between stations despite spatial differences in other parameters (Wosu et al., 2022). Because pH governs the solubility and speciation of dissolved heavy metals, the comparatively stable pH regime recorded here suggests that the pronounced station-level differences observed for lead and cadmium are more plausibly explained by differences in point-source loading than by pH-driven differences in metal solubility.

Temperature varied significantly by month ($p=0.033$) but not by station ($p=0.229$), consistent with a seasonally driven rather than site driven temperature regime. Similar month-dominant temperature patterns have been reported across the group's other Niger Delta assessments (Moslen and Daka, 2016; Wosu et al., 2022), reflecting the shared influence of the regional wet–dry seasonal cycle on shallow tidal systems in the area.

Conductivity showed significant monthly variation ($p=0.010$) but no station effect ($p=0.776$), with a declining trend from May ($30.20 \mu\text{S/cm}$) to June ($23.18 \mu\text{S/cm}$) consistent with dilution by rainfall at the onset of the wet season. Salinity showed no significant station or month effect ($p>0.05$), indicating that, unlike conductivity, salinity in this reach of Mgbuodahia River is governed more by tidal mixing with the Bonny River system than by rainfall dilution or station-specific inputs. This decoupling of conductivity from salinity has not been explicitly reported in the group's earlier work and may warrant closer attention in subsequent sampling rounds, particularly given that Wosu et al. (2022) found conductivity to differ significantly between stations on the New Calabar River, in contrast to the pattern observed here.

Dissolved oxygen was consistently low across all stations ($0.62 \pm 0.12 \text{ mg/L}$), with no significant station ($p=0.591$) or month ($p=0.957$) effect, while biochemical oxygen demand was correspondingly elevated ($8.41 \pm 4.20 \text{ mg/L}$, highest at Station 2), together indicating organic

pollution consistent with domestic waste input, though neither station ($p=0.753$) nor month ($p=0.746$) reached statistical significance for BOD. The combination of persistently low dissolved oxygen and elevated BOD across all stations, rather than at isolated points, suggests a diffuse organic loading pattern for Mgbuodahia River as a whole, distinct from the more spatially-discrete heavy metal hotspots, and broadly consistent with the organic pollution status reported for other domestically-impacted Niger Delta creeks by this research group (Moslen and Daka, 2016; Moslen and Ekweozor, 2017). Turbidity and salinity showed no significant station or monthly effects ($p>0.05$ throughout), indicating that turbidity in Mgbuodahia River is governed more by tidal mixing and resuspension of fine sediment than by systematic spatial or seasonal pollution trends. This contrasts with the significant station-level turbidity differences reported for the Choba and Iwofe axes of the New Calabar River, where turbidity reached 62.7 NTU at the most affected station (Wosu et al., 2022), and suggests that turbidity is a less discriminating indicator of localised contamination in Mgbuodahia River than in some of the other systems previously studied.

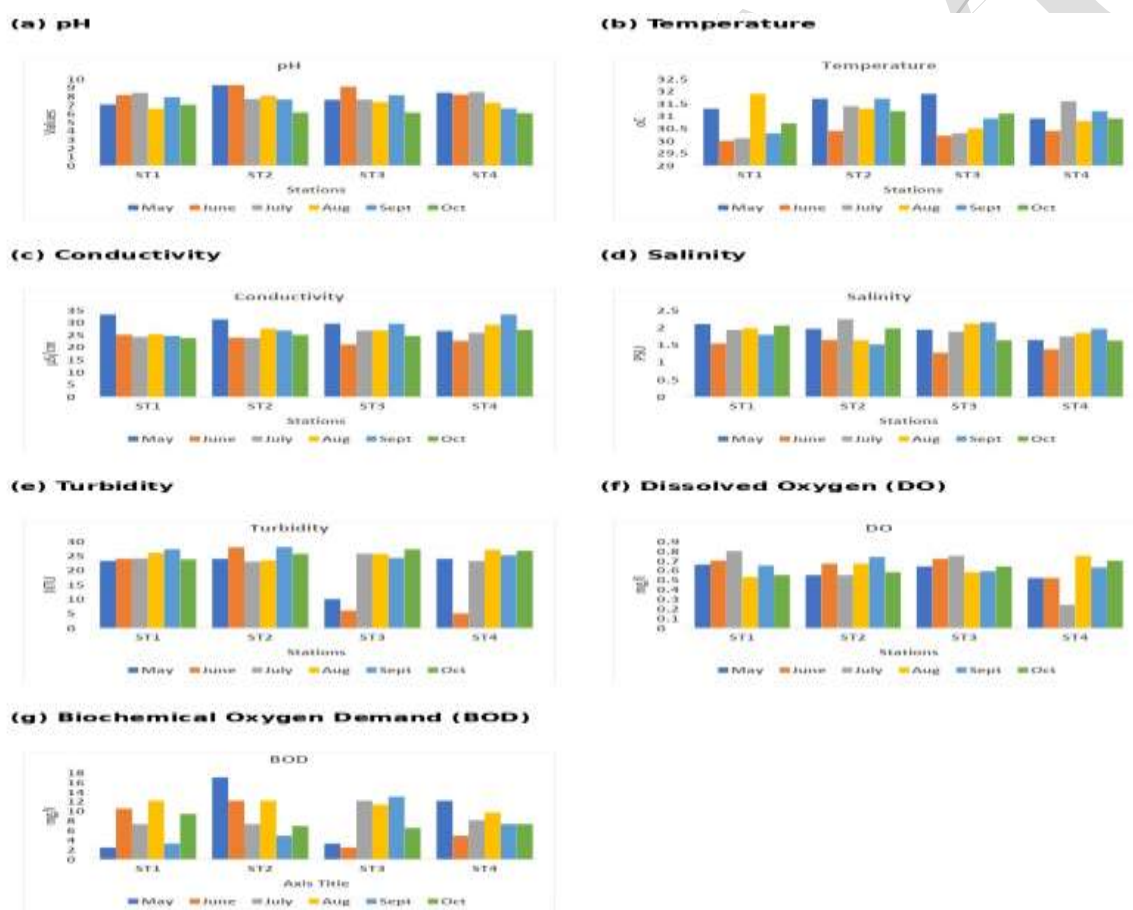


Figure 2. Physicochemical parameters of surface water: (a) pH, (b) temperature, (c) conductivity, (d) salinity, (e) turbidity, (f) dissolved oxygen, and (g) biochemical oxygen demand.

Mean heavy metal concentrations in water by station are presented in Figure 3. Lead was significantly higher at Station 1 than at the other three stations ($p=0.001$), which did not differ significantly from one another, and lead concentrations declined significantly from May to October

($p < 0.001$), a pattern consistent with a persistent but diminishing input near Station 1, most plausibly linked to oil-related or industrial activity upstream. Zinc was significantly higher at Stations 1 and 4 than at Stations 2 and 3 ($p = 0.001$), pointing to a distinct, more localised source of zinc input at the upstream and downstream ends of the sampled stretch, while copper was significantly higher at Station 1 than at Stations 2 and 4 ($p = 0.001$) but, unusually, peaked in October rather than the earlier months ($p = 0.012$), suggesting a delayed or different pollution pathway to the other metals.

Chromium showed no significant station ($p = 0.213$) or month ($p = 0.718$) effect, the only metal for which this was the case, suggesting a diffuse rather than point-source origin. Nickel was significantly higher at Station 3 than at Station 2 ($p < 0.001$) and showed a sharp June peak, roughly double every other month's mean ($p < 0.001$), consistent with an episodic input event such as a discharge or spill rather than a steady, continuous source. Cadmium was significantly higher at Station 1 than at the other three stations ($p < 0.001$) and, like lead, declined significantly from June to October ($p = 0.001$).

Heavy Metals in Surface Water

Heavy metal concentrations in surface water were analyzed for lead, zinc, copper, chromium, nickel, and cadmium across the four stations and six months. The presence of these metals indicates contamination from anthropogenic sources such as industrial discharge, oil exploration, and domestic waste.

Lead: Lead was significantly higher at Station 1 than at the other three stations ($p = 0.001$), which did not differ significantly from one another, and lead concentrations declined significantly from May to October ($p < 0.001$), a pattern consistent with a persistent but diminishing input near Station 1, most plausibly linked to oil-related or industrial activity upstream. Lead (0.33 ± 0.10 mg/L) exceeded the WHO permissible limit of 0.01 mg/L at every station and month, a level substantially higher than that reported for Azuabie and Okujagu creeks, where lead was detected only in July and did not persist across the full sampling period (Moslen and Aigberua, 2018), and higher than the lead levels reported for Ekerekana and Okochiri creeks (Moslen and Ekweozor, 2017). This indicates that Mgbuodahia River is affected by lead inputs at the more severe end of what has been documented across this series of studies within the upper Bonny estuary system

Cadmium: Cadmium was significantly higher at Station 1 than at the other three stations ($p < 0.001$) and, like lead, declined significantly from June to October ($p = 0.001$). Cadmium (0.10 ± 0.06 mg/L) exceeded the WHO permissible limit of 0.003 mg/L at every station and month, again a more persistent and severe exceedance than that reported for Azuabie and Okujagu creeks, where cadmium was likewise detected only intermittently (Moslen and Aigberua, 2018). The cooccurrence of the lead and cadmium hotspots at Station 1, together with their shared declining trend over the sampling period, suggests a common upstream point source affecting both metals.

Chromium: Chromium showed no significant station ($p=0.213$) or month ($p=0.718$) effect, the only metal for which this was the case, suggesting a diffuse rather than point-source origin, similar to the pattern reported for chromium in Azuabie Creek, where station effects were also non-significant despite significant monthly variation (Moslen and Aigberua, 2018). This diffuse chromium pattern, set against the sharply station-specific lead and cadmium patterns, is itself informative: it indicates that not all metals in Mgbuodahia River share a common source, and that at least two distinct contamination pathways – a localised point source and a broader regional background are operating simultaneously, consistent with the interpretation offered for other Niger Delta creeks affected by a combination of industrial discharge and domestic waste (Dixit et al., 2015; Chaoua et al., 2019).

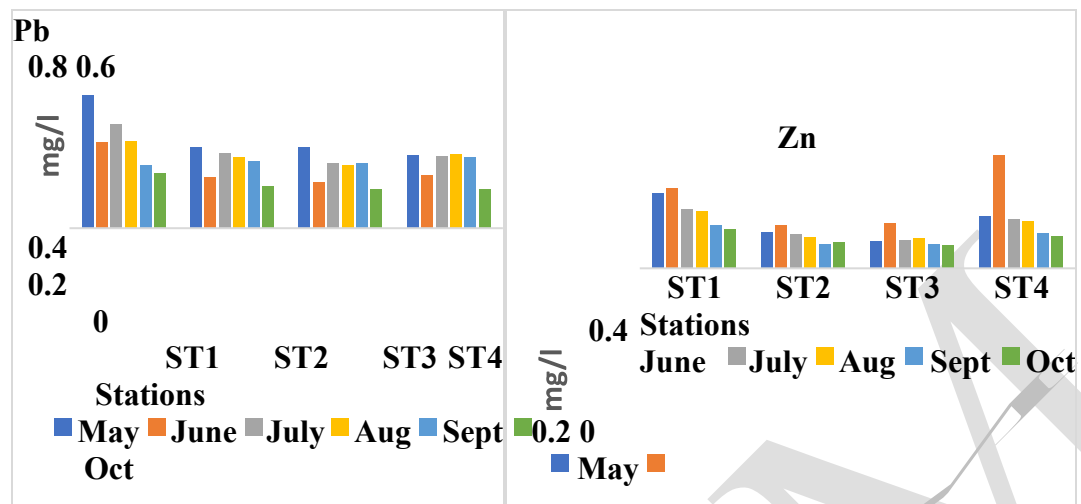
Nickel: Nickel was significantly higher at ST3 than at ST2 ($p<0.001$) and showed a sharp June peak, roughly double every other month's mean ($p<0.001$), consistent with an episodic input event such as a discharge or spill rather than a steady, continuous source. This episodic nickel pattern has not been reported at comparable magnitude in the group's earlier Azuabie and Okujagu creek assessments (Moslen and Aigberua, 2018), and its timing a single sharp peak rather than a gradual seasonal trend suggests that it should be treated as a discrete pollution event warranting targeted follow-up sampling around ST3 rather than as evidence of a chronic, ongoing input.

Copper: Copper was significantly higher at ST1 than at ST2 and ST4 ($p=0.001$) but, unusually, peaked in October rather than the earlier months ($p=0.012$), suggesting a delayed or different pollution pathway compared to lead and cadmium, which both declined over the same period. This decoupling of copper's temporal trend from that of lead and cadmium, despite sharing Station 1 as a common spatial hotspot, further supports the interpretation that Mgbuodahia River receives inputs from more than one contamination source or pathway operating on different timescales.

Zinc: Zinc was significantly higher at ST1 and ST4 than at ST2 and ST3 ($p=0.001$), pointing to a distinct, more localised source of zinc input at the upstream and downstream ends of the sampled stretch, without a corresponding significant monthly effect. This two-ended spatial pattern for zinc parallels the site-discrimination pattern reported for Azuabie Creek, where Principal Component Analysis distinguished Station AZ1 from the other stations on the basis of zinc concentration specifically (Moslen and Aigberua, 2018), and suggests that zinc loading in Mgbuodahia River is similarly tied to activities concentrated at specific points along the river rather than distributed uniformly along its length.

Table 1: Summary of ANOVA Tables for Parameters examined

Parameter	P-value(Location)	P-value(Time)
Temperature	0.251	0.069
pH	0.519	0.003
Turbidity	0.331	0.116



E.C	0.776	0.010
Salinity	0.554	0.294
DO	0.591	0.957
BOD	0.753	0.746
Lead	0.001	0.000
Zinc	0.001	0.003
Copper	0.001	0.012
Chromium	0.213	0.718
Nickel	0.000	0.000
Cadmium	0.000	0.001

*Significance level = $p < 0.05$

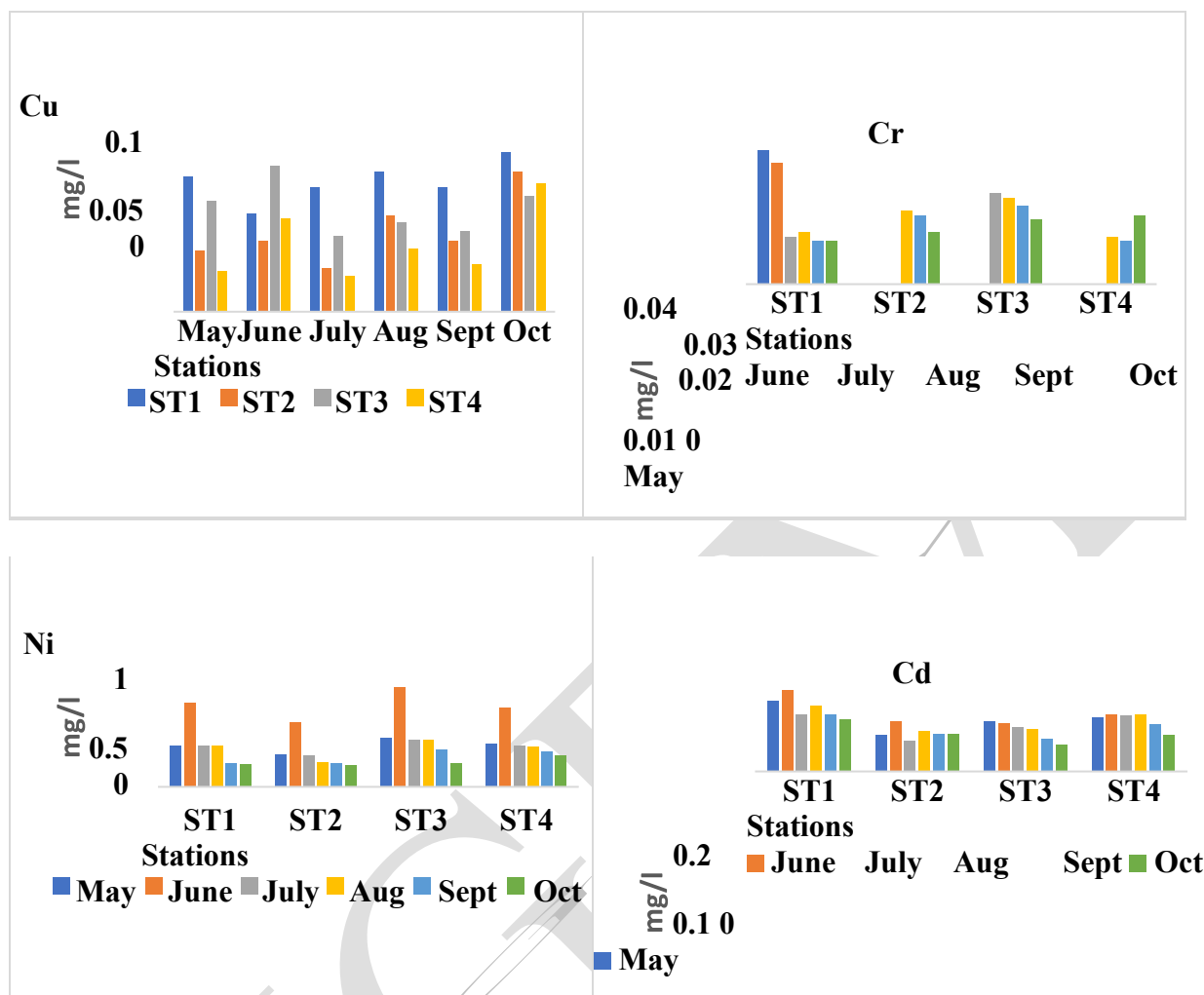


Figure 3. Heavy metal concentrations in surface water: (a) lead, (b) zinc, (c) copper, (d) chromium, (e) nickel, and (f) cadmium.

PCA Surface Water Variables

The principal component analysis result for water parameters is given in Figure 4. Results show that PC1 explains the largest portion of variance in the data while PC2 describes the next largest portion in the data, orthogonal to PC1. BOD has a long vector implying it contributes strongly to the variance captured by the PCA. Turbidity also has a relatively long vector, another important driver of variation. Other variables like Salinity, pH, and Temperature have short vectors near the origin meaning, they contribute less to the variance explained by PC1 and PC2. Variables close to the origin are either: weakly represented by these two PCs, or vary less compared to BOD and Turbidity. BOD and Turbidity point in very different directions, meaning they are weakly correlated or negatively correlated. PC1 looks to be driven mainly by Turbidity due to suspended particles / clarity while PC2 appears to be driven mainly by BOD as a result of organic pollution / oxygen demand).

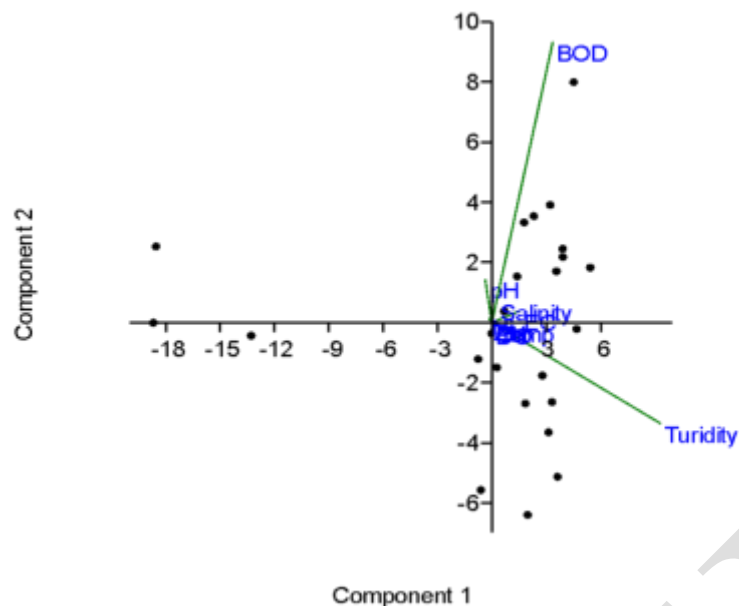


Figure 4. Principal component analysis of surface-water physicochemical variables.

Conclusion

The physicochemical parameters varied across sampling stations, with significant spatial and temporal differences observed for several parameters, indicating changing environmental conditions in Mgbuodahia River. Heavy metals were detected in the surface water, confirming pollution of the ecosystem. Principal Component Analysis pointed to anthropogenic sources, industrial discharge, oil exploration, and domestic waste as key drivers, indicating that a mixture of localised point-source and regional background contamination affects this river. Comparison with earlier work on Azuabie and Okujagu creeks, Ekerekana and Okochiri creeks, the Orashi River, and the Choba/Iwofe axis of the New Calabar River shows that Mgbuodahia River sits at the more severe end of the lead and cadmium contamination gradient documented across the upper Bonny estuary system. This study provides a physicochemical and heavy-metal baseline for the river's surface water and supports continuous monitoring and regulation of discharge sources.

Recommendations

Recommendations arising from this study include regular monitoring of heavy metals in the surface water; regulation of industrial discharge and waste disposal into the river by government and environmental agencies; increased public awareness of the pollution risk; review and enforcement of proper sewage and effluent discharge practices around Mgbuodahia River; strict enforcement of environmental protection policies in the Niger Delta region; and further research to build on this baseline.

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Declaration of Conflicting Interests

The authors declare that there are no conflicts of interest regarding the publication of this article.

Author Contributions

Neeuweh, JA: conceptualization, field sampling, laboratory analysis, data curation, original draft preparation. Moslen, M: conceptualization, supervision, methodology, review and editing. Green, AF: supervision, review and editing. All authors read and approved the final manuscript.

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