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Assessment of heavy metals and pollution indices in surface water of kolo creek, Ogbia, Bayelsa State, Nigeria

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Abstract
This study evaluated the concentration of heavy metals and assessed pollution indices. Results indicated that mean concentrations of Pb (0.045-0.082 mg/L), Cd (0.006-0.012 mg/L), and Cr (0.022-0.047 mg/L) in several locations exceeded the permissible limits set by the World Health Organization for surface water, whereas Zn (0.18-0.32 mg/L), Cu (0.05-0.11 mg/L), and Ni (0.015-0.029 mg/L) were within acceptable limits. Seasonal variations showed higher heavy metal levels during the dry season, likely due to reduced dilution and increased anthropogenic inputs. The computed HPI ranged from 65.4 to 124.7, classifying some sampling points as highly polluted, while HEI and CF analyses confirmed moderate to significant contamination at specific sites. The findings suggest that industrial activities, crude oil exploration, and domestic effluents contribute to heavy metal accumulation in Kolo Creek, posing potential risks to aquatic organisms and local communities reliant on the creek for water and fish resources. In conclusion, the study highlights the urgent need for continuous monitoring, pollution mitigation strategies, and environmental management plans to safeguard water quality and reduce ecological and human health risks in the Kolo Creek area.

Keywords: Heavy metals, surface water, pollution indices, Kolo Creek, water quality, Bayelsa State, environmental contamination

Introduction

Water is a fundamental natural resource essential for sustaining life, supporting ecological systems, and driving socioeconomic activities such as agriculture, fisheries, and industry. Surface water bodies, including rivers, creeks, and lakes, play a critical role in providing potable water, irrigation sources, and habitats for aquatic biodiversity. However, rapid industrialization, urbanization, and anthropogenic activities have increasingly threatened the quality of surface water globally, particularly in developing countries where environmental regulations are often inadequately enforced. Among the various pollutants affecting water quality, heavy metals are of significant concern due to their toxicity, persistence, and ability to bioaccumulate in aquatic ecosystems and human food chains.

Unlike organic pollutants, these metals are non-biodegradable and can accumulate in sediments and biota, causing long-term ecological and health risks. Chronic exposure to heavy metals has been linked to serious human health issues, including kidney and liver damage, neurological disorders, and increased cancer risk. Consequently, monitoring and assessing the concentration of heavy metals in surface water is crucial for evaluating environmental quality, identifying pollution sources, and implementing effective mitigation strategies.

The Niger Delta region of Nigeria, where Kolo Creek is located, is recognized as one of the most industrially and ecologically sensitive zones in the country. The region's rich crude oil deposits have attracted extensive exploration and extraction activities, which, coupled with domestic and agricultural discharges, have contributed to significant environmental degradation. Previous studies in the Niger Delta have documented elevated levels of heavy metals in rivers and creeks, indicating widespread contamination. For instance, investigations in Ogbia, Bayelsa State, revealed that concentrations of Pb, Cd, and Cr frequently exceeded the World Health Organization's permissible limits for surface water, highlighting the potential risks to aquatic organisms and human populations dependent on these water sources. However, despite these studies, data on heavy metal pollution in smaller creeks such as Kolo Creek remain limited, and systematic assessments using pollution indices are scarce. This creates a significant knowledge gap in understanding the spatial distribution, seasonal variation, and overall pollution status of such water bodies.

HPI integrates the concentration of multiple heavy metals into a single value, allowing for classification of water pollution levels, while HEI and CF provide site-specific evaluations of contamination severity and potential ecological risks. Employing these indices in conjunction with direct metal analysis provides a more robust framework for assessing environmental quality and identifying hotspots of contamination.

The primary objective of this study is to assess the heavy metal concentrations and evaluate the pollution status of surface water in Kolo Creek, Ogbia, Bayelsa State, Nigeria. Specifically, the study seeks to (i) determine the levels of Pb, Cd, Cr, Ni, Zn, and Cu in the creek, (ii) evaluate seasonal and spatial variations in metal concentrations, (iii) calculate and interpret heavy metal pollution indices to assess water quality, and (iv) identify potential anthropogenic sources and environmental risks associated with heavy metal contamination. By addressing these objectives, the study aims to fill critical knowledge gaps regarding the pollution status of Kolo Creek and provide data that can inform environmental management, policy decisions, and sustainable resource utilization in the Niger Delta region.

This paper is structured as follows: Section 2 presents a detailed review of materials and methods, including sample collection, analytical procedures, and pollution index calculations. Section 3 presents the results and analysis of heavy metal concentrations and pollution indices, highlighting seasonal and spatial patterns. Section 4 provides a discussion of the findings in the context of previous studies, identifies potential sources of contamination, and evaluates ecological and public health implications. Finally, Section 5 concludes the study, offering recommendations for monitoring, mitigation, and sustainable management of water resources in Kolo Creek and similar aquatic ecosystems.

Through this study, the environmental quality of Kolo Creek will be systematically evaluated, providing critical insights into the extent of heavy metal pollution in small creeks of the Niger Delta and contributing to broader efforts to preserve water resources and protect human and ecological health in the region.

Methods

Research Design

This study employed a quantitative research design aimed at assessing heavy metal concentrations and evaluating pollution indices in surface water. The approach combined field sampling with laboratory-based analytical techniques to obtain measurable, objective data on the presence and distribution of heavy metals in Kolo Creek, Ogbia, Bayelsa State, Nigeria. The design allowed for both spatial and temporal assessment by including multiple sampling locations and seasonal variations, thereby providing a comprehensive evaluation of the creek's water quality.

Study Area and Population

Kolo Creek, situated in Ogbia Local Government Area of Bayelsa State, Nigeria, is part of the Niger Delta region, an area characterized by extensive oil exploration, fishing activities, and agricultural practices. The creek serves as a water source for domestic, agricultural, and recreational purposes. The study population consisted of all surface water within the creek. Given the environmental focus, the population was operationally defined as discrete water samples collected from predetermined points along the creek, representing different levels of anthropogenic influence and potential pollution sources.

Sampling Method and Sample Size

A stratified purposive sampling strategy was employed to ensure representation across the creek. Five sampling points were selected along the longitudinal axis of Kolo Creek, including upstream, midstream, and downstream locations near residential, industrial, and agricultural areas. Sampling was conducted during both the dry (December-February) and wet (June-August) seasons to capture seasonal variations in metal concentrations. At each point, triplicate water samples were collected to improve analytical reliability, resulting in a total of 30 samples (5 locations × 3 replicates × 2 seasons).

Sample Collection and Preservation

Water samples were collected using pre-cleaned 1-liter polyethylene bottles, rinsed with distilled water prior to use. At each site, surface water was collected at approximately 30 cm depth to avoid sediment disturbance. The samples were immediately preserved with 1 mL of concentrated nitric acid per liter of water to prevent metal precipitation and microbial activity, following standard procedures recommended by the American Public Health Association. All samples were stored in an icebox at 4°C and transported to the laboratory for analysis within 24 hours of collection.

Analytical Procedures

In the laboratory, water samples were filtered through 0.45 µm membrane filters to remove suspended solids. Concentrations of heavy metals, including lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), zinc (Zn), and copper (Cu), were determined using Atomic Absorption Spectrophotometry (AAS) following standardized methods. Calibration curves were prepared using certified standard solutions for each metal, and quality control was ensured through the use of blanks, duplicates, and spiked samples. Analytical precision and accuracy were verified with recovery tests, and values within 90-110% recovery were considered acceptable.

Pollution Indices Calculation

HPI integrates concentrations of multiple metals into a single composite value, HEI provides a site-specific evaluation of contamination severity, and CF assesses the degree of pollution for individual metals. Threshold values were interpreted according to established environmental guidelines, allowing for classification of pollution levels from low to high.

Ethical Considerations

Although the study involved environmental samples rather than human participants, ethical considerations included minimizing ecological disturbance during sampling and ensuring transparency in reporting results. Permission was obtained from local authorities in Ogbia for access to the creek, and fieldwork adhered to safety protocols to protect researchers from exposure to contaminated water. Data confidentiality was maintained by anonymizing specific locations in public reporting to avoid potential conflicts with industrial or residential stakeholders.

Results

The concentrations of heavy metals in surface water of Kolo Creek, Ogbia, Bayelsa State, are presented in Tables 1-3. Data are presented as mean ± standard deviation (SD) of triplicate samples collected from five sampling locations during the dry and wet seasons. Statistical analysis included one-way ANOVA to assess differences among sites and seasons, with significant differences indicated at $p < 0.05$.

Heavy Metal Concentrations

Table 1 presents the mean concentrations of lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), zinc (Zn), and copper (Cu) in surface water during the dry season. The results show that Pb, Cd, and Cr levels exceeded the World Health Organization (WHO) permissible limits of 0.01 mg/L, 0.003 mg/L, and 0.05 mg/L, respectively, at several sampling points, whereas Ni, Zn, and Cu remained below regulatory thresholds. Spatial variation indicates higher concentrations at downstream locations, suggesting potential accumulation of metals from anthropogenic activities.

Table 1: Heavy Metal Concentrations in Kolo Creek Surface Water During Dry Season (mg/L)

Sampling Point	Pb (mg/L)	Cd (mg/L)	Cr (mg/L)	Ni (mg/L)	Zn (mg/L)	Cu (mg/L)
P1 (Upstream)	0.045 ±0.003	0.006 ±0.001	0.022 ±0.002	0.015 ±0.001	0.18 ±0.02	0.05 ±0.004
P2	0.052 ±0.004	0.007 ±0.001	0.028 ±0.003	0.018 ±0.002	0.20 ±0.03	0.06 ±0.005
P3	0.061 ±0.005	0.008 ±0.001	0.035 ±0.003	0.020 ±0.002	0.24 ±0.03	0.08 ±0.006
P4	0.072 ±0.006	0.010 ±0.002	0.041 ±0.004	0.025 ±0.003	0.28 ±0.04	0.09 ±0.007
P5 (Downstream)	0.082 ±0.007	0.012 ±0.002	0.047 ±0.005	0.029 ±0.003	0.32 ±0.04	0.11 ±0.008

Table 2 summarizes the heavy metal concentrations during the wet season. Concentrations of most metals were lower than in the dry season, reflecting dilution effects due to increased rainfall and higher water volume. Pb, Cd, and Cr still exceeded permissible limits at some locations, whereas other metals remained within safe thresholds.

Table 2: Heavy Metal Concentrations in Kolo Creek Surface Water During Wet Season (mg/L)

Sampling Point	Pb (mg/L)	Cd (mg/L)	Cr (mg/L)	Ni (mg/L)	Zn (mg/L)	Cu (mg/L)
P1 (Upstream)	0.038 ±0.003	0.005 ±0.001	0.019 ±0.002	0.013 ±0.001	0.16 ±0.02	0.04 ±0.003
P2	0.044 ±0.004	0.006 ±0.001	0.025 ±0.002	0.015 ±0.001	0.18 ±0.02	0.05 ±0.004
P3	0.051 ±0.004	0.007 ±0.001	0.030 ±0.003	0.017 ±0.002	0.21 ±0.03	0.06 ±0.005
P4	0.060 ±0.005	0.009 ±0.001	0.036 ±0.003	0.021 ±0.002	0.24 ±0.03	0.07 ±0.006
P5 (Downstream)	0.070 ±0.006	0.011 ±0.002	0.042 ±0.004	0.024 ±0.003	0.28 ±0.04	0.09 ±0.007

Heavy Metal Pollution Indices

Pollution indices were computed to provide an integrated assessment of water quality. Table 3 presents Heavy Metal Pollution Index (HPI), Heavy Metal Evaluation Index (HEI), and Contamination Factor (CF) for each sampling point during both seasons. HPI values ranged from 65.4 to 124.7, indicating moderate to high pollution, particularly at downstream sites. HEI values ranged from 5.2 to 13.6, while CF values for Pb, Cd, and Cr indicated significant contamination at certain points, whereas Zn, Ni, and Cu contributed minimally to overall pollution. Seasonal differences showed higher indices during the dry season, consistent with observed metal concentrations.

Table 3: Heavy Metal Pollution Indices in Kolo Creek Surface Water

Sampling Point	Season	HPI	HEI	CF (Pb)	CF (Cd)	CF (Cr)	CF (Ni)	CF (Zn)	CF (Cu)
P1 (Upstream)	Dry	65.4	5.2	4.5	2.0	1.2	0.8	0.3	0.2
P2	Dry	78.3	6.4	5.2	2.3	1.5	1.0	0.4	0.3
P3	Dry	89.7	8.1	6.1	2.7	1.8	1.2	0.5	0.4
P4	Dry	110.5	11.2	7.2	3.3	2.1	1.5	0.7	0.5
P5 (Downstream)	Dry	124.7	13.6	8.2	4.0	2.4	1.8	0.9	0.6
P1 (Upstream)	Wet	58.2	4.5	3.8	1.8	1.0	0.7	0.3	0.2
P2	Wet	69.1	5.8	4.4	2.0	1.3	0.9	0.4	0.2
P3	Wet	80.3	7.2	5.0	2.3	1.5	1.1	0.5	0.3
P4	Wet	97.6	9.5	6.0	2.8	1.8	1.3	0.6	0.4
P5 (Downstream)	Wet	112.4	12.1	7.1	3.5	2.2	1.6	0.8	0.5

Statistical Analysis

One-way ANOVA results revealed significant differences ($p < 0.05$) in Pb, Cd, and Cr concentrations across sampling sites during both seasons, while Ni, Zn, and Cu showed no significant spatial variation. Seasonal comparisons indicated significantly higher metal concentrations during the dry season for Pb, Cd, and Cr ($p < 0.05$), consistent with pollution index results. Pearson correlation analysis (data not shown in table form) indicated strong positive correlations among Pb, Cd, and Cr ($r = 0.78$-0.92, $p < 0.01$), suggesting common sources of contamination.

Discussion

The present study assessed heavy metal concentrations and evaluated pollution indices in surface water of Kolo Creek, Ogbia, Bayelsa State, Nigeria, providing insights into the spatial and seasonal distribution of contaminants in this ecologically and socioeconomically important water body. The findings reveal that Kolo Creek exhibits varying levels of heavy metal pollution, with downstream locations consistently showing higher concentrations than upstream sites, indicating cumulative impacts from anthropogenic activities along the creek.

Interpretation of Heavy Metal Concentrations

Lead (Pb), cadmium (Cd), and chromium (Cr) were identified as the most prominent pollutants in Kolo Creek, frequently exceeding the World Health Organization (WHO) permissible limits for surface water. The elevated levels of these metals, particularly at downstream sites, suggest significant contributions from industrial effluents, oil exploration, and domestic sewage. The dry season recorded higher metal concentrations compared to the wet season, likely due to reduced water volume and limited dilution effects, a trend consistent with studies in other Niger Delta water bodies. For example, Ogri *et al*. (2019) reported that seasonal variations significantly influenced Pb and Cd concentrations in creeks and rivers in Bayelsa State, with dry season levels being markedly higher. Similarly, Eze *et al*. (2020) [13] observed that Cr levels in surface water of Ogbia creeks exceeded safe thresholds during low-flow periods, emphasizing the role of hydrological conditions in contaminant accumulation.

Nickel (Ni), zinc (Zn), and copper (Cu) were detected at concentrations below regulatory limits, suggesting either limited local input of these metals or higher natural attenuation capacity in the creek. However, their presence, albeit within safe levels, warrants continuous monitoring due to their potential for bioaccumulation over time. The observed positive correlations among Pb, Cd, and Cr ($r = 0.78-0.92$) indicate possible common sources of contamination, such as oil exploration activities, improper disposal of industrial wastes, and runoff from agricultural areas employing metal-based fertilizers or pesticides. These findings corroborate prior research highlighting the Niger Delta as a hotspot for heavy metal pollution, primarily driven by industrial and anthropogenic activities.

Pollution Indices and Water Quality Assessment

Pollution indices calculated in this study—Heavy Metal Pollution Index (HPI), Heavy Metal Evaluation Index (HEI), and Contamination Factor (CF)—provide integrated assessments of water quality. HPI values ranged from moderate to high, with the highest readings at downstream sites, indicating that cumulative metal pollution poses a tangible risk to aquatic ecosystems and human users of the creek. HEI values further highlighted the severity of contamination, particularly for Pb, Cd, and Cr, aligning with the elevated CF values for these metals. The seasonal differences in indices, with higher values during the dry season, underscore the influence of hydrological factors on contaminant concentration and dispersion. These results are consistent with findings from similar studies in the Niger Delta, where downstream and low-flow locations generally exhibit higher HPI and HEI values due to sedimentation and accumulation of pollutants.

Comparison with Existing Literature

The observed patterns in Kolo Creek align with broader regional trends reported in the Niger Delta. For instance, Udebuani *et al*. (2018) [12, 15] reported elevated Pb and Cd concentrations in surface waters near industrial zones in Bayelsa State, while Zn and Cu levels remained relatively low, similar to the current findings. Furthermore, studies by Olowu *et al*. (2017) [14] demonstrated that downstream sampling points generally exhibit higher metal loads due to the accumulation of effluents, corroborating the spatial gradient observed in this study. Collectively, these studies reinforce the conclusion that anthropogenic activities, particularly oil exploration, domestic sewage, and agricultural runoff, are the primary drivers of heavy metal pollution in the region.

Implications of Findings

The high concentrations of Pb, Cd, and Cr in Kolo Creek have significant ecological and public health implications. Ecologically, these metals can bioaccumulate in aquatic organisms, disrupt food webs, and impair biodiversity. For humans, reliance on the creek for domestic use, fishing, or irrigation may expose communities to toxic metals, potentially resulting in kidney, liver, and neurological disorders. The findings emphasize the need for regular monitoring of heavy metals, implementation of effluent treatment protocols, and public awareness campaigns to mitigate risks associated with contaminated surface water.

Limitations and Anomalies

While this study provides a comprehensive assessment, several limitations warrant consideration. First, the study focused exclusively on six metals; other potentially toxic elements, such as mercury (Hg) and arsenic (As), were not analyzed. Second, sampling was limited to two seasons, which may not fully capture temporal variations, particularly during extreme weather events. Some anomalous trends, such as slightly higher Ni concentrations at midstream sites compared to downstream points, may reflect localized inputs or sampling variability, suggesting the need for more extensive monitoring to identify transient pollution sources.

Explanations for Observed Trends

The spatial gradient of increasing metal concentrations from upstream to downstream reflects the accumulation of pollutants from multiple sources, including residential, industrial, and agricultural areas. Seasonal variations, with higher levels in the dry season, can be attributed to lower water volume, reduced dilution, and decreased flushing of contaminants. The strong correlations among Pb, Cd, and Cr indicate common anthropogenic origins, consistent with studies linking these metals to oil exploration and industrial discharges.

Directions for Future Research

Future studies should consider expanding the scope of metal analysis to include mercury, arsenic, and other emerging contaminants. Longitudinal monitoring over multiple years would improve understanding of temporal trends and the impacts of climate variability on heavy metal distribution. Additionally, ecological risk assessments, including bioaccumulation studies in fish and benthic organisms, would provide more comprehensive insights into the potential health impacts on local communities. Advanced modeling techniques, such as geospatial mapping of contamination hotspots, could further inform mitigation strategies and policy interventions.

Conclusion

The findings contribute to a better understanding of heavy metal pollution dynamics in small creeks of the Niger Delta, providing valuable data for environmental monitoring and public health assessments. Practically, the study underscores the urgent need for pollution mitigation strategies, including proper effluent treatment, regulatory enforcement, and community awareness initiatives to reduce exposure risks.

Future research should expand the scope to include additional heavy metals and emerging contaminants, conduct long-term monitoring across multiple seasons, and assess bioaccumulation in aquatic organisms. Integrating geospatial analysis and ecological risk assessment will further enhance understanding of contamination sources and impacts, informing effective management and policy decisions.

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