

Ecological risks Assessment of heavy metals from the Kidaro Creek, Niger Delta Nigeria

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This study assessed the concentrations, distribution, and ecological risks of selected heavy metals (Pb, Cd, Ni, V, Cr, and As) in surface water and sediments of Kidaro Creek, Niger Delta, Nigeria during the dry and wet seasons. Surface water and sediment samples were collected from three stations and analyzed using standard analytical procedures. The concentrations of Pb, Cd, Ni, Cr, and V in surface water ranged from 0.355–1.761, 0.119–0.258, 0.320–0.505, 0.045–0.366, and 0.029–0.359 mg/L respectively in the dry season, and 0.284–1.669, 0.008–0.025, 0.214–0.381, 0.278–0.567, and 0.045–0.366 mg/L in the wet season, exceeding World Health Organization (WHO) limits for drinking water, while As ranged from 0.006–0.014 mg/L (dry season) and 0.040–0.181 mg/L (wet season). In sediments, Pb, Cd, Ni, Cr, V, and As ranged from 12.98–47.96, 0.41–3.82, 0.600–7.49, 2.259–12.060, 0.247–5.409, and 0.005–0.129 mg/kg in the dry season and 14.62–49.98, 0.013–0.380, 0.457–9.55, 1.362–13.937, <0.001–0.007, and 0.492–1.220 mg/kg in the wet season. Ecological risk assessment showed extremely high contamination in surface water, with contamination factors ranging from 10.63–435.0 in the dry season and 1.10–228.67 in the wet season, while sediment CF values were generally low (0.011–2.146). Surface water pollution load index (PLI) ranged from 47.72–152.38 in the dry season and 2.89–25.69 in the wet season, whereas sediment PLI ranged from 0.073–0.137 (dry season) and 0.012–0.026 (wet season). The potential ecological risk index (PERI) for surface water ranged from 11105.67–22501.33 in the dry season and 1796.33–3293 in the wet season, indicating extremely high ecological risk, while sediment PERI values ranged from 25.62–145.85 (dry season) and 4.81–16.66 (wet season), indicating generally low ecological risk. Cadmium contributed the largest share of ecological risk (86% in dry season and 53.9% in wet season in surface water; >90% in sediments). The findings indicated that Kidaro Creek is significantly impacted by heavy metal pollution, largely driven by anthropogenic inputs associated with petroleum-related activities in the Niger Delta. Continuous environmental monitoring and effective pollution management strategies are necessary to safeguard the aquatic ecosystem and surrounding communities.

Keywords: Heavy metal, anthropogenic, water pollution, contamination factor, geo-accumulation; Ecological risk assessment, Kidaro creek, Ogoni area.

INTRODUCTION

Environmental pollution is the price of industrialization, urbanization and population growth through the activities of man in the course of technology and economic advancement. While oil exploration and production activities has improved the standard of living, it has released undesirable by-product into the environment, resulting in ecological disasters with consequent damage to both aquatic and human life. The Niger Delta region has not been spared as it has become heavily polluted with hydrocarbons, heavy metals (HMs) are other active elements found in crude oil due to oil exploratory activities, oil spills and most recently, illegal refining of crude oil popularly known as “Kpo Fire” (Chinedu & Chukwuemeka, 2018; Flourizel et al., 2024; Fyनेface et al., 2022; Olukaejire et al., 2024). HMs have been given special attention because of their ubiquity, abundance, resistance to decomposition, bioaccumulation and persistent properties (Anyanwu & Nwachukwu, 2020), which makes eliminating them from

the environment difficult (Ali et al., 2019). These compounds therefore accumulate in sediments or the tissues of organisms, which poses serious threat to organisms, and ecosystems (Malvandi, 2017; Nafagha-Lawal et al., 2022). Some HMs are toxic at low quantities, mutagenic and carcinogenic (Ali & Khan, 2019; Jonathan et al., 2017).

Estuarine ecosystems pollution has been of public concern, following the rate and extent of its degradation (Alahabadi & Malvandi, 2018; Tian et al., 2020). The pollution of these water bodies does not only affect its suitability for domestic and public use, it also affect sediment quality and the distribution and abundance of aquatic organisms (Emuedo et al., 2014; Ribeiro et al., 2018). The rise in HMs contamination of aquatic ecosystems is further exacerbated by its the complex nature for its roles as ‘conduit pipe’ in reception of these metals from external sources and as a ‘reservoir’ and subsequently, lock up these metals in sediment, benthic and other aquatic organisms for further biotransformation (Ezewudo et al., 2021; Tian et al., 2020). Sediment quality is an indicator of aquatic pollution indices, HMs and other organic pollutants concentrate in sediments rendering them major sinks for contamination assessments (Bastami et al., 2014; Shi et al., 2019). When environmental conditions change, these sediments are also potential sources of HMs for various aquatic organisms, allowing it to enter the food chain and eventually, a threat to human health (Malvandi, 2017; Stuyt et al., 2015). Therefore, assessment of sediment quality provides information on the pollution and environmental status of an aquatic ecosystem (Islam et al., 2015; Olu et al., 2019).

Ecological risk assessment is a flexible and systematic approach for integrating and analysing data, assumptions, and uncertainties to determine the likelihood of adverse ecological effects that may have occurred or may occur as a result of exposure to one or more stressors related to human activities (Agah, 2021). The focus of ecotoxicological risk assessment is to establish the potential risk associated with an environment due to anthropogenic impact using various indicators (Contamination factor, Geo-accumulation Index, Pollution load index, and Potential Ecological Risk Index) to predict the environmental quality of the impacted sites (Liao et al., 2022). Worldwide, several studies have been carried out on assessment of the ecological risk of HMs. For example, Hou et al., (2013) conducted a study in water and sediments from Lake Dalinouer, China to estimate the ecological risk and sources of HMs; Tian et al., (2020) conducted a study on China sediments of the Bohai Sea and the Yellow Sea. Several ecotoxicological studies have also been carried out in the Niger delta on sediment and water bodies of different coastal communities in the Niger Delta region: Afolabi & Adesope, 2022 (Niger Delta region); Moslen & Aigberua, 2018, (Azubie Creek); Aigberua et al., 2020 (Taylor Creek), Davies & Anyanwu, 2023 (Bonny River); Moslen & Aigberua, 2018 (Bonny Estuary),

Nwineewii et al., 2018 (New Calabar River). All these studies are significant to environmental quality improvement considering the widespread of many chemicals that can impact the environment negatively (Davies & Anyanwu, 2023); the economy (Ighariemu et al., 2023; Ogunola & Falaye, 2018), and public health (Ebuete et al., 2019). Environmental pollution has become an unavoidable consequence of economic development through industrialization. It is therefore necessary to control pollution to a level where it is not hazardous to man and environment (Igbemi et al., 2019).

This study aimed to (1) investigate the current pollution status of HMs such as Lead (Pb), Chromium (Cr), Nickel (Ni), Vanadium (V), Cadmium (Cd) and Arsenic (As) and their spatial distributions in Kidaro creek, Kegbare-Dere community, Niger Delta, Nigeria, (2) evaluate the ecological risks of HMs in an integrated system, (3) quantify the interactions of the HMs in the sediments and water and the linked environmental factors, (4) identify the potential sources of HMs in the sediments.

Materials and Methods

Study Area

Kegbare-Dere (K-Dere) community lies along the eastern edge of the Niger Delta, in Gokana Local Government Area of Rivers State, Nigeria, a prominent community in Ogoni land and is situated to the northeast of the Imo River. K-Dere community covers an area of approximately 10 square kilometres. Its topographical layout stands at about 100 meters above sea level. K-Dere is positioned approximately on Latitude 04° 39' 14'' North and Longitude 07° 16' 17'' East. K-Dere community is home to 64 oil wells including the Bomu Manifold with major oil exploration and production activities carried out in this area. These activities are associated with frequent cases of crude oil spills with two major crude oil spills witnessed on its terrestrial and aquatic ecosystem in 2006 and 2008. This was followed up by the clean-up activities by Shell Petroleum Development Company (SPDC) in 2008 (Tanee & Albert, 2011). But there are still evidences of oil spills as is visible in oil sheen on the surface water of the area.

The region once covered by thick rain forest has suffered from deforestation and pollution after decades of aggressive oil exploration and exploitation. According to the 2006 National Census Ogoni land has a population of close to 832,000 (NPC, 2006). Kidaro Creek is a tidal dominated marine ecosystem, characterised by mangrove swamps and tidal flats. It is associated with warm temperatures ranging from 26° to 34 °C and tropical climate with alternating wet and dry seasons. Wet season spans from April to October while dry season last from October to March. Similarly, it has vast ecological biodiversity of flora and fauna, examples include aquatic weeds, white and red mangroves, fish, mollusc, crustaceans, crabs among others. Seafood

obtained from the river is a source of sustenance and livelihood to local fishermen. Thus, the creek is economically important since certain commercial activities take place there. Table 1 gives a description of the geophysical characteristics of the sampling stations, and the sampling points location is as presented in Figure 1.

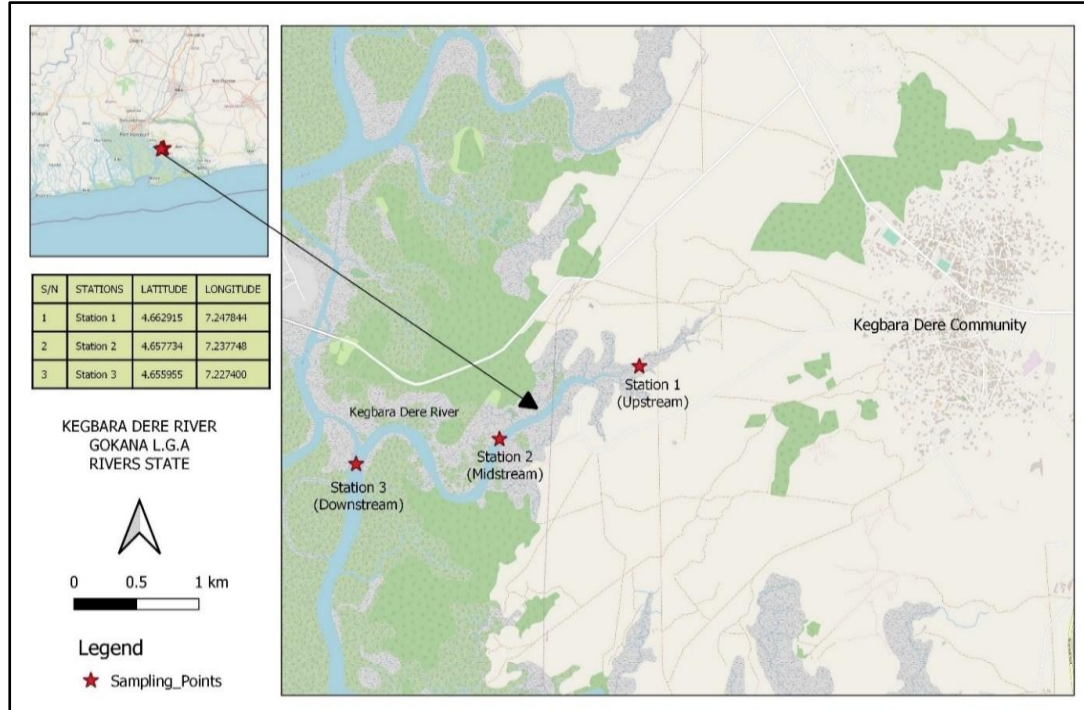


Fig 1: Study Area showing Sampling Stations (Source: Google map, 2020)

Sample Collection

Surface water and sediment, samples were collected in the two seasons namely wet (April - June 2022) and dry season (January - March 2022). The samples were collected from three different points, Viz: Upstream (Station 1), Midstream (Station 2) and Downstream (Station 3) with each point about 1.2km away from the next. A total of thirty-six (36) samples were collected which comprised 18 surface water samples, and 18 sediment samples for dry and wet season investigation.

Table 1: Description of Sampling Stations in Kidaro creek, Keggare-Dere community

S/N	Sampling Stations	Anthropogenic activities	Elevation	Latitude	Longitude
1	Downstream (Station 1)	Boat related activities, receives municipal and domestic effluents from nearby residences, water surface covered by dirt, little or no fishing activity.	456M	4.662915	7.247844
2	Midstream (Station 2)	Residential buildings and public toilets at the shoreline of the river, fishing,	403M	4.667734	7.237748

		recreational, direct defaecation into the river, swimming, bathing, washing.			
3	Upstream (Station 3)	Presence of pipelines.	400M	4.665595	7.227400

Sampling and Preservation

Surface water samples were collected with pre-acid rinsed plastic sample bottles. Water sample collection was by immersion of open bottles by hand into the surface water slowly in a bid to minimize turbulence at a depth of 25 cm into the water. The samples were fixed with two drops of nitric acid to stabilize the content and prevent adsorption of metals to the surface of the container. The collected samples were put into coolers with ice packs and then transported to the laboratory for analysis. Digestion of the water samples was done using concentrated nitric acid (Analytical Grade) according to the method described by (Zhang et al., 2007). 100ml of the water sample of each of the representative water samples were transferred into Pyrex beakers containing 10ml of concentrated nitric acid. The samples were boiled slowly and then evaporated on a hot plate to the lowest possible volume (about 20ml). The beakers were allowed to cool and another 5ml of Conc. HNO₃ was added. Heating was continued with the addition of concentrated nitric acid as necessary until digestion was complete. The samples were evaporated again to dryness (but not baked) and the beakers were cooled, followed by the addition of 5ml of HCl solution (1:1 v/v). The solutions were then warmed and 5ml of 5M NaOH was added, then filtered. The filtrates were transferred to 100ml volumetric flasks and diluted to the mark with distilled water. These solutions were then used for the elemental analysis using Atomic Absorption Spectrophotometer, AAS (Model 210VGP BUCK Scientific, USA).

Composite sediment samples were collected using an Ekman Grab sampler from the three identified sampling points during low tide and wrapped with labelled polythene bags. Collected samples were stored in an ice box for transportation to the laboratory. In the laboratory, the samples were kept in a freezer at -20°C until needed for HM analysis. During digestion, the sediment samples were thawed at room temperature (25°C - 28°C) and put into pre-acid cleaned evaporating beakers. The sediments were then dried at a temperature of 50°C in an oven until a constant weight was obtained. The dried sediment samples were grounded using a porcelain mortar and pestle and sieved through a 2 mm mesh plastic sieve.

Digestion was done using concentrated nitric acid (Analytical grade) and hydrochloric acid in the ratio 1:3 (aqua regia). 2 g of dry sediment was weighed using an electronic weighing

balance into a 50 mL acid cleaned beaker. 9 mL of a freshly prepared mixture of HNO₃ and HCl was added to the sediment and the mixture boiled gently over a water bath till the volume dropped to 20 ml. The digested sample was filtered using a Whatman 0.42 µm filter paper into a 50 ml volumetric flask and topped up to the mark with distilled-deionised water. The filtrate was analysed for HMs using AAS. A blank solution was similarly prepared, using distilled water.

HMs Determination

HMs (Pb, Cd, Ni, V, Cr, and As) in the sediments and water were determined using Atomic Absorption Spectrophotometer, AAS (Model 210VGP BUCK Scientific, USA) a widely employed technique for trace metal analysis in environmental matrices (Okafor et al., 2024). For digestion of samples into a solution for analysis, 1 g of oven-dried sample was weighed using a top-loading weighing scale and transferred into a 250 ml beaker. To prevent contamination or impurities, the beaker was washed with nitric acid and distilled water before it was made available for the transfer of the weighed 1 g sample. With the aid of a dropping pipette, the samples in a 250 ml beaker were mixed with 5 ml of HNO₃ followed by 15 ml of concentrated H₂SO₄ and 0.3 ml of HClO₄. The mixed concentration/sample was digested in a fume cupboard, and heating was allowed till a dense white fume appeared; the samples were indigested for 15mins and allowed to cool off before being diluted with distilled water as recommended in recent heavy metal analytical procedures (Okorie et al., 2024). The diluted sample was then filtered using acid-washed Whatman No. 44 filter paper into a 50 ml volumetric flask and diluted to mark. The sample was then aspirated into an AAS machine at the interval for readings of HMs concentration in each sample of the AAS was significant to the outcome of the analysis, which was consistently done on the instrument before analysing the samples.

Quality Control

To achieve reproducible and reliable results in the determination of HMs, the instrument was recalibrated after immediately every ten run (APHA, 2023). The analytical procedure was checked using spike recovery method (SRM). A known standard of the metals was introduced into already analysed samples and re-analysed. The results of the recovery studies for the metals, were more than 95%. The relative standard deviation between replicate analyses was less than 4%. The limit of detection (LOD) for the metals was 0.001 ppm, with blank values reading as 0.000 ppm for all the metals in deionized water with electrical conductivity value of lower than 5 µS/cm.

Ecological Risk Assessment indices in water and sediments

Several HM pollution indices were applied to assess environmental risk of HMs in sediments and the surface water. They include contamination factor, degree of contamination, pollution load index, geo-accumulation factor, and ecological risk index.

Contamination Factor (CF)

CF is the concentration of a specific HM relative to its background concentration. It is expressed in the equation1 below.

$$CF = \frac{C_{metal}}{C_{background}} \quad \text{Equation 1}$$

Where CF is contamination factor, C_{metal} is the mean metal content in the sample, $C_{background}$ is the concentration of the metal in the surface water or sediment samples. The background value is provided in Table 2. The CF is classified into four grades for monitoring the pollution of a single metal over a period of time categorized as: low ($CF < 1$), moderate ($1 \leq CF < 3$), considerable ($3 \leq CF < 6$) and very high ($CF \geq 6$) (Hakanson, 1980; Saha et al., 2022).

Table 2: Background values used for analysis

HM	Background Values	References
HMs in surface water		
Pb	0.01 mg/l	DPR, 2002
Cd	0.05 mg/l	DPR, 2002
Cr	0.05 mg/l	DPR, 2002
Ni	0.02 mg/l	DPR, 2002
V	0.051 mg/l	CCME, 2016
As	0.01 mg/l	DPR, 2002
HMs in Sediment		
Pb	85 mg/kg	DPR, 2002
Cd	0.8 mg/kg	DPR, 2002
Cr	100 mg/kg	DPR, 2002
Ni	35 mg/kg	DPR, 2002
V	130 mg/kg	CCME, 2007
As	29 mg/kg	DPR, 2002

Degree of contamination (DC)

DC defined as the total of all contamination variables for a given environment, was also employed. The following categories and terminologies were used to describe the degree of contamination by Hakanson (1980): $DC < 7$ indicates a modest level of pollution which is categorized as low degree of contamination; $7 < DC < 14$ represents a moderate level of contamination; $14 \leq DC < 28$ is categorized as considerable degree of contamination where

there are significant traces of contamination in the sediments; while $DC > 28$ specify a very high degree of contamination, indicating serious anthropogenic pollution.

$$DC = \sum CF_{Pb}, CF_{Cr}, CF_{Ni} CF_V CF_{Cd} CF_{As} \quad \text{Equation 2}$$

Pollution Load Index (PLI)

The PLI model was proposed by Tomlinson et al., 1980 to assess the water and sediment environmental quality, was calculated as suggested by (Raju et al., 2012) and calculated using the equation 3 below where CF metals is the ratio between the content of each metal to the background values.

$$PLI = \sqrt[6]{CF_{Pb} \times CF_{Cr} \times CF_{Ni} \times CF_V \times CF_{Cd} \times CF_{As}} \quad \text{Equation 3}$$

Accordingly, PLI was classified into four categories as follows: low pollution level ($PLI < 1$), moderate pollution level ($1 \leq PLI < 3$), significant pollution level ($3 \leq PLI \leq 6$), and high pollution level ($PLI \leq 6$) (Rajeshkumar et al., 2018).

Geo-accumulation Index (*I_{geo}*)

I_{geo} is another indicator that is used to assess HM contamination in water and sediments (Liu et al., 2016) and was originally proposed by Müller, 1979 and expressed in equation 4 as follows:

$$I_{geo} = \log 2 \left(\frac{C_n}{1.5 \times B_n} \right) \quad \text{Equation 4}$$

where C_n is the measured value of an examined metal (n) and B_n denotes the background concentration of the given metal (n) 1.5 is the background matrix correction factor due to diagenesis. The I_{geo} for each metal was calculated and classified as uncontaminated ($I_{geo} \leq 0$), uncontaminated to moderately contaminated ($0 < I_{geo} \leq 1$), moderately contaminated ($1 \leq I_{geo} \leq 2$), moderately to heavily contaminated ($2 < I_{geo} \leq 3$), heavily contaminated ($3 < I_{geo} \leq 4$), heavily to extremely contaminated ($4 < I_{geo} \leq 5$), and extremely contaminated ($I_{geo} \geq 5$) (Müller, 1969).

Potential Ecological Risk (RI) and the Potential Ecological Risk Index (PERI)

The Potential Ecological Risk Index (PERI) was used to evaluate the total risk caused by all the studied metals and was calculated using the ecological risk index (RI) of each toxic metal in the water and sediments. RI, which was proposed by (Hakanson, 1980), was used to assess the comprehensive pollution status in the sediments and environmental effects with toxicology

(Gholizadeh et al., 2019). Ecological risk index is the same as Potential ecological risk index or risk index (RI). The relevant equation is calculated as follows:

$$E_r^i = T_r^i \times CF \quad \text{Equation 5}$$

$$RI = \sum_{i=1}^n E_r^i \quad \text{Equation 6}$$

According to the PERI calculation formula, RI is the individual potential risk, and T_i is the toxicity effect coefficient, with values of Cd = 30, As = 10, Pb = Cu = 5, Cr = 2, and V = 2 (Tian et al., 2017). RI is the ecological risk of HMs in surface water and sediments.

$$PERI = \sum E_{ri1} + E_{ri2} + E_{ri3} + E_{ri4} + E_{ri5} \quad \text{Equation 7}$$

where n = the number of toxic metals and EF = single index of the ecological risk factor. The following expressions have been used by Hakanson (1980) for the potential ecological risk index (Table 3).

Table 3: Indicators and classes of potential ecological risk for metal pollution.

Single index of ecological risk factor (Eri)			Potential ecological risk (RI)	
No. class	Eri value	Ecological risk	RI value	Ecological risk
1	$Eri < 40$	Low	$RI < 150$	Low
2	$40 < Eri < 80$	Moderate	$150 < RI < 300$	Moderate
3	$80 < Eri < 160$	Considerable	$300 < RI < 600$	Considerable
4	$160 < Eri < 320$	Very high	$600 > RI$	Very high
5	$320 > Eri$	Serious	-	-

Source: Hakanson (1980)

Statistical Analysis.

Data collected generated from laboratory analysis were subjected to statistical analysis using mean, standard error mean, Analysis of variance (ANOVA) and multiple range test to determine the differences between stations and seasons with values less than 0.05 ($p < 0.05$) considered to be statistically significant. Correlation matrix and correspondence analysis were carried out using PAST 4.1.1. Charts and graphs were done using Microsoft excel while the analysis was done using Statistical Package for Social Sciences (SPSS), Version 25.

Results and Discussion

HMs Analysis

Results of mean values of heavy metal concentrations in surface water of Kidaro Creek is as presented in Fig 2. Concentration of Pb, Cd, Ni, V, and As showed no significant difference

across sampling seasons and stations ($P < 0.05$). However, Cr levels across the stations had significant difference in the wet season across the sampling station at $P > 0.05$. Pb concentrations in the various stations were within the range of 0.355 - 1.761 mg/L in the dry season and 0.284 - 1.669 mg/L in the wet season. The Pb concentrations were all higher than the WHO set limit of 0.01 mg/L in drinking water. The concentrations of Cd were within the range of 0.119 - 0.258 mg/L in the dry season, and 0.008 - 0.025 mg/L in the wet season; and were higher than the 0.003 mg/L limit set by the WHO for drinking water. Ni values were within the range of 0.32 - 0.505 mg/L for dry season and 0.214 - 0.381 mg/L in the wet season; the concentrations than WHO limit of 0.15 mg/L for drinking water. Cr concentrations ranged between 0.278 - 0.567 mg/L for wet season and 0.045 - 0.366 mg/L in the dry season with measured concentrations higher than WHO recommended limit of 0.05mg/L for domestic use. V concentrations ranged between 0.029 - 0.359 mg/L for dry season and 0.045 - 0.366 mg/L in the wet season with concentrations of V higher than WHO recommended limit of 0.05mg/L for domestic use. As concentrations ranged from 0.040 - 0.181 mg/L for wet season and 0.006 - 0.014 mg/L in the dry season and were lower than the WHO recommended value of 0.05 mg/L in domestic use. Concentrations of metals were in increasing order of $As < V < Cd < Cr < Ni < Pb$ for dry season and $V < As < Cd < Cr < Ni < Pb$ for wet season in surface water.

The result of HMs levels in the sediment is presented in Figure 3. In sediment samples analysed, concentration of Pb, Cd, Ni, V, and As showed no significant difference across sampling seasons and stations ($P < 0.05$). However, Chromium, and Nickel levels across the stations had significant difference at $P > 0.05$ with no significant difference recorded in the seasons. Pb concentrations in the various stations were within the range of 12.98 - 47.96 mg/Kg in the dry season and 14.62 - 49.98 mg/Kg in the wet season which lower than the DPR limit of 85 mg/Kg. The concentration of Cd in the stations was within the range of 0.41 - 3.82 mg/Kg in the dry season, and 0.013 - 0.380 mg/Kg in the wet season and was higher than 0.8 mg/Kg limit set by the DPR. Ni concentrations ranged from 0.600 - 7.49 mg/Kg for dry season and 0.457 - 9.55 mg/Kg in the wet season and was lower than the DPR standard or requirement of 35 mg/Kg. Cr concentrations ranged between 2.259 - 12.060 mg/Kg for dry season and 1.362 - 13.937mg/kg in the wet season and were lower than the DPR recommended value of 100mg/kg. V concentrations ranged from 0.247 - 5.409 mg/Kg for dry season and < 0.001 - 0.007 in the wet season. As concentrations ranged between 0.492-1.220 mg/Kg for wet season and 0.005-0.129 mg/Kg in the dry season which were lower than the DPR recommended value of 29mg/kg.

HM concentrations in both surface water and sediment samples varied as the results showed higher concentrations in sediments than in surface water especially for Pb and Chromium. Average HM concentrations in sediments increased in the order of As<Cd<V<Ni<Cr<Pb (dry season) and V<As<Cd<Ni<Cr<Pb (wet season).

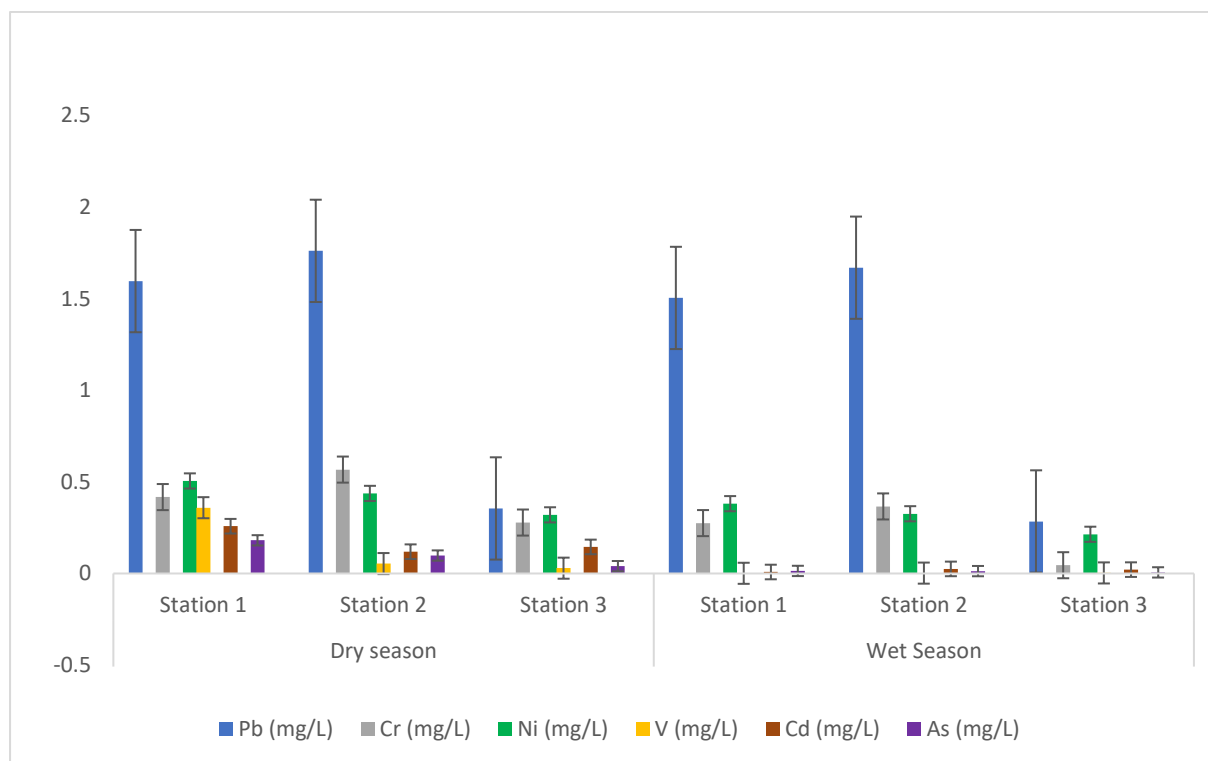


Fig 2: Heavy metals in Surface water

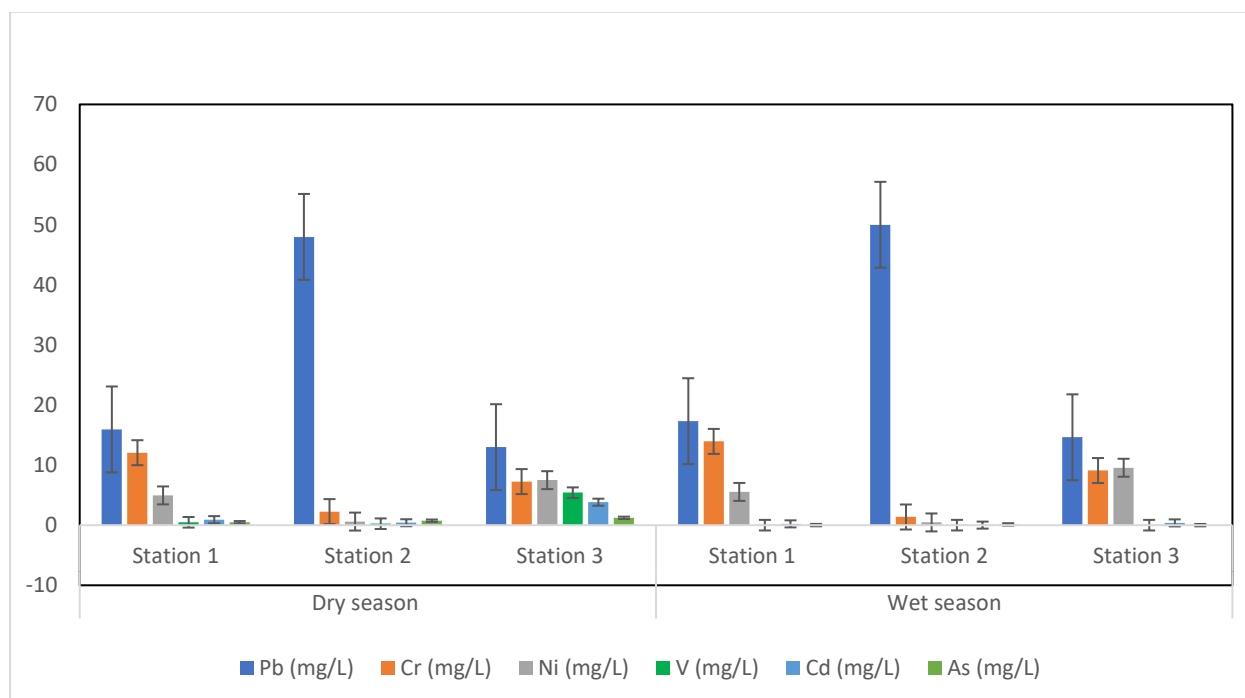


Fig 3: HMs in Sediments

Studies have shown that seasonal influences play a crucial role in the distribution of HMs in the aquatic environment (Hanson et al., 2022; Jonah, 2025; Niampradit et al., 2024; Rilwan et al., 2025; Zhu et al., 2022). It was also observed that the HMs levels in the dry season were higher than the rainy season. This might be due to the reduction of river flow and water volume during the dry season, culminating in their higher concentration in the dry season (Nwadinigwe et al., 2014; Sunday et al., 2025). Increased river flow during the rainy season has been reported to produce a dilution effect, leading to a decline in HMs concentrations in surface water and sediment (Olu et al., 2019; Raimi et al., 2022). Studies have also proven that crude oil extractive activities contributed to heavy metal contamination of the aquatic environment in the Niger delta environment (Anyanwu et al., 2023; Chris et al., 2023; Mankwe et al., 2020). Hence, elevated levels of HMs contaminations in surface waters and sediment of Kidaro Creek, could be attributed to anthropogenic inputs from crude oil activities (Afolabi & Adesope, 2022; Aigberua et al., 2020; Chris et al., 2023; Chris & Anyanwu, 2023; Edori & Iyama, 2020; Moslen et al., 2018; Ojaniyi et al., 2021). These values agreed well with previous results with the concentrations of the measured HMs comparable to those reported in other regions of the Niger delta.

Ecological Risk Assessment

Contamination Factor (CF)

The CF of HMs in surface water and sediments from the Kidaro Creek are given in Figs 4 and 5 respectively. CF for surface water were as follows: As (10.63333) < Ni (42.065) < Pb (82.49) < V (294.67) < Cr (420.67) < Cd (435.0) for dry season; and As (1.1) < V (4.0) > Ni (20.46667) < Cd (45.0) > Pb (76.82) < Cr (228.67) for wet season. This showed surface water was highly contaminated with V, Pb, Cr and Cd with Cr and Cd being the greatest contributors of the pollution. The calculated results of CF for sediment HMs showed that the average CF was as follows: V (0.016) < Cr (0.072) < Ni (0.124) < Pb (0.301) < As (0.427) < Cd (2.146) for dry season and V (0.011) < As (0.048) < Cr (0.081) < Ni (0.148) < Cd (0.255) < Pb (0.321) for wet season.

The CF results indicate that heavy metal contamination in Kidaro Creek is considerably higher in surface water than in sediments, with extremely elevated CF values for Cd and Cr particularly during the dry season. In surface water, CF values ranged from 10.63 for As to 435.0 for Cd in the dry season and from 1.10 for As to 228.67 for Cr in the wet season, indicating very high contamination levels (CF > 6), while for sediment, CF values were generally below 1 for most metals, except Cd which showed moderate contamination in the

dry season ($CF \approx 2.15$). Because the contamination factor is calculated from the ratio of measured concentration to background or reference concentration, higher concentrations in water relative to its baseline value can produce higher CF values for water than for sediment this was also reported by (Islam et al., 2023). Additionally, hydrodynamic conditions such as water flow and seasonal dilution can limit the settling and adsorption of metals onto sediments, keeping them in the aqueous phase (Förstner & Wittmann, 2012). The higher CF values observed during the dry season further reflect reduced water volume and limited dilution, which concentrate pollutants in the water column. Similar observations have been reported in urban rivers where heavy metal concentrations in water exceed those in sediments due to continuous pollution inputs and limited sediment binding capacity (Islam et al., 2023). Higher values of CF recorded for surface waters compared to sediments was reported by Nwankwoala & Angaya (2017). This according to them is because the river sediment and surface water shows chemistry that varies distinctly. Metals in water are often more readily available to cause toxic effects, even at lower concentrations, resulting in higher risk assessment scores (CF) compared to the less mobile, bound metals in sediment (Bokar et al., 2020).

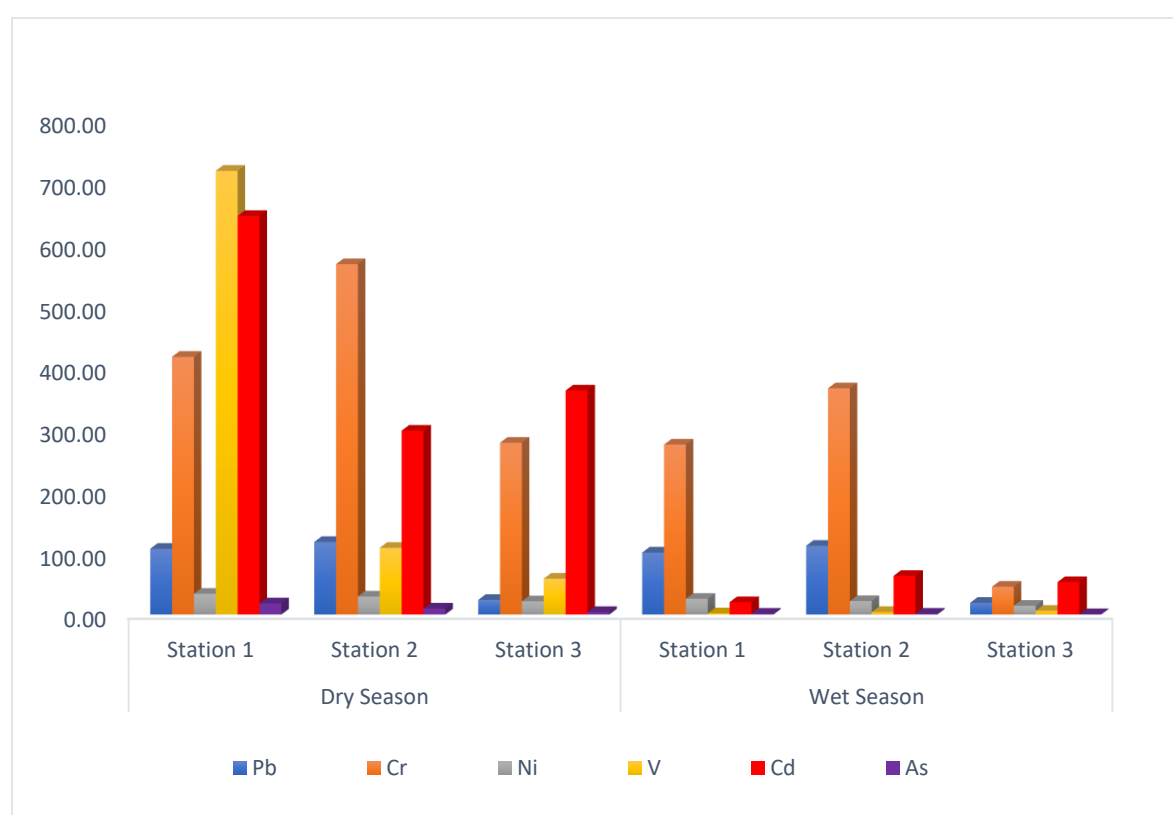


Fig 4: Contamination Factor in Water

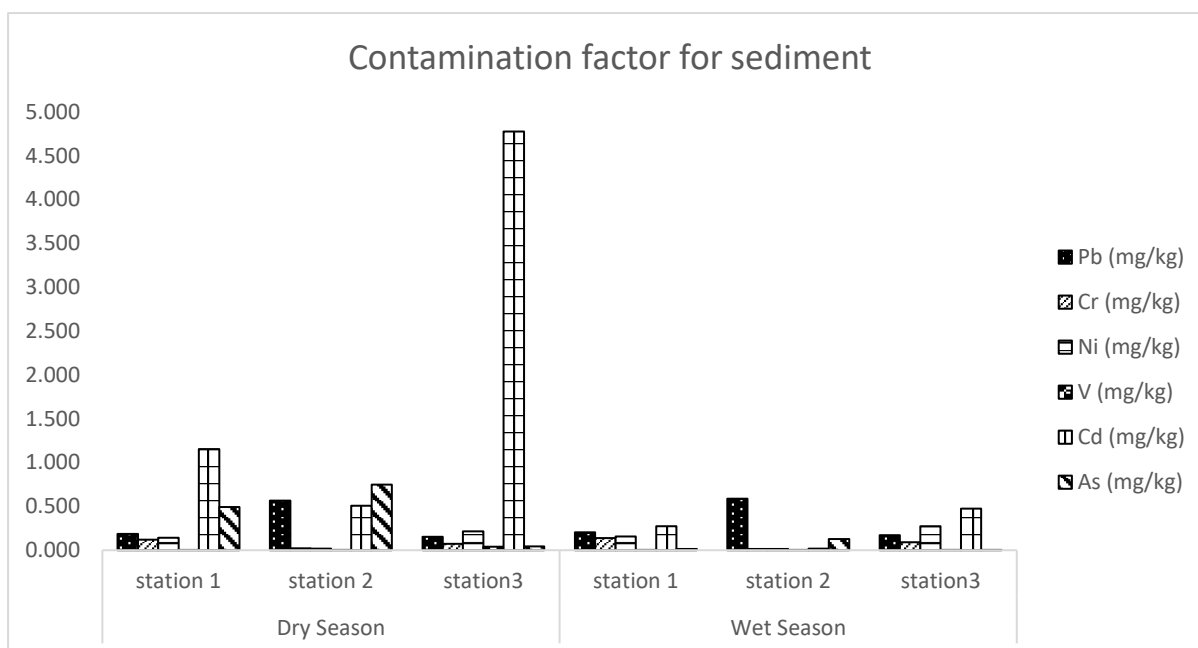


Fig 5: Contamination Factor in Sediments

Degree of Contamination (DC)

The DC for surface water and sediments from the different stations in Kidaro Creek are shown on Fig 6 and 7 respectively. DC in the surface water in the dry season had values ranging from 747.50 - 1938.17 while for the wet season it was 137.30 - 566.80. The DC in all water sample stations were all greater than 32, indicating a high degree of contamination confirming the results of contamination factor. This could be indicating severe impact from anthropogenic activities and their associated waste pollutants. This agrees with Hoang et al. (2020), who obtained similar results, indicating serious anthropogenic pollution.

The DC in the sediments in the dry season had values ranging from 1.86 - 5.30 across the stations and 0.79 - 1.01 for the wet season. The degrees of contamination recorded in all the sediment samples according to the Muller scale were below 6 hence low contamination. Sediment naturally contains higher baseline concentrations of heavy metals compared to water. Therefore, a moderate increase in actual concentration does not yield a high ratio in CF and subsequently in DC values. While increased rainfall and river discharge during the wet season dilute and disperse contaminants, leading to relatively lower DC values, the higher DC values seen during the dry season can be attributed to decreased water flow and dilution capacity, allowing pollutants to accumulate and become more concentrated. These results demonstrate the substantial impact of continuing human activity and seasonal hydrological circumstances on Kidaro Creek's heavy metal pollution status. Such high levels of contamination are usually linked to ongoing human inputs that directly transfer metals into the water system, such as

petroleum-related operations and inappropriate waste disposal (Förstner & Wittmann, 2012; Islam et al., 2023).

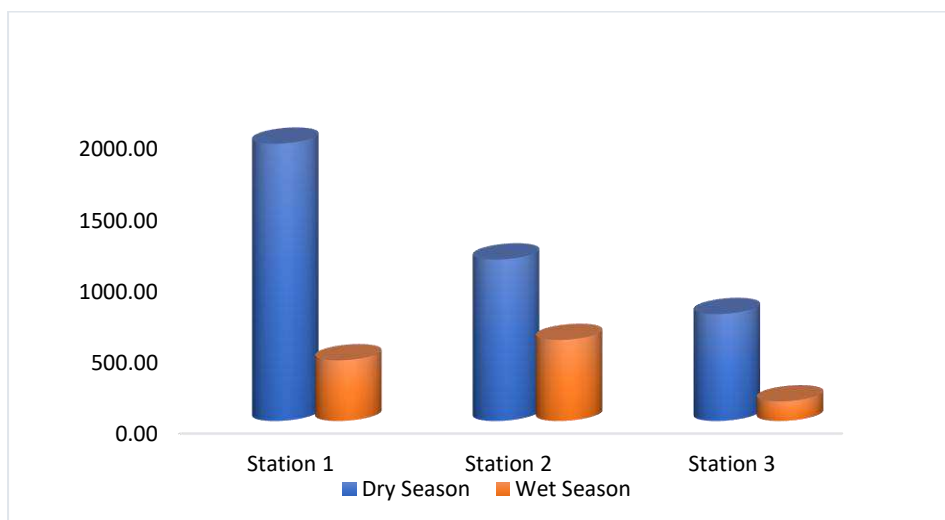


Fig 6: Degree of Contamination in Water

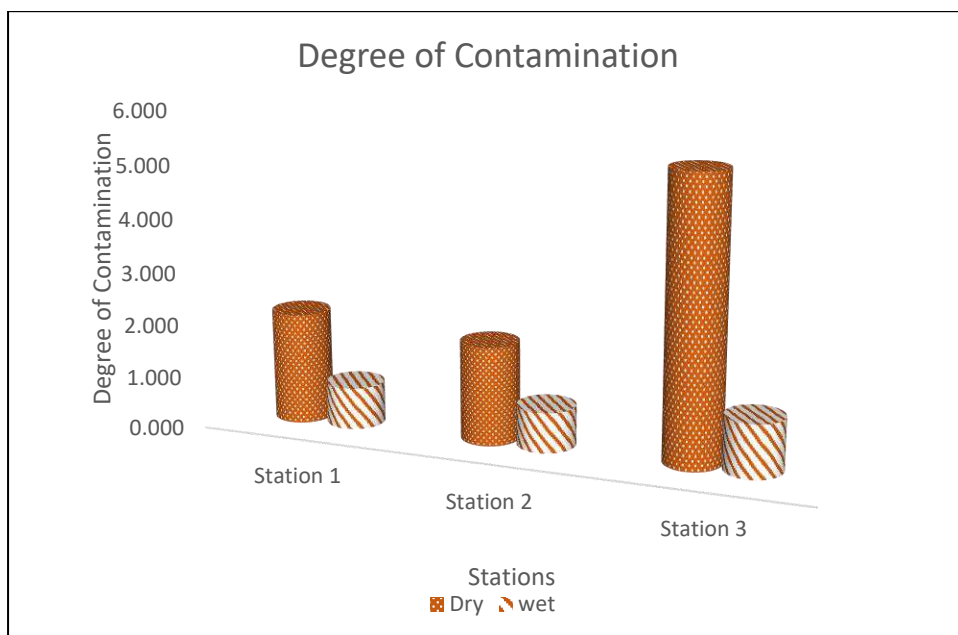


Fig 7: Degree of Contamination in Sediments

Pollution Load Index

The calculated PLI was used to identify the pollution level by integrating all analysed HMs in the three sample stations. The results for PLI for surface water, and sediment are as presented in Fig 8 and 9 respectively. Surface water PLI ranged from 2.89 - 25.69 in the wet season and 47.72 - 152.38 in the dry season across the stations suggesting an extremely toxic pollution with anthropogenic loading, which is a serious concern because Kegbara-Dere is a community that has suffered several cases of oil spills in the past and also undergone remediation action. Sediment PLI ranged from 0.012 – 0.026 in the wet season and 0.073 - 0.137 in the dry season

across the stations indicating a slight contamination according to the pollution index assessment as proposed by Hakanson, (1980). The very high PLI values in the dry season suggest that heavy metals are more concentrated during periods of reduced water flow and dilution. Lower river discharge during dry periods typically leads to increased accumulation of contaminants in the water column, whereas rainfall and surface runoff during the wet season dilute pollutant concentrations and reduce contamination levels (Varol, 2011). Seasonal variations in heavy-metal concentrations have been widely reported in Nigerian rivers, where higher metal concentrations and associated risks occur during the dry season due to reduced dilution capacity (Hassan et al., 2024). The findings from this study were in contrast with the report from Ayodeji et al. (2026) where the dynamic nature of pollution, with higher levels typically found during the wet season was revealed.

The pollution load index (PLI) further corroborated results obtained for other ecological risk indices analysed for this study in terms of water and sediment quality and status. The result of PLI in this present study is similar to research of Afolabi & Adesope (2022), for Ogale, Eleme; Iwegbue et al. (2023) for the Bonny creek; Moslen et al. (2018) on Azuabie and Okujagu creeks. The PLI values for sediments were very low according to the PLI classification, the sediments of Kidaro Creek are not significantly polluted by heavy metals. Sediments commonly act as natural sinks for heavy metals, as metals bind strongly to clay minerals, organic matter, and fine particles, leading to long-term accumulation within the sediment matrix (Förstner & Wittmann, 2012). However, low PLI values may occur when the measured concentrations remain close to natural background levels or when contamination factors are relatively low. The outcome indicated that the concentration values of the HM cannot be taken to have polluted the soil, and the presence of HM can be linked to natural occurrences from weathering rocks and soils (Varol et al., 2022).

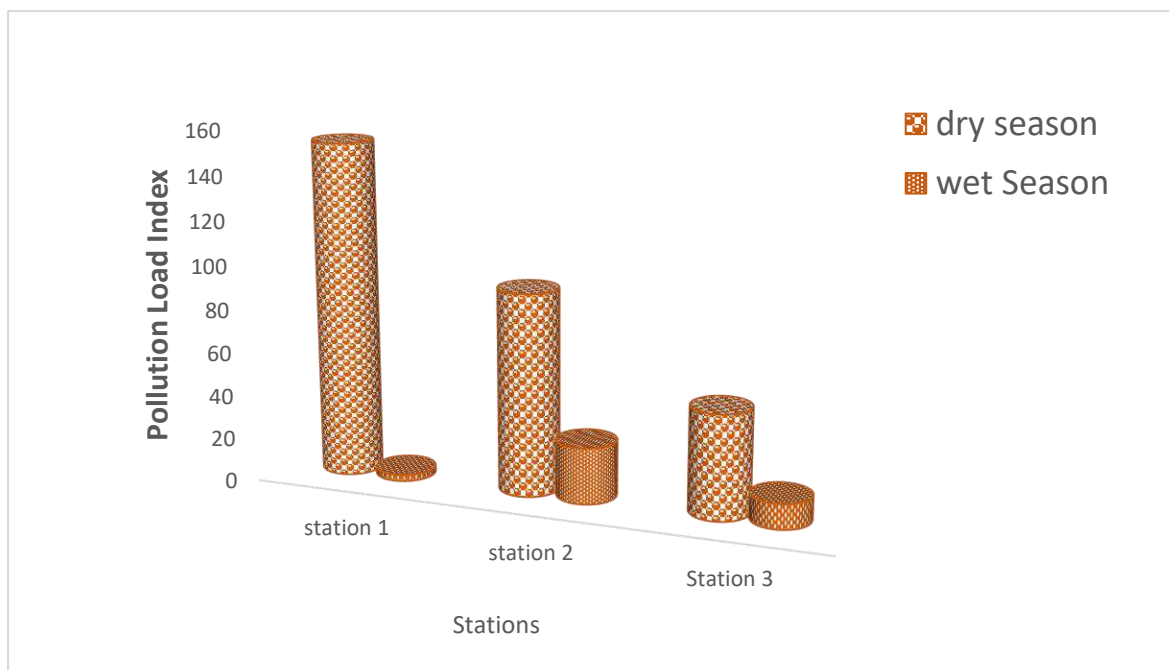


Fig 8: Pollution Load index for water

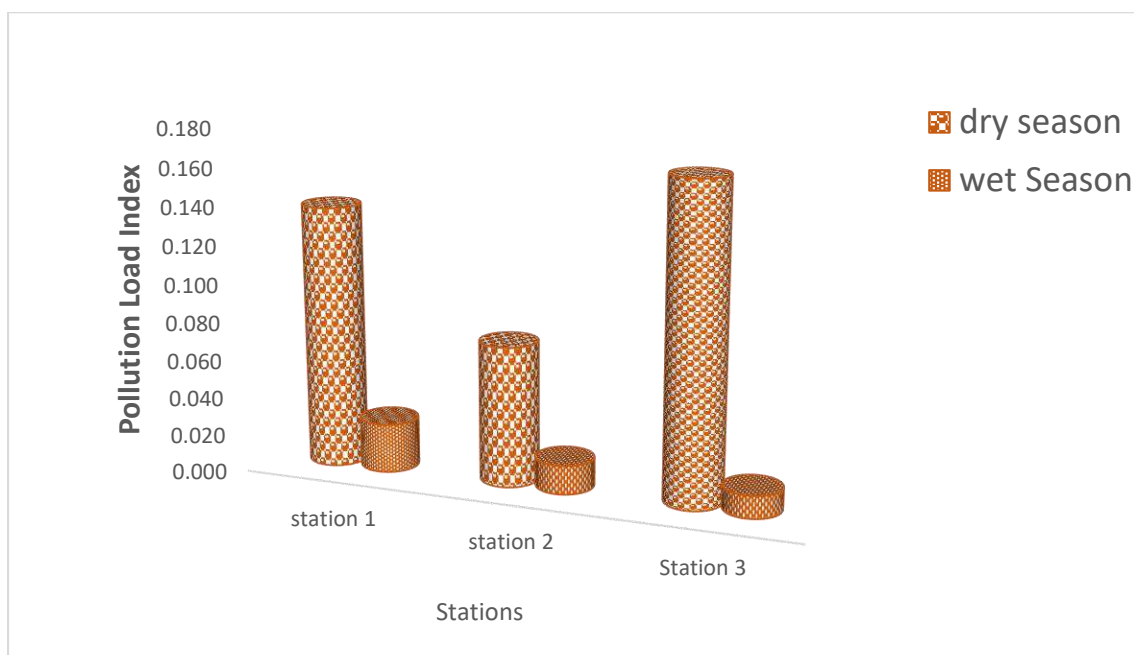


Fig 9: Pollution Load index for sediments

Geo-accumulation Index (I_{geo})

The results of the calculated values of I_{geo} for surface water and sediment of Kidaro creek are shown on Fig. 10 and 11 respectively. I_{geo} results for surface water indicate that Cr (8.07), Cd (8.1), V (6.78), Pb (5.47), Ni (4.2), and As (2.57) during the dry season all exceeded 0, with Cr and Cd falling into the extremely polluted category (class 5), while Pb, V, and Ni are classified as heavily polluted (class 3–4). During the wet season, I_{geo} values decreased slightly but remained high, with Cr (6.78), Pb (5.31), and Cd (4.75) still within heavy to extreme pollution

categories, while Ni (3.73) and V (1.28) were moderately polluted, and As (-1.32) indicated unpolluted conditions. These results suggest that the dry season is characterized by higher contamination intensity, likely due to lower water volume, higher concentrations from anthropogenic inputs, and limited dilution capacity (Vinothkannan et al., 2022). Conversely, the I_{geo} values in sediment showed that the HMs in sediment samples decreased as follows: Cd (0.645) > Pb (0.092) > Ni (0.037) > Cr (0.022) > V (0.009) > As (0.008) for dry season and Cd (0.076) > Pb (0.097) > Ni (0.045) > Cr (0.025) > As (0.001) > V (0.001) for wet season. According to the I_{geo} grades, Kidaro creek sediment was unpolluted or minimally polluted, with Cd showing the highest sediment accumulation however still remained low in the contamination range ($I_{geo} < 1$). This aligns with findings from other studies in the Niger Delta, where sediments often show low I_{geo} values (Afolabi & Adesope, 2022; Ogiesoba-Eguakun et al., 2025). The contrast between high surface water I_{geo} and low sediment I_{geo} highlights the mobility of heavy metals in Kidaro Creek, emphasizing that waterborne contamination represents a more immediate ecological risk than sediment-bound metals. Seasonal variation further supports this: higher dry season I_{geo} values in water reflect concentration effects due to reduced dilution and water volume, whereas wet-season rainfall increases flow and dispersion, lowering water contamination levels. Similar patterns have been reported in other riverine systems under tropical climates, where seasonal hydrology significantly affects I_{geo} values and contamination assessments (Erhenhi & Omoigberale, 2022).

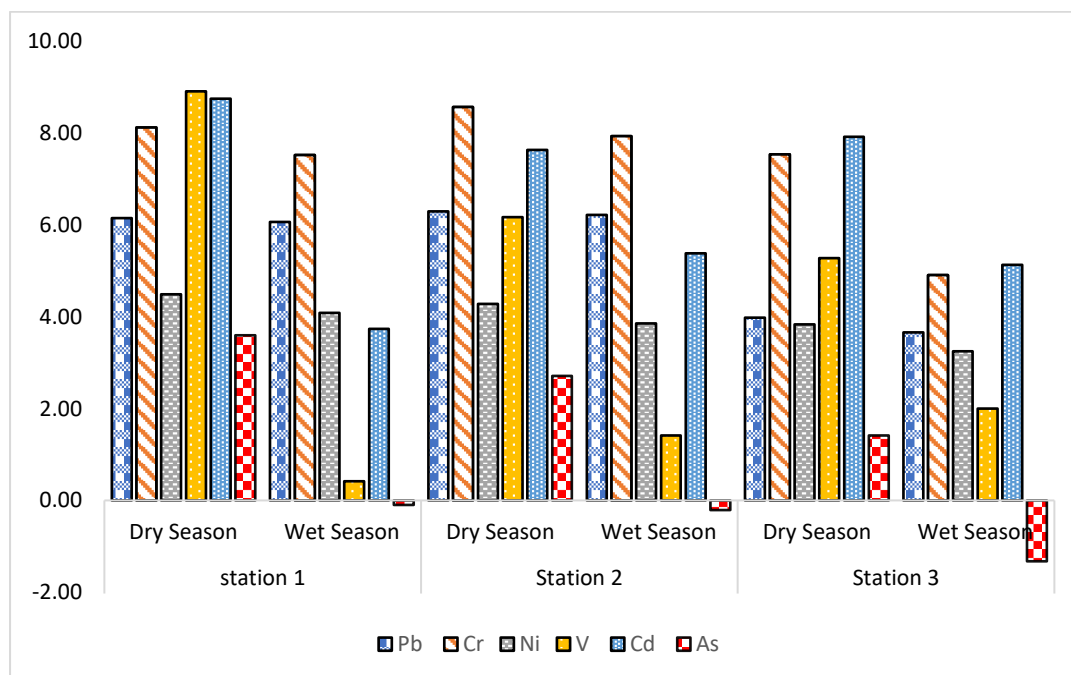


Fig 10: Geo-accumulation Index for water

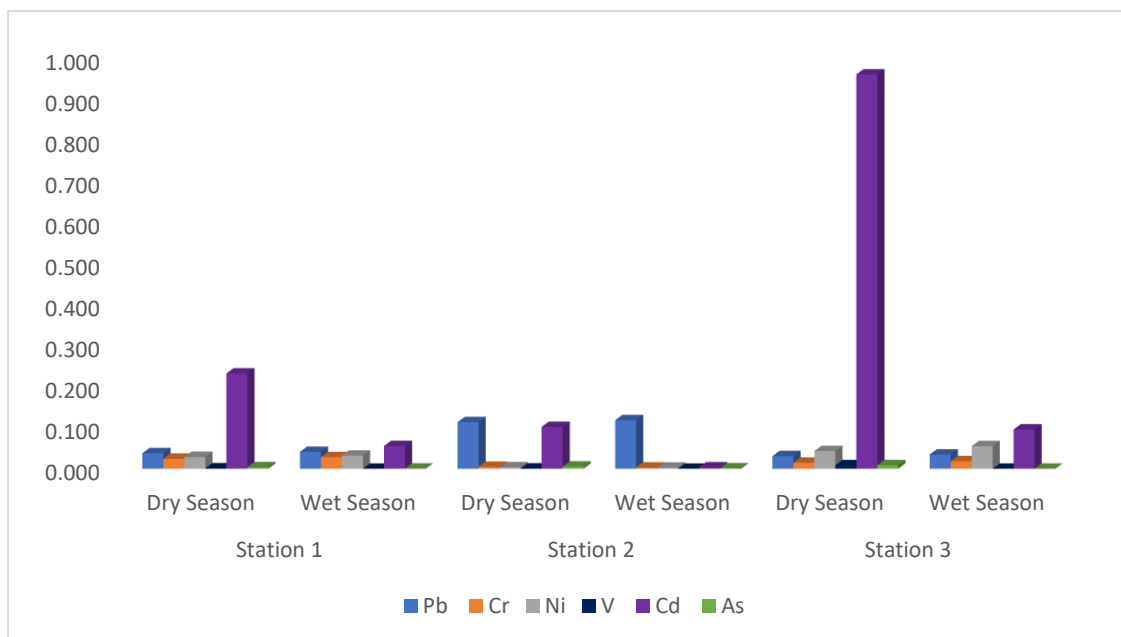


Fig 11: Geo-accumulation Index in Sediment

Potential Ecological Risk (RI) and the Potential Ecological Risk Index (PERI)

The potential ecological risk index (RI), introduces a toxic response factor for a given pollutant (Popoola et al., 2023). The RI of six HMs (Pb, Cd, Ni, V, Cr, and As) across the 3 sampling stations calculated in water and sediment for both dry and wet seasons is presented in Table 4 and 5 respectively. It was found that the average RI for surface waters were ranked in the following order with average contribution of each metal to the total ecological risk is as follows: Cd (86 %) > Cr (5 %) > V (4 %) > Pb (3 %) > Ni (1 %) > As (1 %) in the dry season and Cd (53.9 %) > Pb (23 %) > Cr (18.3 %) > Ni (4.1 %) > As (0.4 %) > V (0.3 %) in the wet season. All the metals constituted serious ecological risk at the studied sites as the risk factors were all above the considerable threshold based on Hakanson classification index ($RI > 160$). These results clearly indicate that cadmium is the dominant contributor to ecological risk in Kidaro Creek surface water, accounting for most of the total RI in both seasons. The disproportionately high contribution of Cd can largely be attributed to its high toxic-response factor, which significantly amplifies its ecological risk in comparison to other metals. Cadmium is widely recognized as one of the most hazardous heavy metals in aquatic ecosystems due to its high toxicity, persistence, and ability to bioaccumulate in aquatic organisms (Jaishankar et al., 2014). The predominance of Cd in the ecological risk profile of Kidaro Creek is consistent with observations from other aquatic systems where cadmium frequently contributes the largest share of ecological risk. For example, Jiang et al. (2012) reported that Cd contributed over half of the total ecological risk in river systems affected by industrial and agricultural activities, emphasizing its high ecological sensitivity relative to other

metals. Although Pb had the highest concentration in the area, it has the least ecological risk factor. This is because Pb has a low toxic response factor and risk is a combination of pollution and toxic response factor. Cr, on the other hand, has the highest pollution level but constituted a lower risk than Cd due to lower toxic response factors.

PERI represents the sensitivity of the biological community to the toxic metal and illustrates the potential ecological risk caused by the overall metals. The PERI of the surface water of Stations 1, 2 and 3 were 22501.33, 11105.67, and 11812 for dry season respectively and 1796.33, 3293, and 1848.97 respectively for the wet season. From the Hakanson classification index on table 3, stations 1, 2 and 3 indicated a serious potential environmental risk in the wet season and a strong potential environmental risk in the dry season. The result shows there was a serious risk to the local ecosystem at all the sites from the studied metals (PERI > 600). A high ecological risk index means that aquatic organisms are exposed to environmental risk. The order of ecological risk of the sites is Station 1 > Station 3 > Station 2 in dry and Station 2 > Station 3 > Station 1 in the wet season. These results clearly demonstrate that the ecological risk posed by heavy metals in the creek is substantially higher during the dry season than during the wet season. The higher dry season PERI values can be attributed to reduced water volume, lower dilution capacity, and increased concentration of dissolved metals, which intensify ecological risk in aquatic environments. Conversely, the lower PERI values during the wet season may be explained by rainfall-induced dilution and enhanced water flow, which reduce heavy metal concentrations in the water column

The average RI for sediments were ranked in the following order with average contribution of each metal to the total ecological risk is as follows: Cd (90.73%) > As (6%) > Pb (2.12%) > Ni (0.71%) > Cr (0.98%) > V (0.04%) in the dry season and Cd (91 %) > As (6 %) > Pb (2 %) > Ni (1 %) > Cr (0.96%) > V (0.04%) in the wet season. All the metals showed low ecological risk as the risk factors were below the considerable threshold (RI < 40) except for cadmium (RI = 143; 96 for dry and wet season respectively). This pattern indicates that cadmium overwhelmingly dominates the ecological risk in the sediment of Kidaro Creek, contributing more than 90% of the total ecological risk in both seasons. The results further indicate that most of the analysed metals (As, Pb, Ni, Cr, and V) exhibited low ecological risk, as their individual risk factors were below the considerable risk threshold (RI < 40). However, cadmium showed moderate ecological risk, with RI values of 143 and 96 during the dry and wet seasons respectively, exceeding the threshold for low risk. This suggests that although the concentrations of most metals in the sediment are relatively low, cadmium contamination

remains a significant environmental concern in the study area. Based on the RI calculations, the PERI of the sediments of Stations 1, 2 and 3 were 41.42, 25.62 and 145.85 respectively for the dry season and 10.48, 4.81 and 16.66 respectively for the wet season. Based on Table 3, Stations 1, 2 and 3, had the low environmental risk. However, Cd showed a high environmental risk due to the presence of specific geochemical conditions, easy mobility in the sediment, having harmful effects at much lower concentrations, and having a very high Tr compared to other metals (Hakanson, 1980; Luo et al., 2011). A high ecological risk index means that aquatic or benthic organisms are exposed to environmental risk due to cadmium toxicity. These results suggest that Station 3 experienced a higher ecological risk during the dry season, likely due to localized pollution sources such as petroleum-related activities. In contrast, the lower PERI values observed during the wet season may be attributed to dilution effects and sediment redistribution caused by increased water flow and rainfall, which reduce the accumulation of metals in sediments.

Table 4: Ecological Risk Factor (RI) and the Potential Ecological Risk Index (PERI) of the toxic metals in Surface Water of Kidaro Creek.

RI	Dry Season					Wet Season				
	Station 1	Station 2	Station 3	Mean RI	Pollution degree	Station 1	Station 2	Station 3	Mean RI	Pollution degree
Pb	532.00	587.00	118.33	412.443	Considerable	501.33	556.33	94.67	576.165	Considerable
Cr	834.00	1134.00	556.00	841.333	High	550.00	732.00	90.00	457.33	Considerable
Ni	168.33	145.67	106.67	140.22	Low	127.00	108.67	71.3	102.32	Low
V	1436.00	216.00	116.00	589	Considerable	4.00	8.00	12.00	8.00	Low
Cd	19350.00	8925.00	10875.00	13050	High	600.00	1875.00	1575	1350.00	High
As	181.00	98.00	40.00	106.33	Low	14.00	13.00	6.00	11.00	Low
PERI	22501.33	11105.67	11812			1796.33	3293	1848.97		
Pollution degree	Serious	Serious	Serious			Serious	Serious	Serious		

Table 5: Ecological Risk Factor (RI) and the Potential Ecological Risk Index (PERI) of the toxic metals in Sediment of Kidaro Creek.

RI	Dry Season					Wet Season				
	Station 1	Station 2	Station 3	Mean RI	Pollution degree	Station 1	Station 2	Station 3	Mean RI	Pollution degree

Pb	0.937	2.821	0.763	2.261	Low	1.018	2.939	0.860	2.261	Low
Cr	0.241	0.045	0.145	0.216	Low	Low	0.027	0.182	0.216	Low
Ni	0.708	0.086	1.071	0.932	Low	0.791	0.065	1.365	0.932	Low
V	0.007	0.004	0.083	0.047	Low	Low	0.0001	1.54	4.72	Low
Cd	34.613	15.187	143.363	96.581	Considerable	8.25	0.488	14.25	96.581	Considerable
As	4.92	7.48	0.421	6.410	Low	0.15	1.29	0.002	6.410	Low
PERI Pollution degree	41.426 Low	25.623 Low	145.845 Moderate			10.487 Low	4.809 Low	16.659 Low		

560

561 Correlation matrix

562 A correlation matrix, ranging from 0 (no link) to 1, represents the intensity of the linear
563 relationship between any two variables. The correlation coefficient in this study was computed
564 using the Microsoft Excel.

565 The results for the metals examined in the surface water samples are displayed in Table 6;
566 Pb/Cr, Pb/Ni, Cr/Ni, Cr/V, Ni/V, Pb/As, Cr/As, V/As, Cd/As and Ni/As exhibited a strong
567 positive correlation. While there was no negative correlation among the metals. A strong and
568 substantial positive correlations suggested chemical affinity, a comparable genetic origin, and
569 common background levels in the samples.

570 **Table 6: Surface water**

	Pb (mg/L)	Cr (mg/L)	Ni (mg/L)	V (mg/L)	Cd (mg/L)	As (mg/L)
Pb (mg/L)	1					
Cr (mg/L)	0.793	1				
Ni (mg/L)	0.747	0.819	1			
V (mg/L)	0.309	0.359	0.740	1		
Cd (mg/L)	0.133	0.478	0.704	0.879	1	
As (mg/L)	0.423	0.613	0.854	0.932	0.921	1

571 Correlation is significant at the 0.05 level (2-tailed).

572 In the sediment, the results for the metals are displayed in Table 7; Pb was negatively correlated
573 to all the metals, Cr was positively correlated to Ni and Cd, but showed negative correlation
574 with V and As. Similarly, Ni was positively correlated with V but negatively correlated with
575 As, while As was positively correlated with Cd. The negative correlation is suggestive that the

metals where from different sources or have nonchemical similarities, strong and substantial positive correlations suggested chemical affinity.

Table 7: Sediment

	Pb (mg/L)	Cr (mg/L)	Ni (mg/L)	V (mg/L)	Cd (mg/L)	As (mg/L)
Pb (mg/L)	1					
Cr (mg/L)	-0.85094	1				
Ni (mg/L)	-0.91635	0.65488	1			
V (mg/L)	-0.38444	-0.0264	0.349483	1		
Cd (mg/L)	-0.46819	0.05903	0.41342	0.990472	1	
As (mg/L)	-0.06407	-0.24997	-0.02441	0.832922	0.841289	1

Conclusion

This work provides the first comprehensive analysis of heavy metal status in Kidaro creek. The results from this study showed that concentrations of HMs in surface water and sediments varied seasonally as higher concentrations were recorded in dry season than in the wet season. This could be a result of water influx through run-offs and rainfalls. Also, HMs concentrations in sediments was higher than those recorded in the surface water. Analytical results show that metal concentrations in the water column were generally high contents of Pb, Cr and Cd, and were anthropogenic, supported by the high values of contamination factor, degree of contamination, index of geo-accumulation, pollution load index, and potential ecological risk index that the surface waters have high pollution/contamination index. In sediments, all the investigated metals were present at detectable levels, with Pb and Cr occurring at relatively higher concentrations compared to the other metals. Seasonal variation played a significant role in the distribution of heavy metals in Kidaro Creek. Generally, higher concentrations were observed during the dry season than in the wet season. This pattern may be attributed to reduced water volume and lower dilution capacity during the dry season, which leads to increased accumulation of contaminants in the aquatic system. In contrast, increased rainfall and water discharge during the wet season likely resulted in dilution and redistribution of pollutants. Ecological risk assessment indices further revealed contrasting pollution patterns between surface water and sediments. Probably due to higher baseline concentrations of heavy metals in sediment compared to water. Therefore, a moderate increase in actual concentration does not yield a high ratio (CF). The CF and DC indicated very high contamination in surface water, particularly for Cd and Cr, whereas sediment contamination remained generally low. Similarly, PLI indicated severe pollution in surface water across all stations, especially during the dry season, while sediments showed only slight contamination. I_{geo} also classified surface water as

heavily to extremely polluted with several metals, whereas sediments were largely categorized as unpolluted to minimally polluted. The potential ecological risk assessment showed that cadmium was the dominant contributor to ecological risk in both water and sediment samples due to its high toxic response factor. In surface water, all the studied metals contributed to considerable ecological risk, with extremely high PERI values recorded across all stations. Conversely, sediments exhibited generally low ecological risk for most metals, although cadmium still posed moderate ecological risk. It is therefore recommended that a detailed and proper clean-up programme should be implemented to reduce the impacts of crude oil pollution and associated HM contamination in the Kidaro Creek in K-Dere community. The creek should also be monitored regularly to reduce the influx of contaminants and ascertain the surface water quality. The result of this study provides insights and serves as a reference to protect the coastal environments of the Ogoni area and promote the sustainable development and utilization of coastal resources.

Author Contributions:

Magdalene Okeh Nafagha-Lawal: Conceptualization, Original Draft Preparation and Writing

Angela Waka: Original Draft Preparation and Data Collection

Chinyere Dike: Sample Analysis, Writing

Emoyoma Udi: Statistical analysis

Samuel Paul: Review and Editing of Manuscript.

All authors have read and agreed to publish this manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Clinical Trial

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Data Availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request

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