Research Article

Selected heavy metals in sediment of Taylor creek due to anthropogenic activities in the Niger Delta region of Nigeria: geochemical spreading and evaluation of environmental risk

Abstract

This study evaluated the geochemical distribution and environmental risk of heavy metals such as cadmium, chromium, iron, zinc, nickel, copper and lead in the Taylor creek within the Niger Delta region of Nigeria. The sediment samples were analyzed by flame atomic adsorption spectrometry. The environmental risk was assessed via standard protocol, using two background scenarios (geometric and median mean). The distribution of heavy metals in the sediment was in the order; iron>zinc>chromium>lead>copper>nickel>cadmium. The cluster analysis, pollution load index, quantification of contamination and geoaccumulation index showed a higher degree of contamination for sediments of Obunagha 2, Okolobiri (1&2) and Ogboloma (1&2). All metals depicted a low risk index even though values were higher in Obunagha 2, Okolobiri (1&2) and Ogboloma (1&2), and lowest in Obunagha 1 and Polaku (1&2). Also, the ecological risk showed moderate contamination for cadmium in some locations. The findings of this study showed that anthropogenic activities along the bank of the Taylor creek is having an influence on the sediment heavy metals which is key in determining the survival rate of benthic fauna and other aquatic organism.

Keywords: ecological risk, geo accumulation index, pollution load index, quantification of contamination, Taylor creek

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Introduction

The rate of environmental pollution has increased probably due urbanization, industrialization and population growth. Pollution of environmental components (soil, water and air) is on the increase in many developing nations.[1] The air pollutants are mainly in the form of odor, noxious gases and air particulates. When aerosols are formed, air particulates have the tendency to be deposited in the soil and surface water systems. The soil play essential role for living organisms as well as human. As such, most human activities are carried out on land. Human activities on soil have direct or indirect effect on soil quality.[1] The soil receives many waste streams emanating from several human activities such as construction works, erection of building and structures, cultivating of farmlands, agricultural and industrial activities. The soil also receives poorly managed wastes resulting from human activities.

During rain fall, most wastes end up in the aquatic ecosystem via runoff.[2–4] The severity of poor waste management practices often deteriorates the potability of surface water system within the proximity of communities in the coastal region of the Niger Delta, especially Bayelsa state where surface water have been reported as the major recipient of solid wastes and sewage.[5–15] Authors have also reported that bathroom and kitchen wastes are channeled to surface waters within Yenagoa metropolis in Bayelsa State.[11,16]

Surface water impacted by several human activities often lead to contamination. The pollution of surface water does not only affect its suitability for domestic use and public consumption but it also affects the sediment quality as well as distribution and abundance of aquatic organisms including macrophytes, planktons (zooplankton and phytoplankton), benthic micro and macro invertebrates, and fishes. Many aquatic organisms have been widely reported as indicator organisms. Fishes and planktons have been widely used to detect the presence or absence of toxicants in the aquatic ecosystem.

Bottom sediments are high valuable. They provide useful information about the quality of aquatic ecosystems. As such, the ability of living organisms to survive in aquatic ecosystems depends on the water and sediment quality. Due to their nature, both organic and inorganic materials found embedded in the aquatic ecosystem are sediments. They are distributed as fine materials (such as clay, silt, and sand with diameter <2 mm); coarse materials (such as gravel, bedrock), (inorganics) and decomposable materials (such as animal matter, aquatic plants, etc), (organics).[16] The characteristics of the sediment are influenced by natural and anthropogenic activities. Again, the drainage system plays an essential role in water and sediment quality. According to Adesuyi et al.,[17] Seiyaboh et al.,[16] sediment quality is essential to an environment due to its complex nature which affects marine, estuarine and fresh water environments.

The Niger Delta has spreads from Benin River in the West to Imo River in the East, and from Palm Point near Akassa in the South to Aboh in the North where the Niger River bifurcates into its two main tributaries.[16,18] Many of the Niger Delta states have major rivers such as the Orashi river in Rivers state, Forcados in Delta state and River Nun in Bayelsa state. Each of these rivers runs their course, bifurcating into several tributaries until they empty into the Atlantic Ocean.

Heavy metals have been widely reported in the environmental matrix (soil, sediment and water) in the Niger Delta region of Nigeria.[19–28] Authors have defined heavy metals as metalloid with specific gravity of ≥ 5 g/cm3.[28,29] They are also known to have high molecular weight and atomic number. Their toxicity to life forms have been widely investigated and studies have shown that lead, cadmium mercury and arsenic have no biological function in living organisms and they are toxic at even low concentration. While essential metals such as zinc, iron, copper, chromium, manganese are needed by living organisms at certain concentration and above the limit it could be detrimental to living organisms. Generally, heavy metals enters in to the environment through emissions from the industries like electroplating, metal finishing, textile, storage batteries, lead smelting, mining, plating, ceramic and glass industries.[28,30] Heavy metals enter the environment through large scale use of chemicals in agriculture and improper disposal of industrial and municipal wastes.[2,15,31,32] Different metals enter the environment through different human activities. For instance, chromium comes from leather tanning, manufacture of catalysts, pigments, paints, fungicides, ceramic and glass, chrome alloy, metal production, and chrome plating.[33] The authors further reported that zinc is obtained from smelters and mining activities and the use of brass, bronze, die-casting metal, alloys, rubbers and paints, while some iron oxides are used as pigments in paints and plastics and as coagulants in water treatment.

In Bayelsa state, several surface waters have been widely studied for their biological, chemical and physical characteristics. However, an in-depth assessment of sediment quality in the study area is scarcely reported. Again, sediments of the area have been studied for their physicochemical characteristics but information about the environmental risk of heavy metals contamination in bottom sediments within vicinities of the creek-lined communities receiving different wastes appears scanty in literature.

Risk assessment of heavy metals using geo-statistical techniques is an essential tool to assess the anthropogenic impact on the natural environment as the spike in contamination level, exceeding background metal loads can be evaluated. In essence, this study aimed at assessing the distribution and ecological risk of sediments of Taylor creek in the Niger Delta region of Nigeria.

Materials and methods

Study area

Taylor creek is a tributary of the Nun River located in Bayelsa state within the central Niger Delta region of Nigeria. The region has two predominant climates namely; wet (April to October) and dry season (November to March) of the following years.[19–21,34] Although the rainfall pattern in the region is beginning to shift from the known conventional periods. This is because the amount of rainfall in the area has been quite high during the supposed dry season months of February and early March, 2019. The topography of the area depicts undulations and depressions with an altitude of about 45 m above sea level. The Taylor creek runs its course along several communities while the areas of sampling were being influenced by human activities that negatively impact on the quality of surface water system of the creek. In the dry season, farms are set up along gradients that slope into the creek which often gets eroded during the wet season. Boating, fishing, swimming and artisanal dredging are some of the activities that take place in the creek. Like other coastal regions in Bayelsa state, municipal solid wastes are discharged into the creek with little or no obstruction in the area. Surface waters in the region also receives sewage through the medium of indiscriminate discharge.[2,3,5–8]

The study area included five (5) communities (with duplicate sampling points established for each community). Hence, the sediments samples were collected from ten (10) spatially different sampling stations viz: Polaku 1 & 2, Koroama 1 & 2, Obunagha 1 & 2, Okolobiri 1 & 2, and Ogboloma 1 & 2 (Figure 1). The characteristic vegetation of the area is that of a tropical swamp forest and some of the waste constituents discharged into the aquatic ecosystem were: pharmaceutical, plastics, paper and packaging, food and agro, metal, agricultural wastes. The houses in the area are unplanned and most of the houses have no proper plumbing and toilet systems (piped water supply and sewerage facilities). The communities are linearly arranged along the creek and major access roads. The presence of nearby farmlands and boating were the common activities associated with all sampling locations. Other point and non-point sources of possible contamination were identified as: Polaku community 1 (nearby gas flare from oil installation, artisanal dredging), Koroama 1 (waste dumpsite), Obunagha 1 (waste dumpsite), Obunagha 2 (waste dumpsite and water channel from the community), Okolobiri 2 (waste dumpsite), Ogboloma 1 (multiple waste dumpsites, bathing, laundry and swimming), Ogboloma 2 (waste dumpsite)

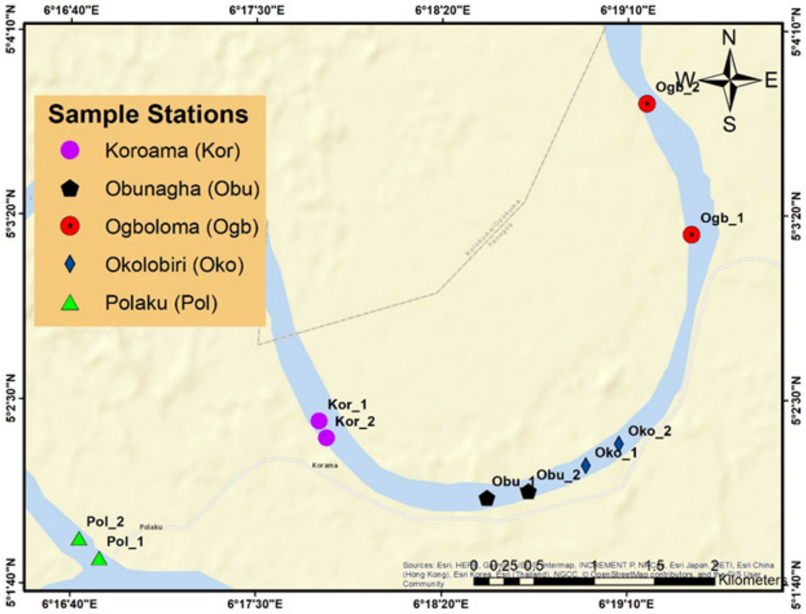

Figure 1 Map of the study area showing all the sampling locations.

Sampling and analytical methodology

Sample collection

Each sampling point was geo-referenced and samples were collected across spatially varying locations of Taylor Creek. Using an Eckmann grab, samples were collected from shallow ends that were close to the river banks. Afterwards, samples were transferred into polyethylene plastic containers. Samples were stored in ice chest before been transported to the laboratory.

Sample processing

Sediment samples were air-dried at room temperature, mixed after grinding, sieved through a 2 mm mesh sieve before being sub-sampled into plastic vials. Glass wares were acid-washed and copiously rinsed with tap water. Further rinsing was done using distilled water. Following this, all wares were drained of water before been stored in a desiccator for 1 hour to allow for adequate drying.

Heavy metals determination

Working standard solutions of 0.5, 1.0, 5.0, 10.0 and 100.0 mg/l were prepared from an AccuStandard-USA stock standard solution of 1,000 mg/l for each of the metals to be analyzed. The instrument was calibrated while reagent and method blank runs were made to satisfy quality control procedure. The following wavelengths were used for metal analysis: Fe (372.0 nm), Ni (232.0 nm), Cd (228.8 nm), Cr (357.9 nm), Zn (213.9 nm), Pb (217.0 nm) and Cu (324.7 nm). Analyte recovery was conducted on spiked samples. The spiked samples were subjected to similar sample processing. The results depicted efficiency in the digestion and recovery process. The percentage recovery and coefficient of variation of spiked replicate samples were: Fe (%R =92.47-95.90%, C.V=0.60-3.45%); Ni (%R=91.17-94.39, C.V=0.71-4.40%); Cd (%R=94.06-97.76, C.V=0.20-1.89%); Cr (%R=91.78-95.53, C.V=0.63-3.18%); Zn (%R=94.45-98.17%, C.V=0.18-1.74%); Pb (%R=89.56-92.59%, C.V=1.42-6.20%); Cu (%R=93.66-97.09%, C.V=0.32-2.77%).

Data analysis

SPSS version 20 was used to carry out the statistical analysis. The duplicate data was presented as mean and the values were converted to charts using Microsoft excel. The spearman rho correlation was carried between the heavy metals while hierarchical cluster analysis was used to show the distribution of heavy metals in sediments.

Environmental risk assessment

Establishment of background values

The background values used in this study was based on geometric mean as considered for assessing environmental risk[33,35] and median-mean that was recommended by Bhutiani et al.,[33] Monakhov et al.,[36] Sarala et al.[37] These means have been used as background values for assessing ecological risks by Bhutiani et al.,[33] Izah et al.,[19–22] Aghoghovwia et al.,[38] Hence this was adopted in this study.

Environmental risks

Several heavy metal pollution indices were applied to assess environmental risk, they included: contamination factor, degree of contamination, pollution load index, geoaccumulation factor, quantification of contamination, enrichment factor, ecological risk index and risk index. The contamination factor and degree of contamination was calculated using Hakanson.[39]

$$\text{Contamination factor}=\frac{\text{Concentration of the respective material in the contaminated sediment(cm)}}{\text{Background values from similar geological area m(bm)}} \qquad (1)$$

Where, Cm is the mean concentration of each metal under study, and Bm is the background concentration. Contamination factor was expressed as; CF<1 (low risk), 1≤ CF<3 (moderate risk), 3≤ CF<6 (considerable risk) and CF≥6 (very high risk).

Degree of contamination =

$$\sum CF_{Fe} + CF_{Ni} + CF_{Cd} + CF_{Cr} + CF_{Zn} + CF_{Pb} + CF_{Cu} \qquad (2)$$

In addition, the degree of contamination was assessed as; CD<8 (low risk), 8≤CD<16 (moderate risk), 16≤CF<32 (considerable risk) and CD>32 (very high risk).

Furthermore, pollution load index provides information about heavy metal toxicity and can be calculated based on the formula presented by Yang et al.,[40] Bhutiani et al.,[33] Ghaleno et al.,[41] Tomlinson et al.[42]

Pollution Load Index =

$$\sqrt[n]{CF_{Fe}\ \mathrm{x}\ CF_{Ni} x CF_{Cd} x CF_{Cr} x CF_{Zn} x CF_{Pb} x CF_{Cu}} \qquad (3)$$

The pollution load index was depicted as; PLI < 1 (no pollution); 1< PLI< 2 (moderate pollution); 2< PLI< 3 (heavy pollution); 3<PLI (extremely heavy pollution).

Also, geo-accumulation index was typically applied to assess the degree of anthropogenic or geogenic accumulated pollutants.[33] This was calculated and classified using the formula presented by Muller,[43] Bhutiani et al.[33]

$$\text{Geo-accumulation index} = Log_2 \frac{HM(s)}{1.5xHM(b)} \qquad (4)$$

Where HM(s) is the measured concentration of heavy metals in the sample, HM(b) is the background value for the heavy metals and the factor 1.5 is used because of possible differences in the background data resulting from lithological variations. Geo-accumulation index was reflected as; Igeo≤0 (uncontaminated), 0<Igeo≤1 (uncontaminated to moderate contamination), 1<Igeo≤2 (moderate contamination), 2<Igeo≤3 (moderate to heavy contamination), 3<Igeo≤4 (heavy contamination), 4<Igeo≤5 (heavy to extreme contamination) and Igeo≥5 (extreme contamination).

Similarly, quantification of contamination (QoC) represents the lithogenic metals.[33,44] It was calculated using the formula presented by Bhutiani et al.[33]

$$\text{Quantification of contamination (\%)} = \frac{(C_n - B_n)}{C_n} \chi 100 \qquad (5)$$

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Where, QoC represents the quantification of contamination, Cn is the concentration of metal in the sample and Bn is the background individual heavy metal concentration. Positive values are an indication of contamination due to anthropogenic activities.

Enrichment factor (EF) is an index used to assess the level of contamination of heavy metals from both natural and anthropogenic sources that exceed background levels.[33,45,46] Iron is the acceptable normalization element.[33,47,48] This is probably due to its significant relative abundance when compared to other test heavy metals being considered in this study. In sediment studies, higher relative concentrations of iron have been reported.[48] Hence, it is not expected to be substantially enriched from anthropogenic sources in sediment.[33] Enrichment factor was calculated using the formula as applied by Bhutiani et al.,[33] El Metwally et al.,[45] Gasiorek et al.,[49] Kowalska et al.,[46] Tang et al.,[50] Also, the classification criteria applied by Sutherland was used.

$$\text{Enrichment factor} = \frac{\dfrac{HM(s)}{Fe(s)}}{\dfrac{HM(b)}{Fe(b)}} \tag{6}$$

Where HM(s) is the concentration of heavy metals in sample, Fe(s) is the concentration of Fe in sample, HM(b) is concentration of heavy metals at reference background values, and Fe(b) is the concentration of Fe in the earth's crust or its reference background value. Where enrichment factor of ≤1 (background rank), 1- 2 (minimal enrichment), 2 – 5 (moderate enrichment), 5 – 20 (significant enrichment), 20 – 40 (very high enrichment) and >40 (extremely high enrichment).

Ecological risk index is used to assess the ecological risk level of toxins and heavy metals in the environment.[33,39] They could be toxic to the environment and its associated biota.[33,51] Ecological risk index and risk index was calculated using the formula provided by Hakanson.[39]

Ecological risk= (Tr) x (CF), where CF is the contamination factor and Tr is the toxic response factor viz: Cr=2, Pb=Cu=5, Cd=30 and Zn=1,[39] Ni=5.[33,52,53] The ecological risks were classified as Er<40 (low), 40≤Er<80 (moderate), 80≤Er<160 (considerable), 160≤Er<320 (high) and Er≥320 (very high).

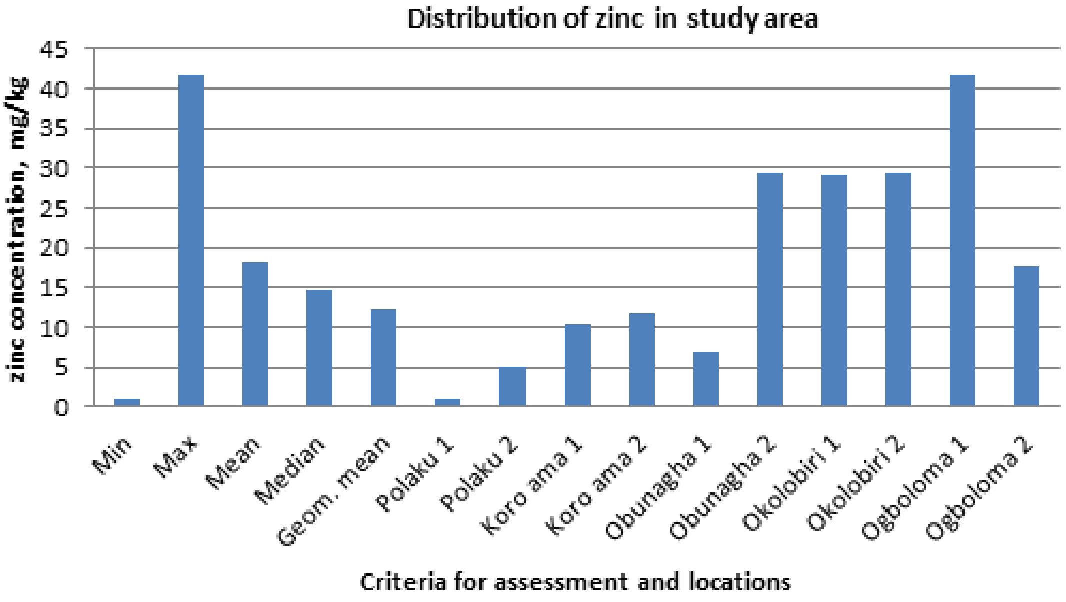
The risk index was calculated as;

$$\text{Risk index} = \sum ER_{Cu} + ER_{Ni} + ER_{Cd} + ER_{Cr} + ER_{Zn} + Er_{Pb} \tag{7}$$

The resultant values were rated as; R'<150 (low), 150≤R'<300 (moderate), 300≤R'<600 (considerable) and R'≥ 600 (very high).

Results and discussion

The distribution of heavy metals in sediments of Taylor creek in the Niger Delta region of Nigeria together with their background values (median and geometric means), and range (minimum and maximum values) is shown in Figure 2. Heavy metals distribution in the area was in the order; iron > zinc > chromium > lead > copper > nickel > cadmium. Similarly, the concentration of heavy metals in the study area is close to values previously reported in cassava mill effluents contaminated soil in a rural community in the Niger Delta, Nigeria by Izah et al.,[20] In addition, values were within the range reported in sediments of the Nun River in the Niger Delta as reported by Aigberua et al.,[54,55] Metal concentrations reflected high level of spreading across the various locations. The coefficient of variation (C.V) was very high for the individual heavy metals viz: zinc (73.96%), lead (84.45%), cadmium (38.06%), copper (94.12%), chromium (112.47%), nickel (71.35%) and iron (69.90). This revealed that the level of spreading of the individual metals across the various locations were in the order; chromium > copper > lead > zinc > nickel > iron > cadmium. Also, most of the heavy metals such as zinc, lead, cadmium, iron, nickel and copper were relatively higher in some locations such as Koroama, Okolobiri and Ogboloma. On the other hand, chromium was higher in Polaku and Okolobiri. This portends the influence of anthropogenic factors in the distribution of heavy metals within the study area.



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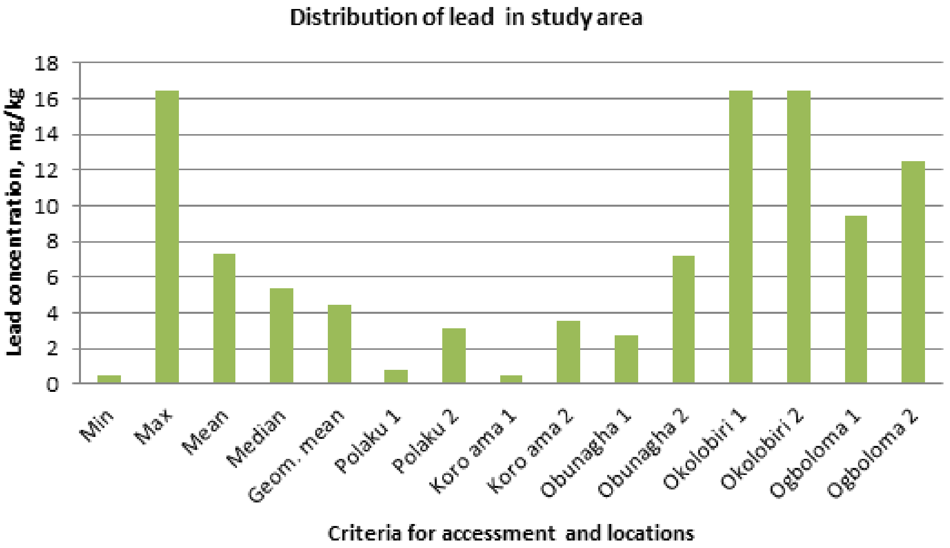

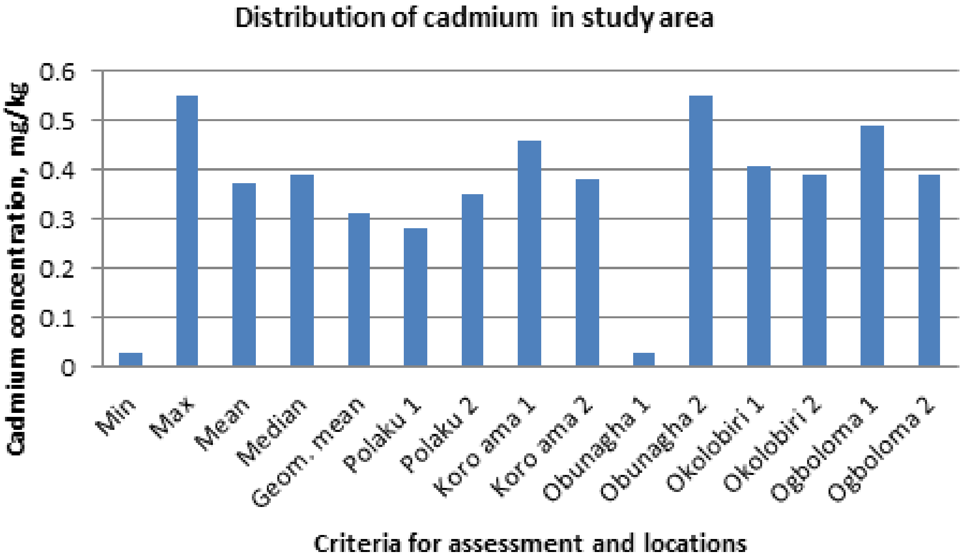

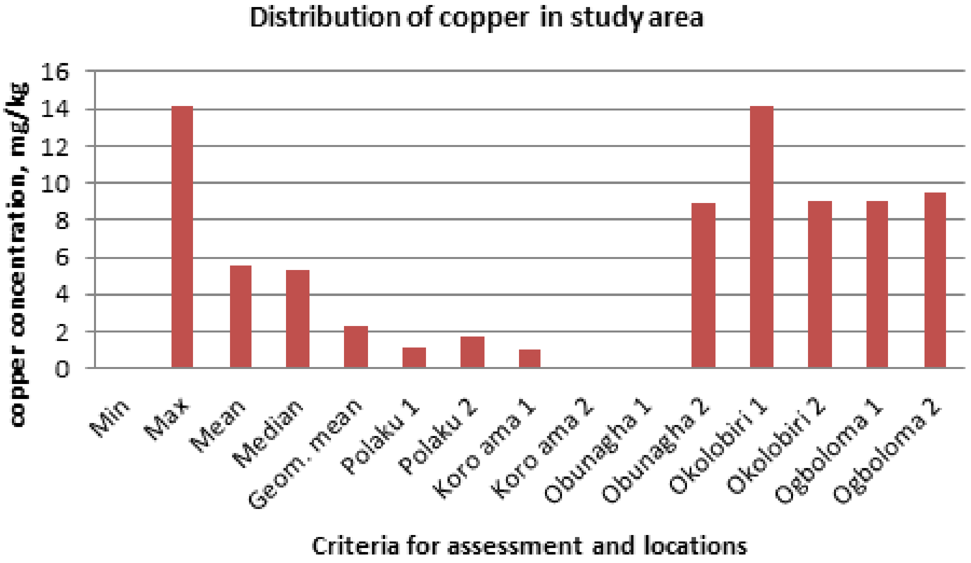

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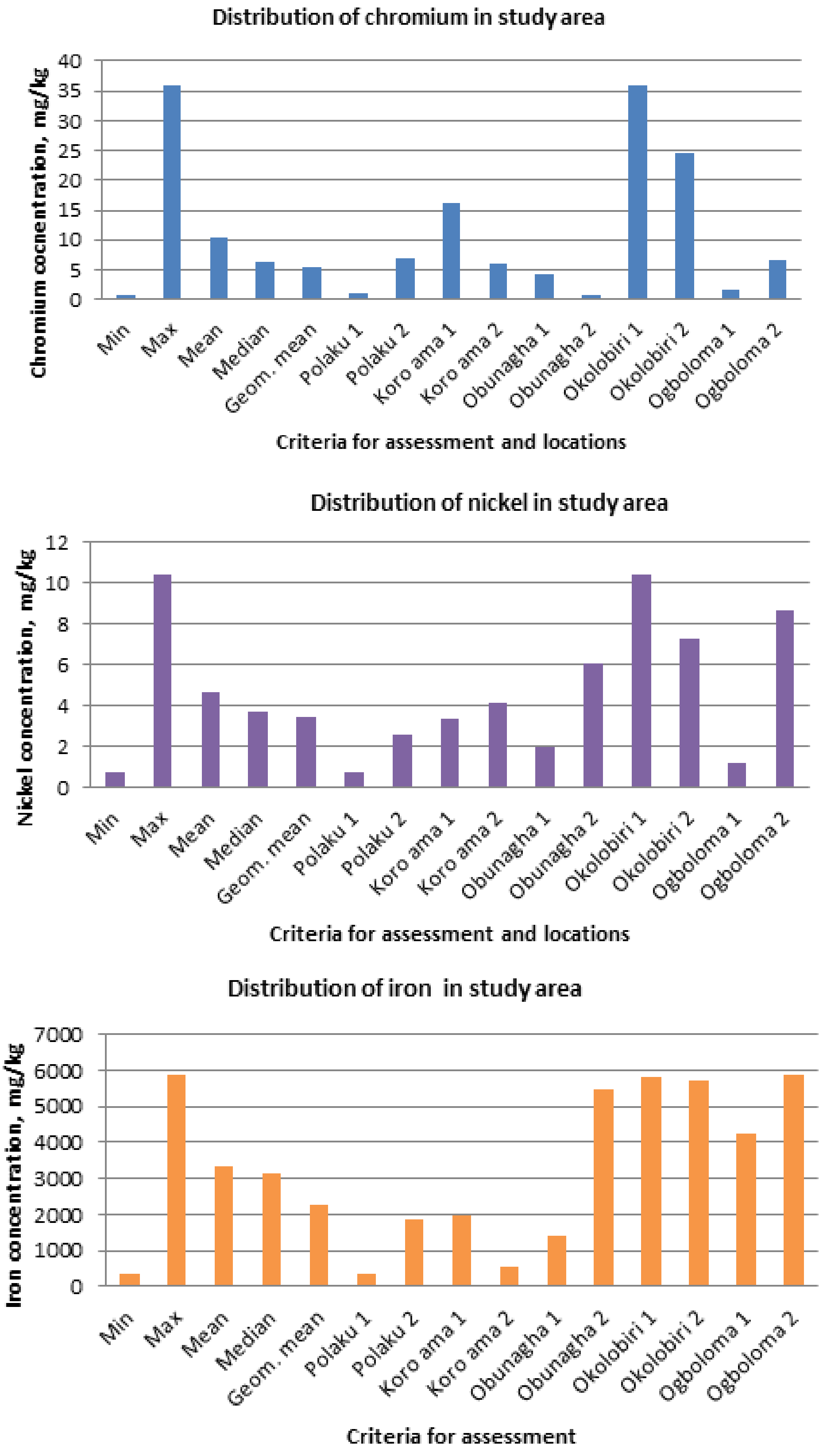

Figure 2 Distribution of heavy metals in the study area in comparison to background levels.

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Table 1 presents the spearman's rho correlation of heavy metals in sediments of the Taylor creek in the Niger Delta, Nigeria. Zinc showed positive significant relationship with lead, cadmium and iron at $p<0.05$. Also, lead correlated positively with copper and iron at $p<0.01$; and with nickel at $p<0.05$. Copper and nickel significantly correlated with iron at $p<0.01$. The correlation values suggest that sediment heavy metals are from diverse sources. Basically, metals from a similar source tend to show significant relationship with each other.[56] Furthermore, metals with significant relationships are indicative of common sources, mutual dependence and identical behavior during transport, while negative correlations appear to be an indication of difference in sources and mutual independence.[20,56] Therefore, the available zinc, lead, copper, nickel and iron observed in the study area depict the tendency to be mutually dependent.

Table 1 Spearman's rho correlation of heavy metals in sediments of the Taylor creek in the Niger Delta region of Nigeria

	Zn	Pb	Cd	Cu	Cr	Ni	Fe
Zn	1						
Pb	0.758*	1					
Cd	0.754*	0.377	1				
Cu	0.62	0.845**	0.509	1			
Cr	0.091	0.37	0	0.347	1		
Ni	0.455	0.721*	0.365	0.602	0.588	1	
Fe	0.685*	0.794**	0.59	0.857**	0.442	0.794**	1

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

**Correlation is significant at the 0.01 level (2-tailed)

The hierarchical cluster analysis (Figure 3) shows the distribution of heavy metals in sediments of the Taylor creek. Two main clusters were formed; cluster 1 (Okolobiri 1 & 2, Ogboloma 1 & 2, and Obunagha 2) and cluster 2 (Polaku 1 & 2, Koroama 1 & 2, and Obunagha 1). Also, some sub-clusters were formed within each of the two main clusters. Basically, closer clusters suggest significant relationship while distant clusters reflect greater degree of disassociation between test metals.[20,57,58] The variation in cluster distance suggests varying anthropogenic influence within the study area.

Table 2 presents the contamination factor, degree of contamination and pollution load index of sediment heavy metals from the Taylor creek. The contamination factor ranged from low ($CF < 1$) to very high ($CF \geq 6$). At Polaku 2, chromium depicted moderate contamination under both background scenarios while cadmium showed moderate contamination under geometric median consideration. At Koroama (1 & 2), cadmium and chromium showed moderate contamination under geometric mean consideration. However, cadmium and chromium showed moderate contamination under median mean consideration at Koroama 1 location alone. In addition, nickel depicted moderate contamination at Koroama 2 under median mean consideration. Like Polaku 1, low contamination was observed for Obunagha 1. At Obunagha 2, cadmium, copper, nickel and iron revealed moderate contamination under both background scenarios, while zinc and lead were moderately contaminated under geometric mean considerations alone. Contamination at Okolobiri (1 & 2) tends from moderate to very high under both background considerations. Contamination factor at Ogboloma 2 was moderate under both backgrounds of study. A similar trend was observed at Ogboloma 1. However, nickel and chromium were low under both background considerations. The degree of contamination ranged from low risk ($CD < 8$) to moderate risk ($8 \leq CD < 16$) while the pollution load index ranged from no pollution ($PLI < 1$) to heavy pollution ($2 < PLI < 3$). Under both background considerations, Polaku (1 & 2), Koroama (1 & 2) and Obunagha 1 revealed low risk while Obunagha 2, Okolobiri (1 & 2) and Ogboloma (1 & 2) showed moderate risk. On the other hand, there was considerable contamination for Okolobiri 1 under median mean and Okolobiri (1 & 2) under geometric mean considerations. This trend was also observed for the pollution load index that depicted Obunagha 2, Okolobiri and Ogboloma as being moderately to heavily polluting. Two groups of sample location (Okolobiri 1 and Ogboloma 1) and (Okolobiri 1 & 2) were exceptions to this trend under the median and geometric mean considerations respectively. The trend reported in this study for both background scenarios had previously been reported by.[20,33] The pollution load index observed in this study suggests that Obunagha 2, Okolobiri (1 & 2) and Ogboloma (1 & 2) areas of the creek are moderately contaminated by heavy metals probably due to human activities.

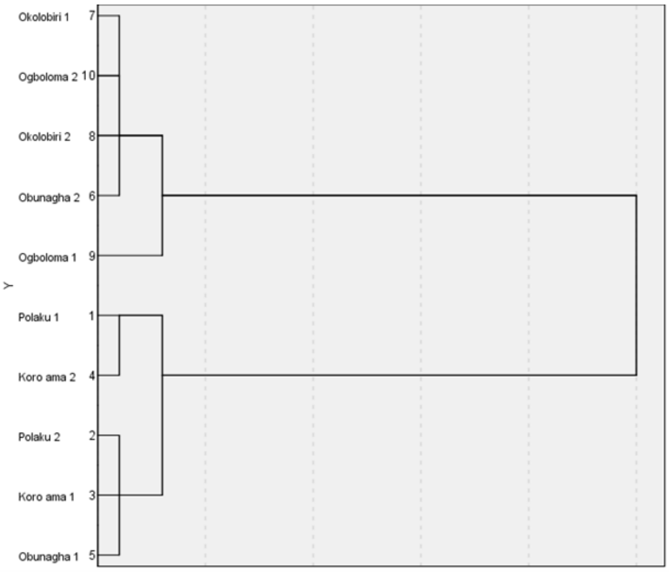

Figure 3 Hierarchical cluster analyses showing the distribution of heavy metals in sediments of the Taylor creek, Niger Delta, Nigeria.

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Table 2 Contamination factor, degree of contamination and pollution load index in sediment heavy metals from the Taylor creek in the Niger Delta, Nigeria

Parameter	Mean type	Polaku 1	Polaku 2	Koro ama 1	Koro ama 2	Obunagha 1	Obunagha 2	Okolobiri 1	Okolobiri 2	Ogboloma 1	Ogboloma 2
Zn	Median mean consideration	0.07	0.34	0.71	0.8	0.47	2	1.99	2.02	2.86	1.2
Pb		0.11	0.43	0.07	0.49	0.37	0.98	2.27	2.26	1.3	1.71
Cd		0.72	0.9	1.18	0.97	0.08	1.41	1.05	1	1.26	1
Cu		0.21	0.32	0.19	0.03	0.02	1.68	2.66	1.7	1.7	1.78
Cr		0.17	1.09	2.57	0.94	0.7	0.13	5.74	3.9	0.25	1.06
Fe		0.1	0.6	0.63	0.17	0.45	1.75	1.88	1.84	1.37	1.89
Ni		0.21	0.69	0.89	1.11	0.52	1.61	2.79	1.94	0.33	2.32
CD		1.59	4.37	6.24	4.51	2.61	9.56	18.38	14.66	9.07	10.96
PLI		0.17	0.57	0.55	0.41	0.24	1.08	2.34	1.95	0.99	1.5
Zn	Geometric mean consideration	0.08	0.41	0.84	0.95	0.56	2.39	2.37	2.4	3.42	1.43
Pb		0.15	0.58	0.1	0.66	0.5	1.34	3.07	3.07	1.76	2.32
Cd		0.9	1.13	1.48	1.23	0.1	1.77	1.32	1.26	1.58	1.26
Cu		0.21	0.32	0.19	0.03	0.02	1.68	2.66	1.7	1.7	1.78
Cr		0.19	1.26	2.98	1.09	0.81	0.15	6.65	4.52	0.29	1.23
Fe		0.14	0.81	0.86	0.23	0.61	2.38	2.55	2.5	1.86	2.57
Ni		0.22	0.74	0.95	1.19	0.56	1.73	2.99	2.08	0.35	2.49
CD		1.89	5.25	7.4	5.38	3.16	11.44	21.61	17.53	10.96	13.08
PLI		0.2	0.68	0.66	0.49	0.29	1.29	2.78	2.33	1.17	1.79

CF < 1 (low contamination); 1 ≤ CF < 3 (moderate contamination); 3 ≤ CF < 6 (considerable contamination); CF ≥ 6 (very high contamination)

CD < 8 (low risk); 8 ≤ CD < 16 (moderate risk); 16 ≤ CF < 32 (considerable risk); CD > 32 (very high risk)

PLI < 1 (no pollution); 1 < PLI < 2 (moderate pollution); 2 < PLI < 3 (heavy pollution); 3 < PLI (extremely heavy pollution)

Table 3 elucidates the index of geo-accumulation in sediment heavy metals emanating from the Taylor creek. The study indicates that there is no contamination at Polaku (1 & 2), Koroama (1 & 2) and Obunagha 1 based on the index of geo-accumulation. However, copper level in sediments of Obunagha 2 tends from uncontaminated to moderately contaminated ($0 < \text{Igeo} \leq 1$). The index of geo-accumulation for lead and chromium depicted moderate contamination under both background scenarios across Okolobiri (1 & 2), while copper was moderately contaminated under geometric mean scenario. Furthermore, nickel showed moderate contamination for Okolobiri 1 under geometric mean consideration. Under geometric mean considerations, copper and zinc depicted moderate contamination at Ogboloma (1 & 2) and Ogboloma 1 respectively, while zinc only showed moderate contamination at Ogboloma 1. The study showed that individual heavy metal contamination spatially varied across locations. The trend observed for the two background scenarios is in accordance with previous studies.[20,33,38] The positive contamination factor and negative index of geo-accumulation suggested that heavy metals in the study area emanates from human activities.[20,33,38] However, there was no significant level of pollution probably due to textural characteristics of the sediment,[59] and/or low metal contamination of some areas as well as the variation factor(1.5) in the index of geo-accumulation equation.[20,33,38,52]

Table 3 Index of geo-accumulation in sediment heavy metals from Taylor creek in the Niger Delta, Nigeria

Parameters	Mean type	Polaku 1	Polaku 2	Koro ama 1	Koro ama 2	Obunagha 1	Obunagha 2	Okolobiri 1	Okolobiri 2	Ogboloma 1	Ogboloma 2
Zn	MM	-4.44	-2.13	-1.08	-0.91	-1.69	0.42	0.41	0.43	0.93	-0.32
	GM	-4.19	-1.88	-0.83	-0.65	-1.43	0.67	0.66	0.68	1.19	-0.07
Pb	MM	-3.28	-1.36	-3.92	-1.18	-1.58	-0.17	1.03	1.03	0.23	0.63
	Gm	-3.01	-1.09	-3.65	-0.91	-1.31	0.1	1.31	1.3	0.5	0.9

Table Continued...

Parameters	Mean type	Polaku 1	Polaku 2	Koro ama 1	Koro ama 2	Obunagha 1	Obunagha 2	Okolobiri 1	Okolobiri 2	Ogboloma 1	Ogboloma 2
Cd	MM	-1.06	-0.74	-0.35	-0.62	-4.29	-0.09	-0.51	-0.58	-0.26	-0.58
	Gm	-0.74	-0.42	-0.02	-0.3	-3.96	0.23	-0.19	-0.26	0.07	-0.26
Cu	MM	-2.82	-2.23	-3.01	-5.84	-5.94	0.16	0.82	0.18	0.18	0.25
	Gm	-1.58	-0.99	-1.77	-4.6	-4.7	1.4	2.06	1.42	1.42	1.49
Cr	MM	-3.16	-0.46	0.78	-0.67	-1.1	-3.57	1.94	1.38	-2.57	-0.5
	Gm	-2.95	-0.25	0.99	-0.46	-0.89	-3.36	2.15	1.59	-2.36	-0.29
Fe	MM	-3.85	-1.33	-1.25	-3.15	-1.74	0.22	0.32	0.3	-0.13	0.33
	Gm	-3.4	-0.88	-0.8	-2.71	-1.3	0.66	0.77	0.74	0.31	0.77
Ni	MM	-2.84	-1.12	-0.75	-0.44	-1.52	0.11	0.9	0.38	-2.19	0.63
	Gm	-2.74	-1.02	-0.65	-0.34	-1.42	0.21	1	0.48	-2.09	0.73

Igeo ≤ 0 (uncontaminated), 0 < Igeo ≤ 1 (uncontaminated to moderately contaminated), 1 < Igeo ≤ 2 (moderately contaminated), 2 < Igeo < 3 (moderately to heavily contaminated), 3 < Igeo < 4 (heavily contaminated), 4 < Igeo < 5 (heavily to extremely contaminated), Igeo ≥ 5 (extremely contaminated)

The enrichment factor of sediment heavy metals from Taylor creek is presented in Table 4. Heavy metal enrichment ranged from background rank (EF ≤ 1) to significant enrichment (5 < EF < 20). At Polaku community, the enrichment factor was within minimal to significant enrichment. This was different from the observed trend for zinc at Polaku (1 & 2), lead and cadmium at Polaku 2, and nickel under geometric mean consideration. On the other hand, the Koroama axis of the creek depicted an enrichment factor ranging from minimal to significant enrichment for cadmium, nickel and chromium under the geometric and median mean considerations. The same trend was observed for zinc under median mean consideration at both Koroama (1 & 2), as well as lead in Koroama 2 for both background scenarios and zinc under geometric mean consideration. At Obunagha, the median mean of zinc in both locations, geometric mean of zinc and copper at location 2, median and geometric means of lead and chromium, and median mean of nickel showed minimal enrichment. Apart from cadmium in locations (1 & 2), the enrichment factor was within minimal to moderate enrichment for the geometric mean of zinc at locations (1 & 2) and geometric mean of nickel at location 2 of the Okolobiri field area. At the Ogboloma sample locations, there was minimal to moderate enrichment for cadmium under both background scenarios, copper under geometric mean scenario at locations (1 & 2), zinc under both background scenarios, copper under median mean consideration at location 1 and nickel under median mean consideration at location 2. The trend in enrichment factor observed for this study is in accordance with previous reports by.[20,33,38] Heavy metal enrichment within sediments of the Taylor creek may have resulted from the presence of multiple waste dumpsites that are heaped along the banks of the creek. Enrichment may likely increase from depositional rate during the wet season. This is because run-offs from dumpsite leachates may find their way into the river and settle on bottom sediments more frequently. Also, the incessant use of the river for recreational or other activities such as swimming, bathing and laundry may be responsible for the disturbance of bottom sediments and redistribution of metals that are partially adsorbed to sediment surfaces.

Table 4 Enrichment factor of sediment heavy metals in the Taylor creek

Parameters	Mean type	Polaku 1	Polaku 2	Koro ama 1	Koro ama 2	Obunagha 1	Obunagha 2	Okolobiri 1	Okolobiri 2	Ogboloma 1	Ogboloma 2
Zn	MM	0.66	0.57	1.12	4.73	1.04	1.15	1.06	1.1	2.09	0.64
	GM	0.58	0.5	0.98	4.15	0.91	1.01	0.93	0.96	1.84	0.56
Pb	MM	1.48	0.98	0.16	3.93	1.12	0.76	1.64	1.67	1.29	1.23
	Gm	1.32	0.87	0.14	3.49	1	0.68	1.45	1.48	1.14	1.09
Cd	MM	6.89	1.5	1.87	5.77	0.17	0.81	0.56	0.54	0.92	0.53
	Gm	6.34	1.38	1.72	5.31	0.16	0.74	0.52	0.5	0.85	0.49
Cu	MM	2.03	0.53	0.29	0.16	0.05	0.96	1.42	0.93	1.25	0.94
	Gm	3.53	0.93	0.51	0.27	0.09	1.67	2.46	1.61	2.16	1.64

Table Continued...

Parameters	Mean type	Polaku 1	Polaku 2	Koro ama 1	Koro ama 2	Obunagha 1	Obunagha 2	Okolobiri 1	Okolobiri 2	Ogboloma 1	Ogboloma 2
Cr	MM	1.61	1.83	4.07	5.58	1.57	0.07	3.06	2.12	0.18	0.56
	Gm	1.37	1.55	3.46	4.75	1.33	0.06	2.6	1.8	0.16	0.48
Ni	MM	2	1.16	1.41	6.56	1.17	0.93	1.49	1.06	0.24	1.23
	Gm	1.58	0.91	1.11	5.17	0.92	0.73	1.17	0.83	0.19	0.97

EF ≤ 1 (background rank), 1 < EF < 2 (minimal enrichment), 2 < EF < 5 (moderate enrichment), 5 < EF < 20 (significant enrichment), 20 < EF < 40 (very high enrichment) EF > 40 (extremely high enrichment)

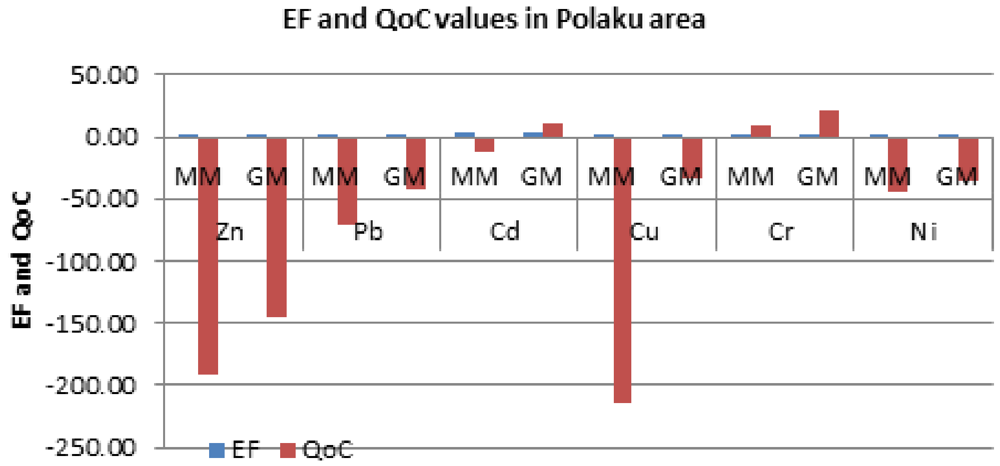
Table 5 elucidates the quantification of contamination of heavy metals in sediments of the Taylor creek. Apart from nickel and chromium in Ogboloma 1, and chromium in Obunagha 2, positive quantification of contamination was observed for all the metals at Obunagha 2, Okolobiri (1&2) and Ogboloma (1 & 2) under both background considerations. In addition, positive quantification of contamination was also observed for chromium under the median and geometric mean considerations, while the geometric mean of cadmium at Polaku 2 and Koroama (1 & 2), median means of cadmium and nickel at Koroama 1 and 2 respectively also reflected positive quantification of contamination. This trend distribution suggests that the contamination may have been due to anthropogenic activities.[20,33,38]

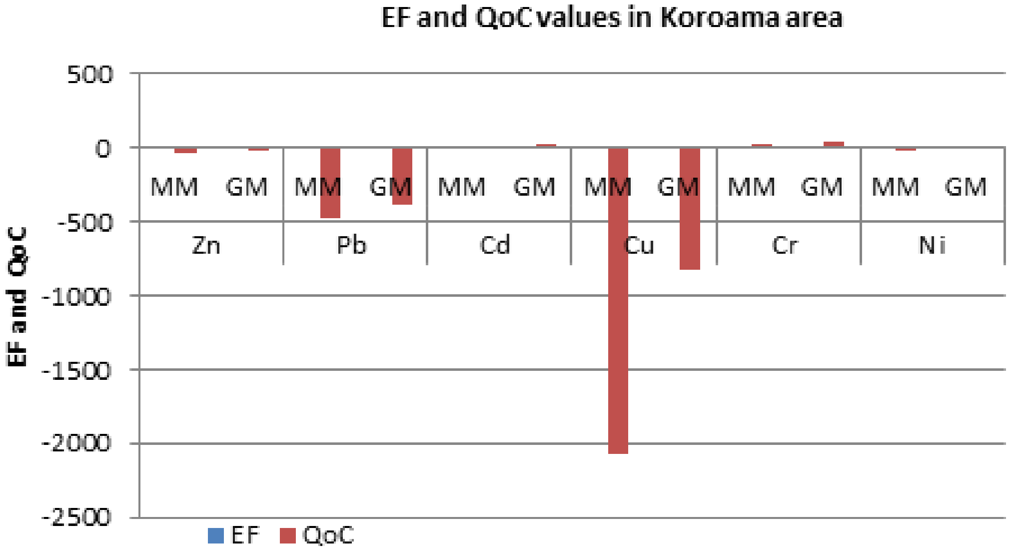
Table 5 Quantification of contamination of sediment heavy metals in the Taylor creek

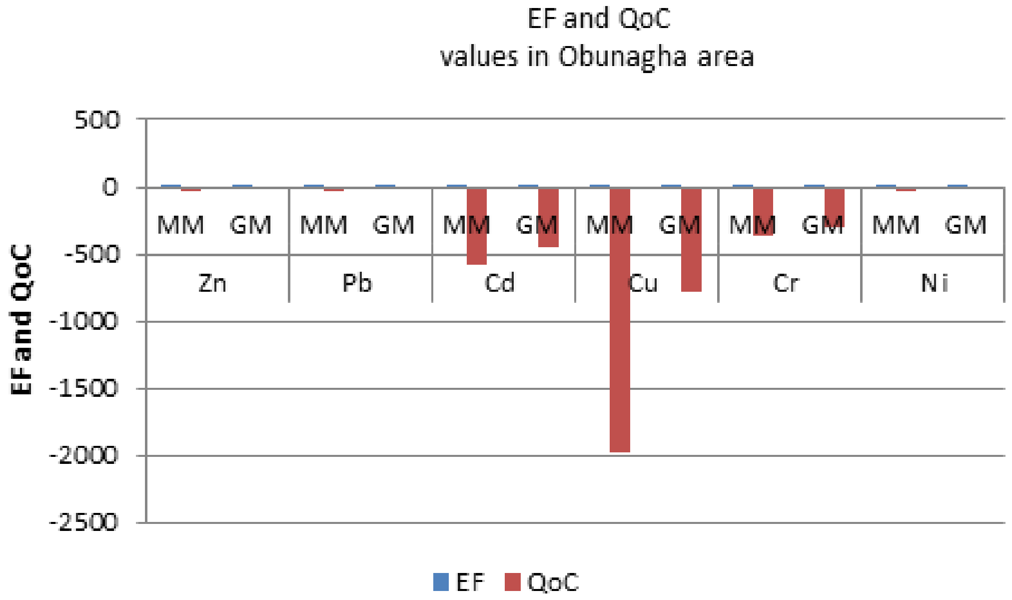
Parameters	Mean type	Polaku 1	Polaku 2	Koro ama 1	Koro ama 2	Obunagha 1	Obunagha 2	Okolobiri 1	Okolobiri 2	Ogboloma 1	Ogboloma 2
Zn	MM	-1347.52	-191.82	-41.39	-25.06	-114.68	50.12	49.67	50.41	65.09	16.7
	GM	-1114.06	-144.75	-18.59	-4.89	-80.06	58.16	57.79	58.41	70.72	30.13
Pb	MM	-546.39	-71.41	-912.26	-50.7	-98.7	25.17	67.47	67.45	43.23	56.91
	Gm	-435.95	-42.12	-739.32	-24.95	-64.75	37.96	73.02	73.01	52.93	64.27
Cd	MM	-39.29	-11.43	15.22	-2.63	-1200	29.09	4.88	0	20.41	0
	Gm	-11.3	10.96	32.25	17.99	-938.76	43.34	23.99	20.1	36.4	20.1
Cu	MM	-371.68	-213.53	-438.38	-3707.14	-4000	40.51	62.36	41.3	41.3	43.78
	Gm	-99.75	-32.77	-127.99	-1512.24	-1636.26	74.81	84.06	75.14	75.14	76.19
Cr	MM	-497.62	8.39	61.12	-6.18	-42.61	-694.3	82.58	74.38	-297.15	5.5
	Gm	-416.64	20.81	66.39	8.21	-23.29	-586.68	84.94	77.85	-243.34	18.3
Fe	MM	-859.67	-67.21	-58.18	-492.16	-123.36	42.79	46.72	45.69	26.89	47.03
	Gm	-606.03	-23.02	-16.38	-335.66	-64.33	57.91	60.8	60.04	46.21	61.03
Ni	MM	-378.85	-44.77	-12.16	9.78	-91.54	38.16	64.22	48.62	-203.66	56.97
	Gm	-346.88	-35.1	-4.68	15.8	-78.75	42.29	66.61	52.05	-183.39	59.84

Figure 4 represents the mean enrichment factor and quantification of contamination for different communities (locations) of study. The values of enrichment factor were positive in all cases and quantification of contamination was negative in all cases except for Okolobiri (1 & 2) and Ogboloma (1 & 2) (for only nickel and chromium). The values in some areas (especially Obunagha 2, Okolobiri and Ogboloma) suggest the impact of human activities and runoff resulting after heavy precipitation.

Table 6 represents the ecological risk index of heavy metals in sediment of Taylor creek. Apart from cadmium in Obunagha 2 under both scenarios, Koroama 1 and Ogboloma 1 under geometric mean consideration, the ecological risk index was mostly low. Previous works by Izah et al.,[19] Bhutiani et al.,[33] Aghoghovwia et al.,[38] has reported similar trend in different environmental components. Similarly, the risk index was low despite its relatively higher values at Obunagha 2, Okolobiri (1 & 2) and Ogboloma (1 & 2). Result from this study suggests higher influence of anthropogenic activities in sediments of the study area. Also, the quantification of contamination, index of geo-accumulation, pollution load index, degree of contamination and contamination factor also show supporting evidence that the sediments have high pollution/contamination index at Obunagha 2, Okolobiri (1 & 2) and Ogboloma (1 & 2). Hierarchical clusters revealed the different sample locations to be within the same main cluster. This could be due to several human activities in the area as well as runoff.


EF and QoC values in Polaku area


EF and QoC values in Koroama area


EF and QoC
values in Obunagha area

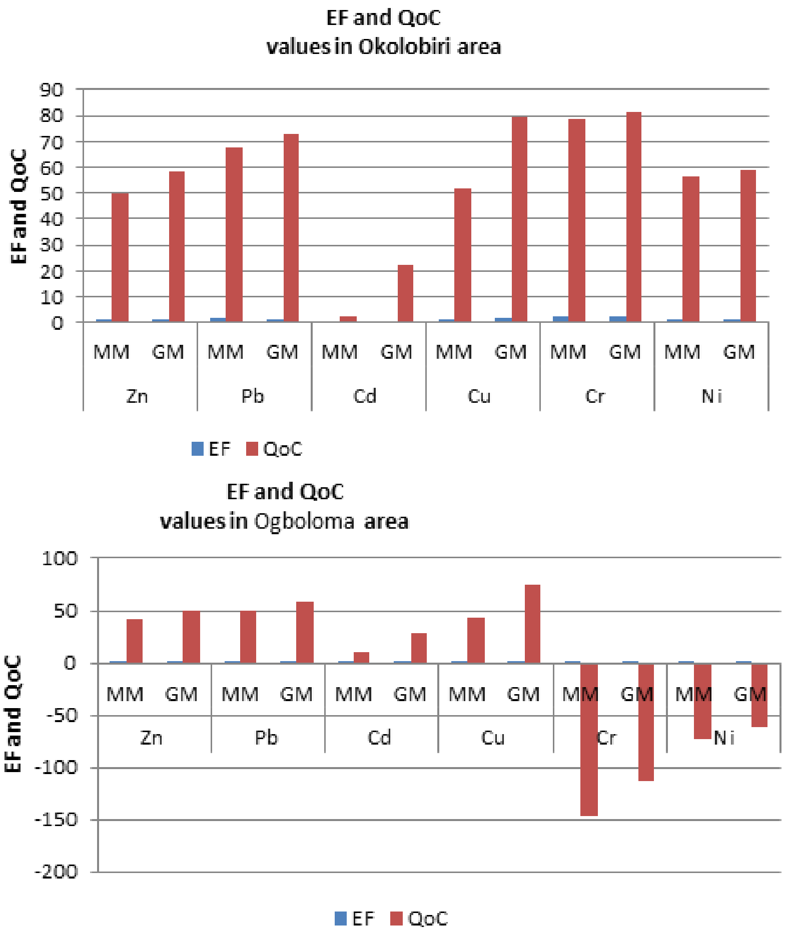


Figure 4 Mean enrichment factor and quantification of contamination for different communities(locations) of study.

Table 6 Ecological risk index of heavy metals in sediment of Taylor creek

Parameter	**Mean type**	**Polaku 1**	**Polaku 2**	**Koro ama 1**	**Koro ama 2**	**Obunagha 1**	**Obunagha 2**	**Okolobiri 1**	**Okolobiri 2**	**Ogboloma 1**	**Ogboloma 2**
Zn	MM	0.07	0.34	0.71	0.8	0.47	2	1.99	2.02	2.86	1.2
Pb	MM	0.55	2.15	0.35	2.45	1.85	4.9	11.35	11.3	6.5	8.55
Cd	MM	21.6	27	35.4	29.1	2.4	42.3	31.5	30	37.8	30
Cu	MM	1.05	1.6	0.95	0.15	0.1	8.4	13.3	8.5	8.5	8.9
Cr	MM	0.34	2.18	5.14	1.88	1.4	0.26	11.48	7.8	0.5	2.12
Ni	MM	1.05	3.45	4.45	5.55	2.6	8.05	13.95	9.7	1.65	11.6
ERI		24.66	36.72	47	39.93	8.82	65.91	83.57	69.32	57.81	62.37
Zn	GM	0.08	0.41	0.84	0.95	0.56	2.39	2.37	2.4	3.42	1.43
Pb	Gm	0.75	2.9	0.5	3.3	2.5	6.7	15.35	15.35	8.8	11.6
Cd	Gm	27	33.9	44.4	36.9	3	53.1	39.6	37.8	47.4	37.8
Cu	Gm	1.05	1.6	0.95	0.15	0.1	8.4	13.3	8.5	8.5	8.9
Cr	Gm	0.38	2.52	5.96	2.18	1.62	0.3	13.3	9.04	0.58	2.46
Ni	Gm	1.1	3.7	4.75	5.95	2.8	8.65	14.95	10.4	1.75	12.45
ERI		30.36	45.03	57.4	49.43	10.58	79.54	98.87	83.49	70.45	74.64

Er < 40 (low risk); Er 40 ≤ Er < 80 (moderate risk); 80 ≤ Er < 160 (considerable); 160 ≤ Er < 320 (high); Er ≥ 320 (very high)

ERI’ <150 (low risk); 150 ≤ R’ < 300 (moderate risk); 300 ≤ R’ < 600 (considerable); R’ ≥ 600 (very high)

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Conclusion

The distribution of heavy metals in sediments of Taylor creek in the Niger Delta region of Nigeria was in the order; iron > zinc > chromium > lead > copper > nickel > cadmium. The coefficient of variation was very high for the individual heavy metals viz: zinc (73.96%), lead (84.45%), cadmium (38.06%), copper (94.12%), chromium (112.47%), nickel (71.35%) and iron (69.90), which is an indication of high level of spread between the various sample locations. Environmental risk assessment indices and cluster analysis showed that the sediment heavy metals were polluted in varying degrees according to the level of anthropogenic burden in a particular area. The positive quantification of contamination, geo-accumulation levels, pollution load index, contamination factor and degrees of contamination revealed that Obunagha 2, Okolobiri (1 & 2) and Ogboloma (1 & 2) was relatively more contaminated from human activities. Consequently, sediment heavy metals depicted varying sources across the study area. Similarly, cluster analysis and correlation also supports this finding. The enrichment factor showed that heavy metals exceeded background levels while the environmental risk of cadmium, nickel, chromium and lead exceeded the contributions from copper, iron and zinc. However, the environmental risk index from heavy metal contamination was generally low. Overall, a comparison of the two background scenarios applied for this study showed the geometric mean to be most suitable for assessing the environmental risk of heavy metals when compared to the median mean.

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Conflicts of interest

The authors declare no conflict of interest arising from this publication.

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