Original Research Article

Risk Assessment and Distribution of Heavy Metals in Water and Sediments alongIbelebiriAxis of Kolo Creek, Ogbia Local Government Area, Niger Delta Region of Nigeria.

ABSTRACT

This study was conducted to investigate the riskand distribution of heavy metals (Zn, Ni, Cr, Cu, Pb, Co, and Cd) in water and sediments along Ibelebiri axis of Kolo creek in Ogbia L.G.A., Niger Delta region of Nigeria. Water and sediment samples were also collected from a control site. The samples were digested using acid mixture and the filtrates obtained were analysed using atomic absorption spectrophotometer fitted with inductive coupled plasma atomic emission spectroscopy(ICP-AES).Generally, heavy metal concentrationsshowed a decreasing trend of Cu>Zn>Pb>Cr>Cd>Co>Ni for water samples. The mean concentration of these metals: Ni, Cr, Zn and Cu recorded in this study is below international recommended limits. But, Pb, Cd levels in locations LC1, LC3 and LC4 are above the international recommended limits. The heavy metals in the sediments showed a decreasing trend of Zn>Pb>Cu>Co>Cr>Ni>Cd. The concentrations of these metals -Cd, Pb, Ni, Cr, Cu and Zn are below the permissible limit set by DPR. However, Co values at locations LC3 and LC4 are slightly above the DPR target value of 20 mg/kg for sediments.Using the geoaccumulation index (Igeo) classification, the sediments across the four locations are uncontaminated with Cd, Cr, Cu, Zn, Co and Ni. But, the sediments in locations LC1, LC3 and LC4 are moderately contaminated with Pb. Similarly, the contamination factor(CF) classification, revealed low contamination of Cd, Cr, Cu, Zn, Ni and Co across the four locations; moderate contamination of Pb in the four locations. Finally, principal component analysis(PCA) identified two major factors: uncontrolled combustion processes such as artisanal refinery activities and gas flaring from nearby flow stations, may have contributed to the pollution of the water and sediments in the study area.

Key words: Heavy metals, risk, pollution, contamination, accumulation.

1. INTRODUCTION

Rivers are a crucial conduit for the entry of sediment, salt, and chemical components into lakes and seas in the hydrologic cycle of the planet (1). Every year, a significant amount of heavy metals are extracted from the earth's crust in order to advance the economy and satisfy daily human needs (2). Heavy metals are released into rivers during the mining and production process through atmospheric sedimentation or industrial wastewaters. The bulk is concentrated in sediments, and only a minor portion is dissolved in water bodies. The foundation of food webs and an essential component of aquatic environments is sediments. However, they also act as pollution sinks (3). Heavy metals are accepted and transported by rivers, and river sediment not only acts as a significant sink and transporter of heavy metals but also as a possible source of secondary pollution, which can also indicate the level of contamination (4). Additionally, heavy metal pollution often has a long half-life, a wide distribution, and is easily accumulated and stabilized in the environment, endangering human health either directly or through the food chain (5,6). One of the greatest environmental issues in the world today is heavy metal contamination in rivers brought on by social, economic, and industrial activity (7), which has caught the attention of academics. A study (8) was carried out on the effect of refinery and petrochemical effluent on water quality of Ubeji Creek Warri, Southern Nigeria. The study showed obvious pollution of the creek but that there has been an improvement in the treatment of Warri Refinery and Petrochemical effluent before it is discharged. However, pollution arising from uncontrollable combustion processes from artisanal refineries, gas flaring and biomass which releases atmospheric particulates especially black carbon has been a major concern to environmentalist in recent times. These particulates are easily washed down and get into the sink. The buildup of heavy metals in the sediment poses a long-term threat to the aquatic habitats (4).

In Bayelsa State, due to poor management of municipal and industrial effluents, water bodies including the Ibelebiri stream which discharges into Kolo creek have been adversely affected. The unsustainable environmental practices,socio-economic issues have worsened spatially in the last two decades. Consequently, there has been increase in water-borne diseases, a decline in water value, various ecological and human health risks. A study (9)was carried out on the heavy metal distribution and assessment of ecological risk in surface waters and sediments within the flow stations in Kolo creek, Nigeria. Severally other studies investigated the concentration of heavy metals in water and sediments of Kolo creek and some aquatic animals found in the sediments (10,11,12). The attention of the creek is obviously because of the presence of Shell Petroleum flow station at Imirigi which is one the communities through which theKolo creek traverses. Previous studies on the Nembe river have focused on the river water chemistry and physicochemical properties in the river water (13,14) and few studies on seasonal and spatial distribution of heavy metals (15,16). However, in the scope of our knowledge, there has hardly been any detailed studies on the heavy metal contamination of Kolo creekat Ibelebiriwatershed which traverses through other communities including Imirigi where Shell Petroleum flow station is located. Therefore, this study is aimed at investigating other sources ofheavy metals in the creek beside the flow station or pollution due to oil and gas production.

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2. MATERIALS AND METHODS

2.1 Study Area

Ibelebiri is a community in Ogbia Local Government Area of Bayelsa State. The climate of the area is characterized bya relatively dry season (November – March)period with occasional precipitation and wet season (April – October). The annual rainfall varies between 2500 –3000mm. Mean temperatures are as high as 32^{o}C with humidity of about 81% in the dry season and about 92% in the wet season (17). The inhabitants are predominantly farmers and fishermen. Some are engaged in petty trading, and some are civil servants. The major source of water is the creek; rainwater stored in tanks and a few boreholes owned by some individuals.

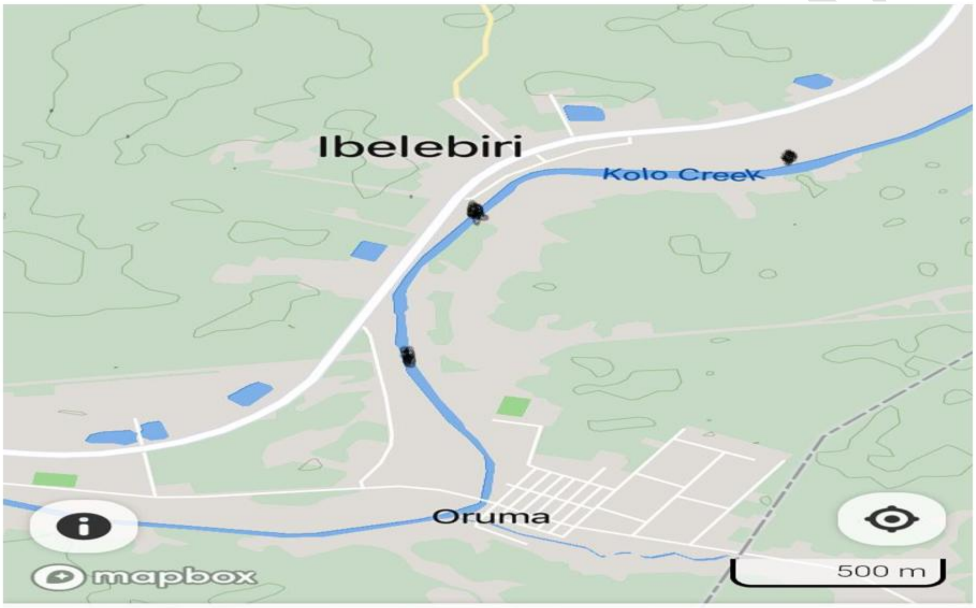

Fig. 1: Map of Study Area showing sampling locations(black dots)
(source:www.mapcarta.com/17024300)

2.2 Sample Collection and Preparation

Periodic seasonal sampling (November and December 2021 – January 2022), (March – May 2022) and (June – August 2022) was done using standard procedure. Watersamples werecollected fromKolo creek at Ibelebiri community axis- (location 1: before Ibelebiri community, location 2: within Ibelebiri community, location 3: after Ibelebiri community and location 4: used as control- at approximately 500m apart)into pre-cleaned 1L plastic containers, acidified with few drops of nitric acid, and stored in a refrigerator until analysis. Sediment samples were collected using plastic grabs from the same locations where water samples were collected from, and transferred into well-labeled, pre-cleaned polythene bags. Samples were then transported to the laboratory and kept in a refrigerator at −4 °C before analysis. Similarly,a sample of water and its sediment were also collected from the university town of Otuoke, presumably a more 'pristine' environment to serve as the control.The sediment samples were freeze-dried, crushed in an agate mortar, passed through a nylon 100-mesh sieve (<0.15 mm) and stored in pre-cleaned polythene bags at 4 °C in the dark before analysis.

2.3 Digestion of samples

2.3.1 Water samples

100 ml of water samples was placed in a 250 ml conical flask, 10 ml of 1M HNO_3 was added, placed in a digestion block and heated at 150^{o}C until the mixture reduced to about 25 ml. The mixture was removed from the block, cooled, filtered using a Whatman No. 40 filter paper, transferred to a 100 mL volumetric flask and made up to mark with 1M HNO_3 (18).

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2.3.2 Digestion of sediment samples

Wet digestion of sediment samples was carried out as follows: 2.00 g sample of sediment sample was placed in 50 mL conical flasks. 10 mL of aqua regia (1:3 HNO_3:HCl) mixture was added, followed by 5 ml of perchloric acid and covered with a dish. This mixture was then placed in a digestion block and heated at 150^{o}C until the acid mixture reduced to about 5 ml. The mixture was removed from the block, cooled, filtered using a Whatman No. 40 filter paper, transferred to a 100 mL volumetric flask and made up to mark with 1 M HNO_3 (18).

The filtrates obtained from digestion of water and sediment were analysed using anInductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES).

2.4 Ecological Risk Assessment of Heavy Metals Pollution in Sediment

2.4.1 Geo-accumulation Index (I_{geo})

TheI_{geo}has been applied widely toassess soil and sediment contamination, which is defined by the following equation (19):

$$Igeo I_{geo} = log_2\left(\frac{C_n}{1.5B_n}\right)$$

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Where *Cn* is the measured concentration of heavy metal (*n*) assayed in sediment samples and *Bn*is the geochemical background value of heavy metal (*n*). The value of 1.5 is introduced to minimize the possible variations in the background values due to lithogenic effects.

A scale of I_{geo}indicates differences in the contamination level where it denotes uncontaminated sediments when $I_{geo} \leq 0$ (class 1); uncontaminated to moderately contaminated when $0 < Igeo \leq 1$ (class 2); moderately contaminated when $1 < I_{geo} \leq 2$ (class 3); moderately to heavily contaminated when $2 < I_{geo} \leq 3$ (class 4); heavily contaminated when $3 < I_{geo} \leq 4$ (class 5); heavily to extremely contaminated when $4 < I_{geo} \leq 5$ (class 6); and extremely contaminated when $I_{geo} > 5$ (class 7).

2.4.2 Contamination Factor (CF)

The *CF* is the ratio of the measured concentration of a given metal in the sediment to its background value, which has been classified into four grades as low contamination ($CF < 1$), moderate contamination ($1 \leq CF < 3$), considerable contamination ($3 \leq CF < 6$), and very high contamination ($CF \geq 6$) (20).

2.4.3 Pollution Load Index (PLI)

The PLI of a single site is the *n*th root of *n* number of multiplied together Contamination factor (CF) values. The CF is the ratio obtained by dividing the concentration of each metal in the sediment by the baseline or background value.

$PLI = (CF1 \times CF2 \times CF3 \times \cdots\cdots \times CFn)1/n$

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Site indices can be treated in the same way to give a zone or area index. Therefore, PLI for a zone is the *n*th root of *n* number of multiplied together PLI values. A PLI value of zero indicates perfection, a value of one indicates the presence of only baseline levels of pollutants, and values above one would indicate progressive deterioration of the site and estuarine\ quality (21). $PLI > 1$ suggests that pollution exists; otherwise, there is no pollution.

2.5 Correlation Matrix and Factor Analysis

Correlation matrix and principal component analysis was performed on the obtained data using SPSS package version 20.0. Only values which is 0.5 and above were retained. Also, factors with eigen values equal or greater than unity was considered.

2.6 STATISTICAL ANALYSIS

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Statistical analysis was carried out using SPSS package version 20.0.

3. RESULTS AND DISCUSSION

3.1 Heavy Metals Concentration in Water

The result of seasonal average of heavy metals (Ni, Cr, Cu, Pb, Zn, Co, Cd) concentration collected from water samples from the Kolo creek is presented in Table 1.The heavy metal with the highest concentration is Cu with a mean value of 0.283±0.064 mg/l at LC1. The range of Cu concentration in LC1 is from 0.210 to 0.330 mg/l. Contrally, the lowest measured concentration is that of Ni at locations LC3 and LC4, with mean values of 0.001±0.000 mg/l and 0.001±0.000 mg/l respectively. The range of Niconcentrations at locations LC3is from 0.000 to 0.001 mg/l and in LC4, from 0.000 to 0.001 mg/l respectively. The table also showed that some heavy metals have significant differences in distribution and concentrations across different locations. For example, the mean value of Cu at LC1 is 0.283±0.064 mg/l, which is significantly higher than the mean value of 0.016±0.007 mg/l measured at LC4. The same could be observed in Cr at LC1, with mean value of 0.005±0.004 mg/l significantly higher than the 0.002±0.001 at LC4. This probably suggests that there could be some factors that affect the distribution of heavy metals in the Kolo creek. The heavy metals generally,showed a decreasing trend in concentration: Cu > Zn > Pb > Cr > Cd > Co > Ni.The mean concentration of these metals: Ni, Cr, Zn and Cu recorded in this study are below international recommended limits(22,23).However, Pb and Cd concentrations in locations LC1, LC3 and LC4 recorded in this study,may have exceeded the international recommended limits (22,23). This suggests a pontential health risk of lead poisoning in the study area. Elevated level of Pb can cause adverse effect in aqauatic and human lives in the area. Chronic exposure to lead at a very low level could lead to neurological and reproductive problems (24).Exposure to lead (Pb) causes loss of memory, nausea, insomnia, anorexia, and weakness of joints, irritation and could maketumour to arise (25,26). There is alsorisk of cadmium poisoning in the study area.The mean concentration of Cd obtained in this study is well below the range of 0.01to 0.03 mg/l obtained in Bomadi Creek in the Niger Delta of Nigeria (27). The mean concentration of Cd, Pb, Zn and Cu obtained in this study are below the range obtained in riverBenue (28). Again, the mean concentation of Zn, Cd, Ni and Cr obtained in this study are below the values, but Cu and Pb are comparable with the values obtained in river Ureje, Ado Ekiti (29). The level of cadmium, lead and nickel in this study are greater than the value determined in a study byUzoekwe and Aigberua (9) in the surface waters within the flow stations in Kolo Creek, Nigeria. Furthermore,zinc (Zn) concentrations from this study of Kolo creek at Iberiberi axis is comparable with the value range observed in the Orashi river (30).

Table 1: Heavy metals concentration (mg/l) inKolo creek atIbelebiricommunity

Location	Ni	Cr	Cu	Pb	Zn	Co	Cd
LC1	0.002[a]±0.002 (0.000-0.003)	0.005[a]±0.004 (0.001-0.008)	0.283[a]±0.064 (0.210-0.330)	0.020[b]±0.000 (0.019-0.022)	0.044[a]±0.005 (0.039-0.048)	0.002[a]±0.001 (0.001-0.002)	0.004[a]±0.006 (0.001-0.011)
LC2	0.002[a]±0.001 (0.001-0.002)	0.002[a]±0.002 (0.000-0.004)	0.026[b]±0.002 (0.025-0.028)	0.020[b]±0.002 (0.018-0.021)	0.038[b]±0.002 (0.036-0.040)	0.002[a]±0.000 (0.002-0.002)	0.003[a]±0.004 (0.001-0.008)
LC3	0.001[a]±0.000 (0.000-0.001)	0.002[a]±0.001 (0.001-0.003)	0.015[b]±0.001 (0.010-0.022)	0.027[a]±0.005 (0.022-0.032)	0.040[ab]±0.003 (0.038-0.043)	0.001[a]±0.001 (0.001-0.002)	0.006[a]±0.005 (0.001-0.010)
LC4	0.001[a]±0.000 (0.000that of - 0.001)	0.002[a]±0.001 (0.001-0.002)	0.016[b]±0.007 (0.011-0.024)	0.025[ab]±0.003 (0.022-0.028)	0.040[ab]±0.002 (0.038-0.041)	0.001[a]±0.001 (0.001-0.002)	0.006[a]±0.004 (0.001-0.009)

NB:Values are expressed as mean ± standard deviation (range in parenthesis). Means in the same column bearing different superscripts are significantly ($p<0.05$) different. LC1: location 1 before Ibelebiri community. LC2: Location 2 within Ibelebiri Community. LC3: Location 3 after Ibelebiri community. LC4: Location used as Control.

3.2 Heavy Metals Concentration in the Sedimentsof KoloCreek at IbelebiriCommunity

The result of seasonal average of heavy metals (Ni, Cr, Cu, Pb, Zn, Co, Cd) concentrations in sediments sampled from Kolo creek atIberiberi axis is presented in table 2 below.The results showed thatZn at LC1 with a mean value of 35.865±0.000 mg/kg had the highest concentration. The Zn concentration in the sediment at LC1 ranged from 0.048 to 35.865 mg/kg. Thelowest concentration measured in the sediments at LC1 (Cd with a mean value of 0.016±0.000 mg/kg). The Cd concentrations at LC1 ranged from 0.011 to 0.016 mg/kg. The results also showed that some of the trace metals estimatedshowed a significant spatial variation. For example, the mean value ofNi at LC4 is 0.032±0.002 mg/kg, while a lower value of 0.025±0.000 mg/kg was obtained at LC1. Thus, there could be factors responsible for the distribution of heavy metals in the sediments.Generally, the heavy metals concentrations in the sediments showed a decreasing trend of Zn > Pb > Cu > Co > Cr > Ni > Cd. The results also revealedthat measured values forCd, Pb, Ni, Cr, Cu and Zn are below the permissible limit (31, 32). However, a measured value forCo at locationsLC3 and LC4 appears to beslightly above the permissible limit value of 20 mg/kg for sediments (31,32). This suggests the sediments in these locations may have been contaminated with Co.The levels of concentrations of nickel and cadmium observed in this study are below the concentrations reported by Uzoekwe and Aigberua (9) for surface waters within the vicinity of a flow station in Kolo Creek, Nigeria.Though,the mean value of Pb inLC2 is below the permissible level, the concentration obtainedat LC1 and LC3 are higher than the level observed by Uzoekwe and Aigberua (9) in the surface waters within the flow station in Kolo creek, Nigeria. The mean concentration of Zn obtained from the sediments in locationsLC1 and LC3 are above the value while the mean concentration of Cu obtained in this study are above the value measured at river Benue (28). The mean concentration of Cd, Cr, and Ni are found to be lower than the levels got in the studyofdredged and non-dredged rivers in Lagos, Nigeria (33). The mean concentration of Cu in LC 1 and 3 are higher than the levels obtained in Meghna River ecosystem (34). Furthermore, the mean levels of Cr, Ni and Cd are lower than the levels obtained in Meghna River ecosystem (34).Finally, Pb concentration obtained from sediments collected fromsampling locations LC1 and LC3 in this study are relatively higher than the levels observed in Belawan Harbor (35).

Table 2:Heavy metals concentration (mg/kg) in sediments ofKolo creek at Ibelebiri community

Location	Ni	Cr	Cu	Pb	Zn	Co	Cd
LC1	0.025^{a}±0.000 (0.003-0.025)	0.041^{a}±0.000 (0.008-0.041)	20.251^{b}±0.000 (0.330-20.251)	35.553^{a}±0.000 (0.020-35.865)	35.865^{a}±0.000 (0.048-35.865)	16.325^{a}±0.000 (0.002-16.325)	0.016^{b}±0.000 (0.011-0.016)
LC2	0.027^{a}±0.009 (0.002-0.033)	0.045^{a}±0.012 (0.004-0.053)	23.560^{a}±0.630 (0.026-24.006)	31.601^{b}±1.330 (0.021-32.538)	30.675^{ab}±3.280 (0.036-32-995)	18.217^{a}±5.500 (0.002-22.105)	0.021^{a}±0.007 (0.008-0.0021)
LC3	0.035^{a}±0.020 (0.001-0.036)	0.036^{a}±0.000 (0.002-0.036)	24.006^{a}±0.000 (0.022-24.006)	30.664^{b}±0.000 (0.028-30.664)	28.355^{b}±0.000 (0.043-28.355)	22.105^{a}±0.000 (0.001-22.105)	0.021^{a}±0.000 (0.010-0.021)
LC4	0.032^{a}±0.002 (0.001-0.033)	0.037^{a}±0.001 (0.002-0.038)	23.117^{a}±1.260 (0.024-24.006)	31.331^{b}±0.940 (0.022-31.998)	30.311^{ab}±2.770 (0.041-32.266)	21.104^{a}±1.420 (0.001-22.105)	0.020^{a}±0.001 (0.009-0.021)

NB: values are expressed as mean ± standard deviation (range in parenthesis). Means in the same column bearing different superscripts are significantly ($p<0.05$) different. LC1: location 1 before Ibelebiri community. LC2: Location 2 within Ibelebiri Community. LC3: Location 3 after Ibelebiri community. LC4: Location used as Control

Table 3:Therange ofgeoaccumulation index (mean in parenthesis) of the heavy metals in sediments studied.

Sampling Location	**Geoaccumulation index**						
	Pb	**Cd**	**Cr**	**Cu**	**Zn**	**Co**	**Ni**
LC1	-10.040 to 0.760 (-2.840)	-4.770 to -4.230 (-4.230)	-14.190 to -11.840 (-12.620)	-7.830 to -1.890 (-3.870)	-11.190 to -1.650 (-4.830)	-13.870 to -0.881(-5.210)	-15.290 to -12.230 (-13.250)
LC2	-9.970 to -0.630 (-2.930)	-5.230 to -3.840 (-4.320)	-15.190 to -11.470 (-12.900)	-11.490 to -1.640 (-4.950)	-11.610 to -1.770 (-5.120)	-13.870 to -0.440 -(5.130)	-15.870 to -11.830 (-13.420)
LC3	-9.550 to 0.550 (-2.820)	-4.910 to -3.840 (-4.190)	-16.190 to -12.020 (-13.410)	-11.740 to -1.640 (-5.010)	-11.350 to -1.990 (-5.110)	-14.870 to -0.440 (-5.250)	-16.870 to -11.700 (-13.470)
LC4	-9.900 to 0.610 (-2.910)	-5.060 to -3.840 (-4.290)	-16.190 to -11.950 (13.390)	-11.610 to -1.640 (-5.000)	-11.420 to -1.800 (-5.070)	-14.870 to -0.440 (-5.300)	-16.870 to -11.830 (-13.560)

LC1: location 1 before Ibelebiri community. LC2: Location 2 within Ibelebiri Community. LC3: Location 3 after Ibelebiri community. LC4: Location used as Control

Table 4: The range of contamination factor (mean in parenthesis) of the heavy metals in sediments studied.

Sampling Location	Contamination factor						
	Pb	**Cd**	**Cr**	**Cu**	**Zn**	**Co**	**Ni**
LC1	0 to 2.540 (1.690)	0.060 to 0.080 (0.070)	0	0.010 to 0.410 (0.270)	0 to 0.480 (0.320)	0.000 to 0.820 (0.540)	0
LC2	0 to 2.320 (1.510)	0.040 to 0.110 (0.080)	0	0 to 0.480 (0.310)	0 to 0.440 (0.270)	0 to 1.110 (0.610)	0
LC3	0 to 2.190 (1.460)	0.050 to 0.110 (0.090)	0	0 to 0.480 (0.320)	0 to 0.380 (0.250)	0 to 1.110 (0.740)	0
LC4	0 to 2.290 (1.490)	0.050 to 0.110 (0.080)	0	0 to 0.480 (0.310)	0 to 0.430 (0.270)	0 to 1.110 (0.700)	0

LC1: location 1 before Ibelebiri community. LC2: Location 2 within Ibelebiri Community. LC3: Location 3 after Ibelebiri community. LC4: Location used as Control

Table 5:Pollution load index (PLI) of the studied area

Sample location	PLI
LC1	0.371
LC2	0.393
LC3	0.441
LC4	0.418

LC1: location 1 before Ibelebiri community. LC2: Location 2 within Ibelebiri Community. LC3: Location 3 after Ibelebiri community. LC4: Location used as Control

3.3Ecological Risk Assessment of Heavy Metals Pollution in Sediments

3.3.1 Geoaccumulation Index

The result of geoaccumulation index (Igeo) in sediments collected from Kolo creek transversing through Ibelebiricommunity in Ogbia L.G.A. is presented in table 3.Using the geoaccumulationindex classification, the sediments across the four locations are uncontaminated with Cd, Cr, Cu, Zn, Co and Ni. The sediments collected from some locations LC1, LC3 and LC4 are moderately contaminated with Pb.The uncontaminated sediments imply that it is likely that thesedimentsheavy metal concentrations are within natural background range or have minimal anthropogenic influence. The negativevalues obtained for the geoaccumulation index calculation implies that the sediments have low ecological risk to the aquatic environment and living organism. However, sediments moderately contaminated with Pb due to anthropogenicactivities pose serious ecological and human health risk.

3.3.2 Contamination Factor (CF) of Heavy Metals in the Sediments.

The results of the contamination factor of heavy metals in the studied sediments samples are shown in table 4.According to the CF classifcation, there is low contamination of the ecosystem by Cd, Cr, Cu, Zn, Ni and Co across the four locations. Finally, there is moderate contamination of Pb across the locations studied. This implies that Pb has been introduced into the sediments from human activities, such as industrial emissions, vehicular exhaust, leaded gasoline.

3.3.3 Polution Load Index (PLI)

A *PLI*of < 1 indicates there is no pollution in the 4 locations studied or that the concentration of the pollutants is below detention limit as shown in Table 5. This suggests that the study area is free from heavy metal contamination or that the contamination is very low. However, using the PLI alone,may not reflect the true status of the sediments (36) because it does not consider the bioavailability, toxicity and speciation of the metals.

3.4 Principal Component Analysis

The result of principal component (PCA) is represented in table 6. Two major factors were identified; uncontrolled combustion process, such as artisanal refinery activities and gas flaring from nearby flow station. The percentage variance and cumulative results further highlighted the emergence of a pollution source other than gas flaring.

Table 6: PCAof Heavy Metals in Sediments

Component	Eigen value	% Variance	Cumulative %
1	5.663	80.896	80.896
2	1.321	18.866	99.762

Two factors identified: Uncontrolled combustion processes and activities from nearby oil and gas production including gas flaring.

The choice of Ibelebiri community through which Kolo creek flows before it gets to Imiringi is in order to investigate if there are other pollution determinants at Ibelebiri or a pollution source other than activities due to hydrocarbon production such as gas flaring. Although wind direction can determine eventual deposit of particulate matter arising from gas flaring, plume of gas flaring at Imiringi flow station shows otherwise.

4.CONCLUSION

This study showed that water flowing from Kolo creek alongIbelebiri community axis had Pb and Cd in concentrations deemed unsafe, and with sediments that had Co in concentrations above approved level. This should raise concerns as this could lead to serious health issues in the community. PCA result identified two major factors; uncontrolled combustion processes such as artisanal refinery activities and gas flaring from nearby flow stations. Thesescontributed to the pollution of the water and sediments in the studied area. Though several studies attributed pollution of the creek to mainly oil and gas production at Imirigi, this study reveals an emerging source of heavy metal contaminants that ultimately contribute tothe pollution load of Kolocreek.

Comment [i-[6]]: Recast

Comment [i-[7]]: Author may suggest possible solution to the emerging source of heavy metal contaminant.

Comment [i-[8]]: After conclusion, a section may be dedicated for the “declaration of competing interest” by the author since it is also a requirement for the reviewer

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