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ORIGINAL ARTICLE

Heavy metal pollution and ecological geochemistry of soil impacted by activities of oil industry in the Niger Delta, Nigeria

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Abstract The aim of the study was to assess the metal pollution of the soil around two crude oil flow stations in the Niger Delta, Nigeria and perform the ecological geochemistry of soil. Soil samples were collected by systematic random sampling around the flow stations in Kokori and Kolo Creek, Niger Delta Nigeria. The concentrations of Zn, Pb, Ni, Cr and Cd in the soil were determined by Atomic Absorption Spectrophotometry after wet-digestion in acid mixture of $HNO_3 + HCl + H_2O_2$. Mean concentration values of Zn, Pb, Ni, Cr, and Cd in the soil of both Kokori and Kolo Creek were higher in some cases by several orders of magnitude than the Control values except for Ni in Kokori and Pb in Kolo Creek. The levels of Index of geo-accumulation (I-geo) were no pollution to low pollution except Cr in Kolo Creek that indicates strong pollution. Nemerow integrated pollution index (NIPI) also indicates the soil of Kokori and Kolo Creek to be of moderate and high levels of pollution respectively with Zn majorly contributing to the pollution status in Kokori while Cr, Zn and Ni are the major pollutants in Kolo Creek. However, a different pollution pattern was observed in the single potential ecological risk assessment of metals in the soil. Cd and Cr in Kokori and Cr, Cd and Ni in Kolo Creek portend ecological risk with the following patterns; Cd = Cr > Zn = Pb = Ni and Cr > Cd = Ni > Zn = Pb respectively. Comprehensive potential ecological risk (RI) assessment indicated low potential ecological risk for Kokori and Kolo Creek; and the major contributors are Cd, Ni and Cr. Therefore, there is urgent need to remediate these metals that could pose ecological risk so that further buildup would be prevented, and avert any potential harm to ecological functioning of the areas.

Keywords Niger Delta · Oil spill · Heavy metal · Pollution · Index of accumulation · Potential ecological risk

Introduction

The oil industry in the Niger Delta of Nigeria has contributed immensely to the growth and development of the country but the unsustainable oil exploration activities has rendered the Niger Delta region one of the most severely damaged ecosystems in the world (Adati 2012). The activities of the oil industry has posed detrimental effects on the environment of the oil producing areas through exploration and production operations. The impacts resulting from oil spills, drilling mud and fluid, formation waters and effluent discharge are of great concern because of their deleterious effects (Asia et al. 2007; Ite et al. 2013).

The Niger Delta has been reported to have a complex and extensive system of pipelines running across the region and large amounts of oil spill incidences have occurred through the pipelines and storage facility failures (Adati 2012). These failures could be caused by material defect, pipeline corrosion, ground erosion but the oil companies blame most of the spills on sabotage whereas the Nigerian Department of Petroleum Resources (DPR) affirmed that 88 % of the oil spill incidences were linked to equipment failure, oil blowouts from the flow stations, accidental and deliberate releases and oil tankers at sea (Nwilo and Badejo 2005).

Due to the cumulative impacts of petroleum exploration and production, the Niger Delta has been seen as one of the most polluted areas in the world. This is due to severe

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contamination associated with the operations of petroleum industry operations coupled with their lackadaisical attitude towards post spill containment, recovery and remediation responses (Zabbey 2009). The activities of the oil industries have adversely degraded the ecosystem and reduced the biodiversity of the Niger Delta, thereby affecting the general ecology of the area (Kamalu and Wokocha 2011). Sabotage and operational spills have been reported as the major causes of environmental pollution in the oil producing areas of Nigeria (Shell Nigeria 2014). Intentional third-party interference with pipelines and other infrastructure was reported to be responsible for about 75 % of all oil spill incidents and 92 % of all oil volume spilled were from facilities operated by the Shell Petroleum Development Company (SPDC) over the last 5 years (2009–2013) (Shell Nigeria 2014). Operational spills also accounted for about 15 % of the total volume of oil spilled from SPDC facilities in 2013 which has caused an increase to 0.4 thousand tonnes (Shell Nigeria 2014).

Although the ecological effects associated with oil pollution have been spot-wise investigated as stated by Jernelöv (2010), it is obvious that oil exploration and production operations have impacted the agricultural soils, terrestrial ecosystem and pose potential ecological/human health risks to the region (IUCN/CEESP 2006; Ite et al. 2013). One of the environmental problems is the contamination of terrestrial ecosystems of the oil producing communities with toxic metals. Metals such as Zn. Pb, Ni, Cr and Cd have been reported as constituents of Nigeria's crude oil (Dickson and Udoessien 2012), and are also referred to as great pollutants of the environment (Shtangeeva 2006; Fatoba et al. 2015). These pollutants often take years to cause hazards and this makes it difficult to really appreciate their contribution to ecological and human health hazards (Guilbert 2003; WHO 2005). The elevated concentrations of Zn. Pb, Ni, Cr and Cd through oil spills can exert acute or chronic toxicity or both on soil with resultant enhanced absorption by plants, which may bring about bioaccumulation in plants and eventually lead to toxicity along the food chain (Ekundayo and Obuekwe 2000).

Owing to these environmental and ecotoxicological hazards of metal contamination, this study was aimed at (i) determining the level of Zn, Pb, Ni, Cr and Cd in the soil of the areas and, (ii) assessing pollution status of metals in the soil and the ecological risks posed to the environment.

Materials and methods

Description of study areas

The soil samplings were carried out at the SPDC Flow stations in Kokori and Kolo Creek, Niger Delta, Nigeria. SPDC is the largest fossil fuel company in Nigeria, which operates over 6000 km of pipelines and flow lines, 87 flow stations, 8 natural gas plants and more than 1000 producing wells. SPDC has over 20 oil wells in the Niger Delta and produced the second best crude oil in the world due to its low sulphur content (Odjie 1995). Sampling of the Control soils was carried out at a location called Zarama in Ikarama community of the Niger Delta. Zarama is one of the nine fishing and farming communities in the Okordia–Zarama cluster of Ikarama in Niger Delta, Nigeria with little impacts by the oil industry activities.

Kokori (nicknamed oil field town), is geographically located within coordinates 5°40′N, 6°4′E with flat land and situated in the evergreen tropical forest zone of Nigeria which is dominated by the oil palm tree (Akpojotor 2011). In 1958, SPDC carried out an exploration work which led to the discovery of crude oil on Kokori soil.

Kolo Creek (Ogbia) is located within the lower delta plain of Nigeria (Lat. 4°0.53′N and Long. 6°22′E). The area is of swampy topography with vegetation typical of tropical rain forests and the Creek is non-tidal fresh water that empties into the River Nun (Alagoa 1999). The major activity of economic value in the area is exploration and exploitation of crude oil. Oil fields are located in each settlement along the creek, where effluents are discharged into the water body (Ebenezer and Eremasi 2012).

Sample collection and analytical procedure

Forty composite topsoil samples within 0–15 cm depth (three subsamples bulked at each point) were collected by systematic random sampling using a steel soil auger at the SPDC Flow Station Kokori and Kolo Creek respectively (Fig. 1b). Samples were only collected at the front of the Flow Stations because the back of Kolo Creek Flow Station was inundated with water while access to Kokori Flow Station surroundings was prohibited. Ten composite samples were collected at the Control site which serves as the less contaminated/reference area. The samples were transported to the laboratory in properly tagged polyethylene bags. Soil samples were air-dried for 2 weeks to constant weight, sieved through a 2 mm sieve and made into two subsamples for digestion. Approximately 1 g of the subsample was wet-digested in $HNO_3 + HCl + H_2O_2$ according to USEPA 3050B (ratio 4:2:1) method (USEPA 1996) and the supernatant was filtered using Whatman filter paper 42. The determination of metal concentration was carried out by Atomic Absorption Spectrophotometry using Perkin Elmer Analyst 200. The AAS was calibrated for each element using series of standard solutions (CPI, USA) and the correlation of coefficient of each calibrated graph was greater than 0.950. The QA/QC methods adopted were the use of reagent blanks and replicate

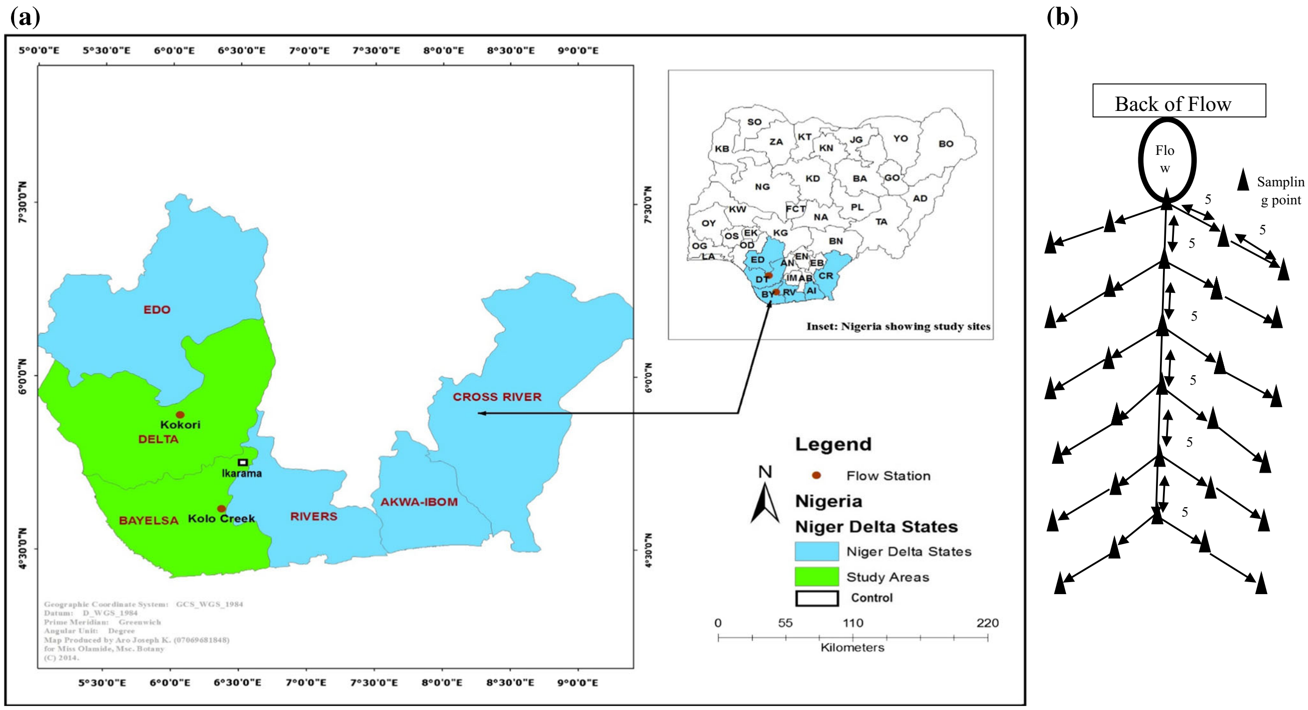


Fig. 1 Showing maps **a** Nigeria indicating the study locations and **b** schematic diagram of sampling procedure

digestion to validate the correctness of the procedure Reference material lake sediment (IAEA-Sl-1) was used to check the reliability of the procedure and instrumentation with percentage recovery between 76 and 95 %. Soil pH was determined potentiometrically in soil/H_2O suspension (1: 2.5 *w/v*) using a glass electrode pH meter (PHS-3C model) and two readings were taken per sample. The soil organic matter (OM) was determined by loss on ignition method (LOI) (Reddy et al. 2009).

Statistical analyses

Statistical analyses were conducted using SPSS 16.0 statistical software. The distribution of the data was tested with the Kolmogorov–Smirnov (K–S) method for Normality and outliers were removed before log-transformation of non-normal distributions were carried out. A multivariate principal component analysis (PCA) was carried out to investigate the relationships among the heavy metals in the soils of Kokori and Kolo Creek using Correlation matric method of Paleontological Statistical Software Package for Education and Data Analysis (PAST) version 2.17b.

Models for ecological geochemistry assessment

In order to unify the assessment results in this study, the background levels in the Control were used as the reference values for calculating indices as proposed by Qingjie et al. (2008) and given in Table 1 according to Qingjie et al. (2008).

Method of heavy metal pollution assessment

Index of geo-accumulation (I-geo) enables the assessment of contamination by comparing the metal level obtained to a background level. According to Muller (1969):

$$\text{I-geo} = \log 2\left[\frac{C_n}{1.5 \times C_m}\right] \tag{1}$$

C_n is the measured concentration of metal in the soil sample (mg/kg) while C_m is the measured concentration in the Control as modified by Qingjie et al. (2008). There is introduction of a constant—1.5 to minimize the effect of possible variations in the background value which may be linked to lithologic variations (Lu et al. 2010).

Pollution index (PI) and Nemerow integrated pollution index (NIPI) were used to assess the degree of heavy-metal contamination (Yang et al. 2011; Jiang et al. 2014) in the soil.

$$\text{PI} = C_i/S_i \tag{2}$$

where C_i is the measured concentration of each metal, Si is the reference level (control level), the PI of each metal is classified as (a) non-pollution (PI <1), (b) low level of

Table 1 Terminologies for classes of degree of contamination

Index[a]	Unpolluted	Low polluted	Moderately polluted	Strongly polluted	Extremely polluted
C_f	<2	2–4	4–16	16–32	>32
Er	$<2T_r^b$	$2T_r$–$4T_r$	$4T_r$–$16T_r$	$16T_r$–$32T_r$	$>32T_r$
I-geo	<0.42	0.42–1.42	1.42–3.42	3.42–4.42	>4.42

[a] Qingjie et al. (2008)

[b] T_r denotes toxic-response (Håkanson 1980)

pollution (1< PI <2), (c) moderate level of pollution (2 < PI < 3), (d) strong level of pollution (3 < PI < 5); and (e) very strong level of pollution (PI > 5) (Yang et al. 2011; Jiang et al. 2014).

The NIPI of the combined metals in the soil is defined as follows:

$$\mathrm{NIPI} = \frac{\sqrt{\mathrm{PI}_{\mathrm{ave}}^2 + \mathrm{PI}_{\mathrm{max}}^2}}{2} \quad (3)$$

where $\mathrm{PI}_{\mathrm{ave}}$ the mean PI value for all studied heavy metal and $\mathrm{PI}_{\mathrm{max}}$ is the maximum PI value of heavy metal. The NIPI is classified as non-pollution (NIPI $\leq$0.7), warning line of pollution (0.7< NIPI $\leq$1), low level of pollution (1< NIPI $\leq$2), moderate level of pollution (2< NIPI $\leq$3) and high level of pollution (NIPI >3) (Yang et al. 2010; Jiang et al. 2014).

Method of determining ecological risk

Contamination factor (CF) is used to describe the contamination of a particular metal in sediment/soil (Håkanson 1980; Cabrera et al. 1999).

$$\mathrm{CF}^i = \frac{C_i}{C_s} \quad (4)$$

where C_i is the content of metal i and Cs is the reference/background value of metal i. Reference value used in this study is the value of metal i in the Control as modified by Qingjie et al. (2008).

Potential ecological risk index (RI) suggested by Håkanson (1980) to evaluate metal contamination from the perspective of sedimentology was used to quantify the potential ecological risk of the presence of heavy metals in the soil of the study areas.

$$\mathrm{RI} = \sum E_r; \sum_{i=1}^{n} E_r^i = T_r^i \times \mathrm{CF}^i \quad (5)$$

where T_r^i is the toxic-response factor for a given substance and CF^i is the contamination factor. The toxic-response (T_r) values of Zn, Pb, Ni, Cr and Cd by Håkanson (1980) are 1, 5, 9, 2 and 30 respectively. The following terminologies are used for the potential ecological risk index (RI): RI <150, low ecological risk; 150$\leq$ RI <300, moderate ecological risk; 300 $\leq$ RI < 600, considerable ecological risk; and RI >600, very high ecological risk. The modified Er classes according to Qingjie et al. (2008) are presented in Table 1.

Results and discussion

Preliminary metal concentration description

The descriptive statistics of concentrations of heavy metals in the soil from Kokori, Kolo Creek and the Control are presented in Table 2. The soils in Kokori and Kolo Creek were acidic with pH ranged between 4.2–6.9 (avg. 5.39) and 3.3–6.8 (avg. 5.39), respectively; while Control soil was less acidic with pH 5.55 The metal speciation, solubility and adsorption to solid phases are intimately connected to the pH and numerous studies have found a significant effect of soil pH on metal bioavailability (Cavallaro and Mcbride 1984; Alloway 1995; Stehouwer et al. 2006). It has also been reported that crude oil alters soil biochemistry parameters such as reduction in the pH which might be attributed to the production of organic acids by microbial metabolism (Atuanya 1987; Osuji and Nwoye 2007).

Mean OM of Kokori and Kolo Creek were 0.99 and 0.45 %, respectively, and these values were relatively low; showing that the soils were infertile whereas OM of the Control was relatively fertile (1.89 %). Soil OM plays an important role in determining the concentrations of pollutants as soil that is rich in organic matter could offer more functional groups (like COO– groups) that could form complexes with metals and make metals ions unavailable in soil (Baker et al. 1995; Odero et al. 2000). Therefore, the low OM contents of the soils in this present study may increase metal bioavailability in the soil through reduce organic exchange sites for metals, thereby increasing their ecotoxicology.

Zn concentrations ranged from 23.6 to 69.0 and 24.6 to 65.0 mg/kg in Kokori and Kolo Creek respectively. Ranges of Pb were from 4.9 to 6.1 and 0.02 to 5.05 mg/kg while Ni concentrations ranged from 0.45 to 3.9 and 5.0 to 11.9 mg/kg in Kokori and Kolo Creek, respectively. Cr and Cd concentrations ranged from 4.9 to 11.2 and 0.00 to 1.85 mg/kg in Kokori while in Kolo Creek, the ranges were

Table 2 Descriptive statistics of physico-chemical and heavy metal concentrations in soil of the study locations

	Mean	Min.	Max.	SD	Skewness	Kurtosis	K-S	Outliers	Transformation
Kokori ($n = 40$)									
pH	5.39	4.2	6.9	0.94	0.230	−1.425	0.200	Nil	NA[a]
OM (%)	0.99	0.14	2.00	0.49	−0.196	2.444	0.200	Nil	Log normal
Zn (mg/kg)	45.65	23.6	69.0	12.7	0.241	−0.420	0.200	1	NA
Pb (mg/kg)	5.49	4.9	6.1	0.39	0.250	−1.132	0.200	Nil	NA
Ni (mg/kg)	1.99	0.45	3.9	1.03	0.313	−1.176	0.170	Nil	NA
Cr (mg//kg)	6.91	4.9	11.2	1.67	1.405	4.340	0.014	2	NA
Cd (mg/kg)	0.84	0.00	1.85	0.60	0.378	1.926	0.200	Nil	NA
Kolo creek ($n = 40$)									
pH	5.04	3.3	6.8	0.94	−0.115	−0.091	0.200	Nil	NA
OM (%)	0.45	0.03	1.0	0.27	0.461	−0.338	0.200	1	Log normal
Zn (mg/kg)	46.97	24.6	65.0	11.32	−0.165	−0.674	0.200	Nil	NA
Pb (mg/kg)	1.38	0.02	5.05	0.56	0.671	−0.341	0.145	Nil	NA
Ni (mg/kg)	7.4	5.0	11.9	1.71	0.603	0.507	0.200	1	NA
Cr (mg//kg)	12.33	0.95	26.0	6.85	0.411	−0.407	0.200	Nil	NA
Cd (mg/kg)	0.70	0.15	1.85	0.48	0.931	0.230	0.200	Nil	NA
Control ($n = 10$)									
pH	5.55	5.10	5.63	0.61					
OM (%)	1.89	1.46	2.35	0.11					
Zn (mg/kg)	13.12	11.2	22.8	2.56					
Pb (mg/kg)	2.82	1.35	3.67	2.30					
Ni (mg/kg)	2.26	1.96	3.87	1.20					
Cr (mg//kg)	2.51	2.15	2.95	0.62					
Cd (mg/kg)	0.34	0.28	0.56	0.12					

[a] Not applicable

from 0.95 to 26.0 and 0.15 to 1.85 mg/kg, respectively (Table 2).

The mean concentrations of Pb, Ni and Cr differed significantly ($p < 0.05$) between Kokori and Kolo Creek in the following pattern: Pb ($t = 9.849$, $p < 0.000$); Ni ($t = 11.909$, $p < 0.000$) and Cr ($t = 3.369$, $p < 0.002$) (Fig. 2b–d). There was no significant difference in the concentrations of Zn ($t = 0.321$, $p < 0.750$) and Cd ($t = 0.781$, $p < 0.440$) between Kokori and Kolo Creek (Fig. 2a, e).

Relationship among the pH, OM and heavy metals in the soils of Kokori and Kolo Creek

A multivariate-PCA using Correlation matrix was conducted to investigate the relationship among the soil pH, OM and heavy metals in the soils of Kokori and Kolo Creek. The resulting PCA Biplot is presented in Fig. 3. According to Fig. 3a, Cr and Zn have a strong correlation suggesting that the two metals reached the soil through the same pathway. Pb and Cd in the soil of Kokori also correlated strongly which implies that they have the same route to the soil. It is also evidently clear from the reduced angle that each metal shared among themselves in the PCA Biplot that Cr, Zn, Pb and Cd may possibly have the same source. However, the pathway and source of Ni in the soil of Kokori may be different from that of Pb, Cd, Cr and Zn since Ni was positioned perpendicularly to other metals. Significant relationship existed between OM and Pb and Cd, which signifies that OM plays a major role in the presence of Pb and Cd in the soil. It is also clear that the pH had a strong relationship with Cr and Zn, thereby influencing their presence in the soil. In Fig. 3b, Zn and Cr likewise Ni and Pb formed separate associations in the soil which indicate that they share the same pathway into the soil. Cd was at perpendicular position to other metals, thereby suggestive of different source and pathway. OM also plays significant role in the presence of Zn and Cr in the soil as earlier reported for Kokori, but Ni and Pb are influenced by the soil pH (Fig. 3b).

Geochemistry assessment of metals in the soil of the study areas

The index of geo-accumulation of metals in the soil of the study areas are presented in Fig. 4. In the soil of Kokori,

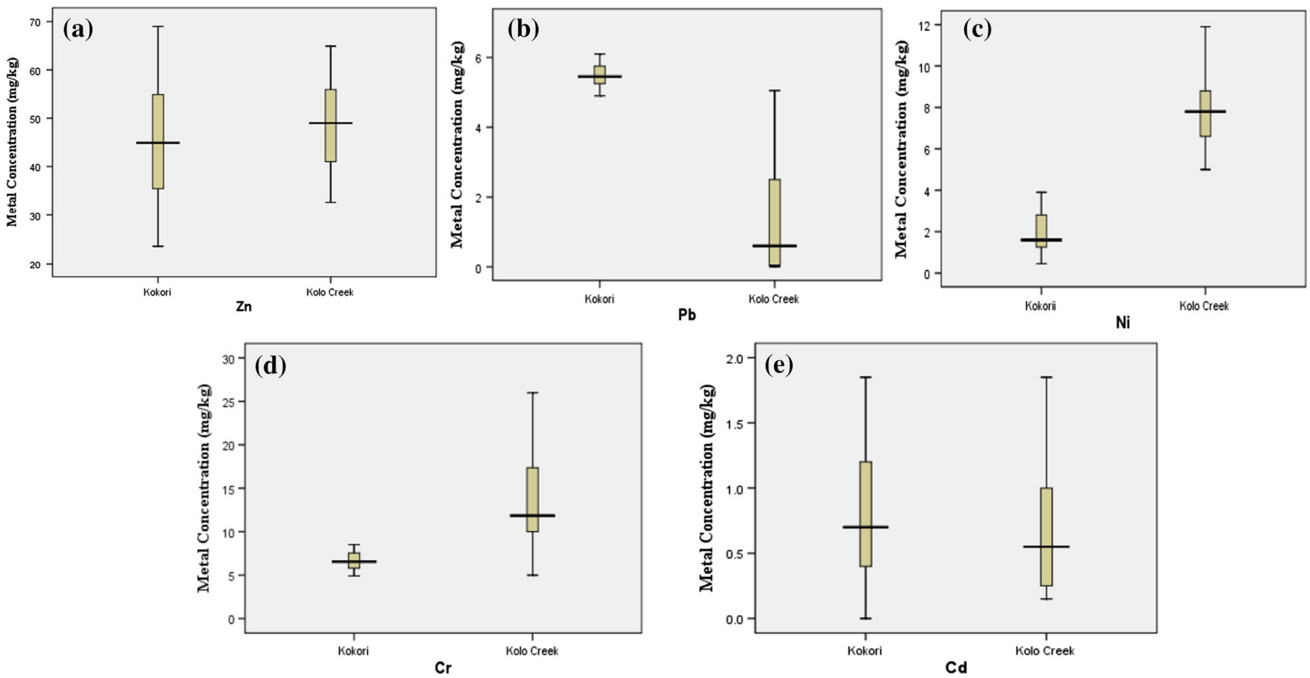
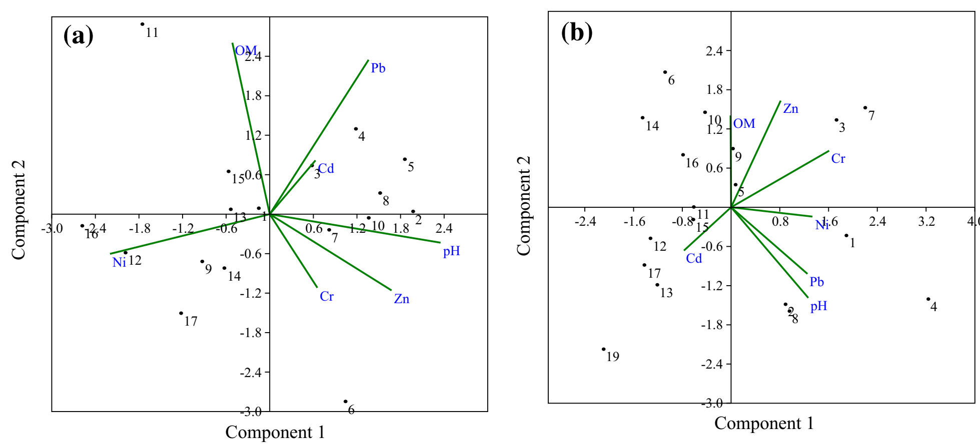


Fig. 2 Inferential statistics of concentration (mg/kg) of **a** Zn, **b** Pb, **c** Ni, **d** Cd and **e** Cr in soil of Kokori and Kolo Creek, Niger delta, Nigeria (*Whiskers* represent the minimum and the maximum values)

Fig. 3 PCA Biplot of heavy metals in the soil of **a** Kokori and **b** Kolo Creek, Niger delta, Nigeria



mean I-geo index of Pb (I-geo = 0.36) and Ni (I-geo = −0.93) were categorized under no pollution status while Zn (I-geo = 1.19), Cr (I-geo = 1.23) and Cd (I-geo = 0.50) were within the low pollution status. For soil of Kolo Creek, Pb (I-geo = –3.10) and Cd (I-geo = −0.15) were within the no pollution status while Zn (I-geo = 1.17) and Ni (I-geo = 0.95) showed low pollution status. Only Cr with mean I-geo = 4.36 showed strongly polluted status in Kolo Creek (Fig. 4). The anthropogenic introduction of Zn and Cr into the soil pose major environmental concern in the soil of Kolo Creek.

Heavy metal pollution assessment by PI and NIPI (Yang et al. 2010; Jiang et al. 2014) in relation to the background area of heavy metals in the soils are presented in Table 3. The mean PI of Pb, Cr and Cd in Kokori ($PI_{Pb} = 1.95$, $PI_{Cr} = 2.75$ and $PI_{Cd} = 2.47$) were <3.0 which indicates that the soils were moderately polluted by Pb, Cr and Cd. The PI value for Zn (PI = 3.48) in Kokori was >3.0, indicating the soil of the area had strong level of pollution by Zn while Ni with PI = 0.88 showed no pollution of the soil. In the case of Kolo Creek soil, only Cd showed moderate pollution ($PI_{Cd} = 2.06$) and Pb portrayed no pollution status ($PI_{Pb} = 0.49$). Zn ($PI_{Zn} = 3.58$), Ni ($PI_{Ni} = 3.27$) and Cr ($PI_{Cr} = 4.91$) had a very strong level of pollution by these heavy metals (Table 3). The relatively high PI values of Zn, Cr, and Cd in both locations is an

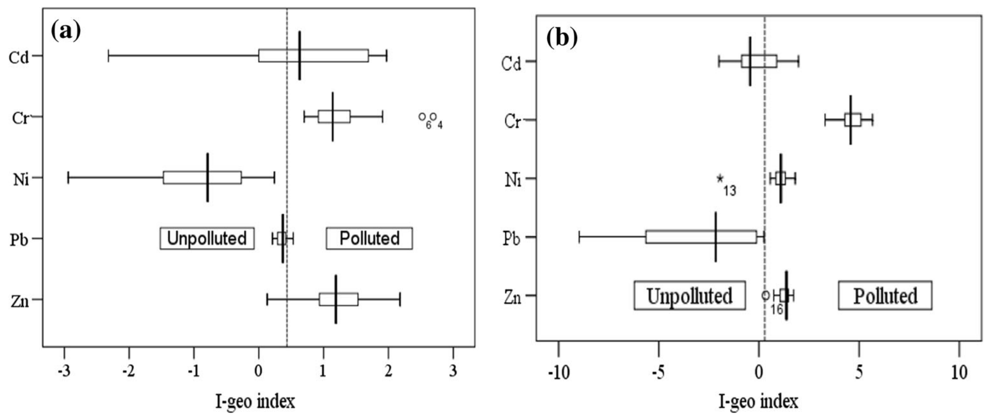


Fig. 4 Index of geo-accumulation (I-geo) for metals in the soil of **a** Kokori and **b** Kolo Creek, Niger delta, Nigeria (*whiskers* represent the minimum and maximum values)

Table 3 Pollution index (PI) and Nemerow integrated pollution index (NIPI) of heavy metals in the soil

PI	Zn	Pb	Ni	Cr	Cd	
Kokori						
Minimum	1.78	1.74	0.23	1.95	0.00	
Maximum	5.26	2.16	1.73	4.46	5.44	
Mean	3.48	1.95	0.88	2.75	2.47	NIPI = 2.95
Kolo creek						
Minimum	1.87	0.01	2.21	0.38	0.44	
Maximum	4.95	1.79	5.26	10.3	5.44	
Mean	3.58	0.49	3.27	4.91	2.06	NIPI = 4.04

indication of the presence of serious metal pollution (Mmolawa et al. 2011; Yang et al. 2011) and clearly shows that the areas have been polluted by anthropogenic input (Lu et al. 2012). The patterns of PI in the Kokori and Kolo Creek are as follows: Zn > Cr > Cd > Pb > NI and Cr > Zn > Ni > Cd > Pb respectively. The Nemerow integrated pollution index (NIPI) value of metals in soil of Kokori was 2.94 and the NIPI value for Kolo Creek was 4.04. The NIPI values were in the classes of moderate and high levels of pollution respectively according to Yang et al. (2010); and this is an indication that the operations of the oil industry has significantly impacted the ecology of the region. However, impact of the oil industry is more pronounced in Kolo Creek than Kokori.

Ecological risk assessment of metals in the soil of the study areas

Contamination factor (CF) of metals in the soil ranged from unpolluted status to low pollution status in Kokori [0.80 (Ni) to 3.48 (Zn)] while CF ranged from no pollution to moderate pollution status in Kolo Creek [0.49 (Pb) to 4.91 (Cr)] (Table 4). Single ecological risk index (Er) for metals in the soil of Kokori showed that Zn, Pb and Ni are in the class of no pollution while Cr and Cd showed low pollution status (Table 4). This is an indication that the area is contaminated with Cr and Cd which should be remediated to avert possible ecological disaster. For soil from Kolo Creek, Zn and Pb are in the class of unpolluted, Ni and Cd were categorized into low pollution class while Cr was in the class of moderate pollution. The major pollutants that may pose ecological problems in Kolo Creek are Ni, Cr and Cd which should be looked into for possible remediation. The Comprehensive

Table 4 Ecological geochemistry assessment of soil metal of Kokori and Kolo Creek, Niger delta, Nigeria

	Zn	Pb	Ni	Cr	Cd	
Contamination factor (CF)						
Kokori	3.48	1.95	0.88	2.75	2.47	
Kolo creek	3.58	0.49	3.27	4.91	2.06	
Single ecological risk index (Er)						RI
Kokori	3.48	9.75	7.92	5.50	74.1	100.75
Status[a]	Unpolluted	Unpolluted	Unpolluted	Low pollution	Low pollution	
Kolo Creek	3.58	2.45	29.43	9.82	61.8	107.08
Status	Unpolluted	Unpolluted	Low pollution	Moderate pollution	Low pollution	

[a] Qingjie et al. (2008)

potential ecological risk (RI) for soil from Kokori (RI = 100.75) and Kolo Creek (RI = 107.08) indicated low ecological risk of metals (Table 4).

Cd was the key influencing factor that contributed to the potential ecological risk of Kokori while Cr, Cd and Ni were the influencing factors promoting potential ecological risk in Kolo Creek. These metals which are major constituents of crude oil (Osuji and Onojake 2004; Osuji and Achugasim 2010) are hazardous as several studies have shown that metals, such as Cr, Cd and Ni are responsible for certain diseases of man like renal problem, liver cirrhosis and cancer (Gustav 1974; ATSDR 2000; Bada and Olarinre 2012). These metals especially Cd could also affect the ecological functioning of the area when present in elevated concentrations (Ogunkunle and Fatoba 2013); so it is important that remediation process should be employed in earnest to reduce the levels in order to avert any potential hazard.

Conclusion

This study provides important information about the levels of Zn, Pb, Ni, Cr and Cd in soils impacted by oil exploration. The assessment of the geochemistry of the soil showed that the soil of Kokori was polluted by Zn, Cr and Cd while Zn, Ni and Cd were the major pollutants in Kolo Creek. The pollution status of these metals in the soil translated into a low potential ecological risk with RI = 100.75 and 107.08 for Kokori and Kolo Creek respectively. The low pollution levels of Cr and Cd in Kokori; and low pollution status of Ni and Cd in addition to that moderate pollution level of Cr in Kolo Creek were the main contributing factors to the potential ecological risk of the two areas.

There is the need for concerted efforts both by the Nigerian government and the oil industry to carry out soil remediation/ecological restoration to avert possible potential ecological disaster from soil pollution by Cr and Cd in Kokori and Ni, Cr and Cd in Kolo Creek. The information provided will also be useful for environmental planning, risk assessment and decision makers in the oil industry and by environmental managers and the Nigerian government.

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