

Application of Pollution Indices for the Assessment of Heavy Metal Pollution in Flood Impacted Soil

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Authors' contributions

This work was carried out in collaboration amongst all three authors. Author AKI designed the study, wrote the protocol, performed the statistical analysis, managed the literature search and wrote the first draft of the manuscript with assistance from authors CYA and CW. All three authors read and approved the final manuscript.

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ABSTRACT

The flood in 2012, which was recorded as the most devastating in the past 40 years in Nigeria, that caused colossal loss in material wealth, could also be a source of heavy metal pollution, especially at the lower reaches of the flood where deposition of flood transported materials occurs. Heavy metals (Fe, Ni, Cd, Cr, Zn, Cu and Pb) concentrations were determined in soil samples from two locations, an area submerged by the flood water (flooded) and an area at a higher elevation than the flood water (unflooded), which served as the control. The soil pH, texture, Total Organic Carbon, and Cation Exchange Capacity were also determined. Standard laboratory methods were employed for all the analyses. The soil in this study was characterized as sandy/clay/loam soil following the particle size analysis, with an average pH of 4.6 in the flooded soils and 6.5 in the unflooded soils. Total Organic Carbon (TOC) ranged from (0.936-1.989)% in the flooded soil and (0.663-0.939)% in the unflooded soil. Cation Exchange Capacity (CEC) was higher in the flooded soil (1.936-3.234) meq/100 g, than in the unflooded soil (1.164-1.722) meq/100 g. The results of

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the heavy metals revealed that heavy metals concentrations were higher in the flooded soil samples compared to the unflooded soil samples. There was also evidence of leaching of heavy metals. Eight Pollution Indices for heavy metals were applied to the data which comprised of four single pollution indices (The Contamination Factor, Ecological Risk Factor, Enrichment Factor and Index of Geo-accumulation) and four integrated pollution indices (Average Pollution Index, Degree of Contamination, Ecological Risk Index and Nemerow Pollution Index) to evaluate the soil pollution status. Amongst the pollution indices, the Nemerow Pollution Index was the most stringent. It was recommended as the pollution index to be applied for safety considerations.

Keywords: Flood; heavy metals; pollution indices; soil pollution.

1. INTRODUCTION

The flood in 2012 that affected fringing communities of the Niger River and Niger Delta Basin was recorded as the most devastating flood in the past 40 years by the Red Cross [1]. The flood resulted from the evacuation of water from Ladgo Dam in Cameroun and Jebba Hydro Power Plant, Kainji Dam and Shiroro Dam in Nigeria [2] and lasted for a period of three months. While communities in the elevated at higher altitudes experienced Flash Floods within a shorter period of time, lands in the Niger Delta Basin experienced both Flash and Stagnant Floods for a longer period of time.

Flood water has the capacity of transporting materials from one point to another, especially in this scenario, where the flood originated from more elevated lands and moved down to lower lands in the form of Flash Flood. The flood transported materials mainly sediment onto the low lands where the water becomes relatively stagnant [3] as in the case of Niger Delta University situated in Southern Ijaw Local Government Area of Bayelsa State, Nigeria.

Amongst the materials transported by floods, heavy metals bound to soil particles could be present. Such particles could be from rock weathering, soil erosion and dissolution of water soluble salts. Contaminant remobilization during flood, also contribute to increase in contaminant levels on the flood plain.

In this study, the levels of Fe, Ni, Cd, Cr, Zn, Cu and Pb were determined in flooded topsoil and un-flooded topsoil, to evaluate the level of pollution as a result of the flood. The bottom soils from both flooded bottom and un-flooded sites were also analyzed. This was to enable the determination of possible heavy metal percolation into the subsoil.

Pollution Indices were used to evaluate the level of soil contamination by the afore-mentioned heavy metals.

1.1 Pollution Indices

Eight Pollution Indices were applied to the data which comprised of four single pollution indices (The Contamination Factor, Ecological Risk Factor, Enrichment Factor and Index of Geo-accumulation) and four integrated pollution indices (Average Pollution Index, Degree of Contamination, Ecological Risk Index and Nemerow Pollution Index) to evaluate the soil pollution status.

1.2 Contamination Factor

The contamination factor is described as the contamination by a given toxic substance in a lake or a sub-basin suggested by Hakanson [4] and is stated in equation (1)

$$(C_f^i = \frac{\bar{C}_{0-1}^i}{C_n^i}) \quad (1)$$

Where \bar{C}_{0-1}^i is the mean concentration of the heavy metal "i" in at least 5 samples from a site and C_n^i is the pre-industrial reference level for the heavy metal. In this case, the control (unflooded) site was regarded as the reference level with respect to the recent flood. The following terminologies were used to describe the contamination factor:

- $C_f^i < 1$ – Low Contamination Factor
- $1 \leq C_f^i < 3$ – Moderate Contamination Factor
- $3 \leq C_f^i < 6$ – Considerate Contamination Factor
- $C_f^i > 6$ – Very High Contamination Factor

1.2.1 Ecological risk factor

An ecological risk factor E_r^i is used to quantitatively express the potential ecological

risk of a given contaminant. This was also suggested by Hakanson [4] as

$$E_r^i = T_r^i \cdot C_f^i \quad (2)$$

Where T_r^i is the toxic-response factor for a given substance; C_f^i is the contamination factor.

The following terminologies are used to describe the risk factor:

$E_r^i < 40$ – *Low potential ecological risk*
 $40 \leq E_r^i < 80$ – *Moderate potential ecological risk*
 $80 \leq E_r^i < 160$ – *Considerate potential ecological risk*
 $160 \leq E_r^i < 320$ – *High potential ecological risk*
 $E_r^i \geq 320$ – *Very High potential ecological risk*

1.2.2 Enrichment factor

The enrichment factor (EF) was initially developed to speculate on the origin of elements in the atmosphere, precipitation or seawater [5,6], but it has been progressively extended to the study of soils, lake sediments, peat tailings and other environmental materials [7].

The formula to calculate EF is:

$$EF = \left(\frac{C_i}{C_{ie}} \right)_S / \left(\frac{C_i}{C_{ie}} \right)_{RS} \quad (3)$$

Where C_i is the concentration of element “i” in the sample of interest or the selected reference sample and C_{ie} is content of an immobile element in the sample.

So $\left(\frac{C_i}{C_{ie}} \right)_S$ is the heavy metal to immobile element ratio in the sample of interest, and $\left(\frac{C_i}{C_{ie}} \right)_{RS}$ is the heavy metal to immobile element ratio in the selected reference sample [8].

The selected reference sample is usually an average crust or a local background sample [9-11]. In this work, the heavy metals concentrations of a geographically similar but unaffected plot was used as control and its values expressed as the local reference levels, as done by Pam et al. [12]. Fe was considered as the immobile element [8].

The categories of enrichment are as stated below:

$EF < 2$ – *Depletion of mineral enrichment*
 $2 \leq EF < 5$ – *Moderate enrichment*
 $5 \leq EF < 20$ – *Significant enrichment*
 $20 \leq EF < 40$ – *Very high enrichment*
 $EF > 40$ – *Extremely high enrichment*

1.2.3 Index of geo-accumulation

Index of geo-accumulation (I_{geo}) was originally defined by Muller in 1969, in order to determine the levels of metal contamination in sediments [13], by comparing current concentrations with pre-industrial levels. It is calculated by the following equation (4):

$$I_{geo} = \log_2[C_i/1.5C_{ri}] \quad (4)$$

Where C_i is the measured concentration of the examined metal “i” in the soil and C_{ri} is the geochemical background concentration of the metal “i”. A factor of 1.5 was used to correct possible variations in background values for a given metal in the environment.

The geo-accumulation index I_{geo} as defined by Muller and applied by Buccolieri et al. [14] is classified as follows:

$I_{geo} \leq 0$, Class 0 – *Unpolluted*
 $0 < I_{geo} \leq 1$, Class 1 – *From Unpolluted to Moderately Polluted*
 $1 < I_{geo} \leq 2$, Class 2 – *Moderately Polluted*
 $2 < I_{geo} \leq 3$, Class 3 – *From Moderately Polluted to Strongly Polluted*
 $3 < I_{geo} \leq 4$, Class 4 – *Strongly Polluted*
 $4 < I_{geo} \leq 5$, Class 5 – *From Strongly Polluted to Extrtremely Polluted*
 $I_{geo} > 5$, Class 5 – *Extrtremely Polluted*

1.2.4 The degree of contamination

The degree of contamination was originally defined as the sum of all contamination factors. Equation (5) shows the calculation.

$$C_d = \sum_{i=1}^m C_f^i \quad (5)$$

Where C_f^i is the single index of contamination factor and “m” is the count of the heavy metal species. The following terminologies were used

for the description of the degree of contamination:

$C_d < m$ – low degree of contamination
 $m \leq C_d$
 $< 2m$ – moderate degree of contamination
 $2m \leq C_d$
 $< 4m$ – considerable degree of contamination
 $C_d > 4m$ – very high degree of contamination

[15,16].

1.2.5 The potential Ecological Risk Index (RI)

The potential Ecological Risk Index (RI) was described in the same manner as degree of contamination hence defined as the sum of the risk factors as shown in Equation (6).

$$RI = \sum_{i=1}^m Er^i \quad (6)$$

Where Er^i is the single index of ecological risk factor and “m” is the count of the heavy metal species. The following terminologies were used for the Potential Ecological Risk Index:

$RI < 150$ – low ecological risk
 $150 \leq RI < 300$ – moderate ecological risk
 $300 \leq RI < 600$ – considerate ecological risk
 $RI > 600$ – very high ecological risk

1.2.6 Average of pollution index

An average of pollution index (PI_{Avg}) can be defined using Equation (7).

$$PI_{Avg} = \frac{1}{m} \sum_{i=1}^m P_i \quad (7)$$

Where P_i is the single pollution index of heavy metal “i” and “m” is the count of the heavy metal species. A PI_{Avg} value of > 1.0 indicates low quality soil because of contamination [17].

1.2.7 Nemerow pollution index

A Nemerow Pollution Index ($PI_{Nemerow}$) has been widely applied to assess the quality of soil [18] and is defined by Equation (8):

$$PI_{Nemerow} = \sqrt{\frac{(\frac{1}{m} \sum_{i=1}^m P_i)^2 + P_{i\max}^2}{2}} \quad (8)$$

Where P_i is the single pollution index of heavy metal “i”; $P_{i\max}$ is the maximum value of the single pollution indices of all the heavy metals and “m” is the count of the heavy metal species.

The quality of the soil environment was classified into 5 grades from Nemerow Pollution Index:

$PI_{Nemerow} < 0.7$ – safety domain
 $0.7 \leq PI_{Nemerow} < 1.0$ – precaution domain
 $1.0 \leq PI_{Nemerow} < 2.0$
 – slightly polluted domain
 $2.0 \leq PI_{Nemerow} < 3.0$
 – moderately polluted domain
 $PI_{Nemerow} > 3.0$ – seriously polluted domain

2. MATERIALS AND METHODS

2.1 Sampling

Soil samples were collected using a stainless steel hand auger. The samples were collected from five points (0-30 cm depth) at each soil sampling location (flooded and unflooded) forming a square grid with approximately 25m sides. The soil samples were collected at the centre and the four corners of the square grid.

The soil samples were collected from two different sites in Niger Delta University. One at the back of Niger Delta University library where it was flooded for the duration of the flood and the other opposite the Vice Chancellor’s residence where there was no flood. Twenty soil samples were collected in all. Ten samples from the flooded area and the other ten from the unflooded area. At each sampling point, topsoil was collected from 0-15 cm and bottom soil from 15-30 cm. A Global Positioning System (GPS) was used to record the geographical co-ordinates of the sampling points. The samples were collected into clean polythene bags, stored in ice-chest and transported to the laboratory for analysis.

The sampling grid for the flooded area is within the boundary co-ordinates $04^{\circ} 58' 36.3''$ and $04^{\circ} 58' 36.0''$ north of the equator and between $006^{\circ} 06' 18.3''$ and $006^{\circ} 06' 18.9''$ east of the Greenwich Meridian while the unflooded area was within the boundary co-ordinates of $04^{\circ} 58' 40.3''$ and $04^{\circ} 58' 43.3''$ north of the equator and $006^{\circ} 06' 04.7''$ and: $006^{\circ} 06' 05.9''$ east of the Greenwich Meridian.

2.2 Sample Preparation and Analysis

The soil samples were air dried and homogenized, after removal of unwanted matter (stones, plant materials etc.). The soil was sieved

through a 2 mm sieve and the smaller particle size was used for the various analyses.

2.2.1 Sample digestion

ASTM method D 3974 – 99 was applied in the sample preparation and determination of the heavy metals. 5 g of sieved sample was weighed into a 250 ml beaker and an empty beaker was set up to represent the reagent/glassware blank. In each beaker, 100 ml of distilled water was added, 1.0 ml of concentrated HNO₃ (sp. gr 1.42) and 10 ml of concentrated HCl (sp. gr 1.19) were respectively added. The beakers were covered with ribbed watch glasses and heated at 95°C on a hot plate to avoid splattering during the heating process to ensure that the analyses were as quantitative as possible. The beakers were removed from the hotplate when the remaining solution was between 10 and 15 ml. The contents were allowed to cool to room temperature then each solution was filtered and quantitatively transferred into a 50 ml volumetric flask and diluted to volume with distilled water.

2.2.2 Heavy metals analyses

The Flame Atomic Absorption Spectrophotometer (FAAS), GBC Avanta PM type, was calibrated with prepared working standard solutions from stock solutions (1,000 mg/l Accu Standards Inc, USA) for each of the respective heavy metals to be analyzed. Soil extracts were aspirated into the flame atomizer via the capillary tube attached to the nebulizer unit of the FAAS. Air-acetylene flame was applied, at flow rates of 2 L/min for the fuel and 10 l/min for the oxidant. The instrument settings and conditions were in line with manufacturer's specifications. A prepared working solution of 1 mg/l of each element was introduced after every three samples run to monitor instrument deviation which served as a quality check procedure. Triplicate analysis of each sample was carried out and the mean concentration reported.

Calculation:

The heavy metal concentrations were calculated as percent dry weight samples as shown in equation (9).

$$C = \frac{(Q-S)V}{U} \quad (9)$$

Where: Q = concentration of the element in the digested solution (mg/l)

S = concentration of the trace element found in the blank(mg/l)

V = volume of sample extract (ml)

U = dry weight of the sample (g), and

C = trace element per kilogram of dry sample (mg/kg)

2.2.3 Particle size analysis

51.0 g of air-dried soil was weighed and passed through a 2 mm mesh size sieve, transferred into a "milkshake" mix cup. Fifty millilitres of 5.0% sodium hexametaphosphate along with 100 ml of distilled water was added, mixed using a stirring rod and allowed to stand for 30 minutes. The soil suspension was stirred for 15 minutes and the suspension was transferred from the cup to a glass cylinder. With the hydrometer in the suspension, distilled water was added to the lower blue line so that the volume becomes 1130 ml after which the hydrometer was removed. The top of the cylinder was covered with hand and inverted several times until all the soil went into the suspension. The cylinder was kept on a flat surface and the time was noted. Immediately, the soil hydrometer was placed into the suspension and the first hydrometer reading was taken 40 seconds after the cylinder was put down. The hydrometer was removed and temperature of suspension was measured. The suspension was allowed to stand for 3 hours after which a second hydrometer and thermometer reading were taken. The first reading measures the percentage of silt and clay in suspension while the second reading indicates the percentage of 2 micron (total) clay in suspension.

Calculation:

$$\text{SAND} = 100.0 - [H_1 + 0.2 (T_1 - 68) - 2.0] 2$$

$$\text{CLAY} = [H_2 + 0.2 (T_2 - 68) - 2.0] 2$$

$$\text{SILT} = 100.0 - (\% \text{SAND} + \% \text{CLAY})$$

The results were expressed as the percentages by weight of sand, silt and clay for all soils analyzed.

2.2.4 pH determination

The soil pH was determined in distilled water (1:1 soil to water ratio), with the aid of a Glass-electrode pH meter. Twenty grams of air-dry soil (passed through 2 mm sieve) was weighed into a 50 ml beaker and 20 ml of distilled water added to it. This was allowed to stand for 30 minutes and stirred occasionally with a glass rod. Following this, the electrodes of pH meter were inserted into the partly settled suspension and

the pH measured. The pH meter was calibrated with pH 7.0 and pH 4.0 buffer standards before use.

2.2.5 Determination total organic carbon

Walkley – Black method was used to estimate the amount of organic carbon in the soil samples. 10ml of 1N potassium dichromate was added to a flask containing 1 g of soil and then swirled gently to disperse the soil. 20 ml of concentrated sulfuric acid was added into the flask rapidly using an automatic pipette, the flask swirled more vigorously for one minute and allowed to stand for 30 minutes on a white tile. At the end of this period, 100ml of distilled water was added. About 3-4 drops of indicator (0.025 M ferroin) were added and titrated with 0.5 ferrous sulfate. Percent organic carbon was calculated using the titre values. These values were used to estimate percent organic matter.

2.2.6 Determination of cation exchange capacity

30 ml of 1N ammonium acetate solution was added to 5 gram of soil and shaken for 2 hours. The suspension was centrifuged and the clear supernatant decanted into a 100 ml volumetric flask. 30 ml of 1 N ammonium acetate solution was again added to the residue above and shaken for 30 minutes. The clear supernatant was decanted into the same 100ml volumetric flask. This last step was repeated and clear supernatant transferred into the same volumetric flask. Ammonium acetate was used to make up to the 100 ml mark.

Potassium and sodium ions were determined using flame photometer. Magnesium, calcium and manganese were determined using an atomic absorption spectrophotometer. The results were expressed in meq/100g.

3. RESULTS AND DISCUSSION

The soil in this study was characterized as sandy/clay/loam soil following the particle size analysis, with an average pH of 4.6 in the flooded soils and 6.5 in the unflooded soils. Total Organic Carbon (TOC) ranged from (0.936-1.989)% in the flooded soil and (0.663-0.939)% in the unflooded soil. Cation Exchange Capacity (CEC) was higher in the flooded soil (1.936-3.234) meq/100g, than in the unflooded soil (1.164-1.722) meq/100g. Table 1 below states the descriptive statistics of the heavy metals studied.

The average concentrations of the heavy metals in the topsoil and bottom soil samples for the flooded and unflooded areas are as illustrated in Figs. 1-4.

The levels of heavy metals in the flooded soil were higher than the levels in the unflooded soils except for chromium which 1.52 mg/kg was recorded for unflooded soil as to 1.39 mg/kg in the flooded soil. The highest recorded difference in the unflooded and flooded topsoils was for Pb, which 15.57 mg/kg was recorded for the flooded soil as against 7.67 mg/kg for the unflooded soil.

The difference in Pb between the flooded soil and unflooded soil is even greater in the bottom soil, however, it worthy of note that the high concentration of Pb was contributed mainly from the sample collected at the centre of the grid on the sampling area of flooded (Table 1). The area tends to be shallower than the other points on the grid and thus served as basin during the flood. The recorded value for Pb in flooded bottom soil was 34.23 mg/kg as against the unflooded bottom soil with a value of 6.87 mg/kg (Fig. 2).

Lead is however known to be stable and persistent in soils [19,20] because it is not easily solubilized, especially at pH levels higher than 5.5. The higher concentrations of Pb in the flooded soils as compared to the unflooded soil could be as a consequence of the acidic nature of the flooded soil as compared to the unflooded soil. An average pH of 4.5 was recorded for the flooded soils as against pH of 6.5 recorded for the unflooded soil.

The concentrations of the other metals (Cr, Fe, Ni, Zn and Cu) were as well higher in the flooded bottom soil when compared to the unflooded bottom soil except for Cd that 0.35 mg/kg was recorded the unflooded bottom soil as against 0.31 mg/kg in the flooded bottom soil (Fig. 2). Due to the high mobility of Cd, it is possible that it has been leached beyond the soil depth of this study (30 cm). According to Acosta et al. [21], Cd can be leached outside the soil profile because of its high mobility in soil. Reddy et al. [22], came to a conclusion that as soil pH decreases, the availability and mobility of the metal ions increased due to the chemical forms in which the metals are present in soil solutions, after conducting a study on the solubility and mobility of Cu, Zn and Pb in acidic environments.

The higher acidity of the flooded soil on the other hand could be as a result of the higher TOC values in the flooded soils, which was in the range (0.936-1.989)% as compared to (0.663-0.939)% in the unflooded soil. According to Saint-Laurent et al. [3], this higher TOC could be attributed to organic matter that has been washed down by the flood water. These organic matter contain acidifying compounds (fulvic and humic acids) which could have led to the higher acidity of the flooded soil.

In Fig. 3, it is observed that heavy metals concentrations tend to be higher in the unflooded topsoils than in the unflooded bottom soils except for Cd that a higher value of 0.35 mg/kg was recorded in the bottom soil as compared to 0.24 mg/kg in the topsoil. This observation for Cd corroborates the earlier postulations of the high mobility of Cd.

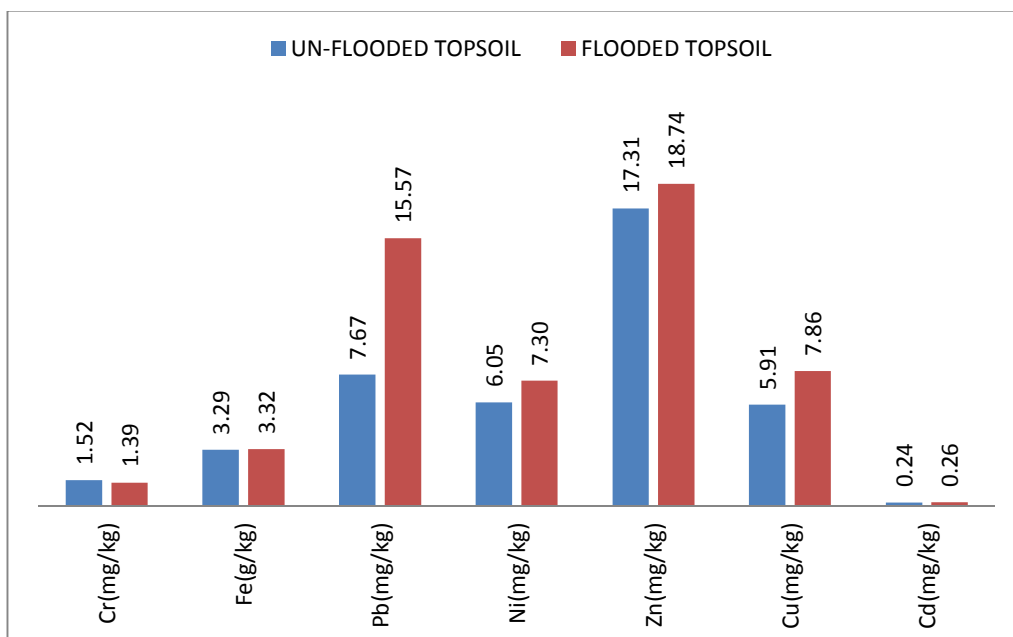


Fig. 1. Average concentrations of heavy metals in unflooded and flooded topsoils

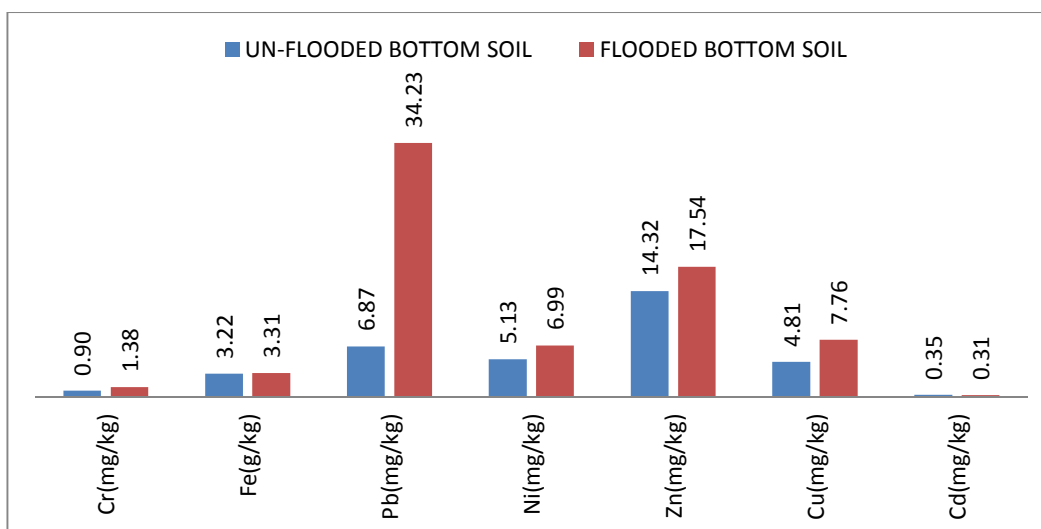


Fig. 2. Average concentrations of heavy metals in unflooded and flooded bottom soils

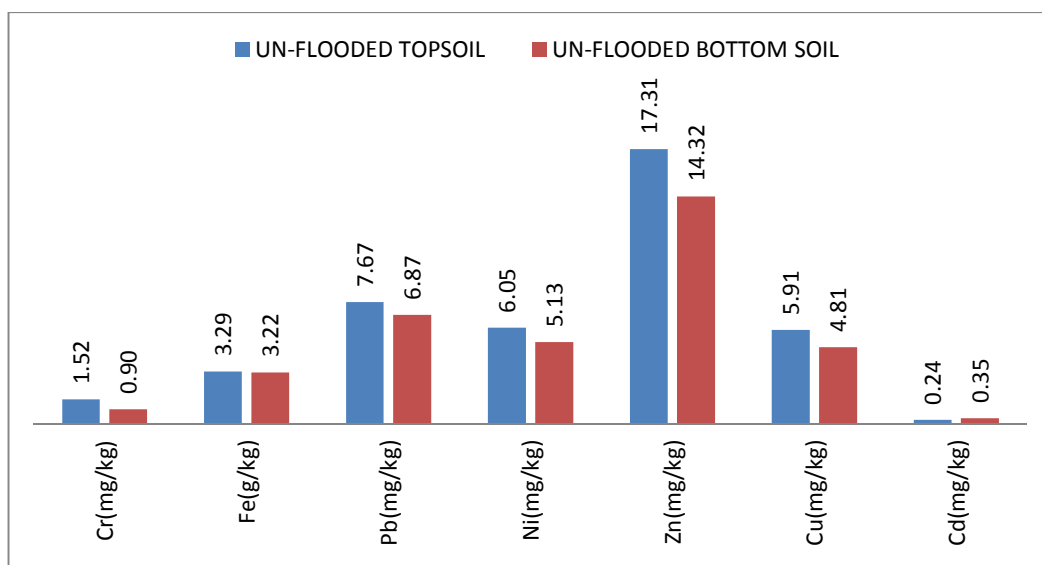


Fig. 3. Average concentrations of heavy metals in unflooded topsoil and unflooded bottom soil

Ordinarily, topsoils tend to have higher concentrations of contaminants, if the soil is undisturbed because deposition of the contaminants from the atmosphere and run-offs get to the topsoil first [23,24].

After the disturbance of the soil by the 2012 flood, there was an alteration of the trend of topsoils having higher concentrations of heavy metals than the bottom soils. The concentration of Pb, for instance became higher in the bottom soil. The difference in the concentrations of the other heavy metals (Cr, Fe, Ni, Zn and Cu) between the topsoil and the bottom soil was not as much as that of Pb, they were slightly higher in the topsoil (Fig. 4). Cadmium still had a higher concentration in the bottom of the flooded soil.

The values of the various concentrations of heavy metals examined so far indicate that the 2012 flood may have led to the increase in heavy metal concentrations in the soils and may have also been responsible for the leaching of the heavy metals to the bottom soil. However, statistically applying students' t-test to test the difference in means of heavy metal concentrations indicated that there was no significant difference between the flooded and unflooded soils and the topsoil and bottom soils for the flooded and unflooded soils at 95% confidence level for most of the of the situations (Table 2). Between the flooded topsoil and the unflooded topsoil, there was no significant difference; however, there was significant difference in levels of Ni, Cu and Zn between the

flooded and unflooded bottom soils. This indicates that the leaching of these metals by the flood was significant. Also between the flooded topsoil and flooded bottom soil, significant differences existed for Cu and Cd, which can be attributed to leaching for Cd, Cu had higher concentration in the topsoil (Fig. 4). For the unflooded topsoil and bottom soil, significant differences were recorded for Cu, Zn and Cd. While Cd concentration was higher in the bottom soil, Cu and Zn concentrations were higher in the topsoil.

Analyzing the outcomes of the evaluations using the pollution indices revealed that majority of the soil samples when evaluated by Muller's Index of Geo-accumulation were classified as unpolluted with heavy metals except for Pb that was classified as "unpolluted to moderately polluted" in the topsoil and moderately polluted in the bottom soil (Table 3). Also, Cu was classified as "unpolluted to moderately polluted" in the bottom soil.

The classification of Pb in the bottom soil as "moderately polluted" calls for concern because of the potential of Pb being leached into the groundwater, considering the fact that Pb is a toxic heavy metal that can cause neurological impairment and malfunctioning of the central nervous system [25-27]. Groundwater is a source of potable water in the study area, though; this study is limited to the soil depth of 30 cm and could not account for the levels of pollution beyond this depth which may possibly be higher.

Table 1. Descriptive statistics of heavy metals in soils (mg/kg)

			Cr	Ni	Cu	Zn	Fe(x10 ³)	Cd	Pb
Flooded soil	Topsoil	SS1T	1.82	6.17	6.69	18.29	3.23 x10 ³	0.23	35.29
		SS2T	0.94	4.56	5.06	20.43	3.24 x10 ³	0.27	9.12
		SS3T	2.35	9.32	9.67	18.2	3.48 x10 ³	0.23	11.21
		SS4T	0.71	8.29	9.22	17.51	3.39 x10 ³	0.23	12.61
		SS5T	1.14	8.14	8.68	19.29	3.28 x10 ³	0.32	9.62
		Range	0.71-2.35	4.56-9.32	5.06-9.67	17.51-20.43	(3.23-3.48) x10 ³	0.23-0.32	9.12-35.29
		Mean	1.39	7.30	7.86	18.74	3.32 x10 ³	0.26	15.57
		Std. Dev.	0.68	1.91	1.94	1.14	0.11 x10 ³	0.04	11.11
	Bottom soil	SS1B	1.41	5.85	6.51	13.73	3.32 x10 ³	0.31	130.35
		SS2B	2.05	6.92	6.97	20.22	3.28 x10 ³	0.24	12.19
		SS3B	1.71	7.65	9.23	15.67	3.39 x10 ³	0.37	11.27
		SS4B	1.25	6.72	7.39	19.16	3.24 x10 ³	0.30	8.43
		SS5B	0.49	7.83	8.72	18.92	3.30 x10 ³	0.34	8.93
			Range	0.49-2.05	5.85-7.83	6.51-9.23	13.73-20.22	(3.24-3.39) x10 ³	0.24-0.37
		Mean	1.38	6.99	7.76	17.54	3.31 x10 ³	0.31	34.23
		Std. Dev.	0.58	0.79	1.16	2.73	0.05 x10 ³	0.05	53.75
Unflooded soil	Topsoil	SS1TC	2.90	6.14	6.87	19.25	3.41 x10 ³	0.28	9.41
		SS2TC	1.89	6.79	6.37	19.22	3.32 x10 ³	0.23	9.32
		SS3TC	2.28	7.10	6.36	17.73	3.27 x10 ³	0.25	8.86
		SS4TC	0.43	4.91	4.83	14.57	3.20 x10 ³	0.23	5.83
		SS5TC	0.12	5.31	5.14	15.78	3.23 x10 ³	0.21	4.91
		Range	0.12-2.90	4.91-7.10	4.83-6.87	14.57-19.25	(3.20-3.41) x10 ³	0.21-0.28	4.91-9.41
		Mean	1.52	6.05	5.91	17.31	3.29 x10 ³	0.24	7.67
		Std. Dev.	1.20	0.94	0.88	2.09	0.08 x10 ³	0.03	2.13
	Bottom soil	Ss1bc	0.23	4.84	5.00	13.39	3.10 x10 ³	0.37	6.61
		SS2BC	1.87	6.14	5.19	14.75	3.39 x10 ³	0.22	7.85
		SS3BC	1.02	5.85	5.27	15.37	3.34 x10 ³	0.38	11.81
		SS4BC	<0.001	4.24	4.32	14.12	3.06 x10 ³	0.37	4.36
		SS5BC	1.36	4.60	4.27	13.95	3.20 x10 ³	0.43	3.73
			Range	<0.001-1.87	4.24-6.14	4.27-5.27	13.39-15.37	(3.06-3.39) x10 ³	0.22-0.43
		Mean	0.90	5.13	4.81	14.32	3.22 x10 ³	0.35	6.87
	Std. Dev.	0.78	0.82	0.48	0.76	0.14 x10 ³	0.08	3.22	

SS-Soil Sample; T-Topsoil; B-Bottom Soil; C-Control

There was moderate contamination by most of the heavy metals analyzed when the Contamination Factor was applied (Table 3). Though, “low contamination” was recorded for Cr in the topsoil while “considerate contamination” was recorded for Pb in the bottom soil. However, the integrated contamination factor for all the heavy metals (Degree of Contamination) as stated in Table 4, revealed that there was

moderate degree of contamination in both the top and the bottom soils. The Average of Pollution Index with respect to Index of Contamination also classified the flooded soils as having “low quality due to contamination” while the Nemerow Pollution Index classified the flooded topsoil as a “precaution domain” and the flooded bottom soil as a “slightly polluted domain”.

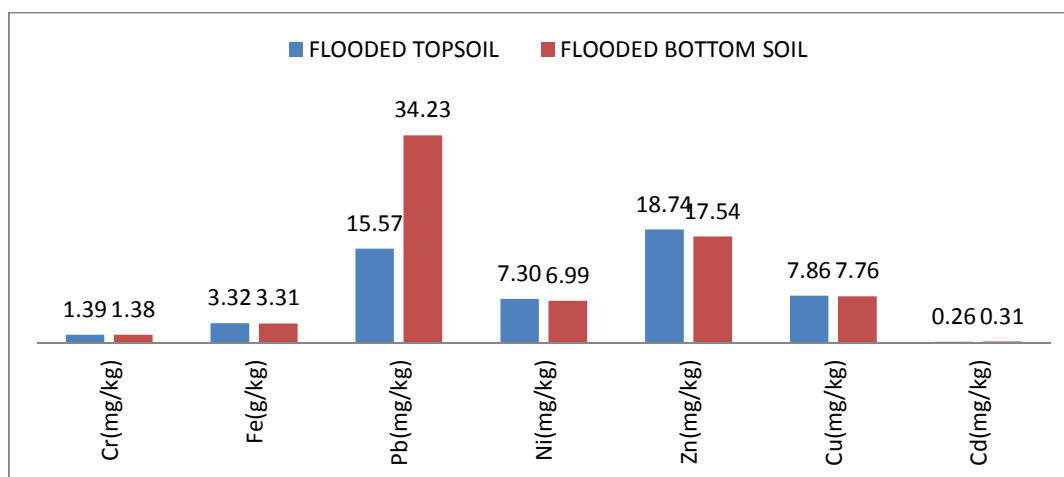


Fig. 4. Average concentrations of heavy metals in flooded topsoil and flooded bottom soil

Table 2. t-test for heavy metals concentrations in the soils at 95% confidence limits

	Heavy metal	Calculated “t”	Remark
Flooded topsoil/unflooded topsoil	Pd	1.56	*
	Cr	0.21	*
	Ni	1.31	*
	Cu	2.05	*
	Zn	1.35	*
	Fe	0.62	*
	Cd	0.75	*
Flooded bottom soil/ unflooded bottom soil	Pd	1.14	*
	Cr	1.12	*
	Ni	3.64	**
	Cu	5.25	**
	Zn	2.55	**
	Fe	1.29	*
	Cd	1.01	*
Flooded topsoil/flooded bottom soil	Pd	1.10	*
	Cr	0.02	*
	Ni	0.33	*
	Cu	2.84	**
	Zn	0.15	*
	Fe	0.44	*
	Cd	2.91	**
Unflooded topsoil/ unflooded bottom soil	Pd	1.68	*
	Cr	0.98	*
	Ni	1.64	*
	Cu	3.42	**
	Zn	7.23	**
	Fe	1.34	*
	Cd	2.48	**

*No Significant Difference; **Significant Difference; Degree of Freedom=8; Critical “t” (2-tailed)=2.31

Table 3. Single pollution indices and levels of pollution

Heavy metal in soil		Contamination factor		Ecological risk factor		Enrichment factor		Index Of Geoaccumulation	
		Value	Terminology	Value	Terminology	Value	Terminology	Value	Terminology
Fe	Top soil	1.01	Moderate contamination	-	Low potential ecological risk	1.00	Depletion of mineral enrichment	-0.57	Unpolluted
	Bottom soil	1.03	Moderate contamination	-		1.00	Depletion of mineral enrichment	-0.55	Unpolluted
Ni	Top soil	1.21	Moderate contamination	6.03	Low potential ecological risk	1.20	Depletion of mineral enrichment	-0.31	Unpolluted
	Bottom soil	1.36	Moderate contamination	6.81		1.15	Depletion of mineral enrichment	-0.14	Unpolluted
Cd	Topsoil	1.07	Moderate contamination	32.00	Low potential ecological risk	1.06	Depletion of mineral enrichment	-0.49	Unpolluted
	Bottom soil	0.89	Moderate contamination	26.57		1.28	Depletion of mineral enrichment	-0.76	Unpolluted
Cr	Topsoil	0.91	Low contamination	1.83	Low potential ecological risk	0.91	Depletion of mineral enrichment	-0.71	Unpolluted
	Bottom soil	1.23	Moderate contamination	2.46		0.90	Depletion of mineral enrichment	-0.28	Unpolluted
Zn	Topsoil	1.08	Moderate contamination	1.08	Low potential ecological risk	1.07	Depletion of mineral enrichment	-0.47	Unpolluted
	Bottom soil	1.22	Moderate contamination	1.22		1.01	Depletion of mineral enrichment	-0.29	Unpolluted
Cu	Topsoil	1.33	Moderate contamination	6.65	Low potential ecological risk	1.32	Depletion of mineral enrichment	-0.17	Unpolluted
	Bottom soil	1.61	Moderate contamination	8.07		1.31	Depletion of mineral enrichment	0.11	Unpolluted to Moderately polluted
Pb	Top soil	2.03	Moderate contamination	10.15	Low potential ecological risk	2.01	Moderate enrichment	0.44	Unpolluted to Moderately polluted
	Bottom soil	4.98	Considerate contamination	24.91		4.44	Moderate enrichment	1.73	Moderately polluted

Table 4. Integrated pollution indices and levels of pollution

	Degree of contamination		Ecological risk index		Average of pollution index(index of contamination)		Average of pollution index(ecological risk factor)		Nemerow pollution index(index of contamination)		Nemerow pollution index(ecological risk factor)	
	Value	Terminology	Value	Terminology	Value	Terminology	Value	Terminology	Value	Terminology	Value	Terminology
Top soil	7.63	Moderate Degree of Contamination	57.74	Low Ecological Risk	1.27	Low Quality Soil due to Contamination	9.62	Low Quality Soil due to Contamination	0.927	Precaution Domain	6.809	Seriously Polluted Domain
Bottom soil	11.30	Moderate Degree of Contamination	70.05	Low Ecological Risk	1.88	Low Quality Soil due to Contamination	11.68	Low Quality Soil due to Contamination	1.351	Slightly Polluted Domain	8.259	Seriously Polluted Domain

The analysis of enrichment factor for the individual metals (Table 3) indicate that there was depletion of heavy metal enrichment for all the heavy metals except for Pb where moderate enrichment was recorded in both the top and bottom soils. In this study, the enrichment factors were calculated by comparing the test soils with an adjacent control site, using the Fe content in the control site, as proposed by Zhang et al. [8] and applied by Likuku et al. [28], as the uncontaminated background concentration.

Ecological Risk Factors were calculated for heavy metals (Pb, Cu, Zn, Cr, Cd and Ni) that their toxic-response factors were available in the literature [29]. Analysis of the ecological risk factor as stated in Table 3, classified all the samples analyzed as having low potential ecological risk with respect to the single, individual heavy metals (Pd, Cu, Zn, Cr, Cd and Ni). The integrated ecological risk index also classified the soils as having a low ecological risk while the Average of Pollution Index and Nemerow pollution Index classified the soils as low quality soil due to contamination and seriously polluted domain, respectively.

The classifications by summative integrated pollution indices (Ecological Risk Index) do not correspond with the classifications by the Average of Pollution Index and the Nemerow pollution Index. While the former classified the soils as having low ecological risk, the latter classified the soils as having low quality due to contamination and seriously polluted.

These pollution indices can be used separately and findings reported separately, but if a choice should be made, the Average of Pollution and the Nemerow Pollution Indices should be chosen for safety purposes. These indices have a more stringent classification as compared to the summative index.

To suffice the above, equation (7) which is the summative of all the EFs of the respective heavy metals is only a part of equation (8). This indicates than equation (8) which is the Average of the Pollution index is an extension/modification of equation (7) and also, the Nemerow Pollution Index is an extension/modification of equation (8) as stated in equation (9).

4. CONCLUSION

This study revealed that the flood of 2012 had an impact on the soil by increasing the levels of the

heavy metals studied. The increase in Pb content was higher when compared to the other metals. The flooded topsoil had higher concentrations of heavy metals than the unflooded soil except for Cr, however, the difference was not statistically significant at 95% confidence limits. There was significant difference in the concentrations of Ni, Cu and Zn between the flooded bottom soil and the unflooded bottom soil which indicates leaching of these heavy metals to a great extent. The same was observed for Cu and Cd in flooded topsoil and flooded bottom soil and also in the unflooded topsoil and bottom soil for Cu, Zn and Cd. Leaching therefore occurred as a consequence of the flood. The leaching of Pb is attributed to the acidic nature of the flooded soil. Furthermore, the acidic nature of the flooded soil is attributed to humic and fulvic acids contributed to the soil by organic matter that must have been carried along and deposited by the flood. Limitation of the soil depth in this study did not reveal the possible leaching of heavy metals beyond 30 cm depth and the potential risk of groundwater contamination.

Of the eight pollution indices applied in the analysis of heavy metal pollution, the Nemerow Pollution Index (an integrated pollution index) had the strictest ranking. It is therefore recommended for the evaluation of soil contamination by heavy metals for safety purposes.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Daily Times. 2012 Flood Disaster, Worst in 40 Years - Red Cross on August 5, 2013 - 7:17pm By Augustine Aminu; 2013. Available:<http://www.dailytimes.com.ng/article/2012-flood-disaster-worst-40-years-red-cross> (Accessed 27th February, 2015).
2. Vanguard. Timeline of recent flood incidents in Nigeria on October 17, 2012 /in News 12:10 am/Comments By Abutu Agada; 2012. Available:<http://www.vanguardngr.com/2012/10/timeline-of-recent-flood-incidents-in-nigeria/> (Accessed 27th February, 2015)
3. Saint-Laurent D, Gervais-Beaulac V, Baril F, Matteau C. Spatial variability of heavy metals in alluvial soils in relation to flood

- risk zones in Southern Quebec, Canada. *Air, Soil and Water Research*. 2013;6:1-13.
4. Håkanson L. An Ecological risk index for aquatic pollution control: A sedimentological approach. *Water Research*. 1980;14:975–1001.
 5. Duce RA, Hoffmann GL, Zoller WH. Atmospheric trace metals at remote Northern and Southern Hemisphere Sites: Pollution or Natural? *Science*. 1975;187: 59–61.
 6. Zoller WH, Gladney ES, Duce RA. Atmospheric concentrations and sources of trace metals at the South Pole. *Science*. 1974;183:198–20.
 7. Reimann C, de Caritat P. Distinguishing between natural and anthropogenic sources for elements in the environment: Regional geochemical surveys versus enrichment factors. *The Science of the Total Environment*. 2005;337:91–107.
 8. Zhang LP, Ye X, Feng H, et al. Heavy metal contamination in Western Xiamen Bay sediments and its vicinity, China. *Marine Pollution Bulletin*. 2007;54:974–982.
 9. Chatterjee M, Silva FEV, Sarkar SK, et al. Distribution and possible source of trace elements in the sediment cores of a tropical Macrotidal Estuary and their ecotoxicological significance. *Environment International*. 2007;33:346–356.
 10. Liu WH, Zhao JZ, Ouyang ZY. Impacts of sewage irrigation on heavy metal distribution and contamination in Beijing, China. *Environment International*. 2005; 31:805–812.
 11. Blaser P, Zimmermann S, Luster J. Critical examination of trace element enrichments and depletions in soils: As, Cr, Cu, Ni, Pb, and Zn in Swiss Forest soils. *The Science of the Total Environment*. 2006;249:257–280.
 12. Pam AA, Sha'Ato R, Offem JO. Evaluation of heavy metals in soils around auto-mechanic workshop clusters in Gboko and Makurdi, Central Nigeria. *J. Environ. Chem. and Ecotoxicology*. 2013;5(11):298-306.
 13. Banat KM, Howari FM, Al-Hamada AA. Heavy metals in urban soils of Central Jordan: Should we worry about their environmental risks? *Environmental Research*. 2005;97:258–273.
 14. Buccolieri A, Buccolieri G, Cardellicchio N. Heavy metals in marine sediments of Taranto Gulf (Ionian Sea, Southern Italy). *Marine Chemistry*. 2006;99:227-235.
 15. Caeiro S, Costa MH, Ramos TB. Assessing heavy metal contamination in Sado Estuary sediment: An index analysis approach. *Ecological Indicators*. 2005;5: 151-169.
 16. Pekey H, Karakaş D, Ayberk S. Ecological risk assessment using trace elements from surface sediments of İzmit Bay (Northeastern Marmara Sea) Turkey. *Marine Pollution Bulletin*. 2004;48:946–953.
 17. Bhattacharya A, Routh J, Jacks G, et al. Environmental assessment of abandoned mine tailings in Adak, Västerbotten District (Northern Sweden). *Applied Geochemistry*. 2006;21:1760–1780.
 18. Cheng JL, Shi Z, Zhu YW. Assessment and mapping of environmental quality in agricultural soils of Zhejiang Province, China. *Journal of Environmental Sciences*. 2007;19:50–54.
 19. Shu WS, Ye ZH, Lan CY, Zhang ZQ, Wong MH. Acidification of lead/zinc mine tailings and its effect on heavy metal mobility. *Environ Int*. 2001;26(5–6):389–94.
 20. Bai J, Xiao R, Cui B, et al. Assessment of heavy metal pollution in wetland soils from the young and old reclaimed regions in the Pearl River Estuary, South China. *Environ Pollut*. 2011;159(3):817–24.
 21. Acosta JA, Cano AF, Arocena JM, Debela F, Martínez-Martínez S. Distribution of metals in soil particle size fractions and its implication to risk assessment of playgrounds in Murcia City (Spain). *Geoderma*. 2009;149(1–2):101–9.
 22. Reddy KJ, Wang L, Gloss SP. Solubility and mobility of copper, zinc and lead in acidic environments. *Plant and Soil*. 1995; 171:53-58.
 23. Yisa J, Jacob JO, Onoyima CC. Assessment of toxic levels of some heavy metals in road deposited sediments in Suleja, Nigeria. *American Journal of Chemistry*. 2012;2(2):34-37.
 24. Gunawardena J, Egodawtta P, Goonetilleke A. Atmospheric deposition as a source of heavy metals in urban storm water. *Atmospheric Environment*. 2013; 68:235-242.
 25. Nadal M, Schuhmacher M, Domingo JL. Metal pollution of soils and vegetation in an area with petrochemical industry. *Sci. Total Environ*. 2004;321:59-69.

26. O'chieng EZ, Lalah JO, Wandiga SO. Analysis of heavy metals in water and surface sediment in five Rift Valley Lakes in Kenya for assessment of recent increase in anthropogenic activities. Bull. Environ. Contam. Toxicol. 2007;79:570-576.
27. An YJ. Assessment of comparative toxicities of lead and copper using plant assay. Chemosphere. 2006;62:1359-1365.
28. Likuku AS, Mmolawa KB, Gaboutloeloe GK. Assessment of heavy metal enrichment and degree of contamination around the copper-nickel mine in the Selebi-Phikwe Region, Eastern Botswana. Environment and Ecology Research. 2013; 1(2):32-40.
29. Qingjie G, Jun D, Yunchuan X, Qingfei W, Liqiang Y. Calculating pollution indices by heavy metals in ecological geochemistry assessment and a case study in parks of Beijing. Journal of China University of Geosciences. 2008;19(3):230-241.

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