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Application of pollution assessment models in soil contaminated by heavy metals in two steel rods markets, Port Harcourt, Rivers State, Nigeria

Edori ES [1,*], Iyama WA [2] and Edori OS [1]

[1] *Department of Chemistry, Ignatius Ajuru University of Education Rumuolumeni, P.M.B. 5047, Port Harcourt, Rivers State, Nigeria.*
[2] *Institute of Geosciences and Environmental Management, Rivers State University, Port Harcourt, Rivers State, Nigeria.*

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Abstract

Soil samples were collected at a depth of 0-30cm within two steel markets and a control site in Port Harcourt, Rivers State Nigeria to assess the level of heavy metals (Fe, Pb, Cu, Cd, Cr, Ni and As) in the environment. Atomic Adsorption Spectrophotometer was used to analyze the samples for heavy metals. The concentrations of all the heavy metals in the steel rods markets exceeded that of the control. The results indicated that heavy metals concentrations in the sites were in the order; Mile III > Kala > RSU. The average levels of contamination of heavy metals recorded followed the order Fe > Cr > Cu > Pb > Ni > As > Cd in Mile III, Fe > Pb > Cu > Cr > Ni > As > Cd in Kala and Fe > Cu > Pb > Cr > Ni > As > Cd in RSU (control). Mean concentrations obtained for heavy metals within the months of investigation were; 1420.931±9.155, 7.753±0.184, 8.730±0.050, 2.843±0.124, 9.428±0.122, 7.433±0.047 and 3.732±0.047 mg/Kg for Fe, Pb, Cu, Cd, Cr, Ni and As respectively at the mile III station, while the mean concentrations of heavy metals observed at the Kala station were; 1161.173±1.823, 9.425±0.054, 7.596±0.027, 1.425±0.020, 6.507±0.006, 5.455±0.033 and 1.901±0.010 mg/Kg for Fe, Pb, Cu, Cd, Cr, Ni and As respectively. The mean values of heavy metals concentrations observed at the RSU station within the period were; 892.064±1.025,5.603±0.007, 5.841±0.051, 0.173±0.005, 3.389±0.009, 2.309±0.010 and 0.706±0.006 mg/Kg for Fe, Pb, Cu, Cd, Cr, Ni and As respectively. Pollution assessment models used for assessing the anthropogenic input on the quality of the soil in the area using the control site as the basis of judgment were: contamination factor (CF), pollution load index (PLI), contamination degree (CD), modified contamination degree (mCD), potential ecological risk coefficient (Eir), potential ecological risk index (RI), Geo-accumulation index (Igeo) and anthropogenicity. These indices revealed that the steel markets were contaminated and polluted and poses ecological risks by heavy metals, even though the values obtained were still below the WHO acceptable limits. The steel rods markets need to be adequately monitored and regulated to avoid further soil contamination by heavy metals to a degree that will be dangerous to human health.

Keywords: Contamination; Heavy metals; Pollution indices; Soil; Steel rods

1. Introduction

The soil is a natural resource of great importance due to its ability to act as reservoir and sink for different contaminants, heavy metals inclusive, which results from deposition from manufacturing activities, urban development and industrialization (Liu *et al*., 2014; El-Sherbiny *et al*., 2019). Soil has the ability to act as buffer by controlling chemical and biological contaminants in the air and water (Lutts & Lefevra, 2015). Rapid urbanization and industrialization have influenced soil ecological system. Activities such as mining, construction, waste disposal, energy production and fuel combustion has led to the deposition of heavy metals in urban environments which has brought about severe soil pollution by heavy metals (Kabata-Pendias, 2010; Taghipour, 2011). The pollution of the soil by heavy metals is of

* Corresponding author: Edori OS
Department of Chemistry, Ignatius Ajuru University of Education Rumuolumeni, P.M.B. 5047, Port Harcourt, Rivers State, Nigeria.

utmost and serious concern to human life because of the detrimental effects it poses on man and other living organisms. The soil is the recipient of great amount of heavy metals and other pollutants on daily basis and have the potential to cause disorder in the soil functional system (Sidhu, 2016).

The contamination of the soil by heavy metals is significant to humans due to their harmful effects, non-degradable nature, accumulative effect and persistence in the environment (Ameh, 2014; Nwankwoala & Ememu, 2019). Heavy metals contamination of the soil can be through, development of mineral resources, automobile works and exhaust pollution sources, industrial works, pesticides, herbicides and fertilizers (Yuhu, 2019). Heavy metals are available at low concentrations in the soil and are regarded as contaminants because they are widespread in occurrence and possesses acute and chronic toxicity at certain level of contamination. Heavy metals are known to be carcinogenic and since it does not readily degrade has the ability to affect the biosphere over a long period (Chopra *et al*., 2009). The human body can be easily enriched with heavy metals in the soil through the food chain to cause disorder. Such damages and disorders include mercury poisoning, mental disorder, impairment of the digestive system, nervous system and hematopoietic system (Kaili *et al*., 2018; Yuhu, 2019). Unlike organic pollutants, heavy metals cannot be degraded naturally and can cause alteration in the microbial content of the soil due to its accumulative effects (Smejkalova *et al*., 2003; Lenart-Boron & Wolny-Koladka, 2015).

Heavy metals at high concentrations in the soil cause metabolic activities such as SOD and CAT in plants to be retarded or inhibited and thereby resulting in the decrease of the sensory quality and disorder of metabolic processes in plants (Luning, 2018). Pollution occasioned by heavy metals occur majorly in smelting, electroplating, chemical and mining industries. The level and types of heavy metals differ from region to region (Zhe & Luyu, 2018; Lei, 2018).

Certain geochemical approaches and pollution indices which are useful tools in ecological risk assessment have the ability to interpret the impact of heavy metals on soil ecology and understanding contamination possibilities of the soil, help in providing details about the pollution degree and quality of the soil. These pollution indices include, contamination factor or index (CF), pollution load index (PLI), modified contamination degree (mCD), geo-accumulation index (Igeo), potential ecological risk coefficient (Ei,) ecological risk index (RI), Nemerow integrated pollution index (NIPI) and anthropogenicity (APn%). These pollution assessment models give information on the intensity of anthropogenic input on the contamination of the soil (Mugosa *et al.*, 2016; Nwankwoala & Ememu, 2018).

The significance of metal pollution in the soil of urban settlement has not always been put into consideration. The sudden rise in steel markets over the city of Port Harcourt, Rivers State, Nigeria due to the high demand for steel rods and pipes and other metallic materials for building, road construction and other related works has led to the increase of metals in the soils of the city thereby leading to increased contamination of the soil by heavy metals in the city and its environs. The contamination of the soil by heavy metals can lead to the contamination of the water bodies that abound in the city of Port Harcourt and the air of the city. This research therefore focused on the concentration of certain metals (Fe, Pb, Cu, Cd, Cr, Ni and As) in the soil samples of two iron rods and steel metals markets in Port Harcourt, ecological risks and pollution indices associated with anthropogenic input.

2. Material and methods

2.1. Collection of Soil Samples

Soil samples were collected at random from two iron rods and steel markets (Mile III and Kala) and a control site [Rivers State University (RSU)] in Port Harcourt at a depth of 0-30cm with the aid of soil auger. The samples were collected at three different points as sampling site or location and then properly mixed together to form a composite sample. Soils samples were collected in January, March and May of 2020. After each sampling, the auger was thoroughly washed in water and dried in order that the samples from one location do not influence that of another location. Polythene bags that were already labelled were used in preserving the samples before being transported to the laboratory for treatment and digestion before analysis of the concentrations of heavy metals in the soil samples.

2.2. Sample Pretreatment and Soil Digestion

The samples were dried overnight in an oven at a temperature of 105^{o}C to remove moisture. The dried samples were mechanically sieved in a 0.5mm mesh and ground to about 0.063mm size after being homogenized (Madrid *et al*., 2002; El-Sherbiny *et al*., 2019). The pulverized soil was then weighed (1.00g±0.01) for accuracy and then digested using nitric acid and perchloric acid (HNO_3/$HClO_4$) mixture in the ratio 4:1 in a beaker. The digested samples were heated at a temperature of 40 ^{o}C for an hour interval and was then increased to 140-170 ^{o}C for a period of 4 hours, until a clear solution was observed. The solution was then filtered and diluted to 50ml by addition of deionized water.

2.3. Determination of Heavy Metals

Atomic Absorption Spetrophotometer Model SG71906 was used to determine the concentrations of heavy metals in the soil samples from the steel rod markets (APHA-AWWA-WPCF, 1985). The sample was directly aspirated into a nitrous oxide/acetylene flame under the generation of a cathode lamp at a wavelength specified for the metal to be analyzed. For each metal studied, before the aspiration of any sample, calibration curves were already obtained for blank samples and standards prepared for each metal under investigation. The system monitor displayed the concentrations of every metal at specific absorbance. The concentrations of the metals were measured in mg/Kg of soil sample at a detection limit of <0.001mg/Kg. The heavy metals analyzed were Fe, Pb, Cu, Cd, Cr, Ni and As.

2.4. Pollution Assessment Indices

These are pollution indices which indicate the level of pollution and its intensity due to anthropogenic influence on the soil. The assessment indices used in this research are; contamination index or factor (CF), pollution load index (PLI), degree of contamination (CD), modified contamination degree (mCD), geo-accumulation index (Igeo), enrichment factor (EF), potential ecological risk coefficient (E^i_r), potential toxicity response (RI) and anthropogenicity (APn %).

2.5. Contamination Factor (CF)

This index was calculated using the equation of Lacatusu, (2000). The contamination index is expressed as,

$$CF = \frac{Cn}{Bn}$$

Where; Cn = concentration of the metal and Bn = the background value (concentration) measured from the control site.

2.6. Pollution Load Index (PLI)

This is the general assessment on the level of contamination of the soil by heavy metals. The mathematical expression of Tomlinson *et al.,* (1980) was applied in the calculation thus:

$PLI = [CF_1 \times CF_2 \times CF_3 \times \ldots\ldots\ldots\ldots\ldots\ldots\ldots \times CF_n]^{1/n}$

Where, CF = accumulation factor and n = number of metals.

2.7. Degree of Contamination (CD)

The mathematical expression adopted by Hakanson (1980) was used. The formula is given as

$$CD = \sum_{i=1}^{n} \mathrm{CFi}$$

Where, CD = contamination degree and CF = contamination factor, n = number of heavy metals studied.

Contamination degree is the assessment method that sum up of all the contamination factors of the heavy metals studied. It is the sum of all the heavy metals investigated in the environment studied.

2.8. Modified Contamination Degree (mCD)

This index assesses the total degree of contamination by heavy metal pollution in the area investigated. Hakanson (1980) defined mCD as:

$$mCD = \sum_{i=1}^{n} \frac{CFi}{n}$$

Where CF = contamination factor, n = number of metals analyzed and I = i^{th} metal.

2.9. Geo-accumulation Index (Igeo)

This index compares contamination of the concentration of heavy metals at present and original concentration before any industrial activities took place in the soils under investigation. The computation method adopted by Muller (1981) was used.

$$Igeo = \log_2 [(Cn)/ (1.5Bn)]$$

Where;

Cn = concentration of metal measured, Bn = background value of metal measured from control site, 1.5 = constant that minimized the variation effect on the background concentration due to lithologic processes.

2.10. Potential Ecological Risk Coefficient (E^i_r)

This index was calculated using the formula of Hakanson (1980), and it is expressed mathematically as,

$$E^i_r = T^i_r \text{ x } C^i_r = T^i_r \text{ x } C^i_s / C^i_n$$

Where;

T^i_r = metal toxic response factor, C^i_r = contamination factor, C^i_s = concentration of heavy metals in the soil and C^i_n = background concentration for heavy metals. The response factors for the heavy metals studied are Pb =5, Cu = 5, Cd = 30, Cr = 2, Ni = 5 and As = 10.

2.11. Potential Ecological Risk Index (RI)

This index is calculated using the relation

$$RI = \Sigma E^i_r$$

It is used to calculate the sum of different risk factors and in evaluating the toxic levels of different heavy metals in the soil.

2.12. Enrichment Factor

The formula that expresses this index is mathematically represented as,

$$EF = \frac{\left(\frac{Cn}{Cref}\right) sample}{\frac{Bn}{Bref}}$$

Where,

C_n (sample) = studied element's concentration, C_{ref} = concentration of the referenced element studied in the environment, B_n = reference element background value and B_{ref} = value of the background reference element in the environment referenced in shale's average (Turekian & Wedepohl, 1961).

This index evaluates the geochemical developments among regions and predicts the possible source and origin of the spread of heavy metals in the environment (Pekey, 2006).

2.13. Anthropogenicity (APn %)

This index measured the direct anthropogenic input on the metal level in percentages. The formula used is expressed as,

$$APn\% = [\mu/Bn] \text{ x } 100$$

Where, μ is the measured concentration and Bn is the background value.

The world average values of heavy metals in shale measured in mg/Kg was used as the background value for calculating the anthropogenicity (Edori & Kpee , 2017). The world average values of heavy metals are Fe = 4700, Pb = 85, 45, Cd = 0.3, Cr = 90, Ni = 68 and as = 13.

3. Results and discussion

3.1. Heavy Metal Concentrations in the Steel Rods Markets

The results for the contamination levels of heavy metals in the soil samples from the two steel rods markets and the control station are shown in Tables 1-3, while the mean concentrations of the heavy metals within the months of study are shown in Table 4. The average level of contamination of heavy metals in the soil from Mile III steel rods market were Fe; 1420.931±9.155 mg/Kg, Pb; 7.753±0.184 mg/Kg, Cu; 8.730±0.050 mg/Kg, Cd; 2.843±0.124 mg/Kg, Cr; 9.428±0.122 mg/Kg, Ni; 7.433±0.047 mg/Kg, and As; 3.732±0.047 mg/Kg. In Kala steel rods market, the average concentrations of the heavy metals were; Fe; 1161.173±1.833 mg/Kg, Pb; 9.425±0.057 mg/Kg, Cu; 7.596±0.027 mg/Kg, Cd; 1.425±0.020 mg/Kg, Cr; 6.507±0.006 mg/Kg, Ni; 5.455±0.033 mg/Kg, and As; 1.901±0.010 mg/Kg. In RSU (control station), average concentrations of heavy metals were; Fe; 892.064±1.025 mg/Kg, Pb; 5.603±0.007 mg/Kg, Cu; 5.841±0.051 mg/Kg, Cd; 0.173±0.005 mg/Kg, Cr; 3.389±0.009 mg/Kg, Ni; 2.309±0.010 mg/Kg, and As; 0. 706±0.006 mg/Kg.

The results indicated that the average contamination by heavy metals in the steel rods markets were in the order, Fe > Cr > Cu > Pb > Ni > As > Cd in Mile III, Fe > Pb > Cu > Cr > Ni > As > Cd in Kala and Fe > Cu > Pb > Cr > Ni > As > Cd in RSU (control). The results also indicated that degree of concentrations of all the heavy metals were in the order Mile III > Kala > RSU**.** The fact that the level of heavy metals was more in Mile III may be due to the number of years the market has existed before that of Kala came into place and secondly, it may be due to proximity to drainage. The Kala steel rods market has a better drainage system than that of Mile III. The results also showed that the concentrations of heavy metals within the steel rods markets were below the limit set by World Health Organization (WHO) (1998) except that of cadmium and arsenic. The observation made from the results indicated that the concentration of heavy metals in the control site (RSU) was lower than that of Mile III and Kala. This is an indication that the high level of contamination was due to anthropogenic influence and inputs. The results also showed that the concentration of the studied heavy metals in the sites were still within limits of safety for human health as proposed by Directorate of petroleum Resources (DPR) (1991) and WHO (1998) except for cadmium and arsenic which were slightly above the acceptable limits in the studied area.

Table 1 Concentrations (mg/Kg) of Heavy Metals in Steel Rods Markets' Soil in the Month of January

Sample Area	**Heavy Metals**						
	Fe	**Pb**	**Cu**	**Cd**	**Cr**	**Ni**	**Ar**
Mile III	1421.031	7.650	8.689	2. 716	9.408	7.403	3.694
Kala	1163.001	9.411	7.589	1.440	6.513	5.434	1.903
RSU (control)	892.389	5.612	5.842	0.171	3.389	2.312	0. 710

Table 2 Concentrations (mg/Kg) of Heavy Metals in Steel Rods Markets' Soil in the Month of March

Sample Area	**Heavy Metals**						
	Fe	**Pb**	**Cu**	**Cd**	**Cr**	**Ni**	**Ar**
Mile III	1432.003	8.012	8. 701	2.802	9.586	7.397	3.712
Kala	1161.832	9.363	7.567	1.397	6.499	5.502	1.887
RSU (control)	893.126	5.596	5. 779	0.180	3.378	2.296	0.698

Table 3 Concentrations (mg/Kg) of Heavy Metals in the Steel Rods Markets' Soil in the Month of May

Sample Area	Heavy Metals						
	Fe	Pb	Cu	Cd	Cr	Ni	Ar
Mile III	1409.758	7.598	8.801	3.011	9.289	7.500	3.801
Kala	1158.685	9.501	7.632	1.438	6.508	5.429	1.912
RSU (control)	890.678	5.601	5.903	0.169	3.401	2.320	0. 711

Table 4 Average Concentrations (mg/Kg) of Heavy Metals in Steel Rods Markets in the Sampled Months

Sample Area	Heavy Metals						
	Fe	Pb	Cu	Cd	Cr	Ni	Ar
Mile III	1420.931±9.155	7.753±0.184	8.730±0.050	2.843±0.124	9.428±0.122	7.433±0.047	3.732±0.047
Kala	1161.173±1.823	9.425±0.054	7.596±0.027	1.425±0.020	6.507±0.006	5.455±0.033	1.901±0.010
RSU (control)	892.064±1.025	5.603±0.007	5.841±0.051	0.173±0.005	3.389±0.009	2.309±0.010	0.706±0.006
WHO (1998)	38000	10	30	0.5	100	40	0.5

3.2. Pollution Assessment Indices and Models

3.2.1. Contamination Factor (CF)

The results for the contamination factor or index in the sites studied are shown in Table 5. The results revealed that in Mile III, Fe; 1.593, Pb; 1.384, Cu; 1.495, Cd; 16.434, Cr; 2. 782, Ni; 3.219 and As; 5.286 while in Kala, Fe; 1.302, Pb; 1.682, Cu; 1.300, Cd; 8.237, Cr; 1.920, Ni; 2.362 and As; 2.693. The intervals of contamination used by Hakanson (1980) and adopted by El-Sherbiny et al., (2019) were CF < 1 = low level of contamination, 1< CF < 3 = moderate level of contamination, 3 < CF < 6 = considerable level of contamination and CF > 6 = high level of contamination. Considering the contamination factor classification, the soil from the steel rods market in Mile III was moderately contaminated by Fe, Pb, Cu and Cr, considerably contaminated by Ni and As and very high level of contamination by Cd, while in Kala, Fe, Pb, Cu, Cr, Ni and As were all at moderate level of contamination, but Cd was at high degree of contamination. The contamination factor results indicated that the soil quality of the area investigated has been compromised and deteriorated when compared to the control site. The steel rods markets have affected the contamination level of heavy metals in the study area as in the case of Nwankwoala and Ememu (2018) in the soils of Okpoko near filling stations in Eastern Nigeria and that of El-Sherbiny et al., (2019) within a cement industry in Saudi Arabia.

Table 5 Contamination Factor (CF) of Heavy Metals in the Soil Samples from the Steel Rods Markets

Heavy metals	Sample Area	
	Mile III	Kala
Fe	1.593	1.302
Pb	1.384	1.682
Cu	1.495	1.300
Cd	16.434	8.237
Cr	2.782	1.920
Ni	3.219	2.362
As	5.286	2.693

3.3. Pollution Load Index (PLI), Contamination Degree (CD) and Modified Contamination Degree (mCD)

The results for the pollution load index, (PLI), contamination degree (CD) and modified contamination degree (mCD) are shown in Table 6. The pollution load index intervals of interpretation by Tomilson *et al*., (1980) showed that > 0 PLI ≤ 1, is not polluted to moderate pollution, >1 PLI ≤ 2 is moderate pollution, > 2 ≤ 3 is between moderate pollution to high pollution, > 3 ≤ 4 is high degree of pollution and ≤ 5 is very Kala respectively. From the pollution load index interval of interpretation, it showed that there was high degree of pollution of heavy metals in Mile III steel rods market while that of Kala was between moderate pollution to high pollution. The PLI values obtained in this Work were higher or in the same range with that of El-Sherbiny *et al*., (2019) in a cement factory and lower or within the same range when compared to that of Nwakwoala and Ememu (2018) in Okpoko soils close to filling stations. The high degree of pollution as indicated by the PLI values led to the deterioration of the soil quality within the studied area as observed by Tomilson *et al*., (1980) and corroborated by El-Sherbiny *et al*., (2019). This observation brings to the understanding that the soil within the steel rod markets has been polluted by heavy metals. This observation is similar to the observations reported earlier in other works (Cabrera *et al*., 1999; Odewande & Abimbola, 2008).

The contamination degree observed in the study were 32.193 and 19.493 for Mile III and Kala steel rods markets respectively. Classification of Contamination degree intervals are CD < 8, low contamination degree, 8 ≤ CD ≤ 16, moderate contamination degree, 16 ≤ CD ≤ 32, considerable contamination degree and Cd > 32, is very high degree of contamination. The results therefore indicated that the soil from Mile III steel rods market has very high degree of contamination by heavy metals while the soil of Kala steel rods market has considerable contamination degree by heavy metals.

The modified contamination degree (mCD) calculated from the study were 4.599 and 2.785 for Mile III and Kala respectively. The classification for modified contamination degree (mCD) as suggested by Hakanson (1980) and applied by Nwankwoala and Ememu (2018) were < 1.5; very low contamination level, ≤ 1.5 mCD < 2; low contamination level, ≤ 2 mCD < 4; moderate contamination level, ≤ 4 mCD < 8 high contamination level, ≤ 8 mCD < 16, very high contamination level, ≤ 16 mCD < 32 extreme contamination of high degree and ≥ 32, ultrahigh contamination level. The recorded values from the steel rods markets revealed that Mile III steel rods market had very high level of contamination while the Kala steel market had moderate level of contamination.

Table 6 Pollution Index (PLI), Contamination Degree (CD) and Modified Contamination Degree (mCD) of Soil Samples in the Steel Rods Markets

Assessment Index	**Sample Area**	
	Mile III	**Kala**
PLI	3.069	2.244
CD	32.193	19.496
mCD	4.599	2.785

3.4. Potential Ecological Risk Coefficient (E^i_r) and Potential Ecological Risk Index (RI)

The results for E^i_r and RI are shown in Table 7. The results obtained in the steel markets for E^i_r for the heavy metals were in the order Cd > As > Ni > Cu > Pb > Cr for Mile III and Cd > As > Ni > Pb > Cu > Cr For Kala. The potential ecological risk coefficient values of 493.02 and 247.11 was recorded for Cd in Mile III and Kala then 52.86 and 26.93 was recorded for As in Mile III and Kala respectively. The least value obtained for E^i_r was 5.562 and 3.840 for Cr in Mile III and Kala respectively. The categories used in interpreting potential ecological risk coefficient are; $E^i_r < 40$; low risk, $40 \leq E^i_r < 80$; moderate risk, $80 \leq E^i_r < 160$; considerate risk, $160 \leq E^i_r < 320$; high risk and $E^i_r \leq 320$; very high risk. The potential ecological risk coefficient values obtained for all the heavy metals studied in the steel rods markets were lower than 40 except cadmium in both stations and As in Mile III market. The results therefore indicated that Fe, Pb, Cu, Cr and Ni in Mile III were at low ecological risk and also Fe, Pb, Cu, Cr, Ni and As in Kala were at low ecological risk while As in Mile III was at moderate ecological risk and, Cd in Mile III was at very high ecological risk while in Kala Cd was at high ecological risk.

The terms of classification used for potential ecological risk index are RI < 150; low ecological risk, 150 ≤ RI < 300; moderate ecological risk, 300 ≤ RI < 600; considerate ecological risk and RI > 600; very high ecological risk. The values obtained from the results were 581.947 and 304.60 for Mile III and Kala steel rods markets respectively. The results therefore indicated that both markets under considerable ecological risk.

Table 7 Potential Ecological Risk Coefficient (Eir) and Potential Ecological Risk (RI) of Heavy Metals in the Soil Samples of the Steel Rods Markets

Heavy Metals	Sample Area	
	Mile III	Kala
Fe	NA	NA
Pb	6.92	8.41
Cu	7.49	6.5
Cd	493.02	24.11
Cr	5.562	3.84
Ni	16.095	11.81
As	52.86	26.93
RI	581.947	304.60

3.5. Geo-accumulation Index (Igeo)

Table 8 showed the results calculated for the geo-accumulation index of heavy metals in the steel rods markets. The results for geo-accumulation index obtained for the different metals studied in the steel rods markets were Fe; 0.320, Pb; 0.558, Ni; 0.646 and As; 1.061 for Mile III while Fe; 0.261, Pb; 0.338, Cu; 0.261, Cd; 1.653, Cr; 0.385, Ni; 0.474 and As; 0.540 were recorded for Kala. The interval of interpretation used in classifying geo-accumulation index adopted by Odewande and Abimbola (2008) and used in this work is Igeo < 0, not contaminated, 0 < Igeo < 1, not contaminated to moderate contamination, 1 < Igeo , 2, moderate contamination, 2 < Igeo < 3, moderate to strong contamination, 3 < Igeo < 4, strong contamination, 4 < Igeo < 5, strong to extreme contamination and Igeo > 5, extreme contamination. The results from the steel rods markets indicated that Fe, Pb, Cu, Cr, and Ni in Mile III and Fe, Pb, Cu, Cr, Ni and As in Kala were all greater than zero but less than one, therefore these metals lie in the range of not contaminated to moderate contamination while Cd in mile III was in the range of moderate contamination to strong contamination and As in Mile III and Cd in Kala were in the range of moderate contamination. The geo-accumulation of heavy metals will continue to be on the rise in the soils within the steel rod markets due to the increases demand for building and construction materials. The markets continue to expand due to increase in anthropogenic activities and high demand for steel materials.

Table 8 Geo Accumulation Index (Igeo) of Heavy Metals in the Soil Samples of the Steel Rods Markets

Heavy metals	Sample Area	
	Mile III	Kala
Fe	0.320	0.261
Pb	0.278	0.338
Cu	0.300	0.261
Cd	3.298	1.653
Cr	0.558	0.385
Ni	0.646	0.474
As	1.061	0.540

3.6. Enrichment Factor (EF)

Table 9 showed the enrichment factor for the Mile III and Kala steel rods markets. The enrichment factor categories of interpretations are as follows; EF < 2; minimal enrichment, 2 ≤ EF < 5; moderate enrichment, 5 ≤ EF < 20; significant enrichment, 20 ≤ EF < 40; very high enrichment and EF > 40; extremely high enrichment. The results indicated that Pb, Cr and Ni in both locations were within the range of 2 ≤ EF < 5 and therefore were under the category of moderate enrichment. The results also revealed that Cu and As were in the category $5 \leq EF < 20$, which showed that they are under significant enrichment while Cd in the result was far above the category $EF > 40$, which means that it was under the category of extremely high enrichment.

Table 9 Enrichment Factor (EF) of Heavy Metals in the Soil Samples of the Steel Rods Markets

Heavy metals	Sample Area	
	Mile III	**Kala**
Fe	NA	NA
Pb	3.017	4.488
Cu	6.417	6.832
Cd	313.664	192.262
Cr	3.465	2.926
Ni	3.616	3.247
As	9.496	5.919

3.7. Anthropogenicity (APn %)

Table 10 showed the anthropogenicity of heavy metals in the soil samples of the steel rods markets. In decreasing order of anthropogenic influence, the results showed the order of magnitude as Cd > Pb > Cu > Ni > Fe > Cr > As. The values obtained in percentages revealed that Cd was the most influenced followed by Pb in the steel rods markets. The results agreed with Nwankwoala and Ememu (2018), in a study conducted close to filling stations. The rate of anthropogenic input on the environments of the steel rods markets need to be regulated so that there will be a reduction in the percentage input or influence of the heavy metals in the soils due to human activities. Although anthropogenic input was observed in the control, which was due to some human activities outside steel markets, it was relatively small compared to that of the Mile III and kala steel rods markets. The anthropogenicity of the heavy metals were in the sites were in the order Mile III > Kala > RSU except Pb that was in the order Kala > Mile III > RSU.

Table 10 Anthropogenicity of Heavy Metals in the Soil Samples of the Steel Rods Markets

Heavy Metals	Sample Area		
	Mile III	**Kala**	**RSU**
Fe	3.01	2.46	1.89
Pb	38.77	47.13	28.02
Cu	19.40	16.88	12.98
Cd	947.67	475.00	57.6
Cr	0.105	0.072	0.038
Ni	10.93	8.02	3.40
As	0.287	0.146	0.054

4. Conclusion

The level of heavy metals (Fe, Pb, Cu, Cr, Cd, Ni, and As), in the soils from the two steel markets in Port Harcourt, Rivers State, Nigeria showed that the soil has been contaminated and polluted by heavy metals as compared to the control site. The high concentrations noted were primarily due to the steel rods markets operations in the area. The different pollution index models used to assess the level of contamination of the soils of the steel rods markets such as CF, PLI, Cd, mCD, Igeo, APn%, $\mathbf{E}^i{}_r$, RI, and EF indicated that the soil has been contaminated, polluted, at a risk or enriched by heavy metals. The level of contamination due to high concentration of heavy metals in the two steel rods markets should be of utmost concern to relevant agencies of government and the general public. There is therefore the need to put in place adequate measures that can result in the reduction of anthropogenic activities that bring about the increase in concentrations of heavy metals within the steel rods markets in order to reduce the intake of these heavy metals by man, animals and plants, because of the hazardous nature of heavy metals and its possible health effects on humans.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest exists among the authors.

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