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ASSESSMENT AND MODELING OF HEAVY METAL POLLUTION OF SOIL WITHIN RECLAIMED AUTO REPAIR WORKSHOPS IN ORJI, IMO STATE NIGERIA

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Abstract. The presence and concentrations of toxic heavy metals within a reclaimed section of the Orji mechanic village in Imo State Nigeria were determined using energy dispersive X-ray fluorescence and atomic absorption spectrophotometry. Multivariate and geostatistical models like contamination factor, degree of contamination, pollution load index and index of geo-accumulation were used to analyze the data obtained. Preliminary soil analysis showed the relative abundance of the heavy metals in the order Cd< Cr< As< Co< Mn< Ni< Cu< Pb< Zn< Fe. The observed concentration ranges of these metals at the different sampling points were between 0-44 mg/kg (Ni), 50-363 mg/kg (Pb), 1-25 mg/kg (Cd), 55-102 mg/kg (Cr), 0-35 mg/kg (As), 19-54 mg/kg (Mn), 11-35 mg/kg (Co), 9-203 mg/kg (Zn), 2-90 mg/kg (Cu) and 3654-5134 mg/kg (Fe). The degree of contamination model indicated that the area was highly contaminated by cadmium and arsenic. The index of geo-accumulation model showed that the soil was strongly contaminated by lead, and extremely contaminated by cadmium at some of the sampling points. The activities at the mechanic village in this area significantly affected the accumulation of these heavy metals and immediate soil remediation has been recommended.

Keywords: mechanic village, heavy metal, degree of contamination, index of geo-accumulation.

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Introduction

The increase in human population has been followed directly with increase in the means of transporting people from one point to another. Vehicular transport is the most common system for this purpose in urban areas. The increase in the number of motor vehicles has created employment for auto mechanic artisans who maintain and service them. Due to the large number of vehicles to be worked on daily and need for space to keep them, sections of land called mechanic villages are mapped out by the government of some countries like Nigeria for auto repair activities to prevent unnecessary traffic congestion within the townships.

Many environmentally unfriendly chemical compounds like polycyclic aromatic hydrocarbons, polychlorinated biphenyls, polybrominated diphenyl ethers, petroleum hydrocarbons and heavy metals have entered and polluted the soil and water through many sources [1-8]. The activities at mechanic villages are one of the means by which these toxic pollutants are introduced into the water and soil [9,10]. Researchers have reported high levels of toxic heavy metals in the soil within these mechanic villages [11,12].

Monitoring of heavy metal levels in the soil is of great concern because of their toxicity and ease of leaching into surface and groundwater. In Nigeria, the levels of heavy metals in the soil within auto mechanic workshops have gained research attention in recent times. Pam, A.A. *et al.* evaluated the levels of heavy metals in soils around auto mechanic clusters in Gboko and Makurdi, in central Nigeria [13]. Their results showed that the soil in this area was highly polluted with lead, copper and nickel. Oti, W.J.O. studied toxic metals present in the soil at a mechanic village in Abakaliki Nigeria [14]. He reported that the land area was polluted by nickel, lead, cadmium and arsenic. Heavy metal load in four auto mechanic villages in Abeokuta Nigeria, were studied by Majolagbe, A.O. *et al.* [15]. They reported that lead, copper and cadmium polluted all the sites studied.

In July 2016, a section of the Orji mechanic village was reclaimed by the Imo State Government after more than 30 years of occupation by auto mechanics and scrape metal dealers. Recently, residential buildings have started springing up within this reclaimed area. There are no reports on the level of contamination of the soil in this section of the mechanic village by toxic heavy metals before these activities commenced. Therefore, in this study, the concentrations of toxic heavy metals in this area were assessed, and modeled their contamination and pollution levels.

Experimental

Study area

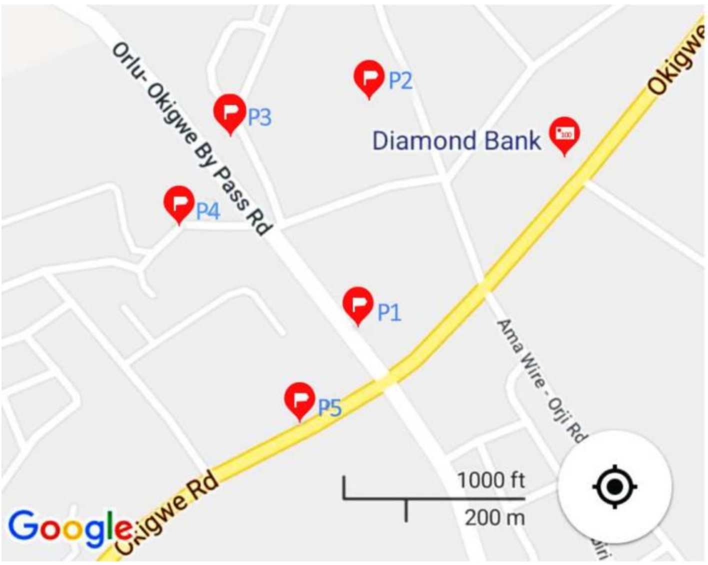
The Orji mechanic village is sited in Owerri North Local Government Area of Imo State. It was set up in 1987 with an area of 0.41 km^2 located in the sandy Benin Formation. Geographically, the area falls between longitude 7^o 3' 50" and latitude 5^o 31' 39". The geology of the area consists of plain soil with particle size ranging between 0.05–2.0 mm, thereby giving the area good drainage. Before the land section in this area was reclaimed, four major groups of artisans namely mechanics, welders, auto electricians and panel beaters operated here. Sections of the study area with buildings under construction are shown in Figure 1.

Sample collection

The sampling design was such that the sampling points were well spread over the study area. Soil samples were collected in July 2018 at five different points marked P1-P5 (Figure 2).

The ground positions of the sampling points were referenced with Garmin GPSMAP 76, a handheld global positioning system (GPS) unit, and are shown in Figure 2.

Figure 1. On-going projects at the reclaimed area.



P1 - ***N 5° 30.9183', E 7° 2.6596'***
P2 - ***N 5° 31.1236', E 7° 2.6597'***
P3 - ***N 5° 31.8900', E 7° 2.5523'***
P4 - ***N 5° 30.9992', E 7° 2.4213'***
P5 - ***N 5° 30.8349', E 7° 2.6216'***

Figure 2. Map of Orji mechanic village showing sampling points and their coordinates.

Preliminary soil analysis

Initial soil analyses at the sampling points were carried out to give a view of all the metals present in the study area. Soil samples were collected from the sampling points at a depth of 20 cm and thoroughly homogenized. 100 g of this mixture were spread on a glass plate and dried in an oven at 105°C for 2 hours. After cooling, it was used for the preliminary determination of the metal content of the soil in the study area.

Heavy metal determination

Four soil samples were collected at a distance of 1 m from each of the five sampling points. The samples were taken at a depth of 20 cm using a soil auger. The subsamples from each sampling point were then homogenized to give a representative sample for that point. They were stored in a dry glass bottle and transported to the laboratory for analysis.

Nitric-perchloric acid digestion was performed, following the procedure recommended by the Association of Official Analytical Chemists (AOAC) [16]. One gram of sample was placed in a 250 mL digestion tube and 10 mL of concentrated HNO_3 was added. The mixture was boiled gently for 30 minutes to oxidize all oxidizable matter. It was cooled and 5 mL of 70% $HClO_4$ was added and the mixture was boiled gently until dense white fumes appeared. After cooling, 20 mL of distilled water were added and the mixture was boiled further for 20 minutes. This solution was cooled and filtered quantitatively into a 100 mL volumetric flask with deionized water.

Instrumentation

Preliminary determination of heavy metals and their percentage content in the filtrates was done using a compact multi-element bench top Energy Dispersive X-ray Fluorescent Analyzer (EDXRF) EDX3600B by Skyray Instrument (precision: 0.0% deviation; detection limit: 0.0001% (1ppm) - 99.99%). The concentrations of the identified heavy metals were determined using Agilent 240 AA Atomic Absorption Spectrophotometer (accuracy level: 99.776%; Precision: 97.568%).

Data analysis

Contamination factor (C_f), degree of contamination (C_d), pollution load index (*PLI*) and index of geo-accumulation (I_{geo}) models were used to assess the contamination and pollution status of the soil in this area.

The C_f was used to ascertain the level of soil contamination by a single element [17]. The C_f is the ratio of the concentration of heavy metals to the background values, and is given by Eq.(1).

$$C_f = \frac{C_m}{C_b} \qquad (1)$$

where, C_m- the concentration of metals, mg/kg;
C_b- the background concentration, mg/kg.

The Nigerian Directorate of Petroleum Resources [18] target values for heavy metals were used as the background values C_b.

The pollution load index (*PLI*) gives a summative indication of the overall level of toxicity at a particular sampling point. The *PLI* value greater than 1 is polluted, less than 1 indicates no pollution, whereas values equal to 1 indicate contaminant loads close to the reference concentration [19]. The pollution load index was determined mathematically using Eq.(2).

$$PLI = \left(C_{f1} \times C_{f2} \times C_{f3} \times \ldots \times C_{fn}\right)^{\frac{1}{n}} \qquad (2)$$

where, n- the number of parameters considered in the study;
C_{fn}- the contamination factor for each individual parameter.

The index of geo-accumulation (I_{geo}) is used for the assessment of contamination by comparing the current and pre-industrial concentrations originally used with bottom sediments [20]. It can also be applied in the assessment of soil contamination. It is calculated using Eq.(3) [21].

$$I_{geo} = log_2\left[\frac{C_n}{1.5B_n}\right] \qquad (3)$$

where, C_n- the concentration of the metals, mg/kg;
B_n- the geochemical background values in fossil argillaceous sediment (average shale).

For this study the B_n values were taken from the world average value in shale (mg/kg) and are given as follows: Fe= 47200, Zn= 96, Pb= 20, Co= 19, Cu= 45, Cr= 90, Ni= 68, Mn= 850, As= 13 and Cd= 0.3.

Results and discussion

The energy dispersive X-ray spectrum of the composite soil sample for the study area is shown in Figure 3. The percentage content of the heavy metals in the composite soil sample increased in the order Cd (0.0001) < Cr (0.0041) < As (0.0110)< Co (0.0292)< Mn (0.0415)< Ni (0.0436)< Cu (0.0644)< Pb (0.0794)< Zn

(0.2481)< Fe (4.6392). The concentrations of these metals at the different sampling points are summarized in Table 1. These data were analyzed using pollution and contamination models, in other to give a clear picture of the nature of the soil in this area. The C_f values as specified by Hakanson, L. [22] are given in four levels and are shown in Table 2.

The degree of contamination (C_d) is the sum of the C_f for the pollutant species for a given sampling site. It is aimed at providing a measure of the degree of overall contamination at a particular sampling point. The C_d levels as specified by Hakanson, L. [22] were used for this study and are shown in Table 3. The values of C_f, C_d and PLI at the sampling points in this study are summarized in Table 4.

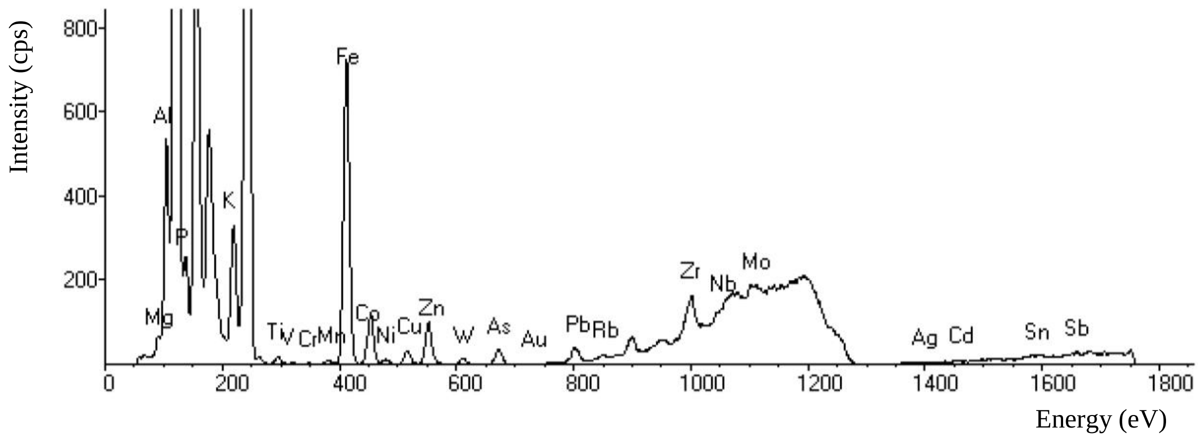


Figure 3. Elemental composition of the composite soil sample.

Table 1

Concentrations of heavy metals in the soil at the sampling points (mg/kg).

Sampling points	*Ni*	*Pb*	*Cd*	*Cr*	*As*	*Mn*	*Co*	*Zn*	*Cu*	*Fe*
P1	2	50	1	102	21	31	11	12	20	3654
P2	44	67	10	88	35	51	35	45	33	5134
P3	ND	363	3	55	7	54	32	203	90	4942
P4	37	89	11	73	27	19	20	9	2	4606
P5	7	163	25	93	ND	26	22	16	17	5048
DPR Target Values	**35**	**85**	**0.8**	**100**	**1.0**	**850**	**20**	**140**	**36**	**38000**

DPR- Department of Petroleum Resources (Nigeria);
ND- not detected.

Table 2

Contamination factor levels.

C_f value	*Level*
$C_f < 1$	Low contamination
$1 \leq C_f < 3$	Moderate contamination
$3 \leq C_f < 6$	Considerable contamination
$6 \leq C_f$	Very high contamination

Table 3

Degree of contamination levels.

Class	*Degree*
$C_d < 8$	Low degree of contamination
$8 \leq C_d < 16$	Moderate degree of contamination
$16 \leq C_d < 32$	Considerable degree of contamination
$C_d \geq 32$	Very high degree of contamination

Sampling point P1 had very high arsenic contamination level and considerable degree of contamination. Very high soil contamination level by cadmium and arsenic was observed at sampling point P2. The values obtained also showed a very high degree of contamination and pollution around this point. Sampling point P3 showed considerable contamination levels by lead and cadmium and high level of contamination by arsenic. The degree of contamination at this point was 21.31, showing considerable degree of contamination. This point also had a pollution load index value of 1.11, which indicated that it was polluted. Sampling point P4 was highly polluted by cadmium and arsenic with very high degree of contamination. Sampling point P5 had very high cadmium contamination level and showed high degree of contamination. The mean values from the models suggested that the study area had very high cadmium and arsenic contamination levels. It also showed that the degree of contamination of the area was very high.

Index of geo-accumulation (I_{geo})

The I_{geo} indices (Table 5) as proposed by Muller, G. [21], were used to classify the level of contamination of the soil by heavy metals. The I_{geo} values at the different sampling points in this study are shown in Table 6.

All the sampling points were moderately to strongly contaminated by lead, and moderately to extremely contaminated by cadmium. Lead and cadmium are therefore the two toxic metals that have accumulated in this area as a result of the activities at the mechanic village. These activities include indiscriminate disposal and subsequent corrosion of worn out car batteries, spray painting of cars and radiator repairs/disposal [23,24].

Table 4

Contamination factor (C_f), degree of contamination (C_d) and pollution load index (*PLI*) of soil samples.

Sampling points	*C_f*										*C_d*	*PLI*
	Ni	*Pb*	*Cd*	*Cr*	*As*	*Mn*	*Co*	*Zn*	*Cu*	*Fe*		
P1	0.06	0.59	1.25	1.02	21.00*	0.04	0.55	0.30	0.56	0.10	25.47*	0.45
P2	1.26	0.79	12.50*	0.88	35.00*	0.06	1.75	0.32	0.92	0.14	53.62*	1.05*
P3	0.00	4.27*	3.75*	0.55	7.00*	0.06	1.60	1.45	2.50	0.13	21.31*	1.11*
P4	1.06	1.05	13.75*	0.73	27.00*	0.02	1.00	0.06	0.06	0.12	44.85*	0.55
P5	0.20	1.92	31.25*	0.93	0.00	0.03	1.10	0.11	0.47	0.13	36.14*	0.55
Mean	0.52	1.72	12.50*	0.82	18.00*	0.04	1.20	0.45	0.90	0.12	36.28*	0.91

**Contaminated/polluted*

Table 5

I_{geo} values and contamination levels.

I_{geo} class	*I_{geo} value*	*Contamination level*
0	$I_{geo} \leq 0$	Uncontaminated
1	$0 < I_{geo} < 1$	Uncontaminated/moderately contaminated
2	$1 < I_{geo} < 2$	Moderately contaminated
3	$2 < I_{geo} < 3$	Moderately contaminated/strongly contaminated
4	$3 < I_{geo} < 4$	Strongly contaminated
5	$4 < I_{geo} < 5$	Strongly contaminated/extremely contaminated
6	$5 > I_{geo}$	Extremely contaminated

Table 6

I_{geo} values of soil at the sampling points.

Sampling points	*I_{geo}*									
	Ni	*Pb*	*Cd*	*Cr*	*As*	*Mn*	*Co*	*Zn*	*Cu*	*Fe*
P1	-5.67	0.74	1.15	-0.40	0.11	-5.36	-1.37	-3.59	-1.76	-4.28
P2	-1.21	1.16	4.47*	-0.62	0.84	-4.64	0.30	-1.68	-1.03	-3.79
P3	-	3.60*	2.74	-1.30	-1.48	-4.56	0.17	0.50	0.42	-3.84
P4	-1.46	1.57	4.61*	-0.89	0.47	-6.07	-0.51	-4.00	-5.08	-3.94
P5	-3.87	2.44	5.80*	-0.54	-	-5.62	-0.37	-3.17	-1.99	-3.81

** Strongly/extremely contaminated*

Conclusions

This study showed that the reclaimed section of the Orji mechanic village in Owerri North, Nigeria is contaminated by lead, cadmium, chromium and arsenic, which are very toxic heavy metals. All the sampling points were highly contaminated by arsenic apart from P5. The pollution load index at P2 and P3 indicated that the soil samples at these points were polluted by these metals. The data from the index of geo-accumulation posited that the soil in this area was extremely contaminated by cadmium at P2 and P5. This model also predicted strong contamination at P3 by lead.

Recommendation

Borehole water is the only source of portable water in Owerri North and the surrounding towns. The level and spread of these toxic metals may be more extreme and wide spread than this study had shown. The water table in this area is at risk of been contaminated by leaching of cadmium, arsenic and lead from the surrounding soil either now or in the near future. The State Government should therefore immediately commence clean up of the soil within this reclaimed area before allowing human settlement and other related activities. This can be done by *in situ* fixation or stabilization, involving the addition of chemicals to the soil which form minerals with these heavy metals, reducing their solubility and leaching ability. Also phytoremediation which involves the use of growing plants to stop the spread of contamination or to extract the metals from the soil can be employed. Regular checks of the portability of borehole water within this area should also be enforced.

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