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Mobility and bioavailability of heavy metals in soils obtained from open-air automobile repair shop in Jos North LGA, plateau state, Nigeria

Abstract

In this work, the forms of Cadmium (Cd), Lead (Pb), Zinc (Zn), Copper (Cu) and Nickel (Ni) were determined in soil samples from four automobile maintenance and repair shops (garages) within Jos North LGA of Plateau State. Samples were collected from garages in Army Engineer (site A), Angwan Rukuba (site B), Farin Gada (site C) and Tudun Wada (site D). The samples collected were prepared and analyzed for the various forms (exchangeable, reducible, oxidizable and residual) of the heavy metals by the Community Bureau of Reference (BCR) sequential extraction techniques and detected using an Atomic Absorption Spectrophotometer (AAS). The result showed Zn concentration as highest in all the sites followed by Cu, and Cd as the least. Cd was only found to be in the exchangeable form at site D and below the detectable limit in sites A, B, and C. Cu however was more associated to the exchangeable forms in sites C and D while in sites A and B it was associated with the oxidizable and residual forms respectively. The residual form of Ni was highest in all the sites while the reducible form showed highest for Pb. Zn was more associated with the exchangeable fraction in all the sites except site A which has more of the residual form. Zn and Cu were found to be mobile and bioavailable in all the sites while Ni was not. However, Pb was mobile and bioavailable in sites B and D, while Cd was only bioavailable in site D. The individual contamination factor (ICF) was highest for Cu, followed by Zn and Pb. This suggests higher risk of Zn, Cu and Pb pollution in garage soils. Hence, the work recommends that a suitable remediation technique be carried out within the study area.

Keywords: sequential extraction technique, soils, mobile, bioavailable, heavy metals, ICF, remediation

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Introduction

The high influx of fairly used vehicles popularly called 'Tokunbo' cars from neighboring countries into Nigeria has resulted to an increased establishment of open air automobile repair shops in the country, and consequently an increased in automobile waste resulting in heavy metal contamination of the soil, surrounding rivers and plants. Garage wastes that could probably contribute to heavy metal contamination are; waste oils, lubricants, discarded oil filters, tyres, acid batteries, paints, gas filters, brake pads, corroded galvanized parts, bearings and nuts.[1] Heavy Metals have severe effects on living organisms (plants, animals, humans) and ultimately on the environment. In humans they enter into body through various ways like ingestion, skin absorption and inhalation.[2] Bioavailability of heavy metals is the fraction of the total amount of the heavy metal in a specific environmental compartment that, within a given time span, is either available or can be made available for uptake by organisms from the direct surrounding of the organism.[3] This indicates that, total metal concentrations do not necessarily correspond with metal bioavailability.[4] The mobility and bioavailability of heavy metals depend on their form (chemical specie) in the soil.[5] The process of identifying and quantifying these different chemical species of metals in a sample is referred to as speciation. Since the heavy metals exist in different forms in the soil, their determination is usually performed using sequential extraction, a method first introduced by Tessier et al.[6] This consists of a series of chemical extractants, each being more drastic in action and of different nature than the previous one.[7] The use of sequential extraction procedure, although more time consuming, gives detailed information about the origin, mode of occurrence, biological and physicochemical availability, mobilization and transport of heavy metals.[6] In this study, the modified Community Bureau of Reference (BCR) sequential extraction procedure by Rauret et al.,[8] was used. This method analyses different fractions of metals in the soil: acid-extractable (water soluble, exchangeable and bound to carbonates), reducible (bound to Fe and Mn oxides), oxidizable (bound to sulphides and organic matter), and residual.[9,10]

Materials and methods

Study area

Jos North Local Government Area is the capital city of Plateau State and is located on latitude 9°56'21.7"North and longitude 8° 54'8" East of Greenwich meridian (GM). Samples for analysis were collected from four different automobile garages situated in different locations of Jos North LGA indicated in Figure 1. The four locations are; Army Engineer, Angwan Rukuba, Farin Gada market and Tudun Wada. The exert spots where the samples were collected are indicated in red colour on the Map (Figure 1). All these automobile garages have hosted these activities for more than 15 years.

Sampling and sample preparation

Samples were collected into new polyethylene bags within depths range of 1-10cm from all automobile garages using the stratified

random sampling design. The samples collected were air-dried for three days and those collected at the same garage site were combined and homogenized to form a representative sample for that site. This was done to avoid bias and give a good representation of each garage site. All representative samples were pulverized to powder using an agate mortar and pestle to particle sizes of nano meters range then collected into polyethylene bags labeled A, B, C, and D, to represent samples from the automobile garages of Army Engineer, Angwan Rukuba, Farin Gada, and Tudun Wada respectively.

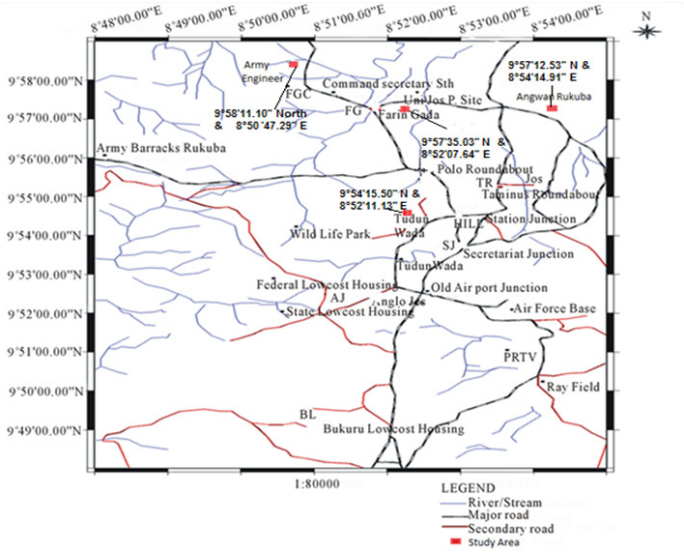

Figure 1 Map of Jos North showing sampling areas.[24]

Methodology

pH determination

A 1.0g soil was weighed into a beaker and 10ml deionized water was added and stirred for 30 minutes. This was allowed to settle for 5 minutes and the pH was measured using a digital pH meter (Lab. Tech. 513425 model).

Determination of soil organic matter (SOM)

Loss on ignition (LOI) analysis was used to determine the soil organic matter using the formulae;

$$\%\ SOM = \frac{(W2 - W3)}{(W2 - W1)} \times 100\%$$

Where W1, W2 and W3 are the weight of empty crucible, weight of crucibles+5g sample after oven-drying for 2 hours at 105°C and weight of crucibles+5g sample after heating for 2 hours at 360°C respectively.

Sequential extraction procedure

In this study, the modified Community Bureau of Reference (BCR) three-step sequential extraction procedure described by Nemati et al.,[11] was used to extract the various forms of heavy metals in the soil samples before the atomic absorption spectrophotometer (AAS) was used to determine the concentration of individual heavy metals in each of the fractions. While, percentage recovery of the sequential extraction was calculated using the formula below;

$$\text{Recovery}(\%) = \frac{\text{Step1} + \text{Step2} + \text{Step3} + \text{Step4}}{\text{Step5}} \times 100$$ [12,13]

Determination of individual and global contamination factor

Individual contamination factors (ICFs) and the global contamination factor (GCF) evaluates the degree of toxicity or risk to the environment and the bioavailability of trace metals in the soil relative to its retention time. In this study, ICFs were calculated for the five metals at all sites as the sum of the concentrations of trace metals extracted in the first three steps (exchangeable/soluble, reducible, and oxidizable fractions) divided by the concentration in the residual fraction.[11] The GCF was calculated by summing the ICFs of heavy metals.[14]

Results and discussion

Soil characteristics

The results obtained for selected physicochemical properties of soil samples are summarized in Figure 2. The pH in the soil samples were in slightly alkaline condition and ranged from 8.10 to 8.20. The values were higher than those reported.[15,16] This type of alkalinity is common in anaerobic soils as a result of oxygen deficiency in the soil caused by spilled engine oils.[17] Heavy metals are mostly insoluble and hence unavailable at high pH.[18] Soil alkalinity also increases the adsorption capacity of oxides, including manganese and iron hydroxides, which are strong natural adsorbents.[19] Values for SOM ranged from 2.023% to 9.177% as seen in Table 1. SOM plays an important role in metal binding.[20] From the results, site C has the highest SOM (9.177%) while site D had the least (2.023%). SOM immobilizes heavy metals at strongly acidic conditions by forming insoluble organo-metallic complexes and mobilizes metals at weakly acidic to alkaline conditions by forming soluble organic metal complexes.[20] The distribution of pH, SOM among the garage sites showed a significant impact of anthropogenic pollution by spilled engine oil and other vehicular waste materials.

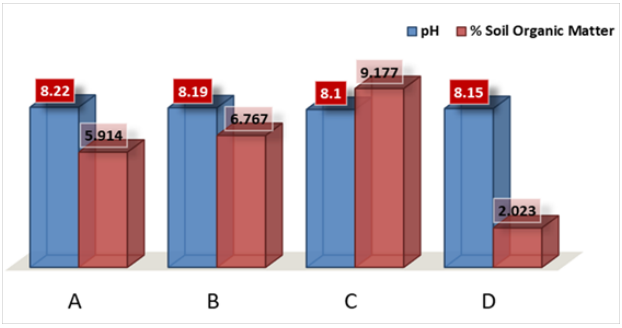

Figure 2 pH and % soil organic matter (SOM) from of soil samples from the four sites.

Total metal concentration and pollution index of the heavy metals in the four garage soils

The total metal concentration and pollution/contamination index of cadmium (Cd), copper (Cu), nickel (Ni), lead (Pb) and zinc (Zn) were given in Table 2. The pollution/contamination index expresses the potential threat posed by the heavy metals.[21] According to,[22] who's work established that the contamination/pollution value index is directly proportional to their level of contamination and pollution of specific metal species in each case. Traditionally, the data obtained from calculation of the contamination/pollution index is grouped into different grades ranging from very slight contamination to excessive pollution (Table 1 & table 2).

The total concentration of Cadmium in the four sample sites were

mostly below the detection limit of the AAS, except that from site D with a TMC of 0.006mg/kg which is below the maximum allowed limit (MAL). Cadmium is very soluble and easily leached away or swept by rain water. It is released from wear and tear of rubber in small quantities and also from the waste engine oil in the small amounts. Apart from the low detection limit of the instrumentation used, it may have been low due to only natural occurrence of the metal. Cadmium concentrations were therefore very low and did not yield enough data for studying its mobility and bioavailability.

Table 1 Total metal concentration (mg/kg) and their corresponding pollution indexes (%), in the sample site

Sample Site	Cadmium		Copper		Nickel		Lead		Zinc	
	TMC	Pi	TMC	Pi	TMC	Pi	TMC	Pi	TMC	Pi
A	BDL	_	1.232±0.002	0.82	0.107±0.003	0.54	0.313±0.000	6.26	25.524±0.005	5.1
B	BDL	_	0.58±0.005	0.39	0.29±0.002	1.45	11.424 ±0.002	228.48	41.496±0.001	8.3
C	BDL	_	5.463±0.007	3.64	0.211±0.006	1.06	1.21±0.002	24.2	37.8±0.004	7.56
D	0.006±0.014	0.6	0.835±0.003	0.56	0.101±0.006	0.51	0.582±0.001	11.64	45.66±0.003	9.132

TMC: total metal concentration Pi: pollution index.

The total concentration of copper in the four sample sites ranges between 0.580±0.000 and 5.463±0.007mg/kg. The concentrations in sites A, B and D were found to be below the maximum allowed limit of copper in soil which is 1.50mg/kg,[23] while only that of site C was higher than the MAL set by FEPA. The contamination/pollution index values showed that; sites A, B, C, and D were very severely contaminated, moderately contaminated, moderately polluted, and severely contaminated respectively (Table 2). For Ni, the total concentration ranges from 0.101±0.006 to 0.29±0.002mg/kg. With site A and D having concentrations below the MAL set by FEPA while site B and C had concentration levels slightly higher than the FEPA limit. The contamination/pollution (c/p) index values showed that site A and D was severely contaminated while site B and C was slightly polluted.

Table 2 Pollution Index for heavy metals

Pollution index interval	Significance
<0.1	Very slight contamination
0.1-0.25	Slight contamination
0.26-0.50	Moderate contamination
0.51-0.75	Severe contamination
0.76-1.0	Very severe contamination
1.1-2.0	Slight pollution
2.1-4.0	Moderate pollution
4.1-8.0	Severe pollution
8.1-16.0	Very severe pollution
>16.0	Excessive pollution

Source: Lacatusu, 2000.

The concentration of Pb in the four sites ranged from 0.582±0.001 to 11.424±0.002mg/kg with the highest concentration found in Angwan Rukuba garage site while the lowest was at Tudun Wada garage. All the sites had Pb concentrations above the MAL set by FEPA. The c/p index values showed that Army Engineer garage was severely polluted while the other garage sites were excessively polluted, with the Angwan Rukuba garage being the most excessively polluted. For Zn, the total metal concentration ranges between 25.524±0.005 in Army engineer garage to 45.660±0.0003 in Tudunwada garage. This level is however low as compared to other studies by Pam et al.[20] and Yahaya et al.[24] The c/p index value showed that site A and C were severely polluted while sites B and D were very severely polluted.

Conclusion

The impact of the activities within the study area is indicated on the increase in the concentration of the heavy metals detected. However, the concentration of all the metals investigated in this study was found to be below the MAL set by major regulatory authorities. There is the need to regulate activities as a way of enhancing the sustainable health needs of the dwellers in the city.

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None.

Conflict of interest

The author declares that there is no conflict of interest.

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