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Effect of Solid Waste Source (Dumpsite Type) on Heavy Metal Contaminations in Urban Soils of Bauchi, Nigeria

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

Heavy metals constitute a major threat to humans due to the fact that they unlike some other pollutants are not biodegradable. Different Sources of these metals when dumped with municipal solid wastes raise the level of heavy metals in dumpsites. A study of the effect of solid waste source on heavy metal contaminations in urban soils of Bauchi, Nigeria was carried out using Atomic Absorption Spectrophotometer. Single and integrated pollution indices were used to assess the impact of human activities on the concentration of heavy metals in soils. The results obtained show that heavy metal contamination of urban soils in Bauchi is strongly affected by the source area of waste materials or the dumpsite type. Heavy metal contaminations based on single pollution indices used give the following trend: Pb > Cd > Ni > Zn > Cr > Mn > Cu >Fe for residential soils; Pb > Ni > Cd > Zn > Cr > Mn > Cu > Fe for commercial soils and Pb > Cd > Ni > Zn > Cu > Cr > Mn > Fe for industrial soils. In view of the discrepancies in results obtained when different reference values are used, the development of a unified contamination classification model named Unified Contamination Classification by Eze at Bauchi (UCCEB) was undertaken resulting in interesting coherence among single pollution indices. The application of UCCEB model enabled the differentiation of anthropogenic-related contaminations from lithogenic-related inputs. The studied sites gave the following results using UCCEB: Residential dumpsite (RES): moderate pollution with respect to Cd,

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Ni, Pb, Zn; low pollution with respect to Cr, Cu, Mn; and deficient pollution with respect to Fe. Commercial dumpsite (COM): moderate pollution with respect to Cd, Cr, Ni, Pb, Zn; low pollution with respect to Cu, Mn; and deficient pollution with respect to Fe. Industrial dumpsite (IND): moderate pollution with respect to Cd, Cr, Cu, Ni, Pb, Zn; low pollution with respect to Mn; and deficient pollution with respect to Fe. Thus the order of multi-element contamination can be summarized as IND>COM>RES.

Keywords: Heavy metals; dumpsite type; pollution indices; UCCEB.

1. INTRODUCTION

Soil has long been regarded as a repository for society's wastes. In the ecosystem, soil is considered a complex, living, seasonally changing and dynamic component which may get polluted from anthropogenic activities [1]. Among these pollutants, heavy metals constitute a major threat due to the fact that they unlike some other pollutants are not biodegradable [2]. Different Sources such as electronic goods, painting waste, used batteries, etc., when dumped with municipal solid wastes raise the level of heavy metals in dumpsites, and dumping devoid of the separation of hazardous waste can further elevate noxious environmental effects [3]. The occurrence of various heavy metals such as Mn, As, Cr, Cd, Ni, Zn, Co, Cu, and Fe in municipal solid waste dumpsites and urban soils was reported by many workers [4-8]. Since these contaminants affect the environmental qualities in and around such open dumpsites, monitoring of soil qualities especially heavy metal content in dumpsite becomes necessary. This can facilitate the recommendation of suitable remedial measures [9]. While various researchers have opined the need for continual monitoring of the concentration of trace metals in soil, most of these studies were carried out in industrial cities with long period of industrialization [10]. Much comparative study has not been done on the effect of different land use types - industrial, commercial and residential uses – on heavy metal contamination in urban soils especially within Bauchi metropolis.

The aim of this research therefore is to assess the effect of solid waste source (dumpsite type) on heavy metal contaminations in urban soils of Bauchi using three types of dumpsites namely industrial, commercial and residential dumpsites. A noble aspect of this work would be the unification (standardization) of pollution indices using background values of heavy metals to enable the differentiation of anthropogenic-related contaminations from lithogenic-related inputs in urban soils. Thus, this study would accentuate the need for a more constant and reliable monitoring of heavy metal concentrations in soils within urban areas.

2. MATERIALS AND METHODS

2.1 Study Area

This study was carried out in three municipal waste dumpsites of Bauchi metropolis (Gudum, Wunti and Rafin Zurfi) as shown in Fig. 1. Bauchi is a city in northeast Nigeria, the capital of Bauchi State. It is located at Latitude 10°18'57"N and Longitude 09°50'39"E, on the northern edge of the Jos Plateau. Being a centre of commercial activities with a population of 316,173 (2004), the city generates large quantity of wastes deposited at designated sites. The dumpsites studied contain mixture of both organic and inorganic waste materials, such as food wastes, papers, metals, tins, glass, ceramics, battery wastes, textile materials, plastics, ash, fine dust, rubber, wood wastes, sewage and other miscellaneous materials.

The three areas were chosen to reflect three different land uses and waste sources. Gudum is an industrial area; Wunti is a commercial area; while Rafin Zurfi is a residential area.

2.2 Soil Sampling

Since surface soils are the first locus of input of metals where they tend to accumulate on a relatively long term basis, 10 surface soil samples were collected randomly from each of the three designated dumpsites at a depth of 0-20 cm. For comparison of the results, soils of uncontaminated area (denoted by the suffix "U") about 100 m away from each contaminated site were also sampled. All the samples were collected during March 2014. The samples were placed in labeled polythene bags and transported to the laboratory. All soil samples were subsequently air-dried to constant weight to avoid microbial degradation [11]. They were homogenized, made lump free by gently crushing repeatedly using an acid pre-washed mortar and pestle, and passed through a 1.5 mm plastic sieve prior to analysis. The pH of each soil sample was also determined using routine method as described by Eze [12].

2.3 Heavy Metal Analysis

One gram of the sieved soil was weighed out and transferred into a 100 cm^3 tall-form beaker. About 20 cm^3 of 1:1 nitric acid (Spectrosol grade) was added and boiled gently on a hotplate until the volume of nitric acid was reduced to about 5 cm^3. Then 20 cm^3 of deionized water was added and boiled gently again until the volume is approximately 10 cm^3. The resulting suspension was cooled and filtered through a Whatman no. 540 filter paper, washing the beaker and the filter paper with small portions of deionized water until a volume of about 25 cm^3 was obtained. The filtrate was then transferred to a 50 cm^3 graduated flask and made up to the mark using deionized water [13].

Heavy metal concentrations of the soil samples were determined using Atomic Absorption Spectrophotometer (AAS) at the National Research Institute for Chemical Technology (NARICT), Zaria. The concentrations of the various metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn) to be determined were obtained directly from the instrument by aspirating the samples into the instrument. Furthermore, Microsoft Office Excel 2013 and SPSS 15 were used for statistical analysis of the data.

2.4 Quantification of Soil Pollution

In order to have an idea about the levels of contamination of the soils around the dumpsites, data obtained were compared with those from the control sample points, taken to be the background (uncontaminated) values. The background value of an element is the concentration of that element obtained from a control site believed to have been undisturbed by anthropogenic activities [14]. Various quantitative indices have been employed to assess the impact of human activities on the concentration of toxic trace metals in soil. In this study, we classified the commonly used pollution indices into two types – single indices and integrated indices. Three single indices were used namely contamination factor, enrichment factor and index of geo-accumulation; while one integrated index was used namely average of pollution index.

2.4.1 Contamination factor (C_f)

An assessment index is generally applied to measure environmental quality of soil, and one simple and well-known single element pollution index is the contamination factor (C_f). Contamination factor is used to describe the contamination of a given toxic substance in an aquatic or terrestrial environment. In calculating C_f, the equation suggested by Håkanson [15] was used as given below.

$$C_f = \frac{C^i_{0-1}}{C^i_n} \quad (1)$$

Where C^i_{0-1} is the mean content of metals from at least five sample sites and C^i_n is the pre-industrial concentration of individual metals. In this study, the concentrations of the control (uncontaminated) samples were taken to represent the pre-industrial concentration as suggested by Victor et al. [16]. C_f can be used to differentiate between the metals originating from anthropogenic activities and those from natural processes and to assess the degree of anthropogenic influence [17].

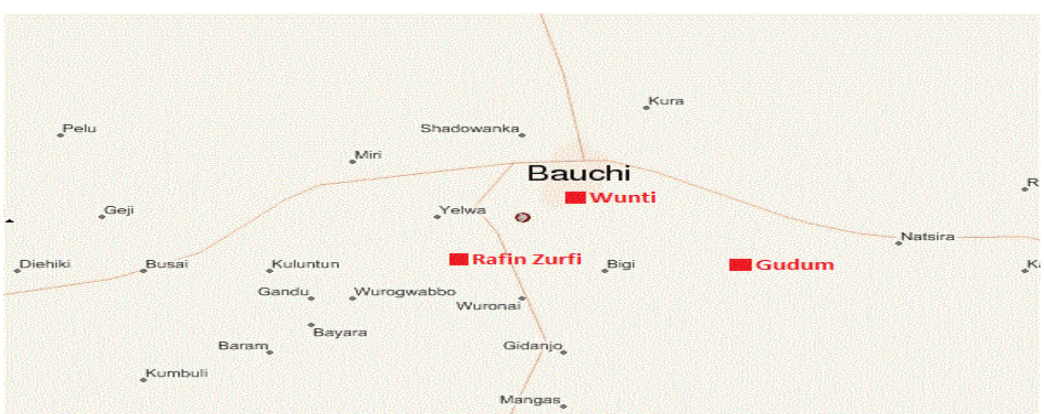

Fig. 1. Map of Bauchi showing the study sites

2.4.2 Enrichment factor (EF)

An index called enrichment factor (*EF*) was initially developed to speculate on the origin of elements in the atmosphere, precipitation, or seawater [18,19] but it was progressively extended to the study of soils, lake sediments, peat, tailings, and other environmental materials [20]. In this study enrichment factor (EF) was used to assess the level of contamination and the possible anthropogenic impact in Bauchi urban soils. The EF was calculated according to the equation generalized by Zoller et al. [18] as:

$$EF = \frac{(C_i/C_{ie})_S}{(C_i/C_{ie})_{RS}} \quad (2)$$

Where C_i is the content of element *i* in the sample of interest or the selected reference sample, and C_{ie} is content of immobile element in the sample or the selected reference sample. So $(C_i/C_{ie})_S$ is the heavy metal to immobile element ratio in the samples of interest, and $(C_i/C_{ie})_{RS}$ is the heavy metal to immobile element ratio in the selected reference sample [21]. The selected reference sample is usually an average crust or a local background sample [22-24]. The immobile element is often taken to be Al [22], Li, Sc, Zr, or Ti [24], and sometimes Fe or Mn [23] has been used. Al (for terrestrial sources) and Na (for oceanic sources) have been used for the purpose of comparing the chemical composition of atmospheric particulate material collected at the South Pole to the composition of the crust or the ocean [20].

2.4.3 Index of geo-accumulation (I_{geo})

An index of geo-accumulation (I_{geo}) was originally defined by Müller in 1969 [25], in order to determine and define metal contamination in sediments [26], by comparing current concentrations with pre-industrial levels. Index of geo-accumulation can be calculated by the following equation:

$$I_{geo} = \log_2 \left[\frac{C_i}{1.5C_{ri}}\right] \quad (3)$$

Where C_i is the measured concentration of the examined metal i in the sediment, and C_{ri} is the geochemical background concentration or reference value of the metal i. In this study, the concentration of the control sample was taken as the reference value. Factor 1.5 is used because of possible variations in background values for a given metal in the environment as well as very small anthropogenic influences.

2.4.4 Average of pollution index (PI_{Avg})

An important integrated index namely, average of pollution index (PI_{Avg}), is used to identify multi-element contamination resulting in increased overall metal toxicity [26]. The PI_{Avg} is calculated as follows:

$$PI_{Avg} = \frac{1}{m}\sum_{i=1}^{m} P_i \quad (4)$$

Where P_i is the single pollution index of heavy metal *i* which in this study are contamination factors, enrichment factors and index of geo-accumulation and m is the count of the heavy metal species. This kind of pollution index was used by Bhattacharya et al. [27] to assess the quality of abandoned-mine-tailings environment.

3. RESULTS AND DISCUSSION

3.1 Effect of pH

Various physico-chemical and biological factors control the mobility of metals in soils [28]. They suggested that a change in pH results in a transfer of element from one phase to another and thus permits the estimation of mobility of heavy metals in the soil. The results as given in Table 1 show that the soil pH values ranges from mild acidic to neutral (6.62 – 7.02). The soil pH seems to have higher effect on the solubility or metal retention in soil. The greater retention and lower solubility of metals occurs at high soil pH [29].

3.2 Heavy Metal Concentrations in the Studied Sites

Table 1 summarizes the results of heavy metal concentrations in the three dumpsites studied. A comparison is made of the levels of heavy metals in the dumpsites with World-soil average given by Kabata-Pendias [30]. Many studies have shown that urban soils receive loads of contaminants that are usually greater than the nearby sub-urban or rural areas, due to the higher anthropogenic activities of urban settlements [31]. This is largely confirmed by this study judging from the concentrations of the metals investigated in the control and dumpsite soils (Table 1). With the exception of Fe, concentrations of the metals in dumpsites are from 3.41 times (for Cu in residential dumpsite) to 13.71 times (for Pb in industrial dumpsite) higher than that of control samples.

From the result of concentrations, it can be noted that the metals in all dumpsite types followed the order: Fe>Mn>Zn>Pb>Ni>Cr>Cu>Cd. Thus, Fe has the highest mean concentrations while Cd has the lowest mean concentrations in all types of dumpsites and source areas. The investigation of soil heavy metal concentrations in urban soils of Bauchi city indicated that the concentrations of Cd, Ni, Pb and Zn in the soils often exceeded the calculated average mean for the world scale of unpolluted soil reported by Kabata-Pendias [30]. Elevated concentrations of Cd, Ni, Pb and Zn in soils are commonly due to anthropogenic (man-made) inputs. In fact, Cd, Ni, Pb and Zn soil pollution appears to be readily affected by anthropogenic factors [32] and have adverse effects on human health [33].

A comparison of metal concentrations in soils at the various dumpsites or waste source area indicated that higher concentrations of Cd, Cr, Cu, Fe, Ni, Pb and Zn were observed in the industrial area, while higher concentration of Mn was observed in the residential area.

3.2.1 Cadmium (Cd)

The mean levels of Cd at the various dumpsites are 0.43 $mgKg^{-1}$, 0.63 $mgKg^{-1}$ and 0.98 $mgKg^{-1}$ for residential, commercial and industrial areas respectively. These values exceed the calculated world-soil average of 0.41 $mgKg^{-1}$ [30] thereby indicating anthropogenic sources. It has been reported that inputs of Cd into soils may be of different origins such as agricultural amendments, sludge and atmospheric deposition [34]. Cadmium has a wide range of uses in the industry, including paints, pigments, electroplating and plastic stabilizer [35]. In addition, many anthropogenic activities can increases soil Cd to the levels well above background levels, such as the burning of fossil fuel and tyres, the use of lubricating oils, vehicle wheels, application of solid wastes from industries and home, sewage sludge, wastewater irrigation and phosphate fertilizer application [36].

3.2.2 Chromium (Cr)

The mean Cr concentrations ($mgKg^{-1}$) at the dumpsites vary from 33.01 to 48.02. Although these values were below the world-soil average (59.50 $mgKg^{-1}$), being more than 4 times higher than that of control sites suggests possible anthropogenic sources of Cr in the urban soils. Various industrial activities such as metal plating, anodizing, dyes, pigments, ceramic, glues, tanning, wood preserving and textiles are reported to contribute Cr [34].

3.2.3 Cupper (Cu)

The observed mean levels of Cu for residential and commercial dumpsites (20.70 $mgKg^{-1}$ and 26.52 $mgKg^{-1}$ respectively) are within the world-soil average (38.90 $mgKg^{-1}$) reported by Kabata-Pendias [30]. However Cu concentrations in industrial dumpsite (43.30 $mgKg^{-1}$) exceeded world-soil average. Cu is used in numerous applications because of its physical properties. High level of Cu at the industrial area can be attributed to the element's many industrial applications such as in copper wires, electrodes, copper pipes and alloys, and vehicle parts. Contribution of Cu may also be envisaged from dumping of solid wastes, application of fungicides, live stock manures, sludges and atmospheric deposition.

3.2.4 Iron (Fe)

Iron is the most abundant element in the earth's crust. The global terrestrial abundance of Fe is calculated to be around 4.5% and it is not considered a trace element in rocks and soils. However, Fe plays a special role in the behavior of several trace elements and is in the intermediate position between macro and micronutrients in plants, animals, and humans [30]. Major sources of iron are the iron oxides such as minerals hematite, magnetite and taconite.

3.2.5 Manganese (Mn)

Manganese (Mn) is among the more abundant elements in the earth's crusts and is widely distributed in soils, sediments, rocks and water [37]. Mn analysis gave mean values of 365.00 $mgKg^{-1}$ (RES), 318.05 $mgKg^{-1}$ (COM) and 342.30 $mgKg^{-1}$ (IND). Although the observed values were less than the world-soil average (488.00 $mgKg^{-1}$) [30], comparison with control samples indicated that Mn concentrations in the study areas were 4 times higher than Mn content in the control soils. Sources of manganese include metal alloys, batteries, glass and ceramic materials.

Table 1. Heavy metal contents (mgkg^{-1}) of the dumpsites against world-soil average

	RES	COM	IND	U*RES	U*COM	U*IND	World-Soil Average[α]
pH	6.94±0.34	6.85±0.37	6.62±0.33	7.02±0.40	7.01±0.38	6.98±0.35	N/A
Cd	0.43±0.12	0.63±0.17	0.98±0.21	0.04±0.01	0.08±0.01	0.08±0.02	0.41
Cr	33.01±7.04	37.01±7.15	48.02±8.02	7.45±0.56	7.25±0.50	8.13±0.52	59.50
Cu	20.70±4.88	26.52±5.01	43.30±5.34	6.07±0.44	7.30±0.47	7.31±0.50	38.90
Fe	1998.42±265.05	1890.03±257.87	2435.91±279.08	1975.20±187.02	1889.04±185.85	2213.56±201.44	No limit[α]
Mn	365.00±85.23	318.05±79.54	342.30±85.39	85.06±27.01	79.09±20.00	83.22±22.43	488.00
Ni	73.05±29.71	70.24±28.99	78.36±26.98	8.09±0.75	8.06±0.72	8.24±0.77	29.00
Pb	136.72±55.05	142.84±58.44	159.67±60.53	11.68±1.02	11.78±1.33	11.65±1.58	27.00
Zn	140.00±30.12	157.68±30.54	160.09±34.26	19.98±0.91	20.40±0.91	20.01±0.95	70.00

*RES: Residential dumpsite (Rafin Zurfi); COM: Commercial dumpsite (Wunti); IND: Industrial dumpsite (Gudum); U*RES: Residential control (uncontaminated) site; U*COM: Commercial control (uncontaminated) site; U*IND: Industrial control (uncontaminated) site; [α][30]*

3.2.6 Nickel (Ni)

The concentrations of Ni in the soils investigated show a distribution mean of 73.05 $mgKg^{-1}$, 70.24 $mgKg^{-1}$ and 78.36 $mgKg^{-1}$ for the residential, commercial and industrial dumpsites respectively. The results are higher than values of 11.5 $mgKg^{-1}$ in Ipeaiyeda et al. [38] and 17.38 - 16.52 $mgKg^{-1}$ recorded by Iwegbue et al. [39]. They are also higher than world-soil average for unpolluted soils (29.00 $mgKg^{-1}$). Further, considering the analyzed values of control soils, it was observed that mean Ni concentrations in the studied dumpsites were about 9 times higher than those of the uncontaminated soils. It is evident that local solid waste and anthropogenic activities such as burning of fuel contribute to the increase in Ni content in the soil of the study area. It may be noted that many domestic cleaning products such as soaps (100 - 700 mg Ni/Kg), powdered detergents (400 - 700 mg Ni/Kg and powdered bleach (800 mg Ni/Kg) may prove to be important sources of Ni in the urban soils [34]. This can as well explain the observed element's higher level in residential soil than commercial soil. Other sources of Ni include food stuffs such as chocolate; automobile batteries; and various paint wastes.

3.2.7 Lead (Pb)

The mean Pb contents vary from 136.72 $mgKg^{-1}$ in residential area to 159.67 $mgKg^{-1}$ in industrial area. The observed values, although are higher than the calculated world average of unpolluted soils (27.00 $mgKg^{-1}$) [30], and are also higher than the observed values in the control soils. Deposition related to transportation sector in general (considering the long residence time of Pb) may be the major source of increase in Pb content in urban soil [40,41]. It is known that lead containing dust particles have a relatively short residence time in the atmosphere, and deposit quickly in the nearby soil, hence contributing to further accumulation of lead on urban soils [42]. Pb has been shown to accumulate to high levels in urban environments from a range of sources including that derived from leaded petrol [43]. Other anthropogenic sources of Pb include use of car batteries, coals, plastics and insecticides.

3.2.8 Zinc (Zn)

The Zn concentrations in the studied soils had mean values of 140.00 $mgKg^{-1}$ (RES), 157.68 $mgKg^{-1}$ (COM) and 160.09 $mgKg^{-1}$ (IND). These observed values were reportedly within the common world range for total Zn concentrations in soil (10 - 300 $mgKg^{-1}$) by Alloway [34], but are higher than the world-soil average of 70.00 $mgKg^{-1}$ for unpolluted soil by Kabata-Pendias [30]. Environmental contamination of Zn is mainly related to anthropogenic input. The anthropogenic sources of Zn are related to industries and the use of liquid manure, composted materials and agrochemicals such as fertilizers and pesticides in agriculture [44]. Zn may be derived from mechanical abrasion of vehicles, as they are used in the production of brass alloy itself and come from brake linings, oil leak sumps and cylinder head gaskets [45]. Some of the studies have also linked high Zn levels in urban soils to accumulation from garden fertilizing, traffic and industry input [41] and also vehicle emissions and tyre and brake abrasion [46].

3.3 Effect of Waste Source (Dumpsite Type) on Metal Occurrence

Table 2 gives the result of the effect of waste source type and dumpsite area on the availability of heavy metals. A comparison of the metal concentrations in various types of dumpsite and source area indicated the following: For Cd, Cr, Cu, Pb and Zn, highest concentrations were observed at industrial dumpsite while least concentrations were seen at residential dumpsite; for Fe and Ni, highest concentrations were observed at industrial dumpsite while least concentrations were seen at commercial dumpsite; for Mn, highest concentration was observed at residential dumpsite while least concentration was seen at commercial dumpsite.

Table 2. Effect of waste source on metal occurrence

Dumpsites	Metals
IND>COM>RES	Cd, Cr, Cu, Pb, Zn
IND>RES>COM	Fe, Ni
RES>IND>COM	Mn

RES: Residential dumpsite (Rafin Zurfi); COM: Commercial dumpsite (Wunti); IND: Industrial dumpsite (Gudum)

3.4 Single Pollution Indices

Single indices are indicators used to calculate only one metal contamination. Three single indices were used namely: contamination factor, enrichment factor, and index of geo-accumulation. In each case, a comparison was made with data obtained from adjoining unpolluted (control) soils, taken to be the background values. Table 3 gives the various classifications of soil pollution (single and integrated) indices based on the standards set by founding researchers (inventors).

3.4.1 Contamination factor (C_f)

Table 4 gives the values of contamination factors for the heavy metals at respective dumpsites. Comparing the results with the four categories of contamination factors given in Table 3, one would conclude that in all the three dumpsites studied, there is high contamination (C_f ≥6) of Cd, Ni, Pb and Zn; considerable contamination ($3 \le C_f < 6$) of Cr, Cu and Mn; and moderate contamination ($1 \le C_f < 3$) of Fe. High C_f values suggest strong anthropogenic influence. Table 5 summarizes the trend of heavy metal contamination at the different dumpsites. As can be seen from the data, for all the three types of dumpsites and waste sources, Pb has the highest metal contamination on the basis of contamination factor while Fe has the least.

3.4.2 Enrichment factor (EF)

The result of heavy metal enrichment of the dumpsites is presented in Table 4. In this study, the concentrations of the control (uncontaminated) samples were taken as the reference concentrations while Fe was taken as the immobile element. Deely and Fergusson [47] proposed Fe as an acceptable normalization (immobile) element to be used in the calculation of the enrichment factor since they considered Fe distribution to be unrelated to other heavy metals. Thus to determine the relative degree of metal contamination, comparisons were made to background concentrations using Fe as the immobile element following the assumption that its content in the crust has not been disturbed by anthropogenic activity, and it has been chosen as the element of normalization because natural sources (98%) vastly dominate its input [48]. The process of standardization helps in evaluating the anthropogenic component over and above the natural component. As can be seen from Table 4, there is a very close similarity between the results of enrichment factors and those of contamination factors, thus validating Fe as a suitable immobile element.

Table 3. Classification of pollution indices (single and integrated)

C_f	Category/Interpretation [15]	I_{geo}	Category/Interpretation [25]
$C_f<1$	Low contamination	$I_{geo} \le 0$	Class 0 (unpolluted)
$1 \le C_f < 3$	Moderate contamination	$0 < I_{geo} \le 1$	Class 1 (unpolluted to moderately polluted)
$3 \le C_f < 6$	Considerable contamination	$1 < I_{geo} \le 2$	Class 2 (moderately polluted)
$C_f \ge 6$	High contamination	$2 < I_{geo} \le 3$	Class 3 (moderately to strongly polluted)
		$3 < I_{geo} \le 4$	Class 4 (strongly polluted)
EF	**Category/Interpretation [18,19]**	$4 < I_{geo} \le 5$	Class 5 (strongly to extremely polluted)
EF<2	Deficiency to minimal enrichment	$I_{geo} > 5$	Class 6 (extremely polluted)
2≤EF<5	Moderate enrichment		
5≤EF<20	Significant enrichment	PI_{Avg}	**Category/Interpretation [27]**
20≤EF<40	Very high enrichment	$PI_{Avg} > 1$	Low quality soil/Multi-element contamination/Anthropogenic inputs
EF>40	Extremely high enrichment		

C_f: Contamination factor; EF: Enrichment factor; I_{geo}: Index of geo-accumulation; PI_{Avg}: Average of pollution index

Table 4. Contamination factors, enrichment factors and index of geo-accumulation of heavy metals at the dumpsites

	Contamination factor (C_f)			Enrichment Factor (EF)			Index of geo-accumulation (I_{geo})		
Metals	$C_{f\ RES}$	$C_{f\ COM}$	$C_{f\ IND}$	EF_{RES}	EF_{COM}	EF_{IND}	$I_{geo\ RES}$	$I_{geo\ COM}$	$I_{geo\ IND}$
Cd	10.75	7.88	12.25	10.63	7.87	11.13	2.84	2.39	3.03
Cr	4.43	5.10	5.91	4.38	5.10	5.37	1.56	1.77	1.98
Cu	3.41	3.63	5.92	3.37	3.63	5.38	1.18	1.28	1.98
Fe	1.01	1.00	1.10	1.00	1.00	1.00	-0.58	-0.58	-0.45
Mn	4.29	4.02	4.11	4.24	4.02	3.74	1.52	1.42	1.45
Ni	9.03	8.71	9.51	8.92	8.71	8.64	2.59	2.54	2.66
Pb	11.71	12.13	13.71	11.57	12.12	12.45	2.96	3.01	3.19
Zn	7.01	7.73	8.00	6.93	7.73	7.27	2.22	2.36	2.41

RES: Residential dumpsite; COM: Commercial dumpsite; IND: Industrial dumpsite

Table 5. Trend of heavy metal contamination based on C_f, EF and I_{geo}

Contamination factor (C_f)	
Waste source (Dumpsite)	**Trend**
Residential	Pb>Cd>Ni>Zn>Cr>Mn>Cu>Fe
Commercial	Pb>Ni>Cd>Zn>Cr>Mn>Cu>Fe
Industrial	Pb>Cd>Ni>Zn>Cu>Cr>Mn>Fe
Enrichment Factor (EF)	
Waste source (Dumpsite)	**Trend**
Residential	Pb>Cd>Ni>Zn>Cr>Mn>Cu>Fe
Commercial	Pb>Ni>Cd>Zn>Cr>Mn>Cu>Fe
Industrial	Pb>Cd>Ni>Zn>Cu>Cr>Mn>Fe
Index of geo-accumulation (I_{geo})	
Waste source (Dumpsite)	**Trend**
Residential	Pb>Cd>Ni>Zn>Cr>Mn>Cu>Fe
Commercial	Pb>Ni>Cd>Zn>Cr>Mn>Cu>Fe
Industrial	Pb>Cd>Ni>Zn>Cu=Cr>Mn>Fe

However when juxtaposed with categories of enrichment invented by Zoller [18] given in Table 3, there occur a somewhat different conclusion. For residential dumpsite: There is significant enrichment (5≤EF<20) for Cd, Ni, Pb and Zn; moderate enrichment (2≤EF<5) for Cr, Cu and Mn; minimal enrichment (EF<2) for Fe. For commercial dumpsite: there is significant enrichment (5≤EF<20) for Cd, Cr, Ni, Pb and Zn; moderate enrichment (2≤EF<5) for Cu and Mn; minimal enrichment (EF<2) for Fe. For industrial dumpsite: there is significant enrichment (5≤EF<20) for Cd, Cr, Cu, Ni, Pb and Zn; moderate enrichment (2≤EF<5) for Mn; minimal enrichment (EF<2) for Fe. This observed difference in pollution categorization is attributed to the use of background values as the reference concentrations in both cases instead of the scarcely-available pre-industrial concentration data required for contamination factors according to Håkanson [15]. This therefore necessitates the unification (standardization) of pollution classification when background values are used instead of pre-industrial values. This is a note-worthy achievement of this research work (treated below). The observed enrichment of 1.00 for Fe is expected since it served as the immobile element in the equation for calculating enrichment factor. The trend of heavy metal enrichment at the different dumpsites is summarized in Table 5. As shown there, for all the three types of dumpsites and waste sources, Pb has the highest enrichment while Fe has the least.

3.4.3 Index of geo-accumulation (I_{geo})

Table 4 gives the results for index of geo-accumulation for the heavy metals at respective dumpsites. The degree of metal pollution is assessed in terms of seven contamination classes invented by Muller [25] as shown in Table 3. The results give the following: All the three dumpsites are unpolluted (I_{geo}≤0) with Fe and moderately polluted (1<I_{geo}≤2) with Cr, Cu and Mn; the residential dumpsite is moderately to strongly polluted (2<I_{geo}≤3) with Cd, Ni, Pb and Zn; the commercial dumpsite is moderately to strongly polluted (2<I_{geo}≤3) with Cd, Ni and Zn, and strongly polluted (3<I_{geo}≤4) with Pb; the industrial dumpsite is moderately to strongly polluted (2<I_{geo}≤3) with Ni and Zn, and strongly polluted (3<I_{geo}≤4) with Cd and Pb. Table 5 summarizes the trend of heavy metal contamination on the basis of index of geo-accumulation. As can be seen from the data, for all the three dumpsites and waste sources, Pb has the highest metal accumulation while Fe has the least.

3.5 Integrated Pollution Index

It is generally agreed that most heavy metal contamination in the surface environment is associated with a mixture of contaminants rather than one metal contaminant [49], thus came the concept of integrated indices. Integrated indices are indicators used to calculate more than one metal contamination, which were based on the single indices. Each kind of integrated index might be composed by the above single indices separately. In this study, average of pollution index was used to determine the presence of multi-element contamination.

3.5.1 Average of pollution index (PI_{Avg})

The average of pollution index as well as the trend of this integrated index in the three different types of dumpsites studied is presented in Table 6. Interpreting the results obtained in view of the standard suggested by Bahattacharya [27] (Table 3), one would classify all the urban dumpsite soils studied as low quality soils due to the presence of multi-element contamination (PI_{Avg}>1). The observed trend for the average of pollution index based on the three single indices (C_f _PI_{Avg}; EF_PI_{Avg} and I_{geo}_PI_{Avg}) is as follows: IND>RES>COM. This indicates that industrial dumpsite exhibits highest multi-element contamination while commercial dumpsite exhibits least multi-element contamination.

3.6 Unification (Standardization) of Pollution Indices Using Background Values

In the above equations, the reference value was used to assess the degree of pollution, but it was not uniform in values. Different reference values such as the pre-industrial reference level, the average crust level, the background level, baseline, national criteria, threshold pollution value, and Sediment Quality Guidelines (effect range low and effect range medium) have been proposed and used by researchers.

However, using different reference values will lead to discrepancy in assessment. For example, the single pollution index value >1.0 would indicate that it is polluted when threshold value (maximum permissible level of metal) was referred while it would indicate unpolluted soil to some extent when background level was referred. This therefore calls for the unification (standardization) of pollution indices using background values. Here, background value is defined as the metal concentration in the adjoining uncontaminated (control) sites which in most cases could be about 100 m away from the contaminated sites or the dumpsites. Such unification using background values is necessary because of the following challenges faced with other reference values: (i) some reference values such as pre-industrial reference level, sediment quality guidelines, etc. are not readily available for all metals; (ii) many countries lack soil quality guidelines indicating the threshold levels or baseline value of heavy metals; and (iii) some reference values such as world-soil average are subject to change due to increasing effect of industrialization on soil metal contents, and thus requires constant update.

In this study, the reference values were the background levels. Using control samples from the same area with each dumpsite ensures similar lithogenic (crustal) contribution of heavy metals. This therefore enables the determination of the level of metal contribution from anthropogenic sources, and hence differentiating anthropogenic-related contaminations from lithogenic-related inputs. When reference values other than the background values (as defined above) were used to calculate single indices, the terminologies on pollution classes would need to be modified. In order to unify the results of pollution indices, we adopted the use of background levels as the reference values for calculating pollution indices and five classes were proposed to describe the degree of contamination. This is similar to the approach used by Gong Qingjie et al. [50]. The unified pollution classification model developed in this study is shown in Table 7, and is named “Unified Contamination Classification by Eze at Bauchi (UCCEB).”

3.7 Evaluation of Heavy Metal Contaminations of the Dumpsites Using UCCEB Classification Model

The developed UCCEB classification model was applied to the results obtained from the studied dumpsites. An interesting coherence was observed among the single pollution indices, thereby validating the new classification model. Table 8 summarizes the pollution levels of the dumpsites by heavy metals based on the UCCEB model thereby giving a reliable result of the effect of solid waste source (dumpsite type) on heavy metal contamination of urban soils in Bauchi, Nigeria.

Table 6. Average of pollution index and its trend among dumpsites

INDEX	RES	COM	IND	TREND
C_f _PI_{Avg}	6.46	6.28	7.56	IND>RES>COM
EF_PI_{Avg}	6.38	6.27	6.87	IND>RES>COM
I_{geo}_PI_{Avg}	1.79	1.77	2.03	IND>RES>COM

C_f _PI_{Avg}: Average of pollution index based on contamination factors; EF_PI_{Avg}: Average of pollution index based on enrichment factors; I_{geo}_PI_{Avg}: Average of pollution index based on index of geo-accumulation; RES: Residential dumpsite; COM: Commercial dumpsite; IND: Industrial dumpsite

Table 7. UCCEB pollution classification using background values of heavy metals

UCCEB pollution classification					
	Pollution class				
Indices	**1: Deficient pollution**	**2: Low pollution**	**3: Moderate pollution**	**4: Strong pollution**	**5: Extreme pollution**
C_f	C_f<2	2≤C_f<5	5≤C_f<16	16≤C_f<35	C_f ≥35
EF	EF<2	2≤EF<5	5≤EF<16	16≤EF<35	EF ≥35
I_{geo}	I_{geo}<0.50	0.50≤I_{geo}<1.75	1.75≤I_{geo}<3.50	3.50≤I_{geo}<4.50	I_{geo} ≥35

C_f: Contamination factor; EF: Enrichment factor; I_{geo}: index of geo-accumulation. Note: the terminologies on pollution classes for the single indices can also be used for the integrated indices calculated from the respective single indices

Table 8. Effect of solid waste source on heavy metal contamination level based on UCCEB classification model

Solid waste source (Dumpsite)	**Pollution class**				
	1: Deficient pollution	**2: Low pollution**	**3: Moderate pollution**	**4: Strong pollution**	**5: Extreme pollution**
Residential	Fe	Cr, Cu, Mn	Cd, Ni, Pb, Zn		
Commercial	Fe	Cu, Mn	Cd, Cr, Ni, Pb, Zn		
Industrial	Fe	Mn	Cd, Cr, Cu, Ni, Pb, Zn		

The result above is a clear indication that among the three dumpsite types studied, the order of multi-element contamination is as follows: Industrial > Commercial > Residential. That is, multi-element contamination is greatest in industrial dumpsite and least in residential dumpsite.

4. CONCLUSION

From the results obtained, it is obvious that heavy metal contamination of urban soils in Bauchi, Nigeria is strongly affected by the source area of waste materials or the dumpsite type. Heavy metal contamination based on single pollution indices used gives the following trend: Pb > Cd > Ni > Zn > Cr > Mn > Cu > Fe for residential soils; Pb > Ni > Cd > Zn > Cr > Mn > Cu > Fe for commercial soils and Pb > Cd > Ni > Zn > Cu > Cr > Mn > Fe for industrial soils. In view of the discrepancies in results obtained when different reference values are used, the development of a unified contamination classification called Unified Contamination Classification by Eze at Bauchi (UCCEB) was undertaken in this study. The application of UCCEB classification model gives the following results: Residential dumpsite (RES): moderate pollution with respect to Cd, Ni, Pb and Zn; low pollution with respect to Cr, Cu and Mn; and deficient pollution with respect to Fe. Commercial dumpsite (COM): moderate pollution with respect to Cd, Cr, Ni, Pb and Zn; low pollution with respect to Cu and Mn; and deficient pollution with respect to Fe. Industrial dumpsite (IND): moderate pollution with respect to Cd, Cr, Cu, Ni, Pb and Zn; low pollution with respect to Mn; and deficient pollution with respect to Fe. Thus the order of multi-element contamination can therefore be summarized as IND>COM>RES.

5. RECOMMENDATIONS

The following recommendations are considered essential based on the results of this research work.

1. In determining the degree of anthropogenic-related contaminations in soils as opposed to lithogenic-related ones, the use of background concentrations of elements instead of pre-industrial reference level, threshold values, national criteria, etc. is highly recommended.
2. The background values as defined here is the concentrations of the elements in control site free from contaminations, usually 100 m away from the dumpsite. A separate control site should be located for each dumpsite when the dumpsites are in different areas. Taking control samples from the same crustal base as the dumpsite ensures that both the dumpsite and control site poses similar lithogenic-based concentrations of the elements. This

will help in differentiating contaminations associated with anthropogenic (human) activities from elemental concentrations based on lithogenic (natural) inputs.

3. The comparison of results of pollution indices obtained with the UCCEB model is highly recommended. This will enable reliable quantification of the degree of pollution in the studied soil.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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