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John JIYA Musa
Federal University of Technology Minna

Julia Bala
Nottingham Trent University

Hassana Ibrahim Mustapha
Federal University of Technology Minna

Elijah Tsado Musa
University of Ilorin

DETERMINATION OF ELEMENTAL COMPOSITION OF SOIL SAMPLES FROM SELECTED DUMPSITES IN NASARAWA, KOGI AND NIGER STATES, NIGERIA

J.J. Musa[1*], J.D. Bala[2], H.I. Mustapha[1], M.Y. Otache[1], E.T. Musa[3], M.P. Akos[1], Y.I. Yerima[1], E.S. Daniel[1]

[1]Department of Agricultural and Bioresources Engineering, [2]Department of Microbiology
School of Life Sciences, Federal University of Technology,
P.M.B. 65, Minna, Niger State, Nigeria
[3]Central Research Laboratory, University of Ilorin, P.M.B. 1515, Ilorin, Nigeria

johnmusa@futminna.edu.ng, Tel: +2348036682747

ABSTRACT

The growing dominance of urban environment with heavy metals through natural and anthropogenic depositions and the potentially adverse health implications following environmental contaminations have focused attention on the disposal of municipal and industrial wastes. This study employed analytical procedures to investigate the concentrations of chromium, iron, copper, zinc, manganese and aluminium at the municipal waste dump site of the study areas. Soil samples were randomly collected from different waste dumpsite across Nasarawa, Kogi, and Niger states and an undisturbed soil 100m away from the dumpsites was chosen as the control. From the result obtained, it was observed that the metals in all dumpsite types followed the order: Mn>Fe>Zn>Cu>Cr>Al. Mn had the highest mean concentration which was recorded in Bida, Borgu and Minna in Niger State while Al was the least detected in all the dumpsites with the lowest mean concentrations (5.7±0.96) recorded in Borgu. Mean concentration of all the metals at the dumpsites was higher than at the control which means there is an anthropogenic contribution from the environment. The concentrations of the heavy metals were generally lower than their respective guideline values for the protection of human and environmental health. However, with prolong practice of dumping refuse at these sites; concentrations of the heavy metals may increase above the recommended limits. Therefore, we recommend that further research be carried out on the heavy metals concentration of the waste materials to identify those that are potential sources of soil contamination to suggest appropriate treatment and disposal methods.

Keywords: Anthropogenic, Heavy Metals, Organic Carbon, Organic Matter, pH

INTRODUCTION

Rapid population growth coupled with urbanization and industrial growth is one of the most severe and growing problems in developing countries such as Nigeria as it causes the shortage of land for both agricultural practices and waste disposal in urban and peri-urban areas (Jafaru *et al.,* 2015). Waste management (WM) refers to the collection, transfer, treatment, recycling, resources recovery and disposal of use-

*Corresponding author

less material in everyday activities. The goals of municipal waste management are to promote the quality of the urban environment, generate employment and income, and protect environmental health and support the efficiency and productivity of the economy (Ogwueleka, 2009). Adewuyi (2004) and Bello and Osinubi (2011) hold the view that, poor management of municipal, biological, agricultural or industrial wastes leads to severe soil and groundwater contamination as well as adverse health effects. Waste disposal in the world is a problem that continues to grow with human civilisation, and no method so far is entirely safe. Research has shown that all forms of waste disposal have adverse effects on the environment, public health and local economies (Abdus-Salam, 2009; Jafaru *et al.*, 2015). Giuliano *et al*., 2007 and Jafaru *et al.* (2015), pointed out that Pollution in soil systems is strictly related to human activities such as industry, agriculture, burning of fossil fuels, mining and metallurgical processes and their waste disposal. Toxic elements from anthropogenic activities such as dumping of waste in random or selected dumpsite lead to heavy metals and metalloids contamination of the soil by biological and chemical mechanisms with a potential impact on human health.

In Nigeria, dumpsites are often used for farming activities due to the rich soil nutrient, in a research by Agyarko *et al*. (2010) it was observed that plants grown on dumpsites performed better than those built on the surrounding areas, as a result of the decayed and composted municipal solid wastes enhances soil fertility (Ogunyemi *et al*., 2003; Agyarko *et al*., 2010). Apart from the local disturbance of the environs, soil profile and structure, heavy metals contained in municipal solid waste are taken up by plants which ends up in our food chain causing widespread of health challenges leading to a loss of biodiversity, amenity and economic well-being of residents in the vicinity of waste dumpsites (Lee *et al*., 2001; Zhang *et al*., 2002; Galan *et al*., 2003; Cui *et al*., 2004).
Municipal solid waste as well as the compost generated from it have been reported to contain a considerable amount of heavy metals (Ukpebor and Unuigbe, 2003; Hargreaves *et al*., 2008; Agyarko *et al*., 2010; Jafarau *et al.,* 2015) that are usually found in soils, in and around waste dumpsites. Compost from municipal solid waste material used in agricultural fields also contributes to elevated levels of heavy metals in agrarian crop produce (Ukpebor and Unuigbe, 2003; Adeniyi *et al*., 2008; Hargreaves *et al*., 2008; Hogarh *et al*., 2008; Agyarko *et al*., 2010; Dasaram *et al*., 2011; Jafaru *et al.*, 2015). For instance, a study conducted by Ukpebor and Unuigbe (2003) in Benin City (Nigeria) showed that dump site soils contained elevated levels of heavy metals as compared to soil samples taken 50 m from the dump site. Though several reports on heavy metal contamination due to municipal solid waste or its compost in waste dumpsites and agricultural soil have been made, such information is very limited in North-central Nigeria. A preliminary survey at the Nasarawa, Kogi and Niger states waste dump site showed that some residential buildings were being constructed very close (about 50-100 m) to the waste dump site. Also, most of the residents were doing some farming or gardening on the dumpsite. These pose a health threat as they were growing their crops on soils that may have been contaminated with unknown levels of heavy metals.

Furthermore, it was observed that burning of waste at the dump site generates a very thick smoke which created severe air pollution and threatened the lives of people in the surrounding communities. It was also observed that individuals would usually go to the dump site to collect the burnt municipal solid waste (loosely termed compost) for their farming activities. Children living around the waste dump site usually came out to play and, in the process, could ingest some soil particles into their bodies. Thus, the location and management of the dump site pose a health hazard to both human beings and animals though heavy metals are natural components of the environment including soil which is of great concern when they are continuously added through refuse dumping. These metals are believed to bio-accumulate in soil and interaction with soil component and consequently enter the food chain through plants or animals (Rubio *et al.*, 2000; Dosumu *et al*., 2003; Mohammed and Elsayed, 2007). Akaeze (2001), from his study in Uyo, Nigeria showed that metals such as Fe, Pb and Cu may also contaminate soil water which constitutes the primary sources of drinking water. Lead is a toxic element, it is contamination of soil, and agricultural land may lead to encephalopathy, renal effect and haematological effects as pointed out by Akaeze (2001) and Eddy *et al.* (2006).

Degradation of soil environment is generally caused by solid wastes of different types, to solve the problem posed in our environment by waste disposal, there must be proper management of solid waste. Solid waste as defined by the United States Environmental Protection Agency is any useless unwanted or discarded material with insufficient liquid content to be free-flowing. The non-free flowing or viscous nature of the solid waste gives rise to the accumulation of solid wastes on some habitable parts of the earth. Solid is an asset when adequately managed, and Nigeria government has invested much in municipal solid waste management in cities, though the goal cannot be said to be achieved.

This study is aimed at determining the elemental composition of the soil samples obtained from some of the significant dumpsites in Nasarawa, Kogi and Niger State in a way to quantify this information, to analyse the result to see if the values are within the acceptable limits and to serve as a baseline data for future monitoring

MATERIALS AND METHODS

Study Sites and Sample Collection

The study was conducted in Nasarawa, Niger and Kogi States; these cities are located within North Central (or Middle Belt) Nigeria (Figure 1). Kogi State sampling points were selected in Okene (Plate I), Dumpsites selected in three different districts of Nasarawa State comprise of Lafia, Akwanga and Angwan Bai (Plate II). In Niger State, three sampling sites were established in Borgu, Bida and Maikun-

FIGURE 1
Map of Nigeria showing the study sites; Kogi, Nasarawa and Niger States

PLATE I
Okene dumpsite in Kogi State.

kele dumpsites (Plate III) in Minna. Kabba (KB), Lokoja (LK). A Reference site (REF) was chosen also 100m away from each of the dumpsites which are also unaffected by any farm practice.

PLATE II
Angwan Bai dumpsite, Nasarawa State

PLATE III
Maikunkele dumpsite, Minna, Niger State

Soil samples were collected randomly from the dumpsites and the reference site using depth calibrated soil auger at a depth level 0-5cm, 5-15cm and 15-30cm. The samples of soil were collected into clean polythene bags and tightly sealed as recommended by Olayinka *et al.* (2014).

Heavy metals Analysis

Soil samples were digested after drying in the oven and ground into fine earth (<2.00 mm) fraction using pestle and mortar. Two grams of sample was weighed into a digestion flask followed by the addition of about 30 mL mixture of concentrated HNO_3 and concentrated $HCLO_4$ in a ratio of 1:1.5. The mixture was digested by heating gently on a digestion rack in a fume chamber for about 30 min until the digest turned colourless with no charred organic matter remaining. It was then allowed to cool and then transferred with distilled water into a 100 mL volumetric flask and made up to volume. The filtrate was analyzed for metals by Atomic Absorption Spectrophotometer (AAS) (Pam *et al.*, 2013).

Statistical Analysis

Data obtained were analysed using MINITAB (version 14.0), statistical software for Microsoft Excel. Results are presented as a mean ± standard deviation. Statistical variations were considered significant at $p<0.05$. Relationships between metals and other controlling factors were determined using the Pearson coefficient in a two-tailed test ($r < 0.01$ and 0.05).

RESULTS AND DISCUSSION

Heavy Metal Concentrations in the Studied Sites

From the effect of concentrations, it was noted that the metals in all dumpsite types followed the order: Mn>Fe>Zn>Cu>Cr>Al as shown in Figure 2. Mn had the highest mean concentration which is recorded in Bida, Borgu and Minna in Niger State while Al is the least detected in all the dumpsites with the lowest mean levels (5.7±0.96) recorded in Borgu.

Mean concentration of all the metals at the dumpsites (Table 1) is higher than at the control which means there is an anthropogenic contribution from the environment (Table 2). Elevated concentrations of Mn, Fe, Zn, Cu and Cr in soils are commonly due to man's inputs except for Al which is unaffected. In this study, there are significant differences (P=0.05) in the concentrations of heavy metals in the soils collected from the dumpsite relative to the control site.

Chromium (Cr). The mean concentrations of Cr in soil ranged from 16.33±3.51 to 66±14.11 mgkg^{-1} in all the dumpsites (Table 1) and are higher than that at the control site (0.6±0.3 to 22±9.64 mgkg^{-1}). The values of Cr obtained in this study were lower than the 900–2000mgkg^{-1} reported by Adefemi and Awokunmi (2009) in dumpsites within Ado-Ekiti town in South West Nigeria. The elevated concentrations were ascribed to deposited waste which contained high concentrations of Cr. Similarly low levels of chromium have been observed in surface soils under waste dumps in Onitsha, Nigeria (Nwajei *et al.*, 2007) and soils around foam manufacturing industry (Oviasogie and Omoruyi, 2007a). The levels of chromium found in this study was relatively low compared to chromium levels reported for soil profiles of automobile workshops (Oguntimehin and Ipimoroti, 2008), urban soils (Umoren and Onianwa, 2005), soil profile automobile mechanic waste dumps (Iwegbue *et al.*, 2006b), crude oil contaminated soils (Iwegbue *et al.*, 2009b) and soils of municipal waste dumps (Osakwe and Egharevba, 2008). The values of Cr obtained in this study are below the target value and intervention values set by DPR (Table 4). It is also below the allowable limits of Cr for some countries; 150mgkg^{-1} in France; 100mgkg^{-1} in Austria and Spain; 60mgkg^{-1} in Germany and Sweden; and 30mgkg^{-1} in Denmark and the Netherlands (Pam *et al.*, 2003). Therefore, most of the values obtained in this study conform to acceptable limits.

As observed by Adelekan and Abegunde (2011), Chromium is one of the heavy metals whose concentration in the environment is steadily increasing due to industrial growth, especially the development of metal, chemical and tanning industries. Other sources of chromium pollution are water erosion of rocks, liquid fuels, and industrial and municipal waste. In this study, a high concentration of Cr was envisaged due to a large number of printing and photography industries, paper mill, leather tanning and fertiliser waste that are dumped within the cities. Although Cr toxicity in the environment is not common, it still presents some risks to human health since chromium can be accumulated on the skin, lungs, muscles, fat, in the liver, dorsal spine, hair, nails and placenta where it is traceable to various health conditions (Reyes-Gutiérrez *et al.*, 2007).

Iron (Fe). The concentrations of Fe ranged from 27.67±3.51 to 74.00±7.55 mgkg^{-1} in all the dumpsites (Table 1) and 5.6±0.0 to 40.67±6.66 mg kg^{-1} at the control sites (Table 2). The levels of Fe found in these sites were lower than values reported in soils in the vicinity of automobile spare parts market (Nwajei and Iwegbue, 2007) and oil fields in Nigeria (Iwegbue *et al.*, 2006a). However, Oviasogie and Ofomoja (2007) reported 1.87-117.67 mgkg^{-1} as available Fe in soils

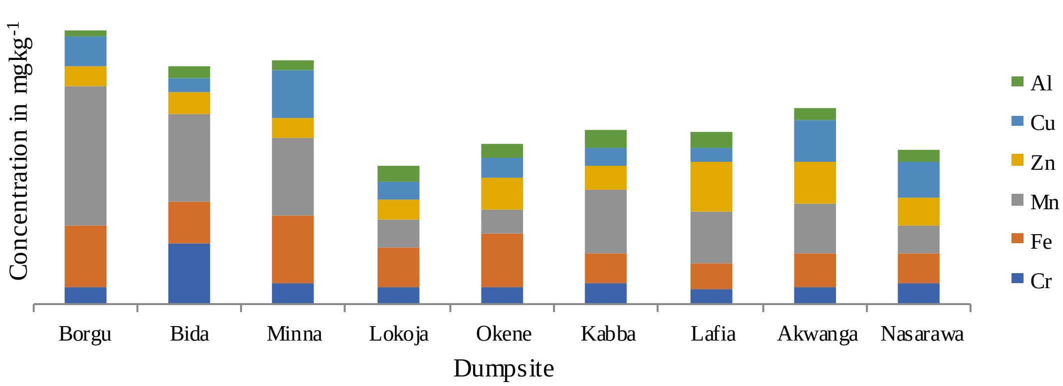

FIGURE 2
Heavy metals concentrations (mgkg^{-1}) at various dumpsites

TABLE 1
Heavy metals content at a dumpsite in different locations (mgkg^{-1})

Study Location	Statistical Distribution	Parameters					
		Cr^{2+}	Fe^{2+}	Mn^{2+}	Zn^{2+}	Cu^{2+}	Al^{3+}
NIGER STATE							
Borgu	Range	12 - 18	51 - 79	106 - 176	19 - 21	32 - 36	5 - 6.80
	Means	18 - 22	66±14.11	149±37.64	20±1.00	33.67±2.08	5.7±0.96
Bida	Range	51 - 79	66 - 81	50 - 131	19 - 28	10 - 24	9.80 - 16.30
	Means	66±14.11	44±3.0	92.67±40.67	23±4.58	15.67±7.37	12.8±3.28
Minna	Range	19 - 26	66 - 81	78 - 86	12 - 26	31 - 62	10.80 - 13.60
	Means	22±3.61	74±7.55	82.33±4.04	20.33±7.37	50.33±16.86	11.87±1.51
KOGI STATE							
Lokoja	Range	17 - 20	27 - 58	23-39	18 to 23	16 to 22	11.3-20.8
	Means	18.5±3.54	43±15.52	30.33±8.08	20.67±2.52	19.33±3.06	15.7±4.8
Okene	Range	16 - 21	53 - 63	23-26	33-37	15-24	14.8-18.7
	Means	18.5±3.54	58±7.07	24.5±2.12	35±2.82	19.5±6.36	16.75±2.75
Kabba	Range	19.70 - 28	20 - 49	62-76	22-29	12 to 29	10.3-22.3
	Means	23.23±4.29	31±15.72	69±7	25±3.61	19.67±8.62	17.67±6.18
NASARAWA STATE							
Lafia	Range	13-20	20-36	43-66	43-61	13-17	16.3-19.3
	Means	16.33±3.51	27.67±3.51	56±11.79	51.67±9.02	15.33±2.08	17.47±1.61
Akwanga	Range	18-21	29-45	48-62	38-48	33-58	10.2-11.8
	Means	19.67±1.52	35.67±8.33	53.33-7.57	43.33±5.03	44±12.77	13±3.56
Nasarawa	Range	19-27	21-46	20-43	28-31	33-41	10.7-13.9
	Means	22±4.36	32.33±12.67	31±11.53	29.67±1.53	37.33±4.04	12±1.68

that have received cassava effluents in Benin City, Nigeria. Similarly, Aina and Sridhar (2004), Oviasogie and Omoruyi (2007b) and Iwegbue *et al*. (2009a) observed lower levels of Fe in soils around foam manufacturing, fertiliser industry and metallic scrap sites respectively as compared to the standards of iron found in these sites. However, even though concentrations of Fe found in these sites fitted into common range found in unpolluted soils (Alloway, 2005), significant amounts of Fe arises from the anthropogenic input.

Manganese (Mn). Manganese (Mn) is among the more abundant element in the earth's crusts and is widely distributed in soils, sediments, rocks and water (Shrivastava and Mishra, 2011). Mn analysis gave values which range from 24.5±2.12 to 149.00±37.64 mgkg^{-1} at dumpsites soil and 4.5±3.53 to 33.00±13.89 mgkg^{-1} at control sites. Although the levels found for Mn are above the control levels, there are no soil quality criteria established for Mn for now (Karen, 2005). However, judging by other reports and mean concentrations observed in this study, it would appear that the levels of Mn in the soils investigated is building up substantially, especially at the Borgu dumpsites, and need to be monitored to prevent any further increase. High level of manganese may be attributed to the composition of metal alloys, batteries, glass and ceramic materials in the dumpsites. The concentrations of manganese found in these sites are similar to levels of manganese in soils that have received the significant impact of crude oil in Nigeria (Iwegbue *et al*., 2009b).

Zinc (Zn). The Zinc content in all the soils ranged from 20.00±1.00 to 51.67±9.02 mgkg^{-1} at dumpsites (Table 1) and 0.67±0.21 to 24.33±3.79 mgkg^{-1} at the control sites (Table 2). These values are higher than those at the control and suggest that there is an anthropogenic contribution. Since no industry exists in the vicinities of these areas, the dumpsites are the major contributor of Zn in the urban soil. The dumpsites have a high composition of composted materials and agrochemicals. Some of the studies have also linked high Zn levels in

TABLE 2
Heavy metals content from reference site in different locations (mg/kg)

Study Location	Statistical Distribution	Parameters					
		Cr^{2+}	Fe^{2+}	Mn2+	Zn2+	Cu2+	Al3+
NIGER STATE							
Borgu	Range	0.40 - 0.90	27 - 38	21 - 26	0.6 - 0.9	0.5 - 0.9	10.6 - 11.3
	Means	0.63±0.25	31.33±5.86	23.33±2.52	0.67±0.21	0.7±0.2	11.03±0.38
Bida	Range	0.60 - 1.10	22 - 30	27 - 31	1.3 - 1.7	0.40 - 0.70	9.70 - 14.4
	Means	0.83±0.25	27±4.36	27.67±3.06	1.53±0.21	0.53±0.15	11.37±2.63
Minna	Range	1.10 - 1.60	35 - 48	24 - 49	1.7 - 2.6	1.60 - 1.80	12.80 – 20.0
	Means	1.33±0.25	40.67±6.66	33±13.89	2.1±0.46	1.70±0.10	16.37±3.60
KOGI STATE							
Lokoja	Range	0.3-0.9	19-21	8.00 – 18.00	11.00 - 14	18.00-19.00	6.6-10.30
	Means	0.6±0.3	20±1.0	12.67±5.03	12.67±1.53	18.33±0.58	10.23±1.85
Okene	Range	0-1.4	0-5.6	0.00-7.70	0.00-28.00	0.00-22.00	0.00-11.50
	Means	1.4±0.0	5.6±0.0	7.7±0.00	28±0.00	22±0.00	11.5±0.0
Kabba	Range	2.2-2.6	18-24	2.00 – 7.00	2.00-2.30	11.00-16.00	8.40-12.00
	Means	2.4±0.28	21±4.24	4.5±3.53	2.15±0.21	13.5±3.54	10.2±2.45
NASARAWA STATE							
Lafia	Range	11.00 – 26.00	17.00 – 28.00	1220-Dec	7-11	14-16	10.6-14.7
	Means	22±9.64	21±6.08	16.67±4.16	8.67±2.08	15±1.0	12.37±2.11
Akwanga	Range	14.00 – 31.00	12.00 – 22.00	15-20	20-27	18-Dec	10.6-11.8
	Means	22.67±8.50	16.67±5.03	17.67±2.52	24.33±3.79	15.33±3.06	12.47±2.27
Nasarawa	Range	16.00 – 27.00	10.00 – 17.00	18-26	17-19	20-28	9.8-16.3
	Means	21.67±5.51	13.33±3.51	21.67±4.04	18±1.0	25±4.36	13.37±3.30

urban soils to accumulation from garden fertilising, traffic, industry input and even vehicle emissions, tyre and brake abrasion (Iwegbue *et al.*, 2006a). However, the concentration of Zn in this investigation is small compared with many other studies (Nwachukwu *et al.*, 2010; Nwachukwu *et al.*, 2011 and Shinggu *et al.*, 2007), although it is comparable to that of soils in Cameroon, South East Korea and that of Yauri, North-West Nigeria (Yahaya *et al.*, 2010). The values of Zn obtained in this study conform to the acceptable limits (Table 3). Although little or no information about the toxicity of Zn in humans, it has been reported that Zn interferes with Cu metabolism (Adelekan and Abegunde, 2011). Furthermore, Iwegbue *et al.* (2006a) stated that an acute oral Zn dose might result in symptoms such as tachycardia, vascular shock, dyspeptic nausea, vomiting, diarrhoea, pancreatitis and damage of hepatic parenchyma.

Copper (Cu). Copper was present in all the soil samples investigated 15.33±2.08 to 50.33±16.86 $mgkg^{-1}$ (Table 1). These values are higher than those at the various control sites (0.53±0.15 to 22.00±0.00 $mgkg^{-1}$) but below the target values and intervention values set by DPR (Table 4). The levels of copper found in all sites in this study were below the maximum allowable limit in most countries; (100 $mgkg^{-1}$) in Australia, Canada, Poland, Great Britain, Japan (125 $mgkg^{-1}$), and Germany (50 $mgkg^{-1}$) (Lacatusu, 2000). Cu is used in numerous applications because of its physical properties. The levels of copper observed in this study were higher than the concentration of copper reported for soil of waste dump sites (Osakwe and Egharevba, 2008), mining sites (Gungshik and Mohammed, 2007), and foam manufacturing industry (Oviasogien and Omoruyi, 2007b). Similar levels of copper have been observed in soils of an oil field in the Niger Delta (Iwegbue *et al.*, 2006a). However, higher levels of copper

TABLE 3
Target values for heavy metals in soils ($mgkg^{-1}$)

Metal	Target value	Intervention value
Cr	100	380
Cu	36	190
Pb	85	530
Zn	140	720
Mn	850*	*
Fe	4.7**	*

**Derived from crystal abundance value ** value in %. Adapted from DPR (2002)*

have been recorded in some contaminated sites (Iwegbue *et al.*, 2006b; Kashem *et al*., 2007).

High level of Cu at the dumpsites may also be envisaged from dumping of solid wastes, application of fungicides, livestock manures, sludge and atmospheric deposition (Nwachukwu *et al.,* 2011).

Aluminium (Al). The concentration of Al in all the sites ranged between 5.7±0.96 to 17.67±6.18 $mgkg^{-1}$ at the dumpsites and 10.23±1.83 to 13.37±3.30 $mgkg^{-1}$ at control sites. The concentrations of Al found in the dumpsites are similar to levels of Al found at the control. Thus, the concentrations of Al in all the sites are purely lithogenic which means there is no anthropogenic input. Al concentrations found in this study are much lower than the mean values of 26580-95270$mgkg^{-1}$ reported by Beyene and Banerjee (2011) and below the target values and intervention values set by DPR (Table 3). The obtained mean values for Al in this study is lower than the world average crustal abundance of 82300$mgkg^{-1}$ in an uncontaminated soil as reported by Mohammed and Bashir (2015).

CORRELATION ANALYSIS

Inter-metal concentration correlation analysis of the heavy metals on the waste dumpsites was conducted using Pearson correlation coefficient. Table-4 shows that a positive correlation value was recorded between Fe/Cr, Mn/Fe, Zn/Fe, Zn/Mn and Cu/Zn in Borgu, Bida, Minna, Lokoja, Okene, Kabba, Lafia, Akwanga and Nasarawa dumpsites. In Borgu, Minna, and Akwanga Al and Cr, Fe, Mn, Zn, Cu show negative correlation while in Bida, Lokoja and Kabba all the metals recorded positive correlation. Generally, the negative correlations between some of the heavy metals suggest that as one of the metal increases in the soil, the other one decrease. Conversely, the positive correlations suggest that all heavy metals concerned could accumulate simultaneously in the soil at the dumpsite.

CONCLUSION AND RECOMMENDATION

The result of this study revealed the presence of chromium, iron, copper, zinc, manganese, and aluminum in the dumpsites soil at an appreciable level. However, the present concentrations of the heavy metals were generally lower than their respective guideline values for the protection of human and environmental health. Significant increase of these metals in the dumpsite relative to the reference point is conected to anthropogenic input except for Al which shows no significant difference from the reference point, these suggest that most of the waste materials disposed at the dumpsite are rich sources of the heavy metals which upon decomposition release these elements onto the receiving soils. Hence, soils around these dumpsites should be of concern to prevent both surface and groundwater contamination; this means that engineered waste management system should be installed in order to safely dispose of all refuse to prevent the general public from being exposed to unnecessary hazards through environmental pollution.

Therefore, we recommend that further research is carried out on the compositions of the waste materials to identify those that are potential sources of heavy metals contamination of soil and suggest appropriate disposal methods. Furthermore, the urban wastes management department must provide machinery for wastes segregation before disposal and incineration. In this way, waste materials which are potential sources of heavy metals contamination of soil might be separated and considered for alternative disposal other the present open dumping and incineration practices.

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TABLE 4
Inter-elemental correlation coefficients of the heavy metals concentration

Locations	Items	Cr^{2+}	Fe^{2+}	Mn^{2+}	Zn^{2+}	Cu^{2+}	Al^{3+}
Borgu	Cr^{2+}	1					
	Fe^{2+}	0.96724	1				
	Mn^{2+}	0.99392	0.97828	1			
	Zn^{2+}	0.97515	0.90133	0.94615	1		
	Cu^{2+}	0.97948	0.90901	0.95226	0.99973	1	
	Al^{3+}	-0.9072	-0.78700	-0.87170	-0.9644	-0.95957	1
		Cr^{2+}	Fe^{2+}	Mn^{2+}	Zn^{2+}	Cu^{2+}	Al^{3+}
	Fe^{2+}	0.9493	1				
	Mn^{2+}	0.87404	0.81262	1			
	Zn^{2+}	0.99201	0.94654	0.92064	1		
	Cu^{2+}	0.92074	0.88756	0.96845	0.96243	1	
	Al^{3+}	0.37828	0.46117	0.68034	0.45581	0.6023	1
		Cr^{2+}	Fe^{2+}	Mn^{2+}	Zn^{2+}	Cu^{2+}	Al^{3+}
Minna	Cr^{2+}	1					
	Fe^{2+}	0.97422	1				
	Mn^{2+}	0.94882	0.98173	1			
	Zn^{2+}	0.94882	0.95232	0.88878	1		
	Cu^{2+}	0.96851	0.96408	0.91087	0.99757	1	
	Al^{3+}	-0.62980	-0.46840	-0.46560	-0.56860	-0.58580	1
		Cr^{2+}	Fe^{2+}	Mn^{2+}	Zn^{2+}	Cu^{2+}	Al^{3+}
Lokoja	Cr^{2+}	1					
	Fe^{2+}	0.84376	1				
	Mn^{2+}	0.89130	0.94357	1			
	Zn^{2+}	0.95203	0.93560	0.98042	1		
	Cu^{2+}	0.35601	0.78154	0.58887	0.52822	1	
	Al^{3+}	0.82985	0.97123	0.98563	0.9498	0.70325	1
Kabba	Cr^{2+}	1					
	Fe^{2+}	0.98964	1				
	Mn^{2+}	0.96844	0.92261	1			
	Zn^{2+}	0.99996	0.98825	0.97073	1		
	Cu^{2+}	0.99650	0.97417	0.98589	0.99724	1	
	Al^{3+}	0.87899	0.80141	0.97010	0.88341	0.91578	1
		Cr^{2+}	Fe^{2+}	Mn^{2+}	Zn^{2+}	Cu^{2+}	Al^{3+}
Lafia	Cr^{2+}	1					
	Fe^{2+}	0.99995	1				
	Mn^{2+}	0.95400	0.95703	1			
	Zn^{2+}	0.99983	0.99997	0.95931	1		
	Cu^{2+}	0.93472	0.93831	0.99827	0.94104	1	
	Al^{3+}	-0.23620	-0.22620	0.06597	-0.2185	0.12453	1
		Cr^{2+}	Fe^{2+}	Mn^{2+}	Zn^{2+}	Cu^{2+}	Al^{3+}
Akwanga	Cr^{2+}	1					
	Fe^{2+}	0.89104	1				
	Mn^{2+}	0.83577	0.99394	1			
	Zn^{2+}	0.99718	0.92261	0.87464	1		
	Cu^{2+}	0.92298	0.99711	0.98271	0.94927	1	
	Al^{3+}	-0.03680	-0.48640	-0.5795	0.11177	-0.41860	1
		Cr^{2+}	Fe^{2+}	Mn^{2+}	Zn^{2+}	Cu^{2+}	Al^{3+}
Nasarawa	Cr^{2+}	1					
	Fe^{2+}	-0.04530	1				
	Mn^{2+}	0.03979	0.99638	1			
	Zn^{2+}	0.30038	0.93924	0.96502	1		
	Cu^{2+}	0.25545	0.95426	0.97622	0.99891	1	
	Al^{3+}	0.99553	0.04929	0.13402	0.38915	0.34565	1

Chemistry Department Ahmadu Bello University Zaria, Nigeria who assisted in carrying out soil analyses.

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