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ASSESSMENT OF HEAVY METAL POLLUTION AND CONTAMINATION IN WASTE DUMPSITES WITHIN GUSAU AREA, NORTHWEST NIGERIA

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ABSTRACT

The aims of this research work are to determine the concentrations of metals present in waste dump soils, to evaluate the metal contamination of the soils using the pollution indices and to identify whether the sources of heavy metals were natural and/or anthropogenic. Analysis of the soil was carried out using EDXRF technique. Three points were assessed from each three wastes dumpsites (Hira Dekodi, Low Cost and Old Market), using portable XRF equipment for the in-situ data acquisition. The data obtained were subjected to statistical analysis and environmental pollution index models. The data showed mean concentrations of the heavy metals analyzed in the following order Fe > Zn > Mn > Cr > Pb > Ni. The mean concentrations of these three metals (Pb, Zn and Cu) exceeded their average crustal abundance, which is an indication of possible contamination. Environmental pollution models applied to the geochemical dataset revealed Zn, Pb and Cu as considerable/moderately contaminated, which generally indicated severe potential contamination in the investigated area. Other metals such as Mn, Cr, Ni and Fe showed low contamination factors. However, from the results of geo-accumulation/ecological risk index of the heavy metals, the study areas were unpolluted and indicated low ecological risk factors with respect to the analyzed parameters. The chemical assay revealed positive and significant relationship between Cu, Pb, Mn and Fe while Cr showed positive and significant relationship with Mn, Fe and Cu. However, Zn shows significant level of relationship only to Mn. Virtually, all the heavy metals showed significant correlation to each other. This, revealed similar sources of enrichment for the heavy metals. These significant correlations might not be unconnected to the weathering, bed rock dissolution and anthropogenic sources.

Keywords: Heavy Metals, Ecological Risk Factor, Pollution index, Health impact, Dumpsites

INTRODUCTION

Human activities on land, in the water and air contributes to the contamination of soil and organisms with potentially toxic substances. High level of land use changes has led to strong risk of heavy metal contamination in Gusau area as reported in the work of Tijani *et al.* (2020). Soils are precious natural resources widely used as environmental indicators and their chemical analysis provide significant information on the degree of anthropogenic activities of an area (Amadi, *et al.*2017).

Urban soils have become highly influenced by anthropogenic activity due to rapid urbanization and industrialization as opined in the work of Li *et al.* (2008). Pollution sources such as vehicular emissions, industrial wastes, dust sedimentation, coal combustion, and other activities exists in the urban soils, thereby making the soil a "sink" of heavy metals (Grosheva *et al.*, 2000, Amadi *et al.*, 2013 and Amadi *et al.*, 2017). In recent, years there has been increasing interests regarding heavy metal contaminations in soils, apparently due to their toxicity and perceived persistence within the aquatic systems. Furthermore, analysis of soil is a useful method of studying environmental pollution by heavy metals (Tijani *et al.*, 2020). According to Sieghardt *et al*., (2005), heavy metals are known to exert their toxicity through dermal, inhalation and ingestion pathways from urban soils. This can result to severe human health consequences. Soil quality is a good indicator of pollution in water column, where it tends to concentrate the heavy metals and other organic pollutants (Birley and Lock, 1999; Saeed and Shaker, 2008; Amadi *et al.*, 2014). The quantity of heavy metals introduced into the soil will increase the heavy metal build-up of the soil and thus increase the concentration of both essential and non-essential metals in the soil which also affect the physical and chemical properties of the soil (Vwioko *et al.*, 2006).

This research is designed to assess the metal pollution and influence of the sources of the toxic metals in the soils of three different waste dumps within Gusau metropolis, Zamfara State.

Description of the Study Area

The study area lies within latitude $12^0$15′N, $12^0$03′N and longitude $6^0$30′E, $6^0$45′E. Three waste dumpsites within the Gusau metropolis were studied, these includes communities like Hira Dekodi, Low cost and area around Old Market respectively (Figure 1). The coordinates of the three waste dumpsites are Hira Dekodi (12^0 09′57.8″N, $06^0$41′10.6″E), Low Cost ($12^0$10′21″ N, $06^0$41′15 ″ E) and Old Market area ($12^0$9′57 ″ N, $06^0$41′10″E).

The study area is characterized by two distinct seasons, the dry and rainy season. The mean annual rainfall in the area was 800 mm while the minimum and maximum temperatures were 24^0C and 40^0C respectively. The dry season is between the month of October to May of the year while the rainy season normally commence from June to September and sometimes reaches October as reported by Zamfara State Government (2001).

The vegetation of the study area is that of the Sahelian Savanah with a variety of short grasses, thorn shrubs and scattered trees which can resist long dry season.

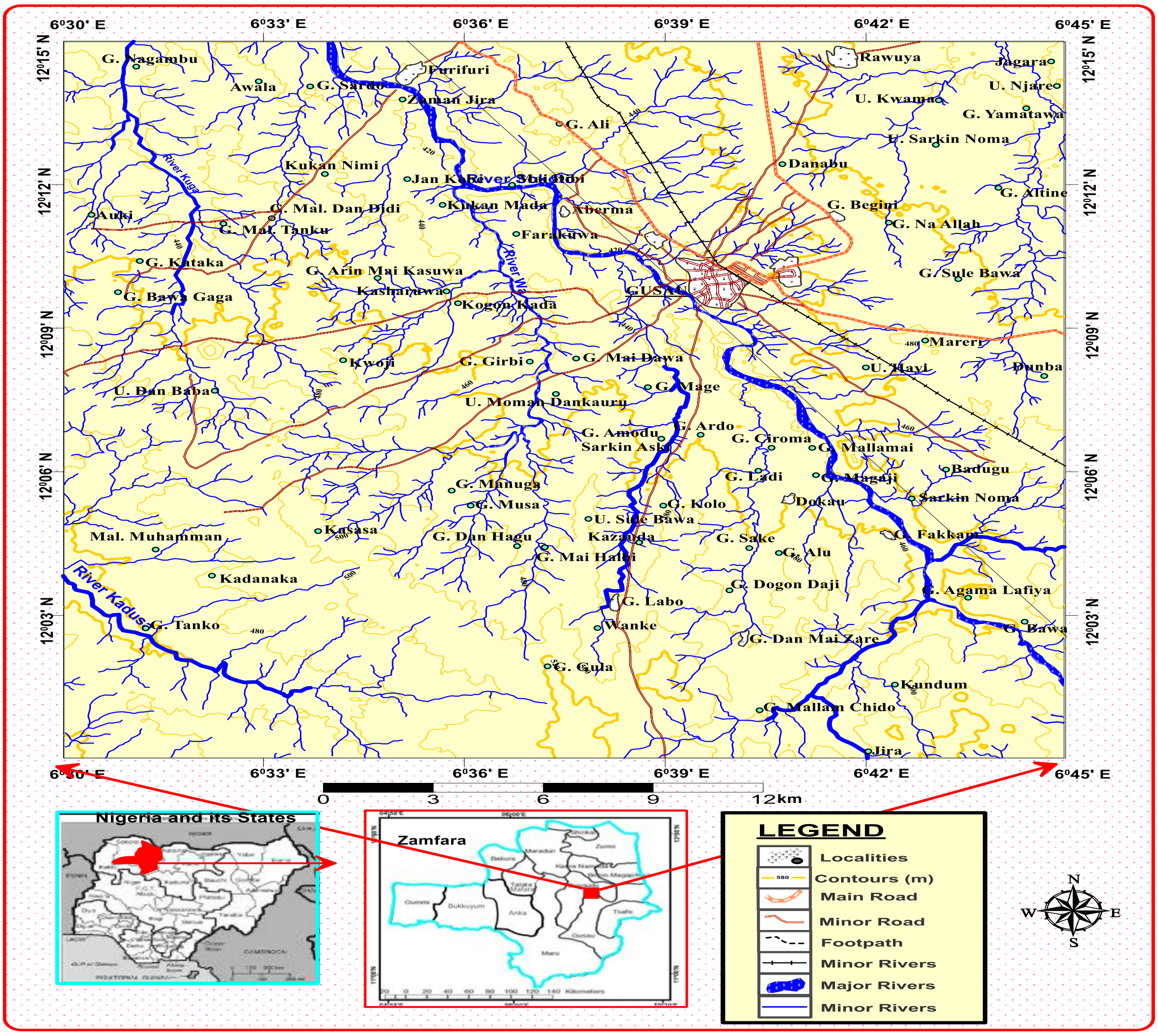

Figure 1: Map of the study area

MATERIAL AND METHODS

Portable X-ray fluorescence spectrometer was used to determine the concentrations of heavy metals of interest (such as Pb, Cu, Fe, Zn, Ni and Cr) in-situ from the three waste dumpsites of interest within the study area. Three points were sampled for the in-situ analysis within the investigated sites.
Under this method, inorganic parameters of interest were identified and quantified using a field portable energy-dispersive x-ray fluorescence spectrometer.

Assessment of soil contamination

Soils have the capability to record the history and degree of pollution. To assess the degree of pollution for a given heavy metal requires that the pollutant concentration be compared with an unpolluted reference material (geochemical background). The reference material represents a benchmark to which the metal concentrations in the polluted samples are compared and measured. Many authors have used the average shale values or the average crustal abundance data as the reference baselines. In this work average shale values (Pb = 20, Zn = 95, Cu = 45, Cr = 90, Ni = 68, Mn = 850 and Fe = 47200) were used as reference material for the background values.
The following environmental pollution models were used to unravel the level of pollution.

Contamination factor (Cf)

The level of metal contamination can be expressed by the contamination factor (Cf). Cf is the ratio between the metal content in the sediment to the background value of the metal (Martin and Meybeck, 1979). It is an effective tool for monitoring the pollution over a period of time and it is calculated as follows

$Cf = C_i$ heavy metal $/C_b$ metal background value (1)

According to Hakanson (1980), CF < 1 indicates low contamination; 1 < CF < 3 is moderate contamination; 3 < CF < 6 is considerable contamination; and CF > 6 is very high contamination.

Contamination degree (Cd)

To facilitate pollution control, Hakanson (1980) proposed a diagnostic tool referred to as ‘degree of contamination’ (Cd) and it is determined as the sum of the CF for each sample:

$$Cd = \Sigma Cf \quad (2)$$

The Cd is aimed at providing a measure of the degree of overall contamination in surface layers in a particular core or sampling site. Hakanson, (1980) proposed the classification of the degree of contamination (Cd) in sediments as: Cd < 6 (low degree of contamination), 6 < Cd < 12 (moderate degree of contamination), 12 < Cd < 24 (considerable degree of contamination), Cd > 24 (high degree of contamination).

Potential contamination index (Cp)

The potential contamination index can be calculated by the following method.

$Cp = C_i$(Metal) sample Max /C_b (Metal)Background value (3)

Where C_i (Metal) sample Max is the maximum concentration of a metal in sediment, and C_b(Metal) Background is the average value of the same metal in a background level. Cp values were interpreted as suggested by (Dauvalter and Rognerud, 2001; Chandranoham *et al*., 2016) where Cp<1 indicates low contamination; 1<Cp<3 is moderate contamination; and Cp>3 is severe contamination.

Ecological Risk Factor

Ecological risk factor (Er) is quantitatively calculated to express the potential ecological risk with equation suggested by Hakanson (1969).

Er= Ti * Cf (4)

Where Ti is the toxic-response factor for a given substance, and Cf is the contamination factor. The Ti values of heavy metals by Hakanson (1980) are given in Table 1.

Table 1: Toxic- response factor by Hakanson (1980)

Pb	Mn	Cu	Zn	Cr	Ni
5	1	5	1	2	5

To describe the ecological risk factor, the following criteria were used: Er< 40, low; 40 ≤ Er < 80, moderate; 80 ≤ Er < 160, considerable; 160 ≤ Er < 320, high; and Er ≥ 320, very high. The risk factor was used as a diagnostic tool for water pollution control, but it was also successfully used for assessing the contamination of soils in the environment by heavy metals.

The potential ecological risk index (RI) is defined as a sum of the risk factors (Equation 5). Hakanson, (1980) and Yang *et al.* (2011) suggested RI represents heavy metals toxicity and environment response to all five risk factors (Pb, Cd, Cu, Zn, and Cr) as total Cr in playground soils. Many studies showed that the presence of toxic heavy metals can cause different type of health problems as reported by Abrahim and Parker, (2008).

RI = ΣEr (5)

To describe the RI, the following criteria were used: RI < 150, low risk; 150 ≤ RI < 300, moderate; 300 ≤ RI < 600, considerable; RI ≥ 600, very high.

Geo-accumulation

Muller, (1983), defined an index of geo-accumulation (Igeo) in order to define and determine metal contamination in soils by comparing current concentrations with pre- industrial levels. Equation (6) can be used for calculation:

Igeo $=Log2[\frac{Ci}{Cr} * 1.5]$ (6)

Where Ci is the measured concentration of the examined metal in the sediment, and Cr is the geochemical background concentration, or 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. There are seven classes of geo-accumulation index (Igeo), as determined by Müller, (1983) : Igeo ≤ 0, class 0, unpolluted; 0 <Igeo ≤ 1, class 1, from unpolluted to moderately polluted; 1 < Igeo ≤ 2, class 2, moderately polluted; 2 < Igeo ≤ 3, class 3, from moderately to strongly polluted; 3 < Igeo ≤ 4, class 4, strongly polluted; 4 < Igeo ≤ 5, class 5, from strongly to extremely polluted; and Igeo > 5, class 6, extremely polluted.

RESULTS AND DISCUSSIONS

The general statistical summary of the three waste dumpsites soil geochemistry with regards to their heavy metal constituents are presented in table 2. Table 3 shows the average crustal abundance of the analyzed metals according to Wedepohl, (1995) as well as Taylor and Mclaennan, (1995). The mean concentration of the seven elements used in this study was compared with maximum allowable limit in upper continental crust (Table 3). The classification by Wedepohl, (1995) and Taylor and Mclaennan, (1995) indicates that the concentration of lead (Pb), copper (Cu), zinc (Zn) and nickel (Ni) were high in the soil while iron (Fe) and manganese (Mn) showed lower concentrations in the soil respectively (Table 3), from the waste dumpsites (Hira Decodi, Low Cost and Old Market communities).

Table 2: General Statistical Summary of the Heavy Metal across the Investigated Sites

Parameters	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness
Pb	0	178	50.12	25.48	649.72	1.99
Mn	0	513.45	290.41	93.09	8666.48	-1.192
Fe	4677.18	29939.65	9813.71	5192.04	26957275	2.525
Cu	3	324.82	45.82	32.21	1037.78	1.291
Zn	0	1749.61	411.59	314.82	99113.67	3.195
Cr	31.35	154.26	67.17	26.29	691.27	2.388
Ni	0	75.62	11.90	22.94	526.33	0.141

Table 3: Mean concentration of Metals in soils around Waste Dumpsites compared with their Average Crustal Abundance (Wedepohl, 1995; Taylor and Mclennann 1995)

Parameters		Guideline for maximum allowable limit in upper continental crust			
		Wedepohl,(1995)	S tatus	Taylor and Mclenna (1995)	Stat us
Pb	39.22	17 ppm	High	20 ppm	High
Mn	290.41	527 ppm	Low	600ppm	Low
Fe	8813.71	30890 ppm	Low	7.07ppm	Low
Cu	35.82	14.3 ppm	High	25 ppm	High
Zn	311.59	52 ppm	High	71 ppm	High

Ni	21.90	18.6 ppm	High	20 ppm	High
Cr	57.17	90 ppm	Low	100ppm	Low

The concentration of lead (Pb) ranging between 0 to 179 ppm with mean value of 50.12 ppm was found to be high above the recommended maximum limit. This could be linked to regional geochemistry of rock type that underlain the study area, as well as contributions from anthropogenic sources. Lead toxicity causes cancer and anemia by impairment of haemo-biosynthesis and acceleration of red blood cell destruction.

Concentrations of copper in the analyzed soil samples varied from 3 to 324.82 ppm with central tendency of 45.82 ppm (Table 2). The slightly elevated concentration of this metal in the soils could have resulted from weathering of copper-rich rocks such as gabbro, basalt and other mafic rock types while granodiorite and granite contributed lowest amount of copper to the soil geochemistry (Pascual *et al.,* 2004; Okunola *et al.,* 2016; Nwankwoala *et al.,* 2017). Anthropogenic sources are equally an underlining factor in the enrichment of copper, particularly leachate from electric wiring, roofing, various alloys, pigments, cooking utensils which were dumped as refuse at the respective sites under investigation.

The concentration of Zinc (Zn) in the study area ranged between 0 to 1749.61 ppm with mean value of 411.59 ppm (Table 2). Soil sample from the locations showed an elevated value of zinc. The zinc concentration in soil is a function of the composition of present rock, as well as anthropogenic activities. One main problem associated with zinc enrichment is its inhibitory effect to the uptake of copper, which is an essential element for plants. Excessive concentration of zinc in soil leads to phyto-toxicity. Acute zinc intoxication could lead to nausea, vomiting, severe anemia and renal failure (Abound and Nandini, 2009). Nickel concentrations in the soil samples ranged between 0 to 75.62 ppm with average value of 11.90 ppm (Table 2). These values were below the average crustal abundance of 80.00 ppm for an uncontaminated soil postulated by Dineley *et al.* (1976), which implies that the soil from the area is uncontaminated with respect to nickel. It is a major component in the production of stainless steels, non-ferrous alloys and super alloys. Other applications of nickel include electroplating, as catalysts, in nickel-cadmium batteries, coins, welding and electronic products (Pascual *et al.,* 2004). The concentration of iron in the study area ranged between 4677.18 to 29939.65 ppm with mean value 9813.71 ppm (Table 2). The concentration of iron (Fe) in soils is dependent upon the source rocks from which the soil is derived, transport mechanism and overall geochemical history.

According to the sediment quality guideline (SQG) proposed by US EPA as reported in the work of Pekey *et al.* (2004), sediment was classified into three classes (Table 4). According this classification the mean concentration of about five analytes was compared (Table 1), and it was found that Pb was unpolluted while Cr, Ni and Cu were moderately polluted, and Zn was heavily polluted.

Table 4: Classification of metal concentration (Pekey *et al.*, 2004)

Pollution limits	Cr	Pb	Zn	Cu	Ni
None polluted	< 25	< 40	< 90	< 25	< 20
Moderately polluted	25 – 75	40 – 60	90 - 200	25 - 50	20 – 50
Heavily polluted	> 75	> 60	> 200	> 50	> 50

Tables 5 to 7 showed the comparative interpretation of the three waste dumpsites investigated. It is obvious that Pb, Zn and Cu concentrations were above the maximum permissible limit while the rest elements indicated low concentration. The waste dumpsite at Hira Decodi and Old Market areas showed significant metal enrichment with respect to Low-Cost dumpsite.

Table 5: Statistical Summary of Heavy Metal from Hira Decodi Dumpsites

Parameters	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Pb	24.53	121.18	48.94	37.97	1.85	3.26
Mn	255.51	427.45	359.45	66.57	-0.77	-0.67
Fe	5456.6	14016.56	8950.99	3546.97	0.535	-1.70
Cu	28.37	124.82	51.44	37.076	2.143	4.74
Zn	218	709.24	354.87	188.83	1.749	2.82
Cr	31.35	78.66	53.38	15.44	0.434	1.71
Ni	0	49.02	14.69	22.97	1.049	-1.39

Table 6: Statistical Summary of Heavy Metal from Low Cost Dumpsite

Parameters	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Pb	0	42.87	26.84	12.83	-1.042	1.46
Mn	0	397.31	251.83	112.81	-1.39	2.98
Fe	3677.18	12799.66	7560.55	2767.38	0.86	0.57
Cu	0	45.16	19.02	19.34	0.16	-2.03
Zn	0	1549.61	329.13	467.93	2.75	7.92
Cr	44.79	96.26	61.12	18.09	1.92	4.22
Ni	0	55.62	21.59	25.83	0.33	-2.39

Table 7: Statistical Summary of Heavy Metal from Old Market Dumpsite

Parameters	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Pb	30.8	92.98	46.79	21.49	2.11	4.84
Mn	232.56	386.64	280.83	50.67	1.82	3.98
Fe	3828.08	27939.65	10307.23	8287.24	2.01	4.52
Cu	0	93.06	44.04	35.24	0.61	-0.97
Zn	115.56	512.93	251.96	136.94	1.32	1.45
Cr	33.72	145.26	57.03	39.65	2.45	6.17
Ni	0	48.08	28.48	20.25	-0.9	-1.04

Correlation Analysis

Correlation matrix was generated for the geochemical data set to decipher the relationship between the heavy metals analyzed and their respectful sources (Ameh, 2019; Ameh and Aina, 2020) as shown in Table 8. The chemical assay revealed positive and significant relationship between Cu, Pb, Mn and Fe while Cr showed positive and significant relationship with Mn, Fe and Cu. However, Zn showed significant level of relationship only to Mn (Table 8). Virtually all the heavy metals revealed significant correlation to each other. This is an indication of similar sources of enrichment, which might not be unconnected to the weathering/bed rock dissolution and anthropogenic sources.

This is also due to the fact that heavy metals are persistent even for a long period of time with little or no change in concentration after introduction into the environment by anthropogenic sources, as they do not undergo biodegradation.

Table 8: Correlation coefficients between the heavy metals of the study area

Parameters	Pb	Mn	Fe	Cu	Zn	Cr	Ni
Pb	1						
Mn	.481*	1					
Fe	0.421	0.422	1				
Cu	.762**	.572**	.471*	1			
Zn	0.217	.525*	0.055	0.333	1		
Cr	0.192	.510*	.817**	.561*	0.445	1	
Ni	0.179	0.125	-0.206	0.054	0.303	-0.134	1

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

Environmental Pollution Index Analysis

The results of contamination factor (Cf) for each measured element in the three waste dumpsites are presented in Tables 9 to 11, as calculated using Equation 1. It was depicted through-out the three waste dumpsites that Zn and Pb showed considerable/moderate contaminations respectively (Tables 9 to 11) though copper revealed moderate enrichment at Low-Cost dumpsite. On the other hand, four heavy metals showed high enrichment factor. This observation is contrary to earlier work by Murana *et al*. 2019. In their work, these authors reported low concentration of these heavy metals from the same area. This result has revealed further enrichment from the dumpsites because of lack of any remedial action. The calculated degree of contamination (Cd) for the three waste dumpsites (Hira Dekodi, Low Cost and Old Market) were 10.74, 8.68 and 9.57 respectively which depict moderate degree of overall contamination in surface layers in the investigated area.

Table 9: Contamination factor (CF) values for soil from Hira Decodi dumpsites

Parameters	Pb	Mn	Fe	Cu	Zn	Cr	Ni
Cf	3.45	0.72	0.89	2.15	5.74	0.51	0.42
Contamination Factor	Moderate Contamination	Low Contamination	Low Contamination	Moderate Contamination	Considerable Contamination	Low Contamination	Low Contamination

Table 10: Contamination Factor (CF) values for soil from Low Cost Dumpsite

Parameters	Pb	Mn	Fe	Cu	Zn	Cr	Ni
Cf	2.34	0.19	0.19	0.72	6.46	0.69	0.42
Contamination Factor	Moderate Contamination	Low Contamination	Low Contamination	Low Contamination	Considerable Contamination	Low Contamination	Low Contamination

Table 11: Contamination Factor (CF) values for soil from Old Market

Parameters	Pb	Mn	Fe	Cu	Zn	Cr	Ni
Cf	3.34	0.53	0.32	0.98	3.65	0.73	0.62
Contamination Factor	Moderate Contamination	Low Contamination	Low Contamination	Low Contamination	Moderate Contamination	Low Contamination	Low Contamination

The soil geochemical data set revealed potential contamination of seven elements analyzed from the three waste dumpsites (Tables 12 to 14). The concentrations of Zn, Pb, Cu and Cr showed severe/moderate potential contamination in the soil of the Hira Decodi and Old Market dumpsites while other elements analyzed remain low in concentration. Though this seems to be slightly different at Low Cost dumpsite where Zn revealed severe potential contamination and Pb, Cu and Cr revealed moderate potential enrichment.

Table 12: Potential Contamination Factor (Cp) values for soil from Hira Dekodi Dumpsites

Parameters	Pb	Mn	Fe	Cu	Zn	Cr	Ni
Cp	6.05	0.50	0.29	2.77	7.46	0.87	0.72
Contamination Potential	Severe Contaminated	Low Contamination	Low Contamination	Moderately Contaminated	Severe Contaminated	Low Contamination	Low Contamination

Table 13: Evaluated Potential Contamination Factor (Cp) values for soil from Low Cost Dumpsite

Parameters	Pb	Mn	Fe	Cu	Zn	Cr	Ni
Cp	2.14	0.47	0.27	1.00	16.31	1.07	0.82
Contamination Potential	Moderately Contaminated	Low Contamination	Low Contamination	Moderately Contaminated	Severe Contaminated	Moderately Contaminated	Low Contamination

Table 14: Calculated Potential Contamination Factor (Cp) values for soil from Old Market Dumpsite

Parameters	Pb	Mn	Fe	Cu	Zn	Cr	Ni
Cp	4.65	0.45	0.59	2.07	5.39	1.614	0.71
Contamination Potential	Severe Contamination	Low Contamination	Low Contamination	Moderately Contaminated	Severe Contamination	Moderately Contaminated	Low Contamination

The geo-accumulation index (Igeo) of the metals is shows in Table 15. The Igeo values calculated using equation 6 for the various metals were in the zero-category indicating that the soils from the various dumpsites were unpolluted.

Table 15: Computed Geo-accumulation Index (Igeo) values for soil from the Dumpsites

Parameters	Hira Decodi	Low Cost	Old Market	Pollution Intensity
Pb	-0.72	-0.19	-0.41	Unpolluted
Mn	0.63	-0.07	0.12	Unpolluted
Fe	-0.08	-0.17	-0.95	Unpolluted
Cu	-0.79	-0.66	-0.69	Unpolluted
Zn	-0.51	-1.65	-0.54	Unpolluted
Cr	0.04	-0.07	-0.96	Unpolluted
Ni	-1.25	-0.78	-0.18	Unpolluted

The results of the ecological risk calculated using equation 5 showed low potential ecological risk response in all the three waste dumpsites as presented in Table 16. The results of potential ecological risk index (RI) of the three dumpsites were 24.37, 15.53, and 22.94 respectively. Over all, these values showed low ecological risk of the investigated sites. However, the dumpsites at Hira Decodi and Old Market need to be evacuated with immediate effect as heavy metal enrichment was evident in those areas.

Table 16: Pollution index for heavy metals from the soil of various Investigated sites

Parameters	Hira Decodi	Low Cost	Old Market	Ecological Risk
Pb	12.24	6.7	11.69	Low Potential Ecological Risk
Mn	0.42	0.29	0.33	Low Potential Ecological Risk
Cu	5.72	2.11	4.89	Low Potential Ecological Risk
Zn	3.74	3.46	2.65	Low Potential Ecological Risk
Cr	1.19	1.37	1.28	Low Potential Ecological Risk
Ni	1.08	1.59	2.09	Low Potential Ecological Risk

CONCLUSION

Environmental pollution models applied to the sets of geochemical data revealed that Zn, Pb and Cu were considerable/moderate contamination and generally indicated severe potential contamination in the investigated area while other analytes such as Mn, Cr, Ni and Fe showed low contamination respectively. However, from the results of geo-accumulation/ecological risk index of the analytes, the study areas were unpolluted and indicated low ecological risk factors with respect to the analyzed parameters.

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CONFLICT OF INTEREST

There is no conflict of interest associated with this research.

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