International Research Journal of Environmental Sciences ISSN 2319–1414
Vol. **14(1),** 1-9, January **(2025)** *Int. Res. J. Environmental Sci.*

Heavy metal composition in recycled metal slag in dumpsites and immediate soils in two industrial towns in Southwest Nigeria

Sanyaolu Victoria T.[1*], Fadayini Oluwafemi[2] and Oshin Toyin T.[3]
[1]Department of Biological Science, Lagos State University of Science and Technology, Ikorodu – Lagos, Nigeria
[2]Department of Chemical Engineering, Lagos State University of Science and Technology, Ikorodu – Lagos, Nigeria
[3]Department of Chemical Science, Lagos State University of Science and Technology, Ikorodu – Lagos, Nigeria
sanyaolu.vt@lasustech.edu.ng

Available online at: www.isca.in, www.isca.me
Received 29th April 2024, revised 17th September 2024, accepted 23rd November 2024

Abstract

The scrap metal recycling processes produce solid, liquid and gaseous wastes among which is a large quantity of solid slag. This study assessed heavy metal (HM) contents in waste slag dumpsites and their immediate soils in two industrial towns in South western Nigeria. Five slag dump sites were selected each in Odoguyan, Lagos State and Ogijo, Ogun State, for this study denoted OD1-OD5 and OG1-OG5 respectively. Samples of slag and immediate topsoil from each location and a control soil from a remote location (X) were randomly collected in three replicates. These were analysed for Cd, Cu, Cr, Pb, Fe and Ni using Atomic Absorption Spectrometry (Perkin Elmer Win Lab AA). Data analysis was conducted using ANOVA, while mean separation was by Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$. The Result showed that the lowest mean HM contents occurred in the control soil samples with only Pb being significantly lower ($P \leq .05$). Significantly highest mean concentration of all six metals ($P \leq .05$) occurred in the slag in Odogunyan, each in different sites, except Cu and Pb where both were highest at OD2. In Odoguyan soil, mean Cu and Cr in all sites were significantly higher ($P \leq .05$) than values obtained in both slag and soil of all sites at Ogijo. Higher mean HM levels in slag did not result in equally higher values in the soil of corresponding sites at Odoguyan. In Ogijo, higher mean HMs also occurred in the slag, except for Cd in all soils and Cu in soils at OG4 and OG5, which were significantly higher ($P \leq .05$) than those in the slag. Higher mean Fe and Pb in slag in locations OG3 and OG5 resulted in higher mean contents in their immediate soils, although values in the slag were significantly higher ($P \leq 0.05$). Furthermore, the mean Cd and Fe contents in the soil of all sites and Cr in OD3 exceeded the limit set by the Federal Ministry of Environment of Nigeria for arable soils, indicating serious health risks in these locations. Treatment and large-scale utilisation of slag are recommended to prevent such risks.

Keywords: Environment, Pollution, Heavy metals, Scrap metal, Recycling industry, Slag waste.

Introduction

Anthropogenic actions, particularly industrial activities, have led to an ever-increasing contribution of toxic heavy metals (HMs) to the environment[1-3]. As a result of the increasing demand for metals, increasingly more HM pollutants have become widespread[4-6]. One way by which heavy metals get to the environment is through industrial activities, especially through industrial discharges[7, 8]. In recent years, such discharges have gradually increased in the environment resulting in higher levels of HMs in the soil[9,10]. This has further resulted in the deterioration of the environment, thereby giving rise to serious adverse effects on plants and animals, including humans[11,12]. Steel manufacturing and scrap metal recycling are some activities that have contributed immensely to increasing levels and types of HMs in the environment'[14]. The activities of metal recycling industries generate diverse forms of waste dumped randomly on soils, ultimately resulting in heavy metal contamination of these soils[13,15]. Reports have indicated that locations close to metal recycling industries are severely polluted by toxic HMs such as Pb, Zn, Cu, Cd, etc.[16,17].

Scrap metal recycling has become a popular technology worldwide adopted in the production of steel from used metal and to prevent the continuous exploitation of raw materials for steel production. However, just like the steel slag is the main solid waste produced during the steel manufacturing process,[18] scrap metal recycling processes produce a large amount of waste in different states (solid, liquid and gaseous), among which is a large quantity of solid slag[19,13]. Slag is the solid by-product left over after the desired metal is separated. In scrap recycling, slag is obtained when scrap metal is melted in an Electric Arc Furnace (EAF) at a high electric current. Slag production by the steel industry has been estimated to be about 96–145 million metric tonnes annually with recent annual estimate being placed at over 1600 million tonnes[21].

Although slag has long been recognised as a valuable by-product of the steel industry[22,23], it has also been documented as a source of environmental contamination[24]. In developed countries, slag wastes are utilised for different applications, the most popular being their incorporation into cement and as a base and sub-base aggregate in road construction[22,25,26].

However, in developing nations, slag wastes are indiscriminately discarded openly[14] and sometimes hidden in nearby bushes.

One significant environmental impacts of such indiscriminate dumping of slags is the leaching of HMs as well as other soluble components into the soil with which they are in direct contact[27-30]. Slags are sources of hazard, because in their non-treated form, they contain high levels of toxic HMs, which could potentially be transferred into the atmosphere, surrounding soils, and surrounding water bodies, whether surface or underground. This could ultimately affect biological organisms including humans[31,32]. The soil characteristics influences the movement of HMs and their consequent contamination of the environment and water bodies by these metals[33]. The decline of water quality in sources of water located near slag dumps due to high levels of metals present in slag's leachates has been reported[34]. Consequently, the continuous and indiscriminate discharge of heavy metals into the surrounding environments poses a danger to the lives of residents around such areas[35]. The dangers posed by HMs emanates from their ability to bioaccumulate in living tissues when they are taken up and the rate at which they accumulate in them exceeds the rate at which they degrade, transform or are eliminated from the body[36,37]. Some edible plants have high accumulation capacity for some HMs in their edible parts. Such metals include Zn, Al, Cu, Fe and many others. The accumulation of these metals at high levels in plants can negatively affect their growth and development, while some high accumulators may remain unaffected. Such plants can serve as important pathway of exposure for people on consumption if grown in HM-contaminated soils[38-41].

Metals may display some levels of toxicity in both plants and animals[42,43]. Although, plants and animals require certain metallic elements in minute quantities to carry out some physiological processes[44,45], higher levels of these elements can become harmful to them[46-48]. At low concentrations, HMs, such as Fe, Cu, Ni, and Zn are essential for maintenance of physiological functions for survival the various life forms[49,50]. However, excessive amounts of these metals could show some health risks that are non-carcinogenic[51]. High levels of Ni have been reported to cause the alteration in the metabolic activities of the plants by preventing the activity of enzymes, cellular respiration and synthesis of chlorophyll[52]. In humans, Ni is a cancer-causing agent whose toxicity can have adverse effects on the immune system. It also has a potential to cause many other health effects, such as cardiovascular disease and respiratory tract cancer[53]. Copper is a vital micronutrient in plant, but at high levels, Cu can be possibly toxic to plants[54].

In humans, excess copper may induce damage caused by excess free radicals, damage to genetic material and reduced cell multiplication[55]. In most severe forms, copper toxicity may lead to rhabdomyolysis, heart and kidney failure as well as numerous health disorders that could ultimately result in death of affected individuals[56].

Some metals on the other hand show highly toxic effects on living organisms even at very low concentrations and have no known functions inorganisms[57]. Lead is a highly toxic metal with no known biological function. It bioaccumulates in the human body causing respiratory impairments. Report has shown that Pb toxicity may also lead to causes comfortable bowel movement, cerebral edema, loss of muscle function, and eventual death[39]. Lead also has serious negative effects on children[58]. Excess concentration of Pb in plants cause damage to chlorophyll, inhibit photosynthetic processes and cause significant reduction in plant growth[59]. Exposure to Cd can result in a variety of adverse effects, such as kidney and liver disorder, damage to the testicles, the adrenal gland and the blood cell production system[60]. Chronic exposure to cadmium may lead to cancer[61-60]. Toxicity to chromium may cause yellowing of leaves and death of some tissues in plant[63]. The International Agency for the Research on Cancer (IARC) classified Cr(VI) as a group 1 human carcinogen owing to its ability to induce cancer by causing changes in the genetic materials[64,65].

Although soil contamination by HM from several sources have been documented, little attention has been paid to contamination caused by slag waste from scrap metal recycling processes in the study area. This occurs largely due to the general belief that recycling is an environment-friendly process, making regulatory agencies to practically neglect the need to closely monitor the activities of these industries. This study assessed heavy metal concentration in slag dumpsites and their immediate soils in Odonguyan and Ogijo areas of Lagos and Ogun states respectively. The area has many metal recycling industries located close to one another, some of which include Land Craft Nig Ltd., Pukit Steel Nig. Ltd., Sun Flag Steel Nig. Ltd., Top Steel Nig. Ltd., African Steel Mills Nig. Ltd., etc. in Odoguyan and Everest Nig Ltd., Monarch Steel, Agriex Nig Ltd., Phonix Steel mill Ltd., Real Infrastructure Nig Ltd., African Fundries Steel Mill, Quantum Steel Company, etc. in Ogijo. Five locations were selected in each study area.

Methodology

Study area: This work was carried out in two neighbouring industrial and boundary towns of Odogunyan in Ikorodu, Lagos state and Ogijo in Ogun state. The coordinates of each location were obtained using the GPS Coordinates. A map showing the locations was also prepared (Figure-1).

Collection of samples: Samples of slag and soil were collected from ten (10) locations where heaps of slag waste produced as by-products of scrap metal recycling, have been deposited; five in Odogunyan in Lagos State designated OD1, OD2, OD3, OD4 and OD5, and five in Ogijo in Ogun state designated OG1, OG2, OG3, OG4 and OG5.

In each location, slag was randomly collected from the heap in three replicates from the heaps. Samples of topsoil were also randomly collected from three spots around and two (2) meters away from the heap. Three of the slag dumpsites used in this study are shown in Figure-2 (A -C). The control soil samples were collected from within the Lagos State University of Science and Technology (Lasustech), Ikorodu campus, a site remotely located at about 5 and 13 Km respectively from Odoguyan and Ogijo study areas.

Samples preparation and analysis: Collected soil samples were air-dried, while samples of slag samples were crushed to fine particles. Both were sieved with a 2 mm sieve. Exactly 10g of both cast and soil were taken in three replicates to the laboratory for analysis. Samples were digested and filtrates from digested samples were analysed for six HMs including Pb, Cd, Cu, Cr, Fe and Ni following standard methods described by the Association of Official Analytical Chemists[66]. The metals were determined on the filtrate of the digested sample using Atomic Absorption Spectrometry (AAS) (Perkin Elmer AA100), using the respective lamps and wavelengths for each metal.

Analysis of data: Data obtained were subjected to analysis of variance (ANOVA) using the statistical package for the social sciences (SPSS) 20.0 software. Mean separations were carried out at a 5% level of significance using Duncan's multiple range test (DMRT). In all parameters analyzed, the results obtained were mean values from three replicates.

Results and Discussion

Results: Results obtained for the mean concentration of each HM considered in this study are presented in Table 1. Results showed that there were significant differences ($P \leq 0.05$) in all metals tested in both the slag and soil samples. It was observed that in all sites in Odogunyan, the mean concentration of all HMs considered was significantly higher ($P \leq 0.05$) in the slag compared to those in the soil as well as those in both slag and soil in Ogijo. The lowest mean HM contents were observed in the control site, but only the mean Pb concentration was significantly lower ($P \leq .05$) than those from samples in all other sites (Table-1).

The mean concentration of heavy metals in slag and soil in Odogunyan: In Odoguyan, the highest mean heavy metal contents in slag were distributed as follows; Cd (327.00±55.69 mg/kg) and Cr (214.87±97.06mg/kg) were observed in location OD1, Cu (590.40±113.54mg/kg) and Pb (362.73±52.03mg/kg in OD2, Fe (41443.33±10188.91mg/kg) in OD3 and Zn (58.27±20.66 mg/kg) in location OD5 (Table-1). These values were significantly higher ($P \leq 0.05$) than those observed in all other samples of both slag and soil of all sites in this study The lowest mean HM in slag for Cd, Cr and Pb were found in location OD3, Cu and Fe in location OD4, while that of Zn occurred in location OD1.

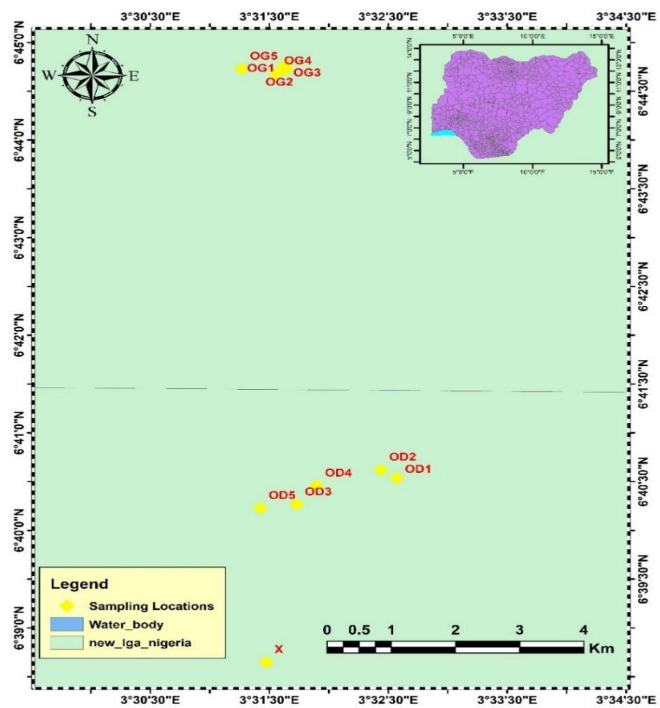

Figure-1: Map of study locations in Odoguyan (OD1-OD5) and Ogijo (OG1- OG5).

A B C

Figure-2 (A-C): Slag waste dumpsites in some study locations.

Table-1: Mean concentration of heavy metals in slag dump of metal recycling factories and immediate soils in study locations at Odogunyan and Ogijo.

Sample type	Study site	Heavy Metal (mg/kg)					
		Cd	Cu	Cr	Fe	Pb	Zn
Slag	OD1	327.00±55.69^{L}	178.63±57.46^{m}	214.87±97.06^{o}	4233.33±1483.61^{f}	103.83±26.20^{n}	26.07±6.84^{j}
	OD2	185.97±59.81^{j}	590.40±113.54^{o}	84.43±20.07^{k}	36806.67±5855.91^{m}	362.73±52.03^{r}	48.80±9.59^{m}
	OD3	137.23±37.91^{i}	263.13±96.12^{n}	75.30±19.52^{j}	41443.33±10188.91^{n}	77.57±28.73^{l}	41.00±18.86^{l}
	OD4	213.63±97.55^{k}	92.17±13.73^{k}	136.97±37.58^{n}	22333.33±11373.99^{i}	81.23±22.37^{m}	27.23±13.74^{k}
	OD5	214.03±60.38^{k}	153.00±43.11^{L}	93.13±21.97^{L}	29903.33±15161.52^{l}	225.70±51.34^{p}	58.27±20.66^{n}
Soil	OD1	22.27±6.32^{d}	64.93±14.72^{g}	67.87±26.97^{i}	2905.33±922.32^{cde}	22.10±4.96^{e}	2.70±0.55^{e}
	OD2	29.77±8.81^{f}	72.27±7.25^{h}	42.67±15.03^{h}	2770.67±84.42^{cde}	52.00±7.37^{i}	4.17±1.39^{fg}
	OD3	28.07±9.37^{ef}	71.63±9.19^{h}	107.47±46.88^{m}	1742.00±497.36^{a}	53.20±16.88^{i}	1.33±027^{bc}
	OD4	46.23±9.46^{h}	76.23±19.61^{i}	68.33±14.07^{i}	2608.00±97.00^{bcd}	71.00±9.75^{k}	4.03±1.51^{fg}
	OD5	34.93±6.27^{g}	82.70±26.43^{j}	38.07±8.28^{g}	3168.00±639.65^{de}	55.53±12.41^{j}	1.97±0.92^{cd}
Slag	OG1	1.67±0.83^{a}	26.20±16.03^{e}	16.63±2.59^{e}	2340.00±586.17^{abc}	39.50±8.54^{g}	1.93±0.63^{cd}
	OG2	2.40±1.45^{ab}	18.87±7.25^{d}	9.70±2.45^{d}	22005.00±8577.79^{i}	26.63±9.29^{f}	3.87±1.20^{f}
	OG 3	3.33±1.76^{ab}	14.57±2.34^{c}	16.80±3.59^{e}	27200.67±10404.36^{k}	26.77±3.58^{f}	2.50±0.95^{de}
	OG 4	1.73±1.18^{a}	6.03±1.84^{b}	15.00±2.72^{e}	23546.67±15137.16^{j}	46.47±8.78^{h}	5.40±1.29^{h}
	OG 5	0.97±0.67^{a}	6.20±1.47^{b}	23.20±5.81^{f}	22114.67±13688.35^{i}	264.70±24.90^{q}	8.17±1.01^{i}
Soil	OG 1	11.50±5.57^{c}	2.63±1.07^{ab}	8.17±2.34^{cd}	3414.33±1274.39^{e}	17.50±6.91^{c}	0.80±0.17^{ab}
	OG 2	5.33±1.79^{b}	3.53±2.73^{ab}	5.23±1.05^{ab}	1945.67±171.94^{ab}	20.60±6.35^{de}	3.83±1.66^{f}
	OG 3	12.17±8.38^{c}	4.60±2.08^{ab}	5.10±2.36^{ab}	9276.33±7767.05^{h}	19.47±3.44^{d}	4.00±1.69^{fg}
	OG 4	14.40±6.48^{c}	29.87±24.11^{f}	5.53±2.21^{ab}	1793.67±266.66^{a}	11.67±7.04^{b}	4.67±0.54^{g}
	OG 5	25.67±21.22^{e}	32.93±28.52^{f}	6.07±3.31^{bc}	5212.00±1664.05^{g}	111.50±10.85^{o}	1.63±0.55^{c}
Control soil	X	0.85±.0.62^{a}	1.10±0.73^{a}	2.87±0.99^{a}	1646.67±435.90^{a}	9.37±1.02^{a}	0.53±0.15^{a}
FMEnv. Limits (for arable soil)		1.00	200.00	100.00	50,000.00	200.00	150.00

Mean values of the same parameter along the same column having the same superscripts are not significantly different (DMRT, $P \leq 0.05$), OD = Odoguyan; OG = Ogijo; FMEnv= Federal Ministry of Environment of Nigeria standard limits.

In the soil, the highest mean Cd and Pb (46.23±9.46mg/kg and 71.00±9.75mg/kg respectively) were observed in locations OD4, Cu and Fe (82.70±26.43mg/kg and 3168.00±639.65 mg/kgin location OD5, Cr (107.47±46.88mg/kg) in location OD3 and Zn (4.17±1.39mg/kg) in location OD2 although mean Zn content in the soil was not significantly different from the value in Location OD4 (4.03±1.51mg/kg) (Table-1).

It was further observed that a higher mean HM in the slag did not give a corresponding higher value of such heavy metal in soil of that location.

Results further showed that in Odoguyan, the lowest mean HM occurred in the soil. Cd, Cu and Pb had the lowest mean HM concentration in location OD1, the lowest mean Fe and Zn in location OD3, while the mean lowest Cr was observed in location OD5 (Table-1). There was no significant difference ($P \geq .05$) between the lowest Fe concentration and mean Fe in the control sample.

The mean concentration of heavy metals in slag and soil in Ogijo: In Ogijo, the highest mean Cd (3.33±1.76mg/kg), Cr (16.80±3.59mg/kg) and Fe (27200.67±10404.36**)** in slag were observed in locations OG3, Pb (264.70±24.90mg/kg) and Zn (8.17±1.01mg/kg) in O5, while the highest mean Cu (26.20±16.03) occurred in OG1. Furthermore, results showed that the concentration of Fe, Pb and Zn in slag also had significantly higher ($P \leq 0.05$) than those recorded for all other samples (Table-1).

In Ogijosoil, the results obtained did not follow the exact pattern observed in Odoguyan study area. It was however observed that the mean concentration of Cd and Cu in the soil at locations OG5 with values 25.67±21.22mg/kg and 32.93±28.52mg/kg respectively were significantly higher ($P \leq 0.05$) than those slags and soil of all sites in the study area. Results in Ogijo also showed that the mean values of Cd in the soil in all sites except OG2 were significantly higher ($P \leq 0.05$) than those in the slag. The highest Pb (111.50±10.85mg/kg) also occurred in OG5, but this was significantly higher than those in all other samples in the study area except in slag at OG5. The highest mean Cr, Fe and Zn were observed in OG1, OG3 and OG4 respectively (-1). It is noteworthy that higher mean Fe and Pb in slag in locations OG3 and OG5 also resulted in corresponding higher mean values of the same metals in the soil of these locations although values in the slag were significantly higher ($P \leq 0.05$).

The lowest mean Cu (2.63±1.07mg/kg) and Zn (0.80±0.17 mg/kg) in the soil in Ogijo were observed in OG1, Cd (5.33±1.79/kg) occurred in OG2, Cr (5.10±2.36mg/kg) in OG3, whereas Fe (1793.67±266.66mg/kg) and Pb (11.67±7.04mg/kg) occurred in OG4 (Table-1).

Discussion: Several reports have shown that most heavy metal pollution is largely caused by anthropogenic activities[4,9,67]. In the present study, the scrap metal recycling industries, through their various activities, are a viable source of heavy metal contamination of the environment. Environmental pollution caused by similar or related industries has also been documented in several studies[13,34,68-70]. Results also showed that piles of solid slag produced as a waste product of the scrap metal recycling process contain higher levels of Cd, Cu, Cr, Pb, Fe and Ni. This result agrees with earlier work by Garcia-Guinea *et al*[13], who reported that steel slag deposits had high levels of metals such as Fe, Mg and Cr. An earlier report showed that slag waste contains various concentrations of possibly harmful trace elements including Cr, Cu, Mn, Mo, Pb, V, W and Zn[32]. Furthermore, the elevated concentrations of HM in slag observed in the present study suggest that these wastes may have been discarded without any treatment to eliminate the toxic metals present in them.

Results obtained in the present study also showed higher levels of tested HMs in the slag compared to the immediate soils of all dumpsites in the two study areas. Also, higher levels of HMs were present in the immediate soils compared to soil from the control site. This suggests that the slag deposits that have accumulated in the soil over time are most probably the origin of toxic metal contaminants in the surrounding soils. Following a study of heaps of steel slag that had accumulated for over 40 years in plots of land and industrial areas in the southern part of Madrid (Spain), it was concluded that the presence of high levels of metal contaminants in soils originated from piles of steel slag that had accumulated over a long time[13]. Another report further showed that the accumulation of steel slag in the vicinity of the Dana Steel Rolling Mill plant in Katsina State, Nigeria, resulted in varying degrees of contamination of various toxic metals in the soil at the recycling facility[70]. All these reports agree with the results obtained in the present study, which indicated that the accumulation of HM-contaminated slag wastes over a long time is the most probable source of HM pollution in the immediate soils of the study sites.

In comparing the two study areas, higher levels of HM were observed in the slag at Odogunyan, compared to those in Ogijo. The differences in the HM content in slag between the two study areas may have resulted from the sources of scrap metal used, the methods of the recycling process, the possibility, possibility and efficiency of treatments to remove toxic metals from slag and the length of time slag has accumulated in the soil[13,71]. The slag in Odogunyan appeared to have been more freshly dumped when compared to the slag found at Ogijo, which was observed to be much older. In this case, a larger proportion of the heavy metal may have leached from the slag into the surrounding soil and over time is also washed away by run-off since the area has high annual rainfall, hence, the lower levels of HM content in both slag and soil in the Ogijo area.

It was further observed that the higher HM content in slag did not necessarily correspond to higher content in the soil. Reports have shown that the release of HM from solid slag and their distribution in the soil depends on several factors including HM reactions in soils, their uptake by plants, weathered products of the slag under varying climatic conditions and many others[13,72]. These site-specific factors may have resulted in variations between the levels of metals in the slag and soil of each study site and how they were distributed in the soils of the study site.

Iron (Fe) had the highest concentration in both cast and soil. High levels of Fe, agree with the results of an earlier report that showed 43% of Fe among HM in slag samples tested[13]. However, it disagrees with a report in another study conducted within a metal recycling facility, where chromium had excessively high contamination, while Fe was moderate[70]. In addition to high levels of iron released by slag, the exceptionally high Fe content in the soils in all study locations, including the control, may have resulted from the soil type of the study area, since soils in Southwestern Nigeria where the study area is located has been classified as being rich in Fe[73].

Cadmium and Fe contents in all sites and Cr in OD3 exceeded the permissible limits of 1.0, 50.0 and 100.0mg/kg respectively for arable soils. These results mean that the soils in these locations may pose serious negative health risks because these metals can enter the groundwater or surface water bodies and accumulate in aquatic organisms[74]. They may also contaminate soils and be absorbed by plants. Through any of these routes, these highly toxic metals could get to humans and other organisms, where they may cause serious health hazards. Therefore, large-scale treatment and use of slag wastes for various purposes is required to prevent their accumulation on the land surface and forestall the risk of soil contamination caused by prolonged slag-stockpiling[75].

Conclusion

Data obtained from this study showed that slag wastes produced from scrap metal recycling activities contain high levels of heavy metals including Pb, Cd, Cr, Fe, Cu and Ni. These metals are also present in varying compositions in the immediate soils where slags are indiscriminately dumped, having leached into the soil from the slag. The Fe and Cr concentrations in the soil of all study sites were beyond the permissible level, thus, portending serious health risks to organisms living in the study area.

Acknowledgements

I wish to acknowledge the contributions of Miss Chukwukere, Gladys C. and Miss, Adebayo, Nimot for their assistance in the collection of samples used in this study and Miss Olawoyin, Aishat, A., who carried out the statistical analysis of the data.

References

1. Nagajyoti, P. C. Lee, K. D. and Sreekanth, T. V. M. (2010). Heavy metals, occurrence and toxicity for plants: a review. *Environmental Chemistry Letters*, 8(3), 199–216 https://doi.org/10.1007/s10311-010-0297-8

2. Kahal A, El-Sorogy AS, Qaysi S, Almadani S, Kassem OM, Al-Dossari A. (2020). Contamination and ecological risk assessment of the Red Sea coastal sediments, southwest Saudi Arabia. *Marine Pollution Bulletin*, 154, 111-125 https://doi.org/10.1016/j.marpolbul.2020.111125

3. Liu, P, Hu, W., Tian, K., Huang, B., Zhao, Y., Wang, X., Zhou, Y., Shi, B., Kwon, B., Kyungsik Choi, Ryu, J., Chen, Y., Wang, T., Khim, J.S. (2020). Accumulation and ecological risk of heavy metals in soils along the coastal areas of the Bohai Sea and the Yellow Sea: A comparative study of China and South Korea. *Environment International*; 137, 105519. https://doi.org/10.1016/j.envint.2020.105519

4. Yang, Z., Lu, W., Long, Y., Bao, X. and Yang, Q. (2011). Assessment of heavy metals contamination in urban topsoil from Changchun City, China. *Journal of Geochemical Exploration*, 108: 27-38. https://doi.org/10.1016/j.gexplo.2010.09.006

5. Gautam P.K., R.K. Gautam, M.C. Chattopadhyaya, S. Banerjee, M.C. Chattopadhyaya, J.D. Pandey (2016). Heavy metals in the environment: fate, transport, toxicity and remediation technologies in: *heavy metals: sources toxicity and remediation techniques* chapter 4 Deepak Pathania ed. Nova Sci Publishers, Vol 60, 101–130

6. Qu L, Huang H, Xia F, Liu Y, Dahlgren RA, Zhang M, Mei K. (2018). Risk analysis of heavy metal concentration in surface waters across the rural-urban interface of the Wen-Rui Tang River, China. *Environ Pollut*., 237, 639-649. https://doi.org/10.1016/j.envpol.2018.02.020

7. Palaniappan, P. R. and Karthikeyan, S (2009). Bioaccumulation and depuration of chromium in the selected organs and whole body tissues of freshwater fish Cirrhinusmrigala individually and in binary solutions with nickel. *Journal of Environmental Sciences*, 21(2), 229–236. https://doi.org/10.1016/S1001-0742(08)62256-1

8. Yan, X, Liu M, Zhong J, Guo J, Wu W. (2018). How Human Activities Affect Heavy Metal Contamination of Soil and Sediment in a Long-Term Reclaimed Area of the Liaohe River Delta, North China. *Sustainability*, 10(2), 338. https://doi.org/10.3390/su10020338

9. Su, C., Jiang, L. Q. and Zhang W. J. (2014). A review on heavy metal contamination in the soil worldwide: Situation, impact and remediation techniques. *Environmental Skeptics and Critics*, 3(2), 24-38

10. Chaoua S., Boussaa S., El Gharmali, A. and Boumezzough A. (2019). Impact of irrigation with wastewater on accumulation of heavy metals in soil and crops in the region of Marrakech in Morocco. *J. Saudi Soci. Agri. Sci.* 18(4), 429–436. https://doi.org/10.1016/j.jssas.2018.02.003

11. Majolagbe A, Oketola A, Osibanjo O, Adams A, Ojuri O (2017). Pollution vulnerability and health risk assessment of groundwater around an engineering Landfill in Lagos, Nigeria. *Chem Int*, 3, 58–68.

12. Fan S. Chen J. Fan C. Chen G. Liu S. Zhou H. Liu R. Zhang Y. Hu H. Huang Z. (2021). Fabrication of a CO2-responsive chitosan aerogel as an effective adsorbent for the adsorption and desorption of heavy metal ions.*J. Hazard. Mater*., 416, 126-225. https://doi.org/10.1016/j.jhazmat.2021.126225

13. Garcia-Guinea, J., Correcher. V., Recio-Vazquez, L., Crespo-Feo, E., Gonzalez-Martin, R. and Tormo, L. (2010). Influence of accumulation of heaps of steel slag on the environment: determination of heavy metals content in the soils. *Anais da Academia Brasileira de Ciências*, 82(2), 267-277. Accessed October 12, 2021, retrieved from https://doi.org/10.1590/S0001-37652010000200003

14. Johnpaul V. Balasundaram, N. and Natarajan, M. (2019). Environmental impact of dumping Ggbfs on lands in Coimbatore. *Int. J. Eng. Adv. Technol*., 8, 332-334

15. Sanyaolu. V.T., Olawoyin, A. A., Fadayini O., Oshin T. T. Oladumiye O. R. and Abdul Raheem, W. (2022). Assessment of Heavy Metal Composition of Plants Growing in Recycled Metal Slag-Polluted Soils in Ogijo, Ogun State. *Nigerian Journal of Ecology*, 18(2), 49-61.

16. Wilson, B., Lang, B. and Pyatt, F.B. (2005). The dispersion of heavy metals in the vicinity of Britannia Mine, British Columbia, Canada. *Ecotoxicol Environ Saf*, 60, 269-276. https://doi.org/10.1016/j.ecoenv.2004.04.005

17. Houessionon MGK, Ouendo ED, Bouland C, Takyi SA, Kedote NM, Fayomi B, Fobil JN, Basu N. (2021). Environmental Heavy Metal Contamination from Electronic Waste (E-Waste) Recycling Activities Worldwide: A Systematic Review from 2005 to 2017.*Int J Environ Res Public Health*, 29, 18(7), 3517. https://doi.org/10.3390/ijerph18073517

18. Olofinnade, O, Morawo, A, Oluwatomisin Okedairo, O., and Boksun Kim, B. (2021). Solid waste management in developing countries: Reusing of steel slag aggregate in eco-friendly interlocking concrete paving blocks production. *Case Studies in Construction Materials*, 14, e00532. https://doi.org/10.1016/j.cscm.2021.e00532.

19. Gunn, J. M. (1995). Restoration and Recovery of an Industrial Region. New York: Springer-Verlag. 19-25 pp.

20. Akinwumi I., Adeyeri, J. and Ejohwomu, O. (2012). Effects of steel slag addition on the plasticity, strength, and permeability of lateritic soil. ICSDEC, 457-464 pp. https://doi.org/10.1061/9780784412688.055

21. Liu, J. and Wang, D. (2017). Influence of Steel Slag-Silica Fume Composite Mineral Admixture on the Properties of Concrete. *Powder Technol*., 320, 230–238. https://doi.org/10.1016/j.powtec.2017.07.052

22. Gomes, J. F. P. and Pinto, C. G. (2006). Leaching of heavy metals from steelmaking slags. *Revista de Metalurgia* 42(6), 409-416 https://doi.org/10.3989/ revmetalm.2006.v42.i6.39

23. Lu, T. H., Chen, Y.L., Shih, P.H., Chang, J.E. (2018). Use of basic oxygen furnace slag fines in the production of cementitious mortars and the effects on mortar expansion. *Construction and Building Materials*, 167, 768-774, https://doi.org/10.1016/j.conbuildmat.2018.02.102.

24. Sylvain, Gouttebroze (2018). Understanding slag formation in cast iron: important for circular economy. Retrieved Aug. 20 from https://www. Lenntech.com/ periodic/element/fe.htm

25. Sharba, A.A. (2019). The Efficiency of Steel Slag and Recycled Concrete Aggregate on the Strength Properties of Concrete. *KSCE J Civ Eng*, 23, 4846–4851 https://doi.org/10.1007/s12205-019-0700-3

26. O'Connor, J., Nguyen, T. B. T., Honeyands, T., Monaghan, B., O'Dea, D., Rinklebe, J., Vinu, A., Hoang, S. A., Singh, G., Kirkham, M. B., & Bolan, N. (2021). Production, characterisation, utilisation, and beneficial soil application of steel slag: A review. *Journal of Hazardous Materials*, 419, [126478]. https://doi.org/10.1016/j.jhazmat.2021. 126478

27. Miller, R and R. Donahue, R. (1995). Soils in Our Environment. 7th Edition, Prentice Hall, London, United Kingdom, 230-235 pp

28. Fällman, A. M. (2000). Leaching of chromium and barium from steel slag in laboratory and field tests — a solubility-controlled process?. *Waste Manag*., 20, pp. 149-154, 10.1016/S0956-053X(99)00313-X

29. Gurcharan and Singh, J, (2003). Water Supply and Sanitary Engineering. 6th edition, New Chand Jain, Delhi, pp 370 - 386

30. Coetzee, J. J., N. Bansal, and E. M. N. Chirwa. (2020). Chromium in environment, its toxic effect from chromite-mining and ferrochrome industries, and its possible bioremediation. *Exposure and Health*,12: 51–62.10.1007/s12403-018-0284-zSearch

31. Mayes, W.M., Younger, P.L. and Aumônier, J. (2008). Hydrogeochemistry of alkaline steel slag leachates in the UK. *Water Air Soil Pollut*., 195, 35-50 https://doi.org/10.1007/s11270-008-9725-9

32. Gomes, Helena I., William M. Mayes, Mike Rogerson, Douglas I. Stewart, Ian T. Burke, (2016). Alkaline residues and the environment: a review of impacts, management practices and opportunities. *Journal of Cleaner Production*, 112(4), 3571-3582 https://doi.org/10.1016/j.jclepro.2015.09.111.

33. Campillo-Cora C, Conde-Cid M, Arias-Estévez M, Fernández-Calviño D, Alonso-Vega F. (2020). Specific Adsorption of Heavy Metals in Soils: Individual and Competitive Experiments. *Agronomy*. 10(8), 1113. https://doi.org/10.3390/agronomy10081113

34. Balogun-Adeleye R.M., Adu J.T., and Adisa R.O. (2022): Assessment and Impacts of Metal Recycling on Groundwater Quality in Ogijo, Ogun State, Nigeria. *FUOYE Journal of Engineering and Technology* (FUOYEJET), 7(2), 244-248. http://doi.org/10.46792/ fuoyejet.v7i2.799

35. Sanyaolu, V. T., Eleyowo, O. O. and Ogundare, C. O. (2018). Heavy metal residues in hair sample of residents around metal recycling factories in Ikorodu, Lagos state, Nigeria. *Ife Journal of Science*, 20(3), 451- 457. DOI: 10.4314/ijs.v20i3.11

36. Agbogidi, O.M., Eruotor, P.G., Akparobi, S.O., Nnaji, G.U. (2007). Heavy Metal Contents of Maize (Zea mays L.) Grown in Soil Contaminated with Crude Oil. *Int.J. Bot*. 3(4), 385-389. DOI: 10.3923/ijb.2007.385.389

37. Kasam, Rahmawati S, Iresha FM, Wacano D, Fauziah IF and Amrullah MA (2018). Evaluation of heavy metal exposure to soil and paddy plant around the closed municipal solid waste landfill: Case study at Gunung Tugel Landfill, Banyumas-Central Java. IOP Conf. Ser. *Mater. Sci. Eng*., 299(1), 9. doi: 10.1088/1757-899

38. LeCoultre and Trent David (2001). A Meta-Analysis and Risk Assessment of Heavy Metal Uptake in Common Garden Vegetables. Electronic Theses and Dissertations. Department of Environmental Health, East Tennessee State University, USA. Paper 113. 64 pp https://dc.etsu.edu/etd/113

39. Singh J and Kalamdhad AS (2011). Effects of heavy metals on soil, plants, human health and aquatic life. *International Journal of Research in Chemistry and Environment*, 1(2), 15–21.

40. Orisakwe, O. E.,. Nduka, J. K. Amadi, C. N Dike, D. O. and Bede, O. (2012). Heavy metals health risk assessment for population via consumption of food crops and fruits in Owerri, South Eastern, Nigeria. *Chemistry Central Journal*, 6, 77. https://doi.org/10.1186/1752-153X-6-77

41. Agbemafle R, Elsie Aggo S, Akutey O and Bentum JK (2019). Heavy metal concentrations in leachates and crops grown around waste dumpsites in Sekondi-Takoradi in the Western Region of Ghana. *Res. J. Environ*. Toxicol., 14(1), 16–25. doi: 10.3923/rjet.2020.16.25.

42. Ciriaková A. (2009). Heavy metals in the vascular plants of Tatra Mountains. *Oecologia Montana*, 18, 23-26. https://om.vuvb.uniza.sk/index.php/OM/article/view/210

43. Saravanan, A., Kumar, P. S., Jeevanantham, S., Karishma, S., Tajsabreen, B., Yaashikaa, P. R., and Reshma, B. (2021). Effective water/wastewater treatment methodologies for toxic pollutants removal: Processes and applications towards sustainable development. *Chemosphere*, 280: 130595. https://doi.org/10.1016/j. chemosphere.2021.130595

44. Zoroddu M.A., Aaseth, J., Crisponi, G. Medici, S. Peana M. and Nurchi V.M. (2019). The essential metals for humans: a brief overview. *Inorg. Biochem*., 195, 120-129, https://doi.org/10.1016/j.jinorgbio.2019.03.013

45. Hall, J.L. (2012). Cellular mechanisms for heavy metal detoxification and tolerance. *Journal of Experimental Botany*, **53**(366), 1-11.

46. Uzondu, J. (2012). The thriving scraps metal business. *Nigerian World*, 1(17), 2012.

47. Turkdogan M.K. Fevzi, K. Kazim, K. Ilyas, T. and Ismail U. (2013). Heavy metals in soil, vegetables and fruits in the endemic upper gastrointestinal cancer region. *Environmental Toxicology and Pharmacology*, 13, 175-179. https://doi.org/10.1016/S1382-6689(02)00156-4

48. Jomova K, Makova M, Alomar SY, Alwasel SH, Nepovimova E, Kuca K, Rhodes CJ, Valko M (2022). Essential metals in health and disease. *Chem Biol Interact.* 367, 110173 https://doi.org/10.1016/j.cbi.2022. 110173

49. Bakshi S, Banik C and He Z (2018). The impact of heavy metal contamination on soil health, In: *Managing soil health for sustainable agriculture.* Reicosky, ed., 2, 1–36. pp DOI: 10.19103/AS.2017.0033.20

50. Engwa, G. A, Ferdinand, P. U., Nwalo, F.N., and N. Unachukwu, M.N. (2019). Mechanism and Health Effects of Heavy Metal Toxicity in Humans. In: *Poisoning in the Modern World - New Tricks for an Old Dog*? Intech Open.doi: 10.5772/intechopen.82511

51. Ghosh, G.C., Khan, M.J.H. and Chakraborty, T.K. (2020). Human health risk assessment of elevated and variable iron and manganese intake with arsenic-safe groundwater in Jashore. *Bangladesh. Sci*, 10, 5206. Accessed October 17, 2023, retrieved from https://doi.org/10.1038/s41598-020-62187-

52. Sreekanth T.V.M., Nagajyothi P.C., Lee K.D., Prasad T.N.V.K.V. (2013). Occurrence, physiological responses and toxicity of nickel in plants. *Int. J. Environ. Sci. Technol.*, 10, 1129–1140. https://doi.org/10.1007/s13762-013-0245-9

53. Chen Q.Y., Brocato J., Laulicht F. Costa M. (2017). Mechanisms of nickel carcinogenesis. In: Mudipalli A., Zelikoff J.T., editors. *Essential and Non-Essential metals. Molecular and Integrative Toxicology*. Springer International Publishing AG; New York, NY, USA:. 181–197 pp DOI: 10.1007/978-3-319-55448-8_8

54. Lange, B.; van der Ent, A.; Baker, A.J.M.; Echevarria, G.; Mahy, G.; Malaisse, F.; Meerts, P.; Pourret, O.; Verbruggen, N.; Faucon, M.P. (2017). Copper and Cobalt Accumulation in Plants: A Critical Assessment of the Current State of Knowledge. *New Phytol.*, 213, 537–551. https://doi.org/10.1111/nph.14175

55. Oe, S., Miyagawa K, Honma Y, Harada M. (2016). Copper induces hepatocyte injury due to the endoplasmic reticulum stress in cultured cells and patients with Wilson disease. *Exp Cell Res.*, 347(1), 192-200. https://doi.org/10.1016/j.yexcr.2016.08.003

56. Harris E. D. (2000). Cellular copper transport and metabolism. *Annu Rev Nutr*, 20, 291-310. https://doi.org/10.1146/annurev.nutr.20.1.291

57. Fasani, E., Manara, A., Martini, F., Furini, A., and DalCorso, G. (2018). The potential of genetic engineering of plants for the remediation of soils contaminated with heavy metals. *Plant Cell Environ*., 41, 1201–1232. https://doi.org/10.1111/pce.12963

58. Yilmaz, A. B. (2005). Comparison of heavy metal levels of grey mullet (Mugil cephalus L.) and sea bream (Sparus aurata L.) caught in Iskenderun Bay (Turkey). *Turk J Vet Anim Sci*., 29(2), 257–62. Accessed Jan 10, 2024, Retrieved from: http://journals.tubitak.gov.tr/veterinary/issues/vet-05-29-2/vet-29-2-10-0301-1.pdf

59. Najeeb U, Ahmad W, Zia MH, Malik Z, Zhou W. (2014). Enhancing the lead phytostabilization in wetland plant Juncus effusus L. through somaclonal manipulation and EDTA enrichment. *Arab J Chem*, 10(2), S3310-S3317 https://doi.org/10.1016/j.arabjc.2014.01.009

60. Tinkov, A.A., Filippini, T, Ajsuvakova, O. P, Skalnaya, M. G., Aaseth, J., Bjørklund, G., Gatiatulina, E. R., Popova, E. V., Nemereshina, O. N., Huang, P.T., Vinceti, M. and Skalny, A.V. (2018). Cadmium and atherosclerosis: A review of toxicological mechanisms and a meta-analysis of epidemiologic studies. *Environ Res*., 162, 240-260. https://doi.org/10.1016/j.envres.2018.01.008

61. Goyer, R.A., Liu, J. and Waalkes M.P. (2004).Cadmium and cancer of prostate and testis. *Biometals*, 17(5), 555-558. DOI: 10.1023/b:biom.0000045738.59708.20

62. Mezynska, M. and Brzóska, M.M. (2018). Environmental exposure to cadmium—a risk for health of the general population in industrialized countries and preventive strategies. *Environ Sci Pollut Res*, 25, 3211–3232 https://doi.org/10.1007/s11356-017-0827-z

63. Ghani A. (2011). Effect of chromium toxicity on growth, chlorophyll and some mineral nutrients of Brassica juncea L. *Egyptian Acad J Biol Sci*, 2(1), 9–15. DOI:10.21608/EAJBSH.2011.17007

64. Dayan, A.D. and Paine, A. J. (2001). Mechanisms of chromium toxicity, carcinogenicity and allergenicity: a review of the literature from 1985 to 2000. *Hum Exp Toxicol.*, 20(9), 439–451. https://doi.10.1191/09603270 1682693062.

65. Zhang, X. H., Zhang, X., Wang, X.C., Jin, L.F., Yang, Z.P., Jiang, C.X., Chen, Q., Ren, X. B., Cao, J. Z., Wang Q. and Zhu, Y. M. (2011). Chronic occupational exposure to hexavalent chromium causes DNA damage in electroplating workers. *BMC Public Health*, 11, 224. https://doi.org/10.1186/1471-2458-11-224

66. AOAC (2005). Official method of analysis. 18th Edition, Association of Official Analytical Chemists, Washington DC.

67. Kiema FM, Owuor PO andKapiyo RJA (2017).Recent Influences of Anthropogenic Activities and Seasons on Heavy Metal Distribution in Shoreline Sediments in Lake Victoria Near Kisumu City, Kenya. *J. Environ Anal Chem*, 4, 201. doi:10.41722380-2391.1000201

68. DeVolder, P. S., Brown, S. L., Hesterberg, D. and Pandya, K. (2003). Metal bioavailability and speciation in a wetland tailings repository amended with biosolids compost, wood ash and sulfate. *Journal of Environmental Quality*, 32(3), 851–864. https://doi.org/10.2134/jeq2003. 8510

69. Sanyaolu V.T. and Adeniran A.A. (2014). Determination of Heavy Metal Fallout on the surrounding Flora and Aquifer: Case Study of A Scrap Metal Smelting Factory in Odogunyan Area, Ikorodu, Lagos- State, Nigeria. *International research journal of environmental sciences*, 3(4), 93-100.

70. Yola, I.A. and Sanni, A.A (2020). Investigating the environmental pollution caused by steel slag in Dana Steel Rolling Mill plant, Katsina. *Bayero FUOYE Journal of Pure and Applied Sciences*, 12(2), 111 – 115. http://dx.doi.org/10.4314/bajopas.v12i2.15

71. Xie, J., Wu, S., Lin, J., Cai, J., Chen, Z. and Wei, W. (2012). Recycling of basic oxygen furnace slag in asphalt mixture: Material characterization & moisture damage investigation. *Construction and Building Materials*, 36, 467-474. https://doi.org/10.1016/j.conbuildmat.2012.06.023

72. Levy, D. B., Barbarick, K. A., Siemer, E. G. and Sommers, L. E. (1992). Distribution and partitioning of trace metals in contaminated soils near Leadville, Colorado. *Journal of Environmental Quality*, 21(2), 185–195. https://doi.org/10. 2134/jeq1992.00472425002100020006x

73. Okusami, T. A., Rust, R. H. and Alao, A. O. (1997).Red soils of different origins from southwest Nigeria: Characteristics, classification, and management considerations.*Can. J. Soil Sci*., 77, 295–307. https://doi.org/10.4141/S96-069

74. Raymond A. Wuana and Felix E. Okieimen (2011). Heavy Metals in Contaminated Soils: A Review of Sources, Chemistry, Risks and Best Available Strategies for Remediation. *International Scholarly Research Notices*, Article ID 402647, 20 pages. https://doi.org/10. 5402/2011/402647

75. Yang, L., Wei, T., Li, S., Lv, Y., Miki, T., Yang, L., Nagasaka, T. (2021). Immobilization persistence of Cu, Cr, Pb, Zn ions by the addition of steel slag in acidic contaminated mine soil. *Journal of Hazardous Materials*, 412,125176.https://doi.org/10.1016/j.jhazmat.2021.125176.