



Heavy Metal Fractionation and Leachability studies on Municipal Solid Waste (MSW) from Lokoja, Kogi State Nigeria

Okorie Edmund^{1*} and Ekele Victor Ojonugwa²

¹Chemistry Unit, Department of Science Laboratory Technology, School of Technology, Federal Polytechnic Idah P.M.B. 1037 Idah, Kogi State Nigeria.

²Biochemistry Unit, Department of Science Laboratory Technology, School of Technology, Federal Polytechnic Idah P.M.B. 1037 Idah, Kogi State Nigeria.

Email address:

*Corresponding author E-mail: okorie.edmund@gmail.com

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ABSTRACT

The heavy metal content and fractionation of dry, partially decomposed and wet Municipal Solid Waste (MSW) from Lokoja, Nigeria was carried out using FAAS detection. The results from the dry MSW sample indicated a concentration of $0.004 \pm 0.001 \mu\text{g/g}$ for Pb in the exchangeable fraction while Cu concentration at the exchangeable fraction is $0.146 \mu\text{g/g}$. The bound to carbonate fraction for Pb was slightly elevated with the concentration of $4.908 \pm 0.001 \mu\text{g/g}$ while the organic content is $2.004 \pm 0.001 \mu\text{g/g}$. The total Pb concentration at the dry MSW was $8.46 \mu\text{g/g}$. Cd and Ni were only detected in the residual fraction with concentration of $0.168 \mu\text{g/g}$ (Cd) and $1.02 \pm 0.001 \mu\text{g/g}$ (Ni). The partially decomposed MSW has a much higher Pb and Cu content with total value of $22.122 \mu\text{g/g}$ and $23.123 \mu\text{g/g}$ respectively. The exchangeable fraction for Pb and Cu are $1.544 \mu\text{g/g}$ (Pb) and $3.582 \pm 0.005 \mu\text{g/g}$ (Cu). This is an indication that at the partially decomposed MSW, Pb and Cu are highly mobile. Their carbonate bound fractions are equally high with concentration of $16.684 \pm 0.004 \mu\text{g/g}$ (Pb) and $12.85 \pm 0.004 \mu\text{g/g}$ (Cu). Cd and Ni had total concentration of $0.135 \mu\text{g/g}$ (Cd) and $1.037 \mu\text{g/g}$ (Ni). The fresh MSW sample indicated only Cu at the exchangeable fraction ($0.786 \pm 0.002 \mu\text{g/g}$) while Cd and Ni were detected only in the residual fractions. Thus, the partially decomposed MSW has the highest concentration of the heavy metal under study. The enrichment factors for Pb, Cd, Cu and Ni have extremely severe enrichment. Pb, Cu, and Ni showed a low risk in the three samples. Cd found at Natako exhibited a moderate risk to the environment and for Ganaja and Felele, the Cd risk index is of low risk to the environment.

1. INTRODUCTION

Indiscriminate open dumping of municipal solid waste (MSW) without prior source segregation has become a usual practice in most developing countries disposal of hazardous

wastes. Such wastes include batteries, paint residues, ash, treated woods and electronic wastes which increase the heavy metal content in MSW dumpsite environment [1]. Management of MSW usually requires knowledge of the leachability of

metals in order to assess the risk of mobility in landfills to human health and environment [2].

A test that involves the study of the metal mobility is usually applied in assessing worst case environmental scenario where components of the sample become soluble and mobile. Previous study has shown that leaching methods such as, acid digestions, Toxicity Characteristics Leaching Procedure, Equilibrium Leach Test, Sequential Extraction, and Multiple Extraction Procedure are employed to remove soluble components from solid matrix [3]. These are common methods used in characterizing materials and others are employed by organizations tailored to particular specifications. Most of these tests are conducted to ascertain the nature of how hazardous the wastes are. The methods used may vary depending on the amount and particle size of leached samples, the type and volume of leachant solution and the leachant delivery time [4].

It is important to know the type and quantity of heavy metals that are contained in each waste and their leachability at various environmental conditions from the dumpsite. This information will help in the assessment of reclamation and hazardous potential of the reclaimed waste, when it is used as compost for agricultural applications. Since the effects of heavy metals is influenced by their form of existence, assessment of the species of metal ions enable us to evaluate the sustainability of mined waste as compost or cover materials [5]. The pollution potential of landfills due to heavy metals can best be evaluated by fractionation of the metal content into various fractions viz exchangeable, acid extractable, reducible, oxidisable and residual fraction [6].

Management of environmental waste is a problem in many urban and rural areas of most countries of the world particularly in developing countries where we still have inadequate waste management infrastructure with uncontrolled open dumps and illegal road side dumps. Such indiscriminate dumping of waste may degrade scarce resources and obstruct the natural landscape, cause soil and water pollution. This ultimately leads to potential health hazard to plants, animals and humans [7]. Land filling is

generally applied as a disposal method for MSW in most developed and developing countries due to such advantages as simple disposal procedure, low cost and landscape restoring effects on pits from mineral working [8]. Objectionable high levels of heavy metals in these waste soils are extremely toxic to plants and humans [9].

Two leachate management strategies are currently in use by modern MSW landfills. These are leachate reticulation and single pass leachate [2]. These methods are currently not in use in the study area. This study aims to investigate the distribution of various heavy metals percolating through the municipal solid wastes.

2. MATERIALS AND METHODS

2.1. *Materials and reagents*

The materials used are: Soil sample, Flame Atomic Absorption spectrophotometer (FAAS) (Buck Scientific Model AVG 210 UK), Sample, container, Weighing balance, Measuring cylinder, pH meter, glass stirrer, 250 ml of beaker, Filter paper, Conical flask. Regents used are: Acetic acid, Nitric acids, Hydrogen peroxide, Hydroxylamine hydrochloride, Ammonium acetate, Distilled water.

2.2. *Method*

Bureau Community of Reference (BCR) Sequential extraction method was used to obtain information about the speciation of metals. It is used also to evaluate the mobility of heavy metals in the soils sample.

2.3. *Sample Collection*

The municipal solid waste (MSW) sample was collected from three different dumpsite locations in Lokoja, Kogi State Nigeria. The samples were transported to the laboratory for further analysis.

2.4. *Sample Preparation*

1.0g of each sample was weighed into a 50 ml flask and the BCR procedure was used for metal extraction [10]. The sequential extraction protocol used, along with the sediment fractions from which metals are released is summarized in Table 1.

Table 1: Summary of the BCR Sequential Extraction Protocol [10].

Fraction	Component extracted	Extraction reagent	Extraction method
Fraction 1 acid soluble	Exchangeable and bound to carbonates	20 ml 0.11 mol HOAc	Shaking at 22±5°C for 16 hr
Fraction 2 reducible	Bound to Fe/Mn oxides	20 ml 0.5 mol NH ₂ OH. HCl (adjusted to pH 1.5 with HNO ₃)	Shaking at 22± 5°C for 16 hr
Fraction 3 oxidizable	Bound to organic matter and sulphides	5 ml 8.8 mol ⁻¹ H ₂ O ₂ (adjusted to pH 2.0 with HNO ₃ another 5 ml 1 mol ⁻¹ NH ₄ OAc (adjusted to pH 2.0 with HNO ₃).	Digesting at room temperature for 1 hr with occasional manual shaking, then cover the tube and heat at 85±5°C for 1 hr, and then remove the cover and reduce the volume to a few milliliters/covers the tube and heat at 85±5°C for 1 hr.
Fraction 4 residual	Metals Lithogenic minerals	Within Aqua regia	And then remove the cover and reduce the volume to near dryness/shaking at 22±5°C for 16 hrs.

3. RESULTS AND DISCUSSION

3.1. Result

Table 2: Result of the speciation of dry MSW sample at Natako site from Lokoja (µg/g)

Fractions	Pb	Cd	Cu	Ni
Exchangeable	0.004±0.001	ND	0.146±0.000	ND
Bound to carbonate	4.908±0.001	ND	0.487±0.000	ND
Bound to organic matter	2.004±0.001	ND	0.114±0.00	ND
Residual	1.544±0.000	0.168±0.000	0.179±0.001	1.020±0.001
Total	8.46	0.168	0.926	1.020
EPA Value	16	0.38	36	30

Table 3: Result of the speciation of partially decomposed MSW at Ganaja site, Lokoja (µg/g)

Fractions	Pb	Cd	Cu	Ni
Exchangeable	1.544±0.0	ND	3.582±0.005	0.025±0.002
Bound to carbonate	16.684±0.004	0.025±0.013	12.85±0.004	0.294±0.001
Bound to organic matter	2.982±0.0	ND	6.40±0.020	ND
Residual	0.912±0.001	0.110±0.002	0.300±0.0	0.718±0.0
Total	22.122	0.135	23.132	1.037
EPA Value	16	0.38	36	30

Table 4: Result of the speciation of fresh MSW sample at Felele site, Lokoja Nigeria (µg/g)

Fractions	Pb	Cd	Cu	Ni
Exchangeable	ND	ND	0.786±0.002	ND
Bound to carbonate	0.614±0.0	ND	0.525±0.007	ND
Bound to organic matter	0.790±0.0	ND	11.808±0.0	ND
Residual	0.785±0.0	0.1183±0.001	0.151±0.001	0.640±0.001

Total	2.189	0.1183	13.27	0.640
EPA Value	16	0.38	36	30

Table 5: EPA Sediment Quality Guidelines (SQG), ($\mu\text{g/g}$)

Metal	Non polluted	Moderately polluted	Heavy polluted	Present study ($\mu\text{g/g}$)		
				Natako Site	Ganaja Site	Felele Site
Pb	<40	40-60	>60	0.004-4.908	0.912-16.68	0.000-0.790
Cd	*	*	> 6	0.000-0.168	0.000-0.11	0.000-0.1183
Cu	<25	25-50	>50	0.114-0.487	0.300-12.85	0.151-11.808
Ni	< 20	20-50	>50	0.000-1.020	0.000-0.72	0.000-0.640

The result of the dry MSW samples at Natako for the speciation of Pb, Cd, Cu and Ni are presented in Table 2. Tables 3 and 4 are the result of the partially decomposed municipal solid waste (MSW) samples at Ganaja and Felele sites respectively. From Table 2, the concentration of Pb ranged from 0.04-4.908 $\mu\text{g/g}$ with the total Pb concentration of 8.46 $\mu\text{g/g}$. Cd was not detected in the first three phases. However, Cd concentration of 0.168 $\mu\text{g/g}$ was observed in the residual phase. Cu was detected with a range of 0.114–0.487 $\mu\text{g/g}$ with a total Cu concentration of 0.812 $\mu\text{g/g}$. Nickel was not detected in first three fractions, though a concentration of 1.02±0.001 $\mu\text{g/g}$ was observed at the residual phase.

For Table 3, which is the partially decomposed MSW sample at Ganaja site, the observed Pb concentration ranged from 0.912-16.684 $\mu\text{g/g}$ with the total Pb concentration of 22.162 $\mu\text{g/g}$. Cd was not observed at the exchangeable and organic matter phases, however a concentration of 0.025±0.013 $\mu\text{g/g}$ and 0.0110±0.002 $\mu\text{g/g}$ was observed in the bound to carbonate and residual fractions respectively. The total Cd concentration is 0.135 $\mu\text{g/g}$. For Cu speciation, the observed concentration ranged from 0.30-12.85 $\mu\text{g/g}$ with the total Cu concentration of 23.132 $\mu\text{g/g}$. Ni was not detected at the organic matter phase, however a concentration of 0.025±0.002 $\mu\text{g/g}$, 0.294±0.001 $\mu\text{g/g}$ and 0.718±0.0 $\mu\text{g/g}$ was observed in the exchangeable fraction, bound to carbonates and residual fractions respectively. The total Nickel concentration is 1.037 $\mu\text{g/g}$.

The result of fresh municipal solid waste at Felele site in Table 4 showed that Pb was not detected in

the exchangeable fractions. However the following Pb concentration was observed in the other fractions 0.614 $\mu\text{g/g}$ (bound to carbonate), 0.790±0.001 $\mu\text{g/g}$ (bound to organic matter) and 0.785 $\mu\text{g/g}$ (residual). Cd was not detected in the first 3 fractions, while Cd concentration of 0.118±0.0 $\mu\text{g/g}$ was observed in the residual fractions. The observed Cu concentration ranged from 0.151-11.808 $\mu\text{g/g}$ with the total Cu concentration of 13.27 $\mu\text{g/g}$. Nickel was not detected in the first 3 Fractions, however a concentration of 0.64±0.001 $\mu\text{g/g}$ was observed in the residual phase.

3.2 Enrichment Factor

Assessment of heavy metal pollution in marine sediments requires knowledge of pre-industrial metal concentrations to act as a reference against which measured values can be compared [11]. So in order to better understand the sediment quality in the inner Bay, levels of metal pollution were evaluated; therefore different techniques for environmental assessment should be considered. One of them is “enrichment factor (EF)” which is a powerful tool to distinguish between anthropogenic and naturally occurring sources of atmospheric aerosols, sediments, soil and solid wastes to determine the degree of modification in the composition [12].

The EF of metal is defined as follows using Nickel as a reference element.

$$EF = \frac{(C_x/C_{Ni})_{sample}}{(C_x/C_{Ni})_{background}}$$

where

$(C_x/C_{Ni})_{sample}$ is the ratio of metal and Ni concentration of the sample and

$(C_x/C_{Ni})_{background}$ is the ratio of metal

and Ni concentration of background (56). The background concentration of Cu, Pb, Cd and Ni in the average shale obtained from Turekian and Wedopohl [13] are used in this study.

Birch [14] divided contamination into different categories based on EF values. EF < 1 demonstrates a no enrichment, EF < 3 is “minor enrichment”, EF = 3-5 is “moderate enrichment”, EF = 5-10 is “moderately severe enrichment”, EF = 10-25 is “severe enrichment”, EF = 25-50 is a very severe enrichment” and EF > 50 is “extremely severe enrichment”

3.3 Potential Ecological Risks Index (RI)

The contaminated soil with heavy metal can enter the human body through several pathways and various exposure approach [15]. Elevated levels of toxic heavy metals in agricultural soil can influence food chain; hence lead to increase in the exposure to several dangerous diseases, such as cancer, leukemia and kidney or liver damage [16]. Therefore, the assessment of potential ecological risks (RI) is necessary, which developed by Hakanson [17], represent the toxicity of heavy metals and their risks levels to the environment. RI value is calculated by the following equation by Hakanson [17].

$$RI = \sum_{i=1}^n \frac{(Ti * Ci)}{Bi}$$

Where Ti is toxicity factor of heavy metals (Cd = 30, Pb = 5, Ni = 5, Cu = 5), Ci is measured concentration of heavy metal (i), B is background concentration of heavy metal (i). The grading for the potential ecological risk index is shown on Table 6.

Table 6: Potential ecological risk index (RI) and

level of risk

RI value	Risk level
RI ≤ 50	Low risk
50 < RI ≤ 100	Moderate risk
100 < RI ≤ 150	High risk
150 < RI ≤ 200	Very high risk
200 < RI	Extreme risk

Table 7: Enrichment factor of MSW site at different locations in Lokoja

Sample	Pb	Cd	Cu	Ni
Natak	54.93	50.0	5.50	55.56
Ganaja	55.01	43.33	54.01	52.63
Felele	87.70	92.0	87.49	90.91

Table 8: Potential Ecological risk index of MSW site at different locations in Lokoja

Sample	Pb	Cd	Cu	Ni
Ganaja	7.473	48.0	4.626	0.092
Natak	2.858	50.4	0.185	0.091
Felele	0.739	35.49	2.654	0.057

3.4 Discussion

The concentration of Pb as observed in the dry and fresh sample are lower than the EPA value of 16 µg/g [18]. This is an indication that Pb basically was not part of the municipal solid waste from homes, industries and environment. The very low value at the exchangeable phase may be ascribed to leaching and pH variation [19]. Cd occurs mostly in the residual phase. Therefore the Cd content as observed in the residual phase may be ascribed to its natural contents in the soil. Because of this, sequential extraction may not be sensitive enough to reveal the Cd concentrations [5].

The concentration of Cu as observed in the exchangeable and bound to carbonate phases is an indication that the Cu content of the MSW at Table 2 and 4 are bioavailable in comparison with the EPA Guideline values (Table 5). Cu in Table 2 and 4 are far below the guidelines values[20]. The Pb concentration in Table 3 that is the partially decomposed MSW sample at Ganaja site Lokoja

indicates a concentration that is above the guideline values as prescribes by EPA [20]. The concentration of Cu observed in exchangeable and bound to carbonate fractions is an indication that the waste is highly polluted with Pb.

It is interesting to note that the MSW at Ganaja site is located at the busiest spot where we have domestic dumps and dumps from a nearby mechanic village. This may likely be a contributing factor to high Pb concentration in the partial decomposed MSW at Ganaja site. This reason may also be attributed to high Cu concentration in the MSW sample site. It is equally worthy of note that Cd and Ni occurred significantly at the partially decomposed municipal solid waste sample (Table 3) than at Table 2 and 4. This reason may equally be attributed to anthropogenic factor.

The enrichment factor analysis (Table 7) showed that all heavy metal under investigation (Pb, Cu, Cd and Ni) have extremely severe enrichment ($EF > 50$). Cd at Ganaja displayed a very severe enrichment with an enrichment factor of 43.33. The Risk Index analysis (Table 8) showed that Pb, Cu, and Ni exhibited a low risk in the three samples, while Cd found at Natako site showed a moderate risk to the environment. For Ganaja and Felele, the Cd risk index is of low risk to the environment.

4. CONCLUSION

The result of heavy metal fractionation and leachability studies on MSW from three different locations showed that the partially decomposed MSW has higher concentration of the metals Pb and Cu than the other two samples which are wet and fresh MSW. The high concentration of Pb and Cu in the exchangeable and bound to carbonate phase is an indication that the MSW site is highly polluted and unfit for agricultural purposes. Bioaccumulation may occur with all the MSW samples with time if they are subjected to agricultural use.

COMPETING INTERESTS

There are no competing interests in this work.

AUTHORS CONTRIBUTION

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