



Heavy Metal Pollution and Ecological Risk Assessment of Sludge Deposits from Selected Wastewater Treatment Plants in Lagos, Nigeria

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ABSTRACT

Sewage sludge is usually generated during treatment in wastewater treatment plants (WWTPs). Its disposal could cause the release of heavy metals into the environment, thereby, causing toxic pollution. This study involved the ecological assessment of sewage sludge samples which were collected from four government-owned wastewater treatment plants located at Alausa, Iponri, Abesan and Oke Afa in Lagos State, Southwestern Nigeria and analyzed the Cadmium (Cd), Copper (Cu), Lead (Pb), Nickel (Ni), and Zinc (Zn) contents using standard methods. The results show that all the heavy metals apart from Cd and Ni that were analyzed had concentrations that fell below regulatory limits, however, the ecological assessments used which included Contamination factor (C_f), Geo-accumulation index (I_{geo}), ecological risk factor (E_r) and potential ecological risk index ($\sum E_r$) recorded varying results. The correlation analysis showed that there was a strong positive correlation between Cu and Pb (0.971), Cu and Ni (0.995), and Pb and Ni (0.945) while there was a marginally negative correlation between Cu and Zn (-0.491), and Ni and Zn (-0.559). There were marginal correlations between Cd and Cu, Cd and Pb, Cd and Ni, Cd and Zn, as well as Pb and Zn. The C_f show a decreasing trend of Cd > Ni > Zn > Pb > Cu with sludge sample results varying from moderately polluted to severely polluted with Cd accounting as the main culprit apart from Oke Afa WWTP. Also, the I_{geo} results were in decreasing trend of Cd > Ni > Zn > Pb > Cu with results ranging from strongly polluted to very strongly polluted for cadmium and unpolluted for Cu, Pb and Zinc. The E_r results were in decreasing trend of Cd > Ni > Cu > Pb > Zn with Cd far exceeding its limits and showing a very high ecological risk while Cu, Pb, and Zn did not pose any serious risk. $\sum E_r$ values indicate that apart from Oke Afa WWTP, the WWTPs exhibited very high ecological risk with Cd accounting for over 90% contribution and subsequent threat to the environment. It is therefore, recommended that sewage sludge from all the WWTPs be treated before reuse for other purposes such as agriculture.

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INTRODUCTION

Sewage sludge is the residual solid material that is left after effluents from wastewater treatment plants (WWTPs) had been treated. The municipal wastewater itself usually consists of a mixture of domestic, commercial, industrial wastewater, and rainwater (Eriksson *et*

al., 2008). There is usually a large deposit of sludge during wastewater treatment in treatment plants and these deposits contain pollutants that are hazardous and must be carefully disposed of in such a way it does not constitute a hazard to the environment (Yang *et al.*, 2017; Sheng *et al.*, 2018). There are about three main ways that

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sewage sludge can be disposed of and these include; By incineration, disposal to landfill sites, and recycled for agricultural uses Each of these methods has the potential of releasing heavy metals into the environment, thereby, causing toxic pollution as a result of non-biodegradable features of the constituent deposits of these toxins in sludge. Some of the heavy metals that may be found in sewage sludge include Lead (Pb), Cadmium (Cd), Zinc (Zn), Chromium (Cr), and Nickel (Ni), and their contents in sludge range from about 1mg/Kg to more than 1,000mg/Kg (Huang and Yuan, 2015; Huang and Yuan, 2016; Yang *et al.*, 2017).

Lagos State in Nigeria with an ever rapidly growing population and relatively high number of industries has an ever-increasing demand for water and the resulting release of wastewater and sludge from its more than four treatment plants is a major concern. There is a paucity of studies conducted on the environmental characteristics and indices of sludge emanating from these treatment plants when compared to other countries with large numbers of industries such as the United States and China. In this study, sewage sludge samples were collected from four government-owned wastewater treatment plants located in Lagos

State, Southwestern Nigeria, and analyzed for heavy metals which were subsequently adopted to carry out an ecological risk assessment.

MATERIALS AND METHODS

Sample Collection, Pretreatment of Sludge, and Instrumental Analysis

Sludge samples were collected immediately after being dewatered from four state-owned wastewater treatment plants located at Iponri, Alausa, Oke-Afa, and Abesan in Lagos state, and transferred to the hydraulics and wastewater laboratory at the Federal University of Agriculture, Abeokuta, Ogun State, Nigeria. The samples were subsequently air-dried and pulverized into powder and stored in jars at room temperature. To determine the concentration of heavy metals, the sludge was first weighed and digested as per standard methods for the determination of the concentration of the selected heavy metals (USEPA, 1996). Analysis for each heavy metal parameter from each of the treatment plants was done in triplicates. The heavy metal concentration from all the sludge samples was compared with the European Union (EU) and the United States Environmental Protection Agency's (USEPA, 1996) maximum permissible limits for sediment/soil/sludge.

Table 1: Maximum permissible limits of selected heavy metals in sewage sludge

Heavy metals	Units	EU Directive 86/278/EEC	USEPA 40 CFR Part 503, 503.13
Cadmium (Cd)	mg/Kg	20 - 40	39
Copper (Cu)	mg/Kg	1000 - 1750	1500
Nickel (Ni)	mg/Kg	300 - 400	420
Lead (Pb)	mg/Kg	750 - 1200	300
Zinc (Zn)	mg/Kg	2500 - 4000	2800

(Source: McGrath *et al.*, 2000; Nilsson and Dahlström, 2005)

Methods of Analysis

To assess the level of pollution and potential ecological risk of heavy metals in the sewage sludge, the following indices were used; Contamination factor (C_f), Ecological Risk Factor (E_r), Potential Ecological Risk Index (R_i), and Geo-accumulation Index (I_{geo}).

Contamination Factor (C_f)

The contamination factor is a single index indicator that is used to evaluate metal

contamination. It is a ratio between an element at the sampled location and the same element at a background site or reference value. It provides information on how a given element has been concentrated at the site under consideration relative to a background site. It is mathematically expressed as;

$$C_f = \frac{C_i}{C_b} \quad (1)$$

where C_f is the contamination factor, C_i is the concentration of metal of interest of a sludge

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sample and C_0 is the concentration of the same metal at a background or reference site. Four levels are used to describe the contamination

factor and are given below in table 2 (Suleiman *et al.*, 2018; Kang *et al.*, 2020).

Table 2: Contaminant Factor (C_f)

C_f Levels	Sludge quality
$C_f < 1$	Low
$1 \leq C_f < 3$	Moderate
$3 \leq C_f < 6$	Considerable
$C_f \geq 6$	Very high

The Geo-accumulation Index (I_{geo})

The geo-accumulation index has been previously used to estimate the level of pollution of heavy metals in different environmental media (Muller, 1969; Lee *et al.*, 2013; Chen *et al.*, 2016). In this method, the index is calculated as

$$I_{geo} = \log_2 \frac{C_n}{1.5B_n} \quad (2)$$

Where C_n metal is the concentration of the measured heavy metal in the sludge sample and B_n is the geochemical reference value of the metal n . The factor 1.5 is usually introduced to make up for any possible variations in the background or control values that may be attributed to lithogenic. Table 5 describes the levels of geo-accumulation.

Table 3: Levels for geo-accumulation index

I_{geo} Levels	Sludge quality
$I_{geo} < 0$	unpolluted
$0 \leq I_{geo} < 1$	unpolluted to moderately polluted
$1 \leq I_{geo} < 2$	Moderately polluted
$2 \leq I_{geo} < 3$	moderately to strongly polluted
$3 \leq I_{geo} < 4$	strongly polluted
$4 \leq I_{geo} < 5$	strongly to very strongly polluted
$I_{geo} > 5$	very strongly polluted

Source: Muller, 1969; Suleiman *et al.*, 2018.

Ecological Risk Factor (E_r):

Ecological risk assessment is used to determine the nature of anthropogenic effects on the environment. The assessment of ecological risks of heavy metals in sewage sludge samples was done using the Ecological Risk factor E_r proposed by Hakanson (1980), expressed as follows;

$$E_r = \frac{C_n}{C_0} \times T_r \quad (3)$$

Where E_r is the ecological risk factor, T_r is the toxic response factor of a certain metal. The values of T_r for each metal are arranged in the order of $Zn=1 < Cr=2 < Cu=Ni=Pb=5 < =30$ (Iwegbue *et al.*, 2013). C_n is the metal content in the soil and C_0 is a background value (reference value of metals in soil). The following description of levels of ecological risk was given in table 3 (Suleiman *et al.*, 2018).

Table 4: Levels for Ecological Risk factor (E_r)

E_r Levels	Sludge quality
$E_r < 40$	low potential ecological risk
$40 < E_r < 80$	moderate potential ecological risk
$80 < E_r < 160$	considerable potential ecological risk
$160 < E_r < 320$	high potential ecological risk
$E_r > 320$	very high potential ecological risk

Source: Hakanson, 1980; Suleiman *et al.*, 2018; Kang *et al.*, 2020.

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The Potential Ecological Risk Index (R_i).

$$R_i = \sum E_r \quad (4)$$

Where R_i is potential ecological risk calculated as the sum of the ecological risk factor

for heavy metals in sludge and E_r is an ecological risk factor.

The following terminology is used to describe the potential ecological risk index in table 5;

Table 5: Levels of Potential Ecological Risk Index (R_i)

R_i Levels	Sludge quality
$R_i < 150$	low ecological risk
$150 \leq R_i < 300$	moderate ecological risk
$300 \leq R_i < 600$	considerable ecological risk
$R_i > 600$	very high ecological risk

Source: Hakanson, 1980; Suleiman *et al.*, 2018.

RESULTS AND DISCUSSION

Results of Physico-chemical analysis

The results of the physico-chemical analysis of the sludge samples are shown below in Table 6 and the abundance of heavy metals was in declining order: $Zn > Ni > Pb > Cd > Cu$ and their range of concentration was recorded as Cd (0 – 60 mg/Kg), Cu (23 – 32 mg/Kg), Pb (44 – 106 mg/Kg), Ni (62 – 600 mg/Kg) and Zn (70 – 358 mg/Kg). It could be seen that apart from the sample Oke Afa WWTP, the cadmium

concentration exceeded both permissible levels endorsed by EU and USEPA. The concentrations of copper, lead, and zinc were all below the permissible limits while the concentration of Nickel apart from the sample from Iponri WWTP also fell below the maximum permissible limits. The results may be an indication that the WWTPs may not be functioning well and that the plants appear not to have been totally overwhelmed beyond its operating efficiency.

Table 6: Heavy metals content in the sludge samples (mg/kg)

Wastewater Treatment Plant	Cd	Cu	Lead	Nickel	Zinc
Alausa	60	25	60	200	166
Iponri	30	32	106	600	70
Abesan	22	24	65	80	358
Oke Afa	ND	23	44	62	104

ND – Not detected.

Descriptive statistics and Correlation analysis

The results of the statistical attributes of the sludge samples are shown below in table 7 with Ni having the highest mean, maximum concentration and range of values as well as

highest variance. This could be attributed to its contents coming from multiple anthropogenic sources that may both be connected and unconnected to the other heavy metal sources.

Table 7: Descriptive Statistics

	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
Cd	4	60	0	60	28.00	24.819	616.000
Cu	4	9	23	32	26.00	4.082	16.667
Pb	4	62	44	106	68.75	26.399	696.917
Ni	4	538	62	600	235.50	250.601	62801.000
Zn	4	288	70	358	174.50	128.627	16545.000
Valid N (listwise)	4						

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The correlation analysis in Table 8 reveal that there were strong positive correlations between Cu and Pb (0.971), Cu and Ni (0.995), and Pb and Ni (0.945) while there was a marginally negative correlation between Cu and Zn (-0.491), and Ni and Zn (-0.559). there were marginal correlations between Cd and Cu, Cd and Pb, Cd

and Ni, Cd and Zn, as well as Pb and Zn. It is probable that Cu, Pb and Ni were produced from the same sources and that Cd may likely be produced from multiple sources other than where the other four heavy metals were sourced from.

Table 8: Correlation Matrix of heavy metals in sludge samples
 Correlation Matrix

		Cd	Cu	Pb	Ni	Zn
Correlation	Cd	1.000	.250	.259	.289	.041
	Cu	.250	1.000	.971	.995	-.491
	Pb	.259	.971	1.000	.946	-.271
	Ni	.289	.995	.946	1.000	-.559
	Zn	.041	-.491	-.271	-.559	1.000

The calculated values of contamination factor which are displayed below in Table 9 indicate the sludge samples from all the WWTPs were highly polluted with cadmium apart from the Oke Afa WWTP which did not record cadmium from its analysis. The results also show that the sludge samples ranged from low to considerably

contaminated apart from the Cd results in all the selected WWTPs. This is an indication that cadmium levels may be coming from industries that produce batteries, alloys, coatings (electroplating), solar cells, plastic stabilizers, etc which are common among industries in Lagos.

Table 9: Contaminant Factor C_f values of the sewage sludge samples

	Alausa	Iponri	Abesan	Oke Afa
Cadmium	75	35.5	27.5	ND
Copper	0.69	0.89	0.67	0.64
Lead	0.71	1.25	0.76	0.52
Nickel	5.71	17.14	2.29	1.77
Zinc	1.19	0.50	0.26	0.74

(ND – Not detected)

The results for geo-accumulation Index are displayed in Table 10 and it reveals that the I_{geo} values for Cu, Pb and Zn were observed to belong to the unpolluted category. However, the values for Cd apart from Oke Afa were classified

as ranging from strongly polluted to very strongly polluted while Nickel values ranged from unpolluted to strongly polluted. The I_{geo} values in the sludge were in decreasing order of Cd > Ni > Zn > Pb > Cu.

Table 10: Results for Geo-accumulation Index values of the sewage sludge samples

Heavy Metals	Alausa	Iponri	Abesan	Oke Afa
Cadmium	5.64	4.64	4.17	0
Copper	-1.12	-0.76	-1.15	-1.22
Lead	-1.09	-0.27	-0.97	-1.51
Nickel	1.93	3.51	0.61	0.24
Zinc	-0.34	-1.60	-2.56	-1.03

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The assessment results of the ecological risk factor displayed in table 11 show that it followed the trend in decreasing order Cd > Ni > Cu > Pb > Zn. The results show that Cadmium far exceeded the limits and showed very high potential ecological risk while nickel ranged from low potential to considerable ecological risk. Copper, lead and zinc did not pose any serious ecological risk. From the potential ecological risk factor results, Alausa, Iponri, and Abesan WWTPs all showed very

high ecological risk with cadmium acting as the main risk with contributions of more than 90% in these treatment plants. The implication of this result is that cadmium poses a very serious threat to the environment and additional treatment is required before the sewage sludge could be used. This result is similar to that obtained in Yang *et al.* (2017) where the sewage sludge produced very high ecological risks with cadmium also being the main culprit.

Table 11: Ecological Risk Factor and Potential Ecological Risk Index values of the sewage sludge samples

Heavy Metals	Alausa	Iponri	Abesan	Oke Afa
Cadmium	2250	1125	825	0
Copper	3.45	4.45	3.35	3.2
Lead	3.55	6.25	3.8	2.6
Nickel	28.55	85.70	11.45	8.85
Zinc	1.19	0.50	0.26	0.74
Potential Ecological Risk Index (R _i)	2286.74	1221.90	843.86	15.39

CONCLUSION

The heavy metals concentration were all within the regulatory limits apart from Cd and Ni, however, their ecological assessment revealed that cadmium posed a great threat to the environment while nickel did not pose as much threat even though its E_r values varied across the four WWTPs. The potential ecological risk factor results show that only the sewage sludge from the WWTP at Oke Afa did not exhibit very high risk due to the non-availability of cadmium in its sludge contents. Cadmium is more likely to pose more harmful effects if the sludge samples containing it are released directly into the environment and therefore adequate remediation efforts should be put in place to minimize its effects before being put to reuse.

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