ANALYSIS OF ADSORPTION PERFORMANCE OF LATERITIC SOIL GEO-POLYMER COMPOSITE DEVELOPED AS A BARRIER IN A SANITARY LANDFILL

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ABSTRACT

Dump site is a threat to the environment, surface and underground water and has been a major concern in environmental sustainability. This study focused on the effects of different doses of metakaolin-based geo-polymer (0, 5, 7.5, and 10 %) on the adsorption of the heavy metals in the soil-geopolymer: leachate solution (1:4) for their optimal contact times. The mixture was filtered and the concentration of residual pollutants in the municipal solid waste leachate was measured after the corked conical flasks were shaken at 150 rpm using an orbital shaker. As the dosage of the adsorbent was increased, the content of heavy metals in the three leachate samples(A, B ,C) decreased gradually as follows: At 0% dosage the concentration are Pb(0.512, 0.493 and 0.43mg/l), Zn(0.412, 0.191 and 0.397mg/l) and Cu(0.091, 0.133 and 0.126mg/l) for Sample A, B and C and at 10% Pb(0.315, 0.325 and 0.253mg/l), Zn(0.024, 0.031 and 0.028mg/l) and Cu(0.022, 0.003 and 0.009mg/l) for samples A, B and C respectively, resulting to the corresponding increase in the percentage removal thus: At 0% dosage the removal efficiency are Pb(19.24%, 26.98%, and 23.63%), Zn(34.98%, 26.98% and 32.98%) and Cu (81.67%, 63.08% and 70.26%) for sample A, B and C respectively and at 10% dosage the removal efficiency are Pb(50.32%,51.49% and 55.38%), Zn(96.26%,94.97% and 95.25%) and Cu(96.26%, 99.22% and 97.85%) for sample A, B and C respectively after treatment. This is in conformity that Metals adsorption efficiency and capacity increases with increase in adsorbent dose. The adsorption capacity of the lateritic soil -geopolymer composite increases with increase in dosage as witnessed. This proves that during the adsorption reaction, the adsorption sites stay unsaturated while the number of sites available for adsorption site grows when the adsorbent dose is increased. It is recommended to explore different ratios of lateritic soil and geopolymer to determine the optimal composition for enhanced mechanical strength and sorption capacity, potentially leading to even more effective landfill liner materials.

Keywords: Adsorption, Lateritic Soil, Geo-polymer, Landfill, Heavy Metals

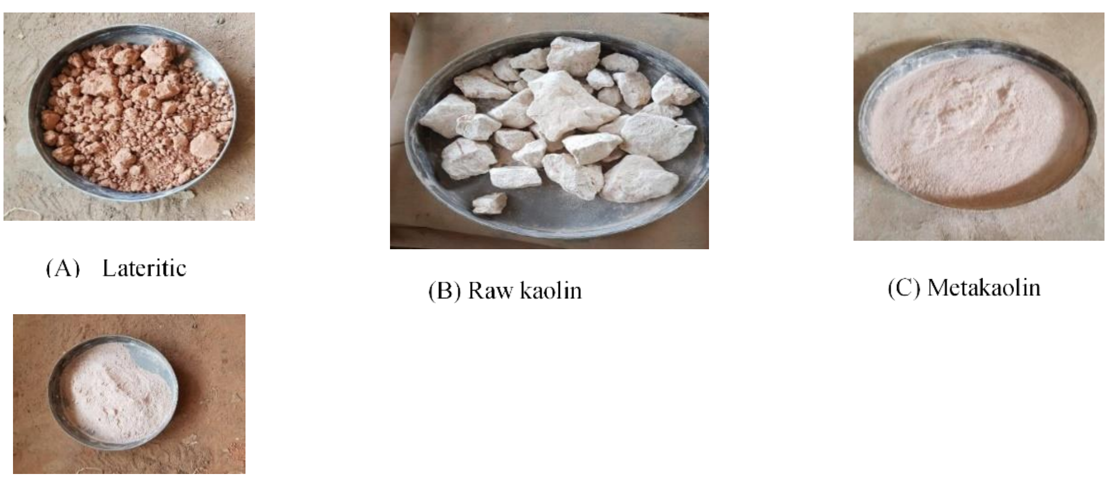
1 INTRODUCTION

Performance evaluation of the adsorption capacity of lateritic soil- geopolymer composite was conducted to ascertain the efficiency of the lateritic soil-geopolymer composite in sanitary landfill leachate heavy metal removal. The leachate from sanitary landfills that is dominated by heavy metals has a high complex formation rate. Heavy metals are extremely persistent in the environment due to their high reactivity and elevated metabolic activity. If these metals are not handled, sanitary landfill leachate helps move them to the soil and water bodies [1, 2, 3]. The optimal conditions for the adsorption performance of lateritic soil geo-polymer composites in sanitary landfill applications are influenced by several factors, including soil composition, moisture content, and the presence of additives like geopolymer. Lateritic soils rich in kaolinite and iron oxides exhibit high sorption capacities for heavy metals, making them suitable for landfill liners [4]. Geopolymers, such as clay-metakaolin, clay-fly ash mixtures, offer a sustainable alternative with high durability and low CO_2 emissions, further enhancing landfill liner performance. Geopolymers contribute to sustainable waste management by utilizing hazardous materials, such as fly ash, which can be treated to reduce heavy metal leachability [5]. This research introduces geopolymers as a promising solution, highlighting their benefits such as high sorption capacity, durability, and mechanical strength. These properties make geopolymers suitable material for use in landfill applications, addressing the limitations of conventional materials. Lateritic soil- geopolymer composite as an adsorbent has proven to be efficient in heavy metal attenuation and as such can be recommended as a good material for liner [4]. In order to maintain environmental sustainability, sanitary landfill leachate treatment is consequently essential [2, 6, 7, 8]. It is desirable to have an environmentally friendly landfill liner to capture leachate generated by the garbage, house it, guard against attacks, and serve as a barrier against dangerous compounds like heavy metals. Stated differently, the primary function of a liner is to stop temporary flows of trash and pollutants into groundwater systems, including aquifers and wells. According to [9], a liner must have the necessary hydraulic conductivity, which is less than or equal to 1 x 10^{-9} m/s, to stop pollutant migration [10, 11]. Waste containment is greatly aided by the engineering qualities of the compacted materials, such as low permeability and stability during construction and operation. Reducing leachate flow and contaminant attenuation is the fundamental goal of containment systems for hazardous and municipal trash [10, 11, 12].

2 MATERIALS AND METHODS

2.1 Materials

The following materials outlined in Plate 1 are used for the research; Leachate samples, Lateritic soil, Kaolin, Metakaolin, Geopolymer, Tap water. The natural kaolin clay utilized came from a natural deposit site in Niger State while the lateritic soil was acquired from a borrow pit in Lapai-Gwari Road borrow pit, Lat: 9°31'15" N and 9°32'30" N and Longitude 6°26'15" E and 6°28'00" E Gidan Kwano Minna, Niger State. The soil samples were disturbed samples. The sample was obtained from a depth not less than 1.5m to avoid organic top soil from mixing up with the sample. Also, the geopolymer was produced through the process of geopolymerization using calcined raw kaolin and the activators (Na_2SiO_3 and NaOH).



(A) Lateritic

(B) Raw kaolin

(C) Metakaolin

(D) Geopolymer

Plate 1. (A) Lateritic Soil (B) Raw Kaolin (C) Metakaolin (D) Geopolymer

2.2 Method

2.2.1 Batch Adsorption Techniques

The sorption capacity of lateritic soil - metakaolin - based geo-polymer composite for the studied pollutants in municipal solid waste leachate was identified using batch equilibrium techniques. All tests are conducted according to ASTM 1987 standard procedures. The investigation focused on the effects of different doses of lateritic soil -metakaolin-based geo-polymer composite (0, 5, 7.5, and 10%) on the adsorption of the heavy metals in the soil-geopolymer composite - leachate solution (1:4) for their optimal contact times. The mixture was filtered and the concentration of residual pollutants in the municipal solid waste leachate was measured after the corked conical flasks were shaken at 150 rpm using an orbital shaker.

2.2.2 Adsorption Isotherm

To investigate the adsorption isotherm for the adsorptive removal of metal ions, the Langmuir and Freundlich isotherm models were employed.

2.2.3 The Langmuir isotherm

The monolayer sorption on the adsorption sites is described by the Langmuir model. It makes the assumption that monolayer sorption energies are homogeneous and indicates that the adsorbate is not migrating on the surfaces.

2.2.4 The Freundlich Isotherm

Based on multilayer adsorption and equilibrium, the Freundlich isotherm characterizes adsorption processes on heterogeneous surfaces and active sites with varying energies. In its linearized form, the Langmuir isotherm is expressed as follows [13].

$$\frac{C_e}{q_e} = \frac{1}{K_L Q_m} + \frac{C_e}{Q_m} \quad (1)$$

where Q_m is the maximum monolayer coverage capacity (mg/g), C_e is the final concentration of the metal ion (mg/L), K_l is the Langmuir isotherm constant (mg/l), and Co is the initial concentration of the metal ion (mg/l). A dimensionless constant, also known as the separation factor (R_l), is expressed as follows [13].

$$R_L = \frac{1}{1+K_L C_O} \quad (2)$$

R_L Show that the adsorption process is favorable, when $R_l = 0$ is irreversible, $R_l = 1$ is favourable, and $R_l > 1$ is unfavorable. The following is a linear representation of the Freundlich isotherm model.

$$\log q_e = \log K_f + \frac{1}{n}\log C_e \quad (3)$$

Where n is the adsorption intensity, C_e is the equilibrium concentration of adsorbate (mg/l), and q_e is the amount of adsorbate adsorbed at equilibrium (mg/g). K_f is the Freundlich isotherm constant [13].

3 RESULTS AND DISCUSSION

An overview of the chemical composition of the lateritic soil used in this study is given in Table 1. Iron oxide (Fe_2O_3), silicon dioxide (SiO_2), and aluminium oxide (Al_2O_3) were the primary chemical elements of the soil. The pH of the soil was 5, indicating a high degree of acidity and leaching tendency.

Table 1. Chemical composition of the lateritic soil used in the study [14]

Oxide	Percentage
SiO_2	46.24
Al_2O_3	28.27
Fe_2O_3	18.04
K_2O	2.43
TiO_2	1.77
MgO	1.10
P_2O_5	0.47
SO_3	0.42
CaO	0.31
Cl	0.26
MnO	0.20
ZrO_2	0.15
Pr_6O_{11}	0.05
SrO	0.5311

3.1 Oxide Composition of Kaolin Metakaolin and Geopolymer

The high proportion of silicon oxide and aluminium oxide in the raw kaolin used for the research (Table 2) makes it an excellent geopolymerization precursor. The sanitary landfill liner's longevity and pollutant adsorption will both be improved by the high-quality geopolymer that is created, as shown by the ratio of silicon to aluminium and the ignition loss. The resulting geopolymer has an open, connected porous structure and a negatively charged surface—all of which are critical for adsorption processes [6].

Table 2. Oxide Composition of Kaolin, Metakaolin and Geopolymer (XRF)

Oxides (Wt %)	Kaolin	Metakaolin	Geopolymer
Fe2O3	3.41	2.78	1.91
Al2O3	28.8	21.06	13.97
SiO2	41.06	39.7	32.79
Cao	3.67	2.63	1.95
SO3	5.71	4,69	3.84
MgO	15.82	8.79	6.02
K2O	1.99	1.92	1.28
Na2O	10.92	15.36	1.33
Loss in Ignition	7.91	5.13	0.992
SiO2/AlO3	1.43	1.89	2.35

3.2 X-Ray Diffraction of Kaolin, Metakaolin and Geopolymer

The XRD result revealed that quartz and kaolinite minerals are abundant in raw kaolin clay. After calcination, peaks related to quartz and kaolinites vanish as demonstrated by Figures 1 and 2. This is because heat treatment causes the water molecules found in the quartz and kaolinite minerals to dihydroxylate. The reduction of crystallinity and rise in amorphousness that accompany this peak disappearance when the kaolin metamorphoses into geopolymer (Figures 1, 2 and 3) translate to an increase in the geopolymer's adsorption and mechanical strength [15].

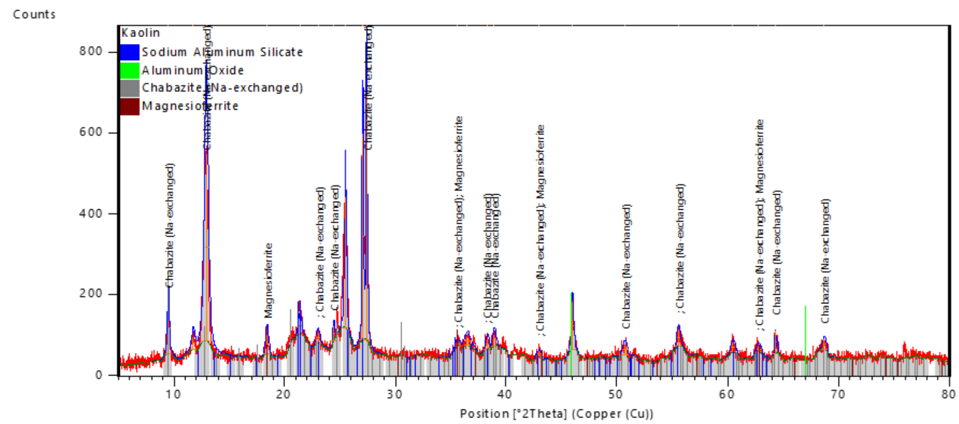


Figure 1. XRD of Kaolin

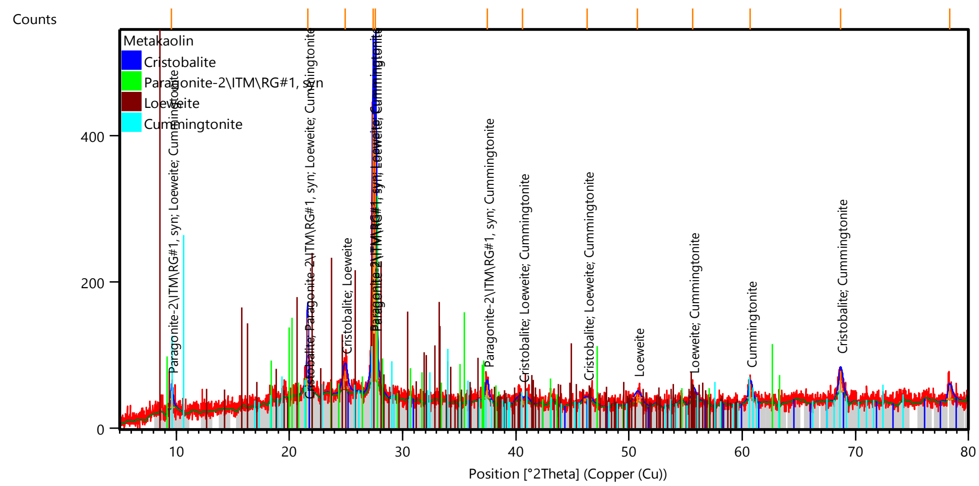


Figure 2. XRD of Metakaolin

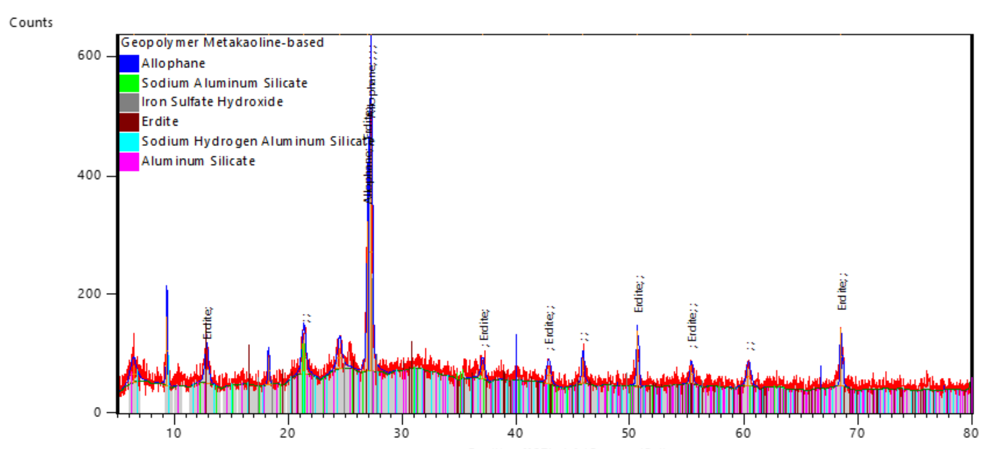


Figure 3. XRD of Geopolymer

Lateritic soil geopolymer composite demonstrated to an extent an increase in heavy metal adsorption with a corresponding increase in geopolymer. This is validated by the upward progressive movement of the graphs in Figures 4 to 9. In leachate sample A as the adsorbent dosage increases the amount of adsorbate adsorbed increases having 0.488mg/g at 0% and 1.276mg/g at 10% for Pb, 0.595mg/g at 0% and 2.1492mg/g at 10% for Zn and 1.624mg/g at 0% and 1.896mg/g at 10% for Cu. Leachate sample B also demonstrates an increase in adsorption with increase in dosage. At 0%, 0.708mg/g of Pb was adsorbed while at 10%, 1.38mg/g of Pb was adsorbed. Also, at 0%, 1.685mg/g of Zn was adsorbed while at 10%, 2.325mg/g of Zn was adsorbed. For Cu at 0%, 0.908mg/g of cupper was adsorbed while at 10% 1.429mg/g of Cu was adsorbed. Conclusively In leachate sample C at 0%, 0.536mg/g of Pb was adsorbed while at 10%, 1.256mg/g was adsorbed. Also, at 0% 0.774mg/g of Zn heavy metal was adsorbed while at 10% 2.248mg/g was adsorbed. Finally, at 0%, 1.192mg/g of Cu was adsorbed while at 10% 1.659mg/g was adsorbed which are all in tandem with other researchers [16, 17, 18].

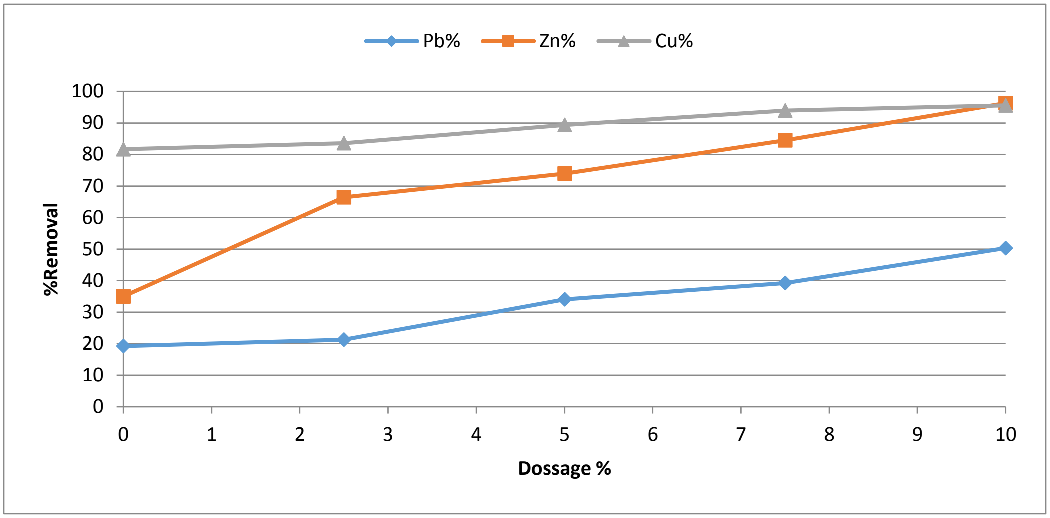


Figure 4. Comparing the relationship between adsorbent Dosage and Percentage removal using Leachate sample A

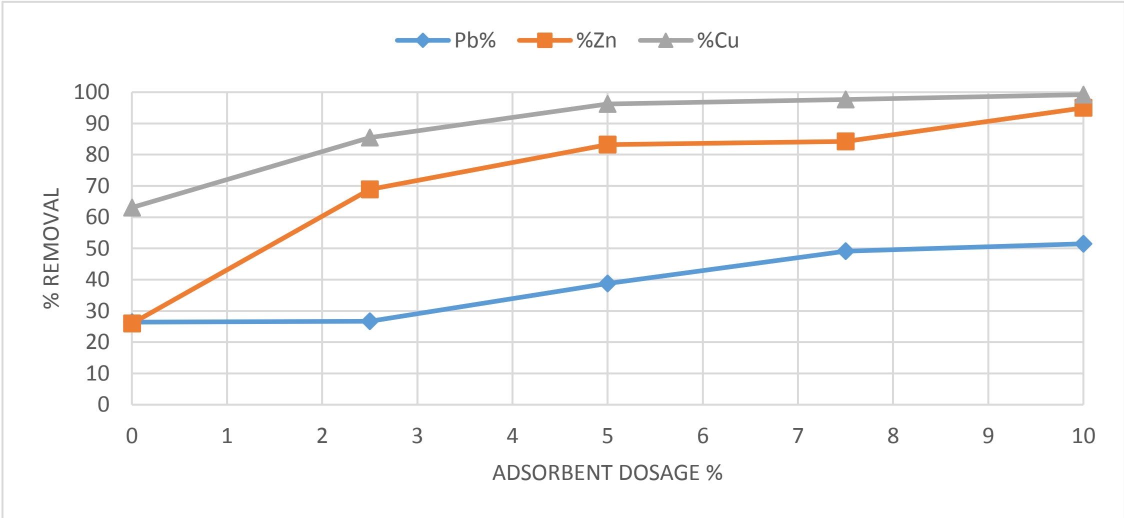


Figure 5. Comparing the relationship between adsorbent Dosage and Percentage removal using Leachate sample B

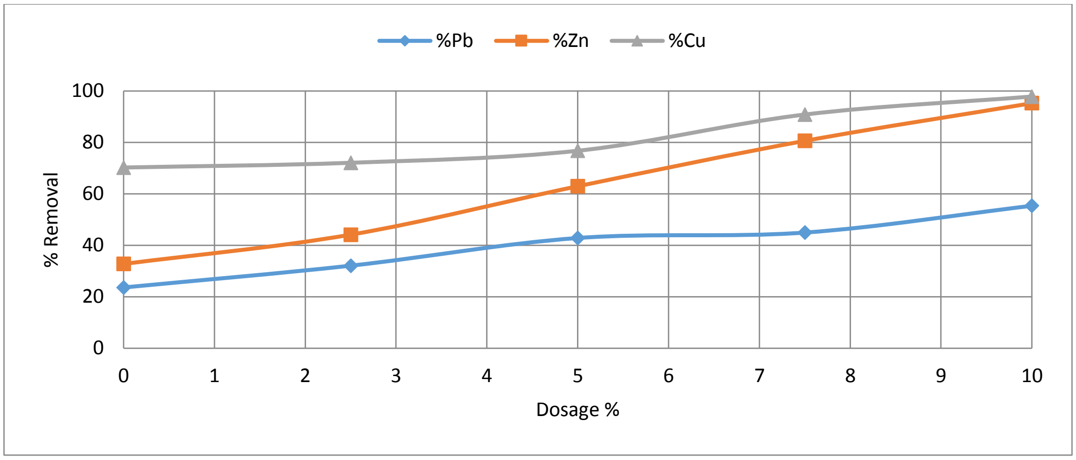


Figure 6. Comparing the relationship between adsorbent Dosage and Percentage removal using Leachate Sample C

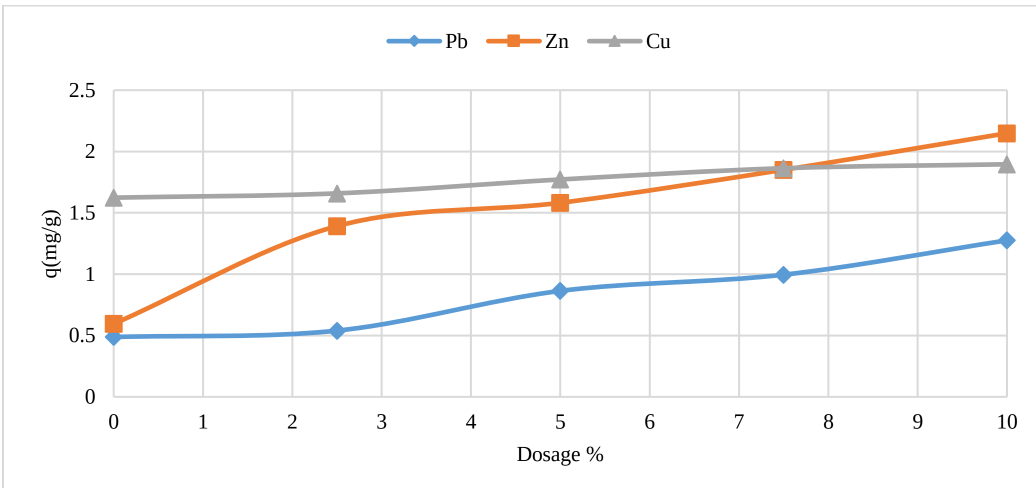


Figure 7. Variation of adsorption capacity with dosage using leachate sample A

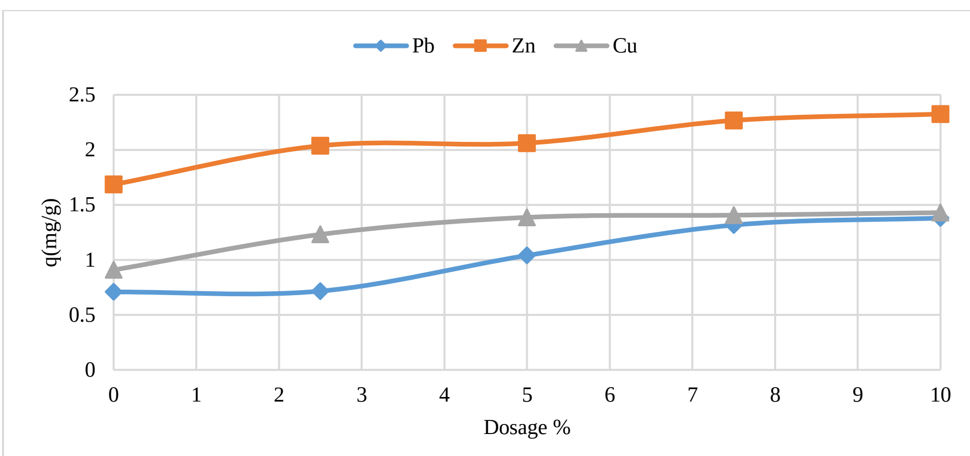


Figure 8. Variation of adsorption capacity with dosage using leachate sample B

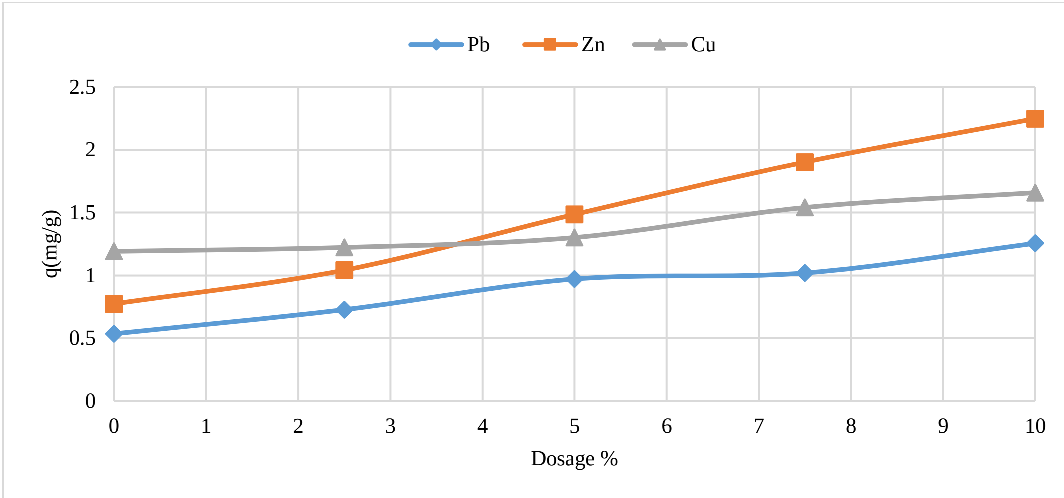


Figure 9. Variation of adsorption capacity and dosage using leachate sample C

The equilibrium values fit the Langmuir isotherm better than the Freundlich adsorption isotherm. The parameters of the adsorption isotherm are shown in Table 3 and plotted in Figures 10 and 11. The more successful adsorption model was selected based on the correlation coefficient (R^2) value. According to Table 3, Sample C had the highest metal ion maximal adsorption capacity (Q_m). All of the samples' R_L values were smaller than 1, indicating that metal ion adsorption on the adsorbents' surface was successful [19, 20].

Table 3. Adsorption Isotherm Studies for the metal ions onto adsorbents

Metal	Sample	Langmuir			Freundlich		
		Q_m	k_L	R^2	k_F	n	R^2
Pb	A	0.241	-3.721	0.94376	0.136	0.498	0.96067
	B	0.553	-14.773	0.90279	0.562	2.604	0.67332
	C	1.563	-200.627	0.99879	1.263	4.774	0.96962
Zn	A	0.358	-4.014	0.98052	0.229	0.616	0.98604
	B	1.597	-65.276	0.99035	1.343	5.988	0.90067
	C	0.898	-203.257	0.99034	0.118	9.025	0.78158
Cu	A	0.302	-4.694	0.93978	0.156	0.637	0.95597
	B	0.767	-17.645	0.92180	0.706	2.762	0.99246
	C	1.167	-163.607	0.99515	0.957	8.052	0.89882

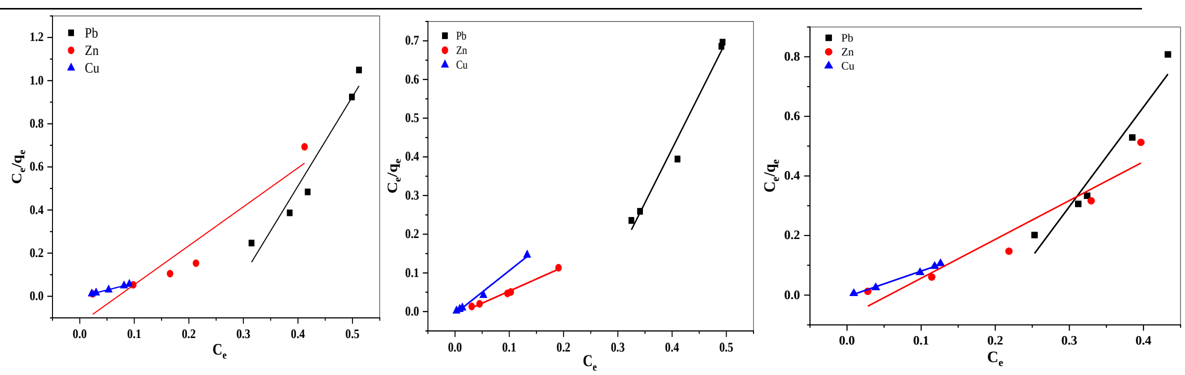


Figure 10. Langmuir isotherm model of metal ions using Leachate samples A, B and C

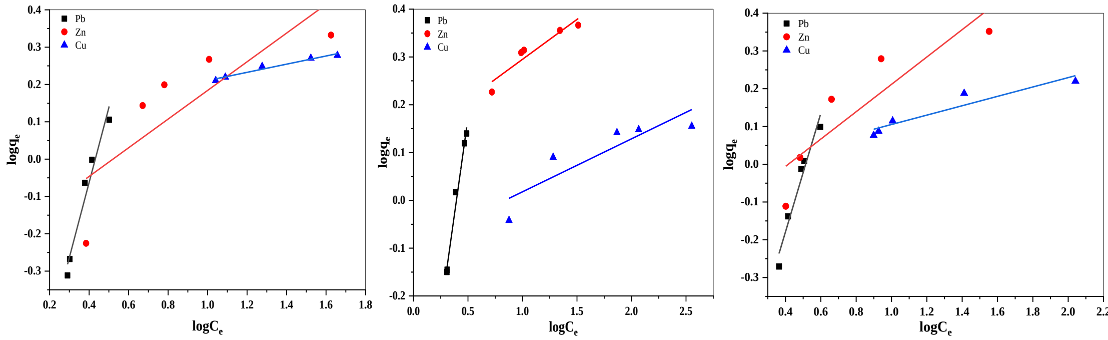


Figure 11. Freundlich isotherm model of metal ions using Leachate samples A, B and C

4 CONCLUSSIONS

As the dosage of adsorbent was increased, the quantity of heavy metals in the three leachate samples gradually decreased, leading to a commensurate increase in the % removal as follows: Pb (19.24%, 26.98%, and 23.63%), Zn (34.98%, 26.98%, and 32.98%), and Cu (81.67%, 63.08%, and 70.26%) for samples A, B, and C, respectively, are the removal efficiencies at 0% dosage. Once treatment is applied, the corresponding removal efficiencies at 10% dosage are Pb (50.32%, 51.49% and 55.38%), Zn (96.26%,94.97% and 95.25%), and Cu (96.26%, 99.22% and 97.85%) for samples A, B, and C. indicating that as the dose of adsorbent increased, so did the metals' adsorption effectiveness. Through the sorption isotherm, it was observed that the adsorption favor's Langmuir isotherm. The synthesized geopolymer using sodium hydroxide and sodium silicate activators, have a notable effect on the removal of heavy metals, achieving more than 70% under optimal conditions of 48 hours and 10% geopolymer which is in consonant with other researchers. In summary, the study concludes that lateritic soil-metakaolin geopolymers are a promising alternative for landfill liner materials, offering significant environmental benefits, mechanical strength, and compliance with regulatory standards.

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