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Assessment of Heavy Metal Contamination in Groundwater Sources Near Dumpsites in Lagos Peri-Urban Communities

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HIGHLIGHTS

- Groundwater near dumpsites showed elevated heavy metal contamination, with concentrations systematically increasing closer to the disposal sites.
- Some groundwater samples exceeded drinking water standards, posing potential health risks to residents.
- Pollution indices classified several groundwater sources as moderately to highly contaminated.

ABSTRACT

In this research, the level of heavy metal contamination was assessed in the groundwater sources located near the dumpsites evaluated within peri-urban communities of Lagos, Nigeria. Well and borehole waters were sourced within the region at varying distances from the dumpsites and evaluated for heavy metals, including chromium (Cr), copper (Cu), zinc (Zn), lead (Pb), cadmium (Cd), and iron (Fe), using standard analytical procedures. Also, key physicochemical parameters such as pH, electrical conductivity, temperature, total dissolved solids, and turbidity were ascertained to evaluate the overall quality of the groundwater. The findings revealed different concentrations of heavy metals across the sampled locations, indicating the influence of dumpsite leachate on groundwater quality. Chromium concentrations ranged from 69.81–83.43% relative contamination levels, copper from 54.51–78.24%, and zinc from 82.15–91.16%, with higher concentrations generally observed in groundwater sources closest to the dumpsites. The contamination was due to variations in pH and the relationship between leachate and groundwater. The pollution analysis revealed several groundwater sources and their affiliation to highly contaminated indices. The research summarises that sources of groundwater around the research area are liable to serious environmental and public health challenges. The study concludes that groundwater resources located near dumpsites in Lagos peri-urban communities are vulnerable to heavy metal contamination and may pose serious environmental and public health challenges if used without proper treatment.

Keywords: Contamination; Dumpsites; Groundwater; Heavy Metal; Peri-Urban Communities

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1. Introduction

The importance of groundwater cannot be overemphasized as far as human survival is concerned. It is the major source of drinking water, used for agricultural purposes, industrial uses, and is most important in poor or developing countries where there are limited resources and facilities for treatment and proper management. In developing countries such as Nigeria, the majority of citizens living in rural settlements depend mainly on borehole or traditional well water for direct consumption and other uses. Based on these known facts, it has become a matter of national concern for the government and citizens to look for means to constitute, implement, and regulate the use of dumpsites within the regions [1]. Dumpsites absorb different kinds of toxic substances, which then infiltrate into the ground; heavy rainfall helps to dissolve soluble substances into the soil to contaminate the groundwater. These substances absorbed into the ground can be heavy metals, pathogens, organic compounds, and other harmful pollutants capable of infiltrating the groundwater, which then poses serious public and environmental health risks, especially in peri-urban communities where waste management policies and standards are not properly implemented [2]. Lagos State is very populated and one of the most populated states in Africa; therefore, it is often exposed to challenges of human management and the waste generated by the people living within areas where government surveillance is limited [3].

Heavy metals are generally known as one of the most hazardous pollutants in groundwater systems. This is because of their toxicity and ability to bioaccumulate within living organisms. Metals such as copper (Cu), zinc (Zn), chromium (Cr), iron (Fe), and Lead (Pb) infiltrate the groundwater through leachate caused by industrial wastes. Heavy metals do not degrade over time like some other pollutants; it remains in the environment for a longer period [4-5]. Groundwater quality assessment includes determination and reduction of the presence of physicochemical properties such as pH, electrical conductivity, total dissolved solids, temperature, turbidity, etc. This assessment helps to ascertain the suitability of the groundwater for domestic use and more. This assessment will help to compare the results to the allowable standards of the World Health Organization (WHO) and the Nigeria Stand for Drinking Water Quality [6-7].

Reported studies show that thermal activation and treatment were employed to increase surface area, porosity, and to analyse the availability of active adsorption sites. Modified clay adsorbents have shown great effectiveness in the removal of various heavy metal-polluted water media. Adsorption mechanisms were also applied, which led to the application of adsorption isotherm, thermodynamics, and kinetic models [8-9]. This study was therefore undertaken to assess heavy metal contamination in groundwater sources located near dumpsites in Lagos peri-urban communities and to investigate the potential application of modified clay as an adsorbent for the removal of selected heavy metals. The findings of this study will contribute to the understanding of groundwater pollution patterns, provide information on the effectiveness of clay-based treatment methods, and support environmental management strategies aimed at protecting public health and ensuring sustainable groundwater utilization [10].

2. Literature Review

2.1. Existing Studies

Literature studies have proven that contamination caused by heavy metals is a widespread environmental issue, especially when it comes to dumpsites where leachates are absorbed into the ground, thereby contaminating the groundwater. The studies revealed that natural and modified clay soils are very good at adsorbing heavy metals and removing them due to high surface areas and their favourable characteristics [1,11,8,12].

2.2. Research Gap

Pollution indices, statistical evaluation, and physicochemical properties analysis have also been combined to carry out a comparative assessment of groundwater quality and contamination risks in the research area. Even though there have been many other similar studies about heavy metals, none of them has expressly evaluated the contamination of groundwater by heavy metals as a result of improper and unregulated or mismanaged dumpsites in Lagos peri-urban communities.

2.3. Comparative Analysis

There are other studies carried out on the causes of heavy metals in groundwater. Some are laboratory assessments of heavy metal removal using clay soil as adsorbents. However, this study is a field-based assessment regarding contamination of groundwater in a dumpsite. This research combines levels of contamination, physicochemical characteristics, pollution indices, and spatial variability to provide useful information on groundwater quality in peri-urban communities [1,8,13].

2.4. Need for Current Research

There is a need to conduct research that will investigate and evaluate the various levels of groundwater contamination in the area. This will help to generate data for monitoring and enforcement of health and safety policies that will checkmate the management of dumpsites in the region.

2.5. Problem Statement

Groundwater is a major source of domestic water in many peri-urban communities in Lagos, Nigeria. However, the indiscriminate disposal of municipal and industrial wastes at open dumpsites has increased the risk of heavy metal contamination through leachate infiltration. The presence of heavy metals such as chromium, lead, cadmium, copper, zinc, and iron in groundwater poses serious health and environmental risks because these metals are toxic, persistent, and can accumulate in living organisms. Despite these concerns, there is not much information on the extent of heavy metal pollution to support effective environmental management and public health protection.

3. Methodology

3.1. Sample Collection and Preparation

The clay soil as well as the well water used as an adsorbent for this research were all collected far away from the University Laboratory. The reagents and apparatus were provided by the University Laboratory staff.

3.2. Clay Collection and Preparation

The sample of clay soil was collected from a rural community in the Lagos axis of Nigeria. The soil sample was collected into a polythene bag in order to protect it against further contamination. The clay samples were subjected to analysis in the Laboratory. The clay was dispersed in water and allowed to settle for a while. Afterwards, the suspended solid particles were separated.

3.3. Effect of pH

The effect of pH was investigated by varying the pH of the aqueous solution at 5.5, 6.5, 7.5, and 8.5. The pH of the solution was adjusted by adding either HCl or NaOH. All the procedures stated for the effect of dosage were repeated, but the adsorbent dosage and the other variables were kept constant, while the pH was varied [14].

3.4. Effect of Temperature

The effect of temperature was investigated by heating the aqueous solution via an electric heater, which was controlled using a water bath at temperatures of 40, 50, and 60 ºC. Again, the procedures stated for the effect of dosage were repeated, but at a constant adsorbent dosage of 1.0g, pH of 6.5, and contact time of 60 min [15].

3.5. Effect of Contact Time

The effect of contact time on the adsorption process was investigated by keeping every parameter constant while running the experiment between 30 minutes and 120 minutes. Again, the procedures stated above were followed accordingly, but at the end of each run, the experiment was stopped, and the process was repeated for a new contact time.

3.6. Effect of Initial Concentration

To enable the application of adsorption isotherms, another set of experiments was prepared according to [8]. Thus, instead of using the well water, distilled water was used and manually polluted by prepared samples of Cr^{6+}, Cu^{2+} and Zn^{2+} from potassium dichromate, copper (II) nitrate and zinc (II) chloride, respectively. Thus, a stock solution of zinc (II) ion was prepared by dissolving 2.668g of zinc (II) chloride in 1 litre of deionised water. Also, a stock solution of chromium (VI) was prepared by dissolving 2.926g of potassium dichromate ($K_2Cr_2O_7$) in 1 litre of deionised water, while a stock solution of copper (II) was prepared by dissolving 3.223g of copper (II) nitrate ($Cu(NO_3)_2$) in 1 litre of deionised water. The subsequent initial concentrations of 25 – 100mg/l for zinc (II), chromium (VI), and copper (II) ions were prepared by diluting the stock solution to the desired concentration.

First, 25mg/l of the prepared initial concentration of each heavy metal ion was poured into a 250 ml conical flask and placed on a rotary disc. Before the addition of the metals, the pH of the solution was adjusted to 6.5 using NaOH and HCl. A constant 1.0g dose of treated clay adsorbent was added to the aqueous solution and stirred using a magnetic stirrer at a stirring speed of 150 rpm. At regulated time intervals of 30 minutes, 10 ml of sample from the solution mixture was drawn using a medical syringe and tested for residual heavy metal concentration until equilibrium was attained. The collected sample was filtered through filter paper, and the heavy metal content in the obtained filtrate was analyzed using an Atomic Absorption Spectrophotometer (AAS). The steps above were repeated for 50mg/l, 75mg/l and 100mg/l of the prepared initial metal concentrations. All the experiments were performed at 29 ºC room temperature [16].

3.7. Estimation of Adsorption Capacity

The percentage of contaminants adsorbed onto the adsorbent was calculated using the formula.

$$\text{Adsorbed metal}(\%) = \frac{C_i - C_f}{C_i} \times 100\% \quad (1)$$

For instantaneous adsorption, the adsorption capacity would be calculated using the formula.

$$Q_t = (C_i - C_t)\frac{V}{w} \quad (2)$$

Where:

Q_t = Concentration of contaminant adsorbed by the clay at time t (mg/g)

C_f = Final concentration of contaminant in the liquid mixture (mg/l)

C_i = Initial concentration of contaminant in the solution (mg/l)

C_t = Concentration of contaminant in the solution at time t (mg/l)

V = Volume of liquid mixture (l)

w = Weight of adsorbent (g)

a. Adsorption Isotherms

$$Q_e = (C_i - C_e)\frac{V}{w} \quad (3)$$

Where:

Q_e = Concentration of metal ions adsorbed by clay at equilibrium (mg/g)

C_i = Initial concentration of metal ions in the solution (mg/l)

C_e = Concentration of metal ions in the solution at equilibrium (mg/l)

V = Volume of liquid mixture (l)

w = Weight of clay particle or dosage (g)

b. Langmuir Isotherm

The Langmuir isotherm model has been used by many researchers, as expressed;

$$Q_e = \frac{Q_m K_L C_e}{1 + K_L C_e} \quad (4)$$

Linearization of equation (4) gives

$$\frac{C_e}{Q_e} = \frac{C_e}{Q_m} + \frac{1}{K_L Q_m} \quad (5)$$

A plot of $\frac{C_e}{Q_e}$ versus C_e would give a slope equivalent to $\frac{1}{Q_m}$ and the intercept as $\frac{1}{K_L Q_m}$.

Where: Q_m = Maximum adsorption capacity (mg/g)

K_L = Energy of adsorption (l/mg)

To further investigate the adsorption system, the Langmuir isotherm was further expressed as a dimensionless parameter called the separation factor R_L, which is used to indicate the favourability of contaminant adsorption from a solution. The adsorption separation factor was expressed as:

$$R_L = \frac{1}{1 + K_L C_i} \quad (6)$$

When $0<R_L<1$, it indicates that the adsorption is favourable; when $R_L>1$, it indicates that the adsorption is not favourable; when $R_L=1$, it indicates that the adsorption is linear; and when $R_L=0$, it indicates that the adsorption is irreversible.

c. Freundlich Isotherm

The Freundlich isotherm is another widely used adsorption isotherm as:

$$q_e = K_f C_e^{1/n} \quad (7)$$

To obtain the constants, the logarithm of both sides of equation (7) was taken to give

$$\log q_e = \log K_f + \frac{1}{n} \log C_e \quad (8)$$

A plot of $\log q_e$ versus $\log C_e$ gives the slope of the graph as $\frac{1}{n}$ and the intercept as $\log K_f$.

Where:

K_f = Freundlich constant

n = Heterogeneity of the adsorption energy across the adsorbent surface

d. Redlich–Peterson Isotherm

$$Q_e = \frac{k_R C_e}{1 + a_R C_e^{b_R}} \quad (9)$$

The linearization of equation (9) gives:

$$\ln\left(K_R \frac{C_e}{Q_e} - 1\right) = \ln(a_R) + b_R \ln(C_e) \quad (10)$$

where:

K_R = Redlich–Peterson constant (l/g)

a_R = Redlich–Peterson constant (l/mg)

b_R = Exponent, which lies between 0 and 1. If $b_R = 1$.

e. Thermodynamic Analysis

The thermodynamics of the adsorption were at temperatures of 29, 40, 50, and 60 ºC.

$$\ln K_e = -\frac{\Delta H^o}{RT} + \frac{\Delta S^o}{R} \quad (11)$$

Where: ΔH^o is the change in enthalpy (kJ/mol), ΔS^o is the change in entropy (kJ/mol.K), R is the gas constant (8.314 J/mol.K), T the absolute temperature (K), and K_e is the equilibrium constant, which is obtained from the Langmuir isotherm (L/mol).

The plot of $\ln K_e$ versus $\frac{1}{T}$ will give the slope as $\frac{\Delta H^o}{R}$ and the intercept as $\frac{\Delta S^o}{R}$, where upon ΔH^o and ΔS^o are determined.

Similarly, the Gibbs free energy change, ΔG^o of the adsorption was obtained from the equation:

$$\Delta G^o = -RT \ln K_e \quad (12)$$

The equilibrium constant, K_e, is expressed as the ratio of heavy metal adsorbed onto the clay particles to the concentration left in the liquid solution at equilibrium. This is expressed as:

$$K_e = \frac{C_{ad}}{C_s} \quad (13)$$

where:

C_{ad} = Concentration of metal adsorbed by the clay at equilibrium (mg/L)

C_S = Concentration of metal left in the solution at equilibrium (mg/L)

3.8. Effect of Adsorbent Dosage

The effect of modified-clay dosage on the removal of heavy metals from contaminated groundwater was investigated using a batch adsorption experiment. Groundwater samples collected from selected wells located at different distances from the dumpsites were homogenized and characterized for their initial concentrations of chromium (VI), copper (II), zinc (II), and iron using standard analytical procedures. The modified clay was dried, gently pulverized, and sieved to obtain a relatively uniform particle size before use as the adsorbent.

For the dosage experiment, measured quantities of the modified clay were added separately to known volumes of groundwater samples in labelled conical flasks. Different adsorbent dosages were investigated while keeping other experimental conditions, including sample volume, initial metal concentration, particle size, pH, agitation speed, temperature, and contact time, constant. The flasks were covered and agitated using a mechanical shaker to ensure adequate contact between the modified-clay particles and the dissolved metal ions.

After the predetermined contact period, the suspensions were separated by filtration or centrifugation to remove the clay particles. The filtrates were subsequently analysed for residual concentrations of Cr(VI), Cu(II), Zn(II), and Fe using appropriate standard analytical methods. A control sample containing the groundwater without modified clay was treated under identical conditions to account for any changes in metal concentration unrelated to adsorption.

The percentage removal of each metal ion was calculated from the initial and equilibrium concentrations using:

Removal efficiency (%) = C0C0−Ce×100

Where C0 is the initial concentration of the metal ion in the groundwater (mg/L), and Ce is the concentration remaining after adsorption at equilibrium (mg/L).

The adsorption capacity of the modified clay was also determined using:

$$Qe = m(C0 - Ce)V$$

Where qe is the equilibrium adsorption capacity (mg/g), V is the volume of groundwater treated (L), and m is the mass of modified clay used (g).

The results obtained at the different adsorbent dosages were plotted as percentage removal against adsorbent dosage to determine the influence of clay dosage on the removal of Cr(VI), Cu(II), Zn(II), and Fe. The optimum adsorbent dosage was considered to be the dosage at which further increases in clay mass produced little or no significant improvement in metal removal. This experiment provided the basis for selecting the appropriate modified-clay dosage for subsequent adsorption, kinetic, and equilibrium studies.

4. Results and Discussion

Fig. 1 shows the different particle sizes of the modified clay soil for diameters of 0.074mm to 4.68mm. The result shows a cumulative percentage increase of 6.03% at sieve number 200 (0.074mm) to 100% at sieve number 4 (4.68mm). The analysis reveals that a good quantity of material was retained, which corresponds to the size of 0.425mm, where the least retained mass was about the 26.24g on sieve number 10, with a particle size of 2mm (Table 1).

4.1. Effect of Adsorbent Dosage

Fig. 2 shows the ratio of the removal of chromium (VI), zinc, iron, copper, etc. from local well waters using the modified clay adsorbent. Among the three metal ions studied, chromium (VI) exhibited the highest adsorption

efficiency across the dosage range, followed by copper (II), while zinc (II) recorded the lowest adsorption values. This trend suggests that the modified clay possessed a stronger binding affinity for chromium ions compared to copper and zinc ions. The enhanced adsorption performance observed with increasing adsorbent dosage may be attributed to the availability of a greater number of active adsorption sites on the clay surface, thereby facilitating increased metal uptake.

4.2. Effect of pH

Fig. 3 shows the influence of pH on the adsorption of $C1^{6+}$, Cu^{2+} and Zn^{2+} ions by modified clay adsorbent. Copper (II) removal was seen to improve from 74.58% to 92.82.87% within the same pH range. Zinc (II) adsorption also increased significantly, with removal efficiencies ranging from 67.40% at pH 5.5 to 84.99% at pH 8.5. The result demonstrates that the percentage removal of the heavy metals increased progressively with an increase in pH.

4.3. Effect of Temperature

Fig. 4 shows a reduction in adsorption capacity with increasing temperature. This behavior may be attributed to the weakening of attractive forces between the metal ions and the active sites on the clay surface, resulting in reduced metal uptake. The findings also show that lower temperatures provide more favorable conditions for the adsorption of Cr^{6+}, Cu^{2+}, and Zn^{2+} onto the modified clay particles.

4.4. Langmuir Isotherm

In Fig. 5, the corresponding Langmuir constants (KL) were determined as 0.0836 L/g, 0.0439 L/g, and 0.3132 L/g for Cr^{6+}, Cu^{2+}, and Zn^{2+}, respectively. Furthermore, the R^2 values obtained were 0.9873 for Cr^{6+}, 0.9890 for Cu^{2+}, and 0.9985 for Zn^{2+}, indicating a strong correlation between the experimental data and the Langmuir isotherm model. The high coefficients of determination confirm that adsorption occurred predominantly as monolayer coverage on a homogeneous adsorbent surface.

4.5.Freundlich Isotherm

The experimental analysis of competitive adsorption of Cr^{6+}, $Cu^{2+,}$ and Zn^{2+} onto clay adsorbent using the Freundlich isotherm is shown in the plot below. Like the Langmuir isotherm, the Freundlich isotherm is widely used to describe the adsorption of contaminants in homogeneous and heterogeneous solutions. Fig. 6 shows the plot of against for the adsorption of Cr^{6+}, Cu^{2+} and Zn^{2+} from aqueous solution. From the plots, Freundlich constants relating to the adsorption energy and n were obtained. From the analysis, K_f was evaluated as 3.1512mg/g for Cr^{6+}, 1.8863mg/g for $Cu^{2+,}$ and 2.0905mg/g for Zn^{2+}, while the index n was evaluated as 1.804 for Cr^{6+}, 1.546 for Cu^{2+}, and 1.762 for Zn^{2+}.

4.6.Kinetics of Heavy Metal Adsorption onto Clay Mineral

Fig. 7 and 8 illustrate the interception between the models and the adsorption process involving surface interactions and diffusion that is influenced by mechanisms. This shows the occurrence of chemisorption over time of metal consumption. From the mathematical models and plots shown in the figure, it was revealed that the rate constants were calculated as $0.0496m^{-1}$.

5. Conclusion

This research topic is very pivotal for protecting public health and making sure our environments are sustainable. The results from this research show that groundwater located around waste disposal sites is vulnerable to contamination by heavy metals emanating from dumpsite leachate. The presence of chromium, copper, zinc, lead, iron, cadmium, and other contaminants in groundwater shows the potential impact of indiscriminate waste disposal practices on water quality. The characteristics of Physicochemical parameters of groundwater play a major role in determining the movement and persistence of heavy metals within aquifer systems. Variations

in pH, conductivity, temperature, and dissolved solids influence the transport and accumulation of contaminants. These measures will contribute significantly to reducing groundwater pollution, protecting public health, and promoting sustainable water resource management in Lagos peri-urban communities and other regions facing similar environmental challenges. In summary, the results illustrate the need for improved waste management practices, continued groundwater monitoring, and the adoption of affordable treatment technologies such as modified clay adsorption. The findings reveal the importance of improved waste management policies and practices that will enhance groundwater potability and treatment measures. This will contribute massively to the reduction in groundwater pollution, thereby protecting public health and also promoting sustainable water resources management in Lagos State and the world at large.

DECLARATIONS

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Use of AI and AI-assisted Technologies: No AI technique was used while preparing this article.
Conflict of Interest: No conflict of interest.
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Figures

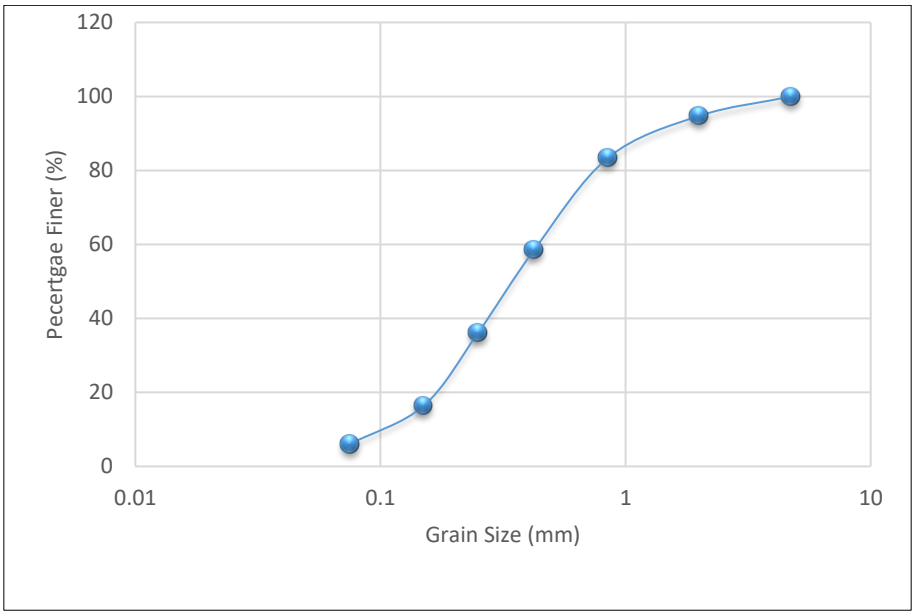

Fig. 1: Particle size distribution of modified clay

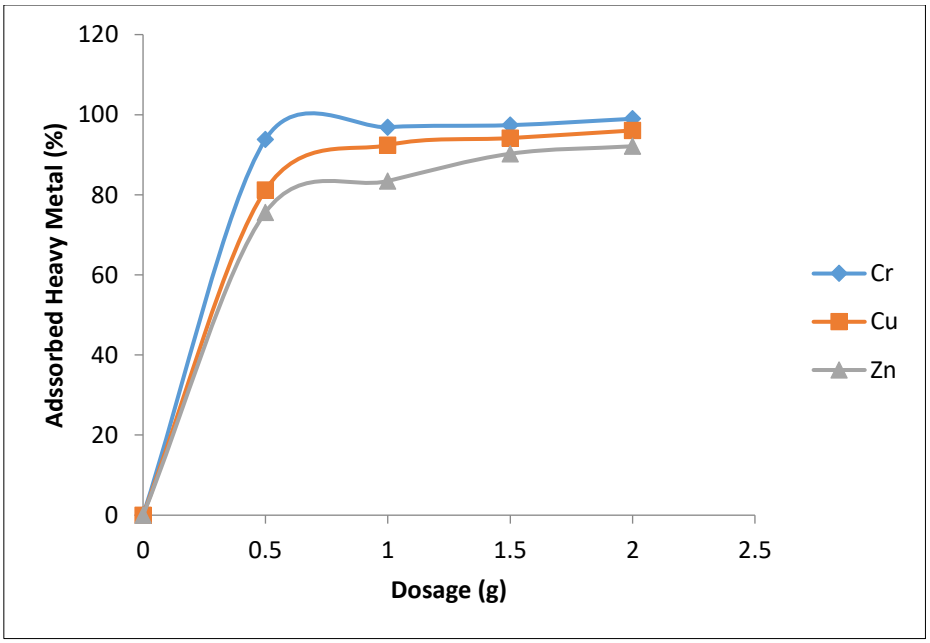

Fig. 2: Heavy metal removal at various doses of clay minerals

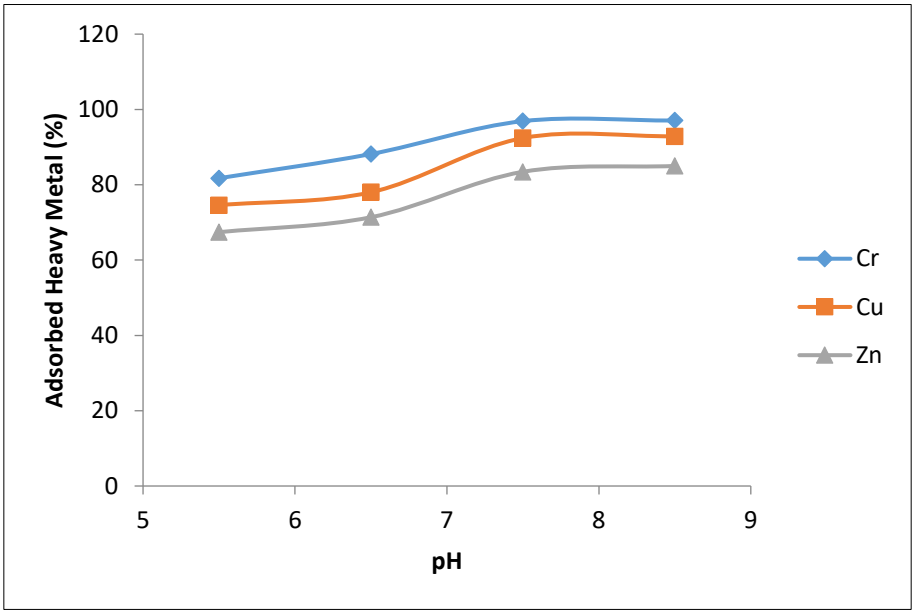

Fig. 3: Heavy metal removed at various solution pH

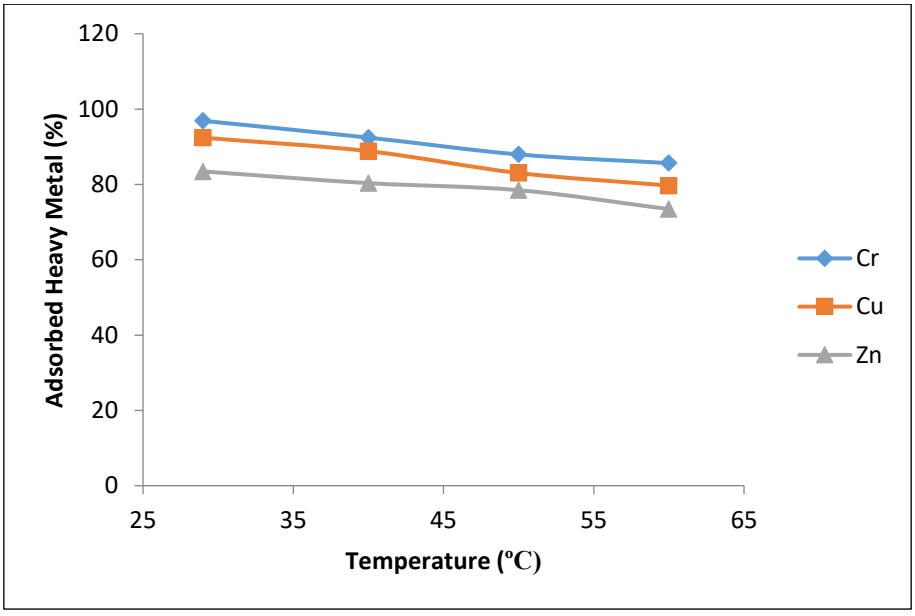

Fig. 4: Heavy metal removal at various temperatures

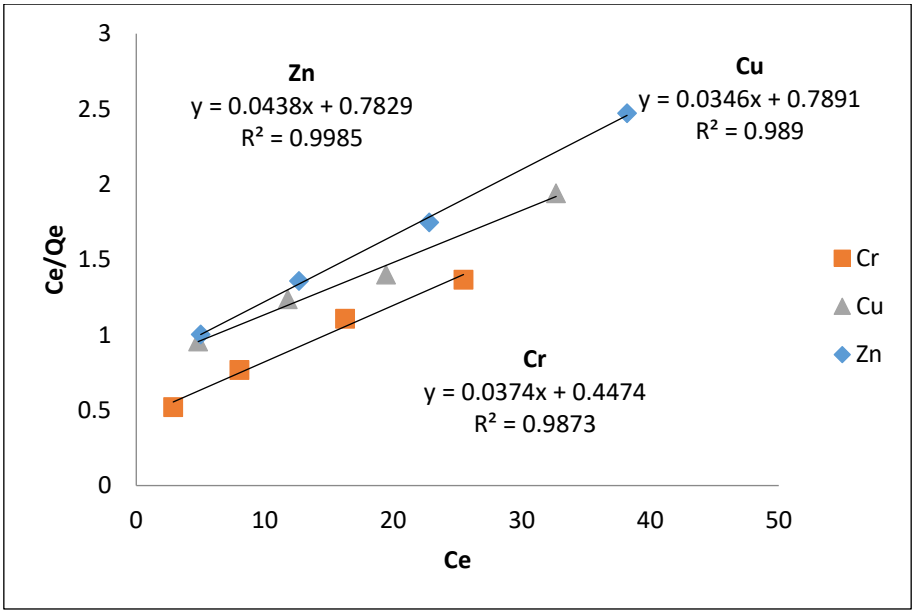

Fig. 5: Langmuir isotherm plots for the adsorption process

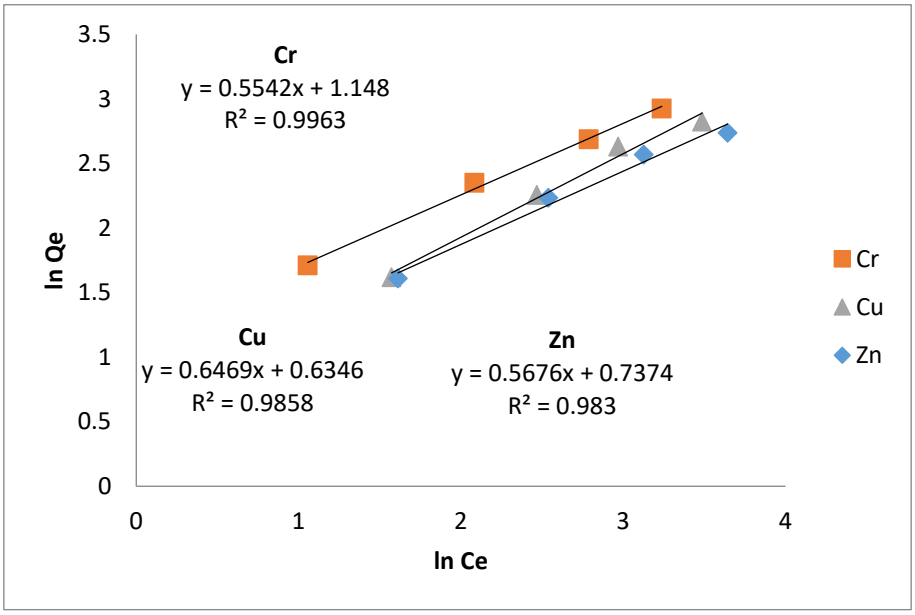

Fig. 6: Freundlich isotherm plots for the adsorption process

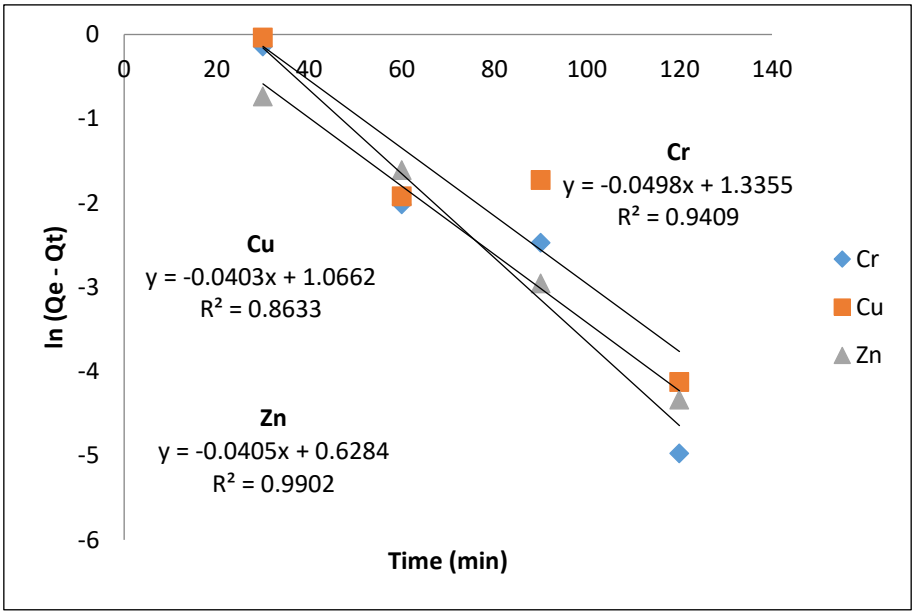

Fig. 7: Pseudo-first-order adsorption kinetics

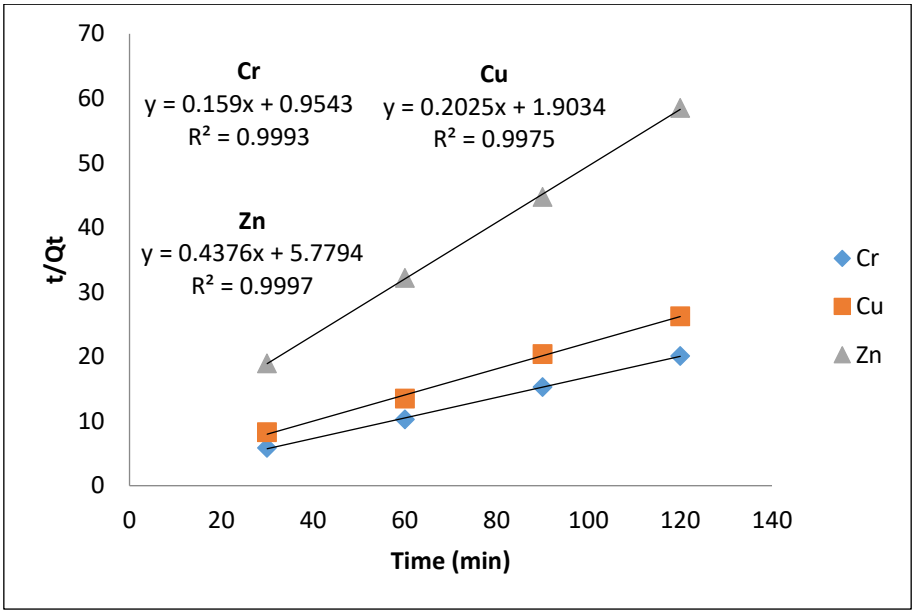

Fig. 8: Pseudo-second-order adsorption kinetics

Tables

Sieve No	Grain Size (mm)	mi (g)	Ri (%)	ΣRi (%)	f (%)
4	4.750	0	0	0	100
10	2.000	26.25	5.25	5.25	94.75
20	0.850	56.38	11.28	16.53	83.47
40	0.425	124.16	24.83	41.36	58.64
60	0.250	112.82	22.56	63.92	36.08
100	0.150	98.53	19.71	83.63	16.37
200	0.075	51.66	10.33	93.96	6.04
Pan		30.20	6.04	100	0

Table 1: Particle size distribution analysis