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Remediation of Chlorides from Water Using *Prosopis Juliflora* Biochars

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Abstract

Chloride (Cl^-) is one of the pollutants that can cause significant health risks when its concentration is high in water. Utilizing adsorption has a superiority in removing pollutants from water due to its large active surface area, small volume, and high adsorption capacity. Biochar can be used in multifunctional applications, including improvement of soil health, mitigation of greenhouse gas emissions, and remediation of contaminated water sources, among others. Herein, slow pyrolysis was used to create biochar, a small grain, permeable carbonaceous solid from *Prosopis juliflora* biomass waste residues. The *Prosopis juliflora* biochar was used to remove Cl^- ions in water. The characteristics of the biochar included a weak acidic pH value and an abundance of surface functional groups. The adsorption capacity of the biochar was then determined through its effectiveness in removing Cl^- ions in water. The FTIR spectra showed O-H stretching at 2,923.17 cm^{-1}, a second peak at 2,923.17 cm^{-1} relating to CO_2 absorption, a peak at 1,631.81 cm^{-1} ascribed to carboxylate (COO^{-1}), and a peak at 1,053.15 cm^{-1} denoting C-O stretching vibration. The Scanning Electron Microscopy characterization indicated that acid treated *Prosopis juliflora* seeds enhances the active sites for desalination while Energy Dispersive X-ray Spectroscopy analysis of the prepared samples shows mesoporosity on both treated and untreated *Prosopis juliflora* seeds. The Brunner- Emmett- Teller results show a type IV isotherm with a relative pressure ($P/Po > 0.8$) in the two samples. The removal capacity of the biochar was then determined through its effectiveness in removing chloride and sodium ions from synthetic water and natural water samples obtained from a borehole in Kalokol. pH 6 gave the best removal capacity after surface modification of the adsorbent. The chloride ion removal efficiency increased with the increased dosage. The adsorption had the best fit in the Langmuir isotherm with an R^2 value of 0.0299 compared to 0.0008 for the Freundlich isotherm. In conclusion, *Prosopis juliflora* biochar is a promising adsorbent for advancing removal of chlorides from saline water to address water quality challenges as well as promote management of the invasive *Prosopis juliflora* species.

Introduction

Water is a requisite resource for both life sustenance and socio-economic development in any country. There is an increasing demand for water globally for both household consumption and agricultural use (Nechifor and Winning 2018). The quality and quantity of surface water are not sufficient for the world's growing demand (Abellán and Alonso 2022). Global water demand is predicted to surpass supply by over 40% by 2030. In developing nations, water demand is predicted to surpass supply by more than 50%, especially in sub-Saharan Africa (Akpen, Aho, and Baba 2018). More than 4 billion people are grappling with severe water scarcity at least every month, whereas half a billion people are experiencing severe water shortages throughout the year (Brauman 2022). Various factors influence the per capita availability of water, which include population increase, economic development, and urbanization (Adeba and Lelisa 2021). Kenya has a per capita water availability of 293 M^3 annually (Kanda, Lusweti, and Odhiambo 2023), which makes it among the water-scarce countries in the world (Mulwa, Li, and Fangninou 2021). Over 18 million people in Kenya today struggle to access clean and safe water (Mulwa,

Li, and Fangninou 2021). Studies show that about 56% of the population has access to a clean water supply (Ondigo, Kebwaro, and Kavoo 2018). In part of Kenya, especially in rural areas, citizens are forced to walk long distances of at least eight miles to access water sources that are highly polluted and relatively unsafe for human consumption (Yu et al. 2019). Access to clean and safe drinking water is a critical global challenge (Hasanpour and Hatami 2020), with increasing concerns over groundwater salinization problems from natural and anthropogenic sources (Li et al. 2020). The anthropogenic sources of salinization include irrigation return flow, industrial and agricultural wastewater, and gas and oil production activities. This leads to the build-up of salts (Na^+ and Cl^-) in the groundwater sources (Nozari et al., 2018). High concentrations of these ions can render water sources unsuitable for consumption, agricultural, and industrial use (Nozari, Azadi, and Zali 2018). Various technologies have been developed to remove sodium and chloride ions from water (Curcio et al. 2015). Even when the sodium chloride levels remain permissible, there is a potential risk associated with prolonged ingestion, such as hypertension (Poorolajal et al. 2016). Numerous research studies have been carried out to address the issue of ion buildup in water (Yunnen et al. 2017). Given the pressing need for an innovative treatment approach, the focus has been on the adsorption process for reducing ion concentrations through both batch and fixed bed methods (Hasanpour et al. 2021). This approach boasts several benefits, including cost-effectiveness, selective removal of ions, and sludge-free desorption (Qin et al. 2006).

Various adsorbent materials, both natural and agricultural waste, have been employed to remove toxic ions (Bilello and DeJohn 2018). A variety of natural adsorbents, such as rice husks, neem tree leaves, sawdust, coconut shells, and rice bran, have also been used to extract different concentrations of ions from aqueous solutions (Sen 2023; Ndiritu et al. 2020). Our study considered the use of *Prosopis juliflora* as an adsorbent material source. *Prosopis juliflora*, commonly known as the Mathenge tree, is a versatile and hardy plant found in arid and semi-arid regions worldwide (Dakhil et al. 2021). It is an evergreen tree, approximately 15 m high and 3 m wide. It is a flexible tree used as timber, feed, shade, fences, and control of soil erosion. It is naturally found in Mexico, the Caribbean, and South America. It has become well-established as an offensive weed in Africa, Asia, Australia, and most parts of the world.

Prosopis juliflora is available in large quantities and has great potential to be applied as a low-cost adsorbent that is environmentally friendly (Nasrat and Jamal 2020). It has been recognized for its potential in various environmental applications, including the removal of ions and contaminants, i.e., Lead, Cadmium, Zinc, and Copper ions from water sources (Al-Ghouti and Razavi 2020). This study, therefore, aimed to investigate the adsorption capabilities of raw and modified *Prosopis juliflora* seeds for Cl^- ions from saline water.

Materials and Methods

Chemicals and reagents

All solutions were prepared in double distilled water. Standard solutions were prepared in 0.1 mol/L sodium acetate solution to maintain constant ionic strength. All the reagents used were of analytical grade. The chloride ion standard solutions were obtained commercially as well as sodium acetate, hydrochloric acid and ammonia

Instrumentation

Fourier Transform Infrared spectrometer (FTIR) (SHIMADZU FTIR 8400S (Kyoto, Japan) spectrometer) was used to profile the treated and untreated *Prosopis juliflora* to indicate the functional groups responsible for uptake of chloride ions. The Scanning Electron Microscope (SEM) was used to provides critical insights into the structural and morphological evolution of the biochar surface due to physical or chemical treatment processes. Energy Dispersive X-ray Spectroscopy (EDS) was used to understand surface elemental composition and changes induced by chemical treatments on the biochar. Brunauer-Emmett-Teller (BET) was used for determination of specific surface area, pore volume, and pore size distribution of the adsorbent

Water sample collection

Water bottles deployed for collection were cleaned and sterilized. Collection containers were then assembled and labelled with relevant information including date, time, and site. Water samples were collected from the pump. Water flow was reduced to a gentle stream, and water was filled into the sample bottle directly from the discharge line. Each collection container was filled to the top, leaving minimal headspace at the top to avoid aeration and spillage during transportation, and closed watertight.

Sampling and selection of Prosopis juliflora

The sites where *Prosopis juliflora* species were growing were purposively sampled. A reconnaissance survey was done in Turkana Central Sub County (Kalokol, Lodwar Township, and Kanamkemer Wards) with reference to existing literature and information from indigenous people to select the sites. Line transects 100 m apart were laid in selected sites with the study *Prosopis juliflora* species. Circular plots with a radius of 20 m were systematically placed at 100 m intervals along the line transects to sample trees for the collection of pods.

Prosopis juliflora seeds collection

Prosopis juliflora pods were collected from established trees growing in circular plots. The pods were directly collected from trees using hand. Pods from different parts of the tree (lower, middle, and top) were collected to get a representative sample of the entire tree canopy. The pods were then opened using scissors to get the seeds for the experiment. The seeds were sorted using hand to remove those

that were broken, damaged by insects, or rotten. Thereafter packed in nylon bags (labelled), transported to Kenyatta University, and stored at room temperature in the laboratory.

Pretreatment of Prosopis juliflora seeds

The collected *Prosopis juliflora* samples were washed thoroughly with deionized water to remove impurities, then cut into small pieces and dried in an oven at 105°C to remove moisture. The dried adsorbents were ground into fine powder and sieved. The powder was then labelled and kept in a desiccator ready for use.

Modification of Prosopis juliflora seeds

Raw powdered adsorbent was mixed with 1N sulphuric acid solution in a predetermined ratio and heated at a temperature of 105°C for 24 hours. The product was cooled and washed with distilled water to remove the excess acid, filtered, and kept in sodium bicarbonate solution $NaHCO_3$ (1%) overnight to eliminate the acid residue.

Optimization

Parameters like time, initial ion concentration, adsorbent dosage, and pH also had an effect on the process of adsorption of sodium and chloride ions and removal efficacy of the raw and treated *Prosopis juliflora* seeds, and one parameter was chosen by maintaining the other parameters constant and changing the parameter under consideration. The parameters were varied as follows: initial ion concentration (10–500 mg/L), contact time (5-160 min), pH (2–10), and adsorbent dosage (1–5 g).

Batch adsorption studies

Adsorption of sodium and chloride ions by the *Prosopis juliflora* adsorbent under batch adsorption was conducted to establish their adsorption capacity under optimized conditions (Redhu and Jain, 2023). This experiment was done using a thermostat water bath shaker that could be constantly shaken. *Prosopis juliflora* powder (1.0 g) was stirred with 50 mL of borehole water in 100 mL borosilicate glass bottles (acidified with HCl, 24 h). The experiment was conducted at various pH values, temperatures, initial ion concentrations, and contact times.

Removal capacity

Removal capacity is important in understanding the efficiency and feasibility of the removal process. Freundlich and Langmuir isotherms were used to determine the removal capacity of chloride ions from water

Regeneration

Reuse and regeneration experiments were done by desorbing the adsorbed sodium and chloride ions in five cycles using 1M ammonium carbonate solution.

Results and Discussion

Characterization

Characterization is a significant process in adsorption, as it entails identification of the physical, chemical, and structural attributes that define how the adsorbent interacts with dissolved salts. The parameters that influence adsorption performance include morphology, surface area, functional groups, elemental composition, and porosity, which necessitates characterization as an important step in the adsorption process. The following are highlights on characterization done using FTIR, SEM, EDS, and BET.

Characterization of biochar biomaterial of Prosopis juliflora using Fourier Transform Infrared Spectrometer

An FTIR spectra (SHIMADZU FTIR 8400S (Kyoto, Japan) spectrometer). The FTIR spectra of the untreated and treated *Prosopis juliflora* powder are shown below, which contained the functional groups that were used to adsorb the sodium and chloride ions. Shimadzu Fourier transform infrared (FTIR 8400S) was used to profile the unaltered and treated *Prosopis juliflora* seeds to indicate the functional groups that work in the uptake of chloride.

The spectrum shown in Fig. 1 describes the FTIR spectra for both the treated and untreated *Prosopis Juliflora* biochar. The CO_2 absorption peak was observed at 2,923.17 cm^{-1} and the stretching of the O-H band of hydroxyl-hydrogen bonded groups at 3,384.17 cm^{-1}. The carboxylate (COO^-) and primary amine (1°) N-H bending are assigned to the absorption band at 1,631.81 cm^{-1}, respectively. The 1,383.95 cm^{-1} is ascribed to aromatic C = C stretch. The band at 1,053.15 cm^{-1} is attributed to C-O stretching bands or the C-N stretch of a straight chain primary amine.

Scanning Electron Microscope Characterization

The SEM analysis provides critical insights into the structural and morphological evolution of the biochar surface due to physical or chemical treatment processes as presented in Fig. 2

From Fig. 2 attached, it was observed that SEM images of untreated *Prosopis Juliflora* seeds (a) exhibits a relatively smooth and compact surface with minimal visible pores at lower magnification (X1), as the magnification increases to maximum of (X3) increase surface roughness and compactness are observed. Lack of pores indicates limited surface porosity and points to poor application in environmental remediation (Tang et al., 2024).

Conversely, the treated *Prosopis juliflora* (b) shows textural changes and at magnification of X1 there are noticeable porosity. Increasing the magnification further to X3 clearly shows the intense cavities, cracks and ridged surface within the sample. This could have been due to the treatment it was subjected to, which promote the breakdown of lignin and cellulosic components thereby exposing the internal pore networks (B. Qiu et al., 2022). The increased porosity was associated with increased uptake of sodium and chloride ions from the experimental water samples.

The Energy Dispersive X-ray Spectroscopy (EDS) characterization

Characterization of biochar using Energy Dispersive X-ray Spectroscopy (EDS) is crucial for understanding surface elemental composition and changes induced by chemical treatments (Vijayan *et al.*, 2025). This study compares the EDS spectra and elemental composition of untreated and chemically treated and raw *Prosopis juliflora* biochars and presented the results in Fig. 3

From Fig. 3, the untreated biochar (a) exhibits strong peaks for carbon (C) and oxygen (O), confirming their dominance in the biochar matrix as they are primarily carbonaceous due to pyrolysis induced during carbonization (Hodoroaba, 2020). Minor peaks corresponding to potassium (K), chlorine (Cl), and sodium (Na) were also observed, indicating the presence of inorganic mineral elements (Vijayan *et al.*, 2025). The presence of alkali metals (Na, K) is common and could be due to bioaccumulation resulting from saline soil in Turkana County. The treated sample (b) exhibited strong spectral signals for carbon showing removal of inorganic probably due to acid treatment (Inyang et al., 2016). There was also new sulfur peak observed possibly due to contamination during modification (Inyang et al., 2016).

Brunauer-Emmett-Teller characterization

The BET analysis is crucial for determination of specific surface area, pore volume, and pore size distribution of the adsorbent. The degassed adsorbent sample was loaded into the BET analyzer where adsorption and desorption isotherms were obtained over relative pressure. Linear region data was used to construct BET plot and calculate the monolayer adsorption capacity from which specific surface area was derived. The surface area characterization was determined using Brunauer-Emmett-Teller and the results presented in Fig. 4a and b

The isotherm in Fig. 4(a) it shows that a type IV isotherm with a relative pressures ($P/Po > 0.8$), characteristic of mesoporous materials with slit-like pores (Qiu et al., 2022). The adsorption and desorption branches do not overlap, indicating capillary condensation in mesopores and the presence of pore structure with limited connectivity or ink-bottle pores (Ren et al., 2022). The quantity-adsorbed peaks at approximately 800 cm^3/g STP, indicating moderate surface area and pore volume. Consequently, Fig. 4(b) represents the isotherm for treated plant biochar, which displays a similar type IV pattern but with significantly higher nitrogen uptake up to 1200 cm^3/g STP. This suggests that the treatment process substantially increased the material's specific surface area and porosity ((M. Qiu et

al., 2022; Tan et al., 2015). The hysteresis loop is also more pronounced, indicating enhanced mesoporosity.

Optimization studies

Effect of pH on Chloride ions removal

The response of pH on chloride ion removal was tested by altering the pH levels, where 0.5 g of treated and untreated *Prosopis juliflora* seed powder was combined with 50ml aqueous chloride solutions with 10–50 ug/ml buffered with 0.1 M sodium acetate. pH of the solution was adjusted between pH 2 and pH 10 by use of a 0.1M solution of nitric acid and sodium hydroxide. The two were stirred at 120 rpm in triplicate over a period of 2hours. Finally, stroke samples were filtered and the ultimate dosages chloride ions were determined. In this study, chloride solutions were buffered at different pH values and shaken using 0.05 g of modified and unmodified *Prosopis Juliflora* biochar adsorbent for 30 minutes.

At pH 2, the final concentration of Cl^- ions for the unmodified *Prosopis Juliflora* biochar was around 400 ppm (Fig. 5). An increase in pH to 4 led to a decrease in final Cl^- ion concentration. An increase of pH to 6 led to a further rise in final concentration, followed by a steady drop to pH 10. For modified *Prosopis Juliflora* biochar, the final Cl^- concentration was less compared to unmodified *Prosopis Juliflora* biochar. The lowest concentration was recorded at pH 6, around 276 ppm. The modification of *Prosopis Juliflora* biochar had improved the Cl^- ions' removal capacity compared to unmodified *Prosopis Juliflora* biochar. At pH 2, there is a high concentration of hydrogen ions that attract the Cl^- and complexes to form compounds, hindering chloride ion removal. At pH 6, there is an observed increase in chloride ion removal. Above pH 6, chloride ion removal decreases due to repulsion between chloride ions and hydroxyl ions.

Effect of initial concentration on Chloride ions removal

The initial concentration of chloride ions was studied by adding 0.5 g of both treated and untreated *Prosopis juliflora* seeds with 50ml of the aqueous solution of 10-50ug/ml chloride solution that was buffered at the optimum pH. Contact time was maintained at 160mins filtered and determination of the concentration of sodium and chloride ions was done by flame atomic adsorption spectroscopy. Each and every treatment was done in triplicate.

Figure 6 shows the Cl^- concentration effect on the efficiency of Cl^- removal. As illustrated, it was determined that the Cl^- removal efficiency decreased by increasing the amount of Cl^- concentration at constant adsorbent dosage (0.05 g), demonstrating an inverse relationship between the efficiency of Cl^- removal and the Cl^- concentration. As the adsorption process begins, the active sites start to adsorb the Cl^-, however, as the concentration of the Cl^- increases, the adsorbent's active sites get saturated and cannot adsorb more ions. By increasing the Cl^- concentration from 600 to 800 ppm, the Cl^- removal percentage assumes a plateau (no further increase) (Sarani et al. 2024). This is due to the saturation of

the active sites. The same trend is observed with the unmodified *Prosopis Juliflora* biochar. The unmodified has a lower Cl^- ion removal efficiency.

Effect of contact time on Chloride ions removal

Contact time effects on chloride ion removal by treated and untreated *Prosopis juliflora* were examined by combining 0.5 g of each sorbent powder with 50ml aqueous chloride solution of 10-50ug/ml that had been buffered with 0.1 M sodium acetate. The pH of the solutions was adjusted with the help of a 0.1M solution of nitric acid and a 0.1M solution of sodium hydroxide. The mixture was left to equilibrate in a shaker at a rate of 120 rpm within a predetermined time span of 5-160 minutes. Then the solutions were centrifuged and the filtrates were analyzed using atomic absorption spectroscopy to measure the absorbance of Cl^- ions.

Contact time plays a key role in determining the time required to attain equilibrium in the adsorption of Cl^- ions. Figures 7. Shows the effect of contact time on the removal efficiency of Cl^- ions. Different time intervals ranging from 0, 50, 100 and150 min were considered for Cl^- ions adsorption. With the increased contact time between Cl^- ions and the adsorbent's surface, the sorption capacity increased up to 100 min, after which the equilibrium point was reached, indicating the occupation of the majority of the available active sites with adsorbates (Rani, Johar, and Jassal 2020). Moreover, the significant increase in the adsorption capacity at an early stage of the contact signified the availability of a greater number of binding sites, which decreases as the sorption of Cl^- ions takes place.

Effect of dosage on Chloride ions removal

The influence of adsorption of sodium and chloride ions on the treated and untreated *Prosopis juliflora seeds* was examined by varying the amount of each adsorbent (1–5 g) in the test solution and other parameters remaining constant. Sodium hydroxide and nitric acid solutions were used to vary the amount of sodium and chloride ion solutions to their optimal pH. The experiments were done thrice in triplicates and stirred for 2–3 hours in plastic bottles in the water bath shaker. After centrifugation, decantation, and filtration, sodium and chloride ion levels were calculated with the help of flame atomic adsorption spectrometry.

The effect of the adsorbent's amount, taken for the adsorption of Cl^- ions from aqueous media, is of prime importance. The experimental results, shown in Fig. 8 indicate the increase in the sorption capacity with the increase in the dosage of adsorbent, from 0 g to 5 g, for Cl^- ions removal. In addition, the increase in the percent adsorption of adsorbates is attributed to the increase in the number of available vacant active sites for the adsorption of adsorbates. However, the decrease in the sorption capacity of the adsorbent is due to partial accumulation of the available active sites. Hence, it can be said that the adsorption percentage is directly related to the dosage of the adsorbent (Kamatchi, Arivoli, and Prabakaran 2022). In this study, the modified and unmodified *Prosopis Juliflora* biochar gave a similar trend in removal efficiency, with the modified showing improved removal efficiency compared to

the unmodified *Prosopis Juliflora* biochar. The experimental results of the present study closely correlate with those of other research in terms of the dosage effect in the removal of Cl^- ions from solutions.

Removal capacity for Chloride ions

Removal capacity is important in understanding the efficiency and feasibility of the removal process. Freundlich and Langmuir isotherms were used to determine the removal capacity of chloride ions from water. The results are presented in Table 1

Table 1
Removal capacity for chloride ions

Adsorbent	Freundlich	Langmuir		
	R^2	R^2	Best isotherm	Removal capacity
Untreated *Prosopis juliflora*	0.870	0.671	**Freundlich**	**0.010**
Treated *Prosopis juliflora*	0.008	0.0299	**Freundlich**	**0.590**

From Table 1, it was observed that the treated and untreated *Prosopis juliflora* fitted well Freundlich with R^2 of 0.8702 and 0.0080 respectively. This indicated that the removal of chloride ions by *Prosopis juliflora* is a chemisorption process. The removal capacity of chloride ions was 0.010 mg/g in untreated *Prosopis juliflora* and 0.59 mg/g in treated *Prosopis juliflora.* This showed that modification of *Prosopis juliflora* for desalination increases the active sides for desalination (Foo & Hameed, 2010).

Adsorption isotherm

To determine the concentration of Cl^- ions at equilibrium in solid and liquid phases, different models are being applied. Whereas the most frequently used models include the Freundlich and the Langmuir adsorption isotherms. In the current study, these two models are being used to determine the adsorption mechanism of Cl^- ions onto the surface of *Prosopis Juliflora* biochar. A detailed description of these two models is given below.

Langmuir adsorption isotherm

The data obtained from the batch adsorption studies of Cl^- ions were studied using the Langmuir adsorption isotherm. This model applies to monolayer adsorption. The empirical formula for the Langmuir adsorption isotherm is given as:

$$\frac{Ce}{Xe} = \frac{1}{XmKb} + \frac{Ce}{Xm}$$

1

Here, the Ce (mol/L) represents the concentration of Cl^- ions at equilibrium, Xm (mol/g) is the maximum adsorption capacity, Xe (mol/g) is the equilibrium adsorption capacity, and Kb (L/g) is the equilibrium constant (Naeem et al. 2024) as indicated in Fig. 9. Linear graphs were obtained by plotting Ce/Xe against Ce for Cl^- ions adsorption. From the graphs, the R^2 for the unmodified and modified *Prosopis Juliflora* biochar were 0.00299 and 0.691, respectively. From the obtained R^2 values, the modification improved the surface by increasing more active sites, hence high-rate adsorption.

Figure 9. (a, b) Langmuir isotherm for unmodified and modified biochar, (c, d) the Freundlich isotherm for unmodified and modified *Prosopis Juliflora* biochar, respectively.

Freundlich adsorption isotherm

The Freundlich adsorption model gives the variation in the amount of solute adsorbed by a unit mass of the solid adsorbent. This model is widely used for heterogeneous systems. It explains both the monolayer adsorption as well as multilayer adsorption mechanisms. The mathematical expression for the Freundlich adsorption isotherm is given by the following relation

Xe = $KfCe^{1/n}$ (**2**)

Where Xe (mol/g) denotes the adsorption capacity at equilibrium, Kf stands for the Freundlich equilibrium constant in the case of highest adsorption, whereas Ce (mol/L) accounts for the concentration of Cl^- ions at equilibrium and n is the adsorption intensity (Naeem et al. 2024) as in Fig. 9. From the graphs, the R^2 for both the unmodified and modified *Prosopis Juliflora* biochar were 0.0008 and 0.7028, respectively. As observed in the Langmuir isotherm, the R^2 value for the modified *Prosopis Juliflora* led to improved surface with an increased number of active sites, implying a high rate of adsorption. Compared to Langmuir, the Freundlich isotherm had a higher R^2 value, which suggests multilayer adsorption and heterogeneous sites, unlike the monolayer adsorption for Langmuir.

Regeneration studies

Regeneration refers to the process of restoring the adsorption capacity of an adsorbent after saturation by removing the adsorbate. This is a crucial aspect in adsorption-based treatment systems since it determines the economic viability, and sustainability of the adsorbent. Effective regeneration makes adsorption a multiple-use process leading to low material costs and cuts down secondary waste disposal challenge (Inyang et al., 2016). Regeneration allows for reuse of the adsorbent, minimizes operational costs and limits environmental impacts associated with disposal of used adsorbent. In practice, an adsorbent that retains a high percentage of its initial capacity after several regeneration cycles is considered suitable for large-scale deployment. The used treated *Prosopis juliflora* was regenerated using 1.0 molar ammonium carbonate solution and the results presented in Fig. 10.

From Fig. 10, it was observed that *Prosopis juliflora* could be recycled for multiple reuses. It was observed that during the first two cycles, the percentage recovery was reduced from 25% to 22% with

increase in number of cycles. The decrease in percentage recovery with increasing regeneration cycles could be due to blockage of active sites as well as changes in the chemistry of *Prosopis juliflora* (Jonas *et al*., 2022).

Conclusion

The *Prosopis Juliflora* biochar was synthesized via pyrolysis technique and shows greater porosity. As a result, the modified *Prosopis Juliflora* biochar was used as an effective and efficient adsorbent for the removal of Cl^- ions for the purification of water. The experimental results at optimized conditions have shown that the modified *Prosopis juliflora* biochar works best at pH 6. The chloride ion removal efficiency increased with the increased dosage. The adsorption had the best fit in the Langmuir isotherm with an R^2 value of 0.0299 compared to 0.0008 for the Freundlich isotherm. Hence, it is concluded that the modified *Prosopis Juliflora* biochar is an effective and potential adsorbent material for the removal of Cl^- ions from water.

Declarations

Conflict of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Figures

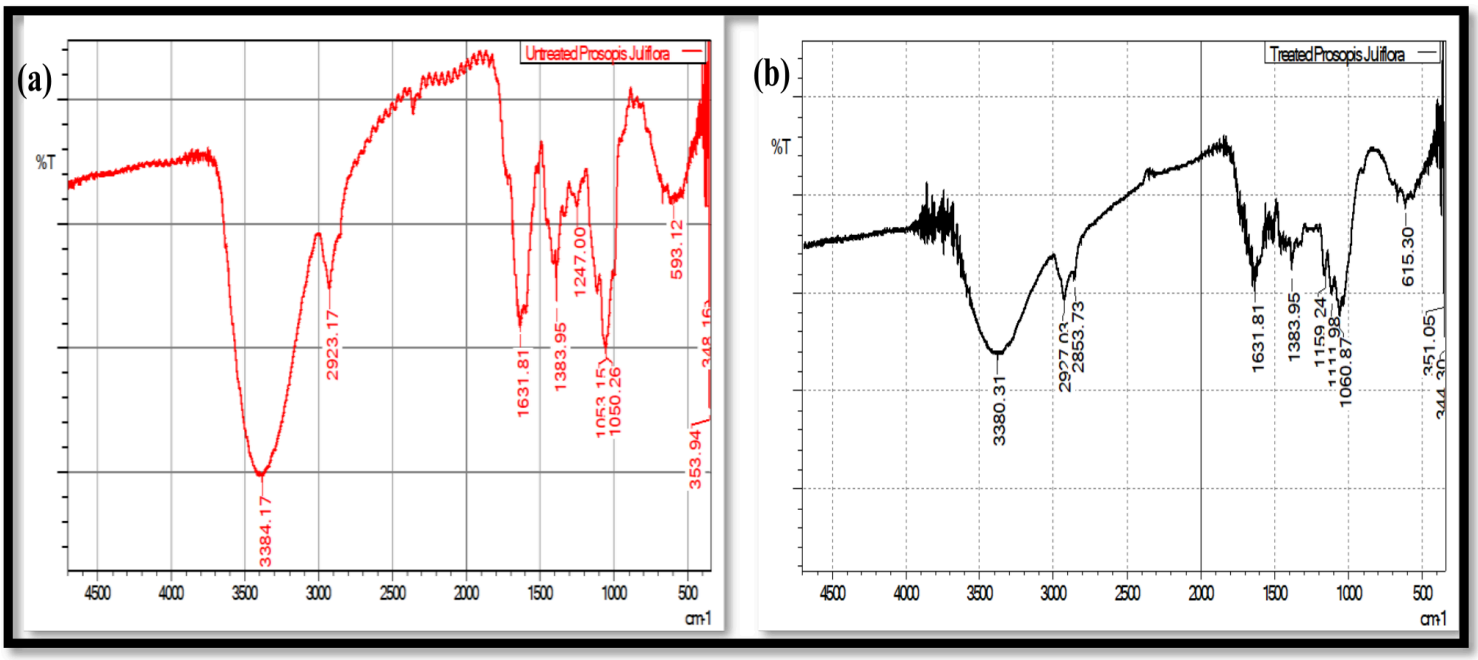


Figure 1

FTIR spectra of *Prosopis Juliflora* biochar.

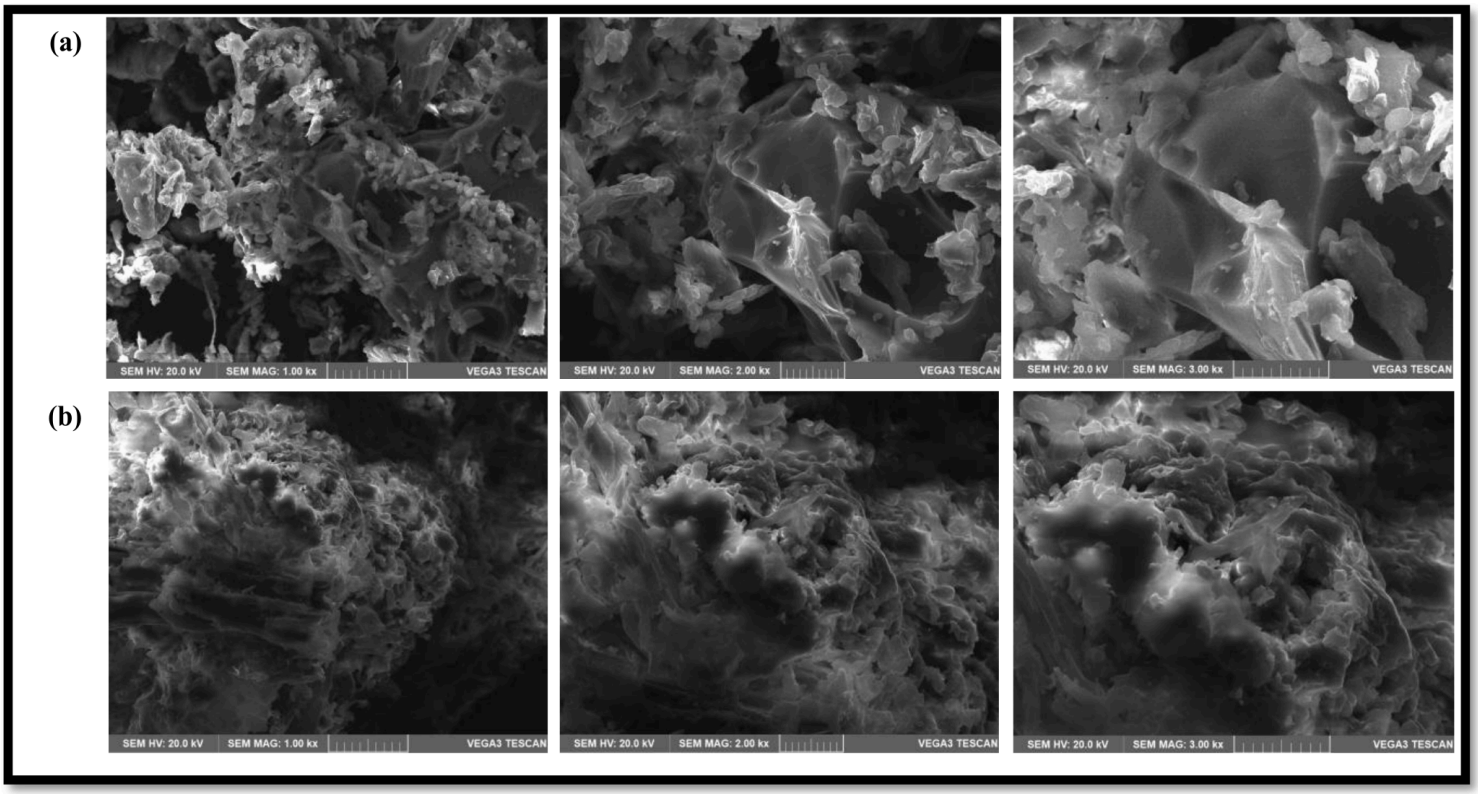
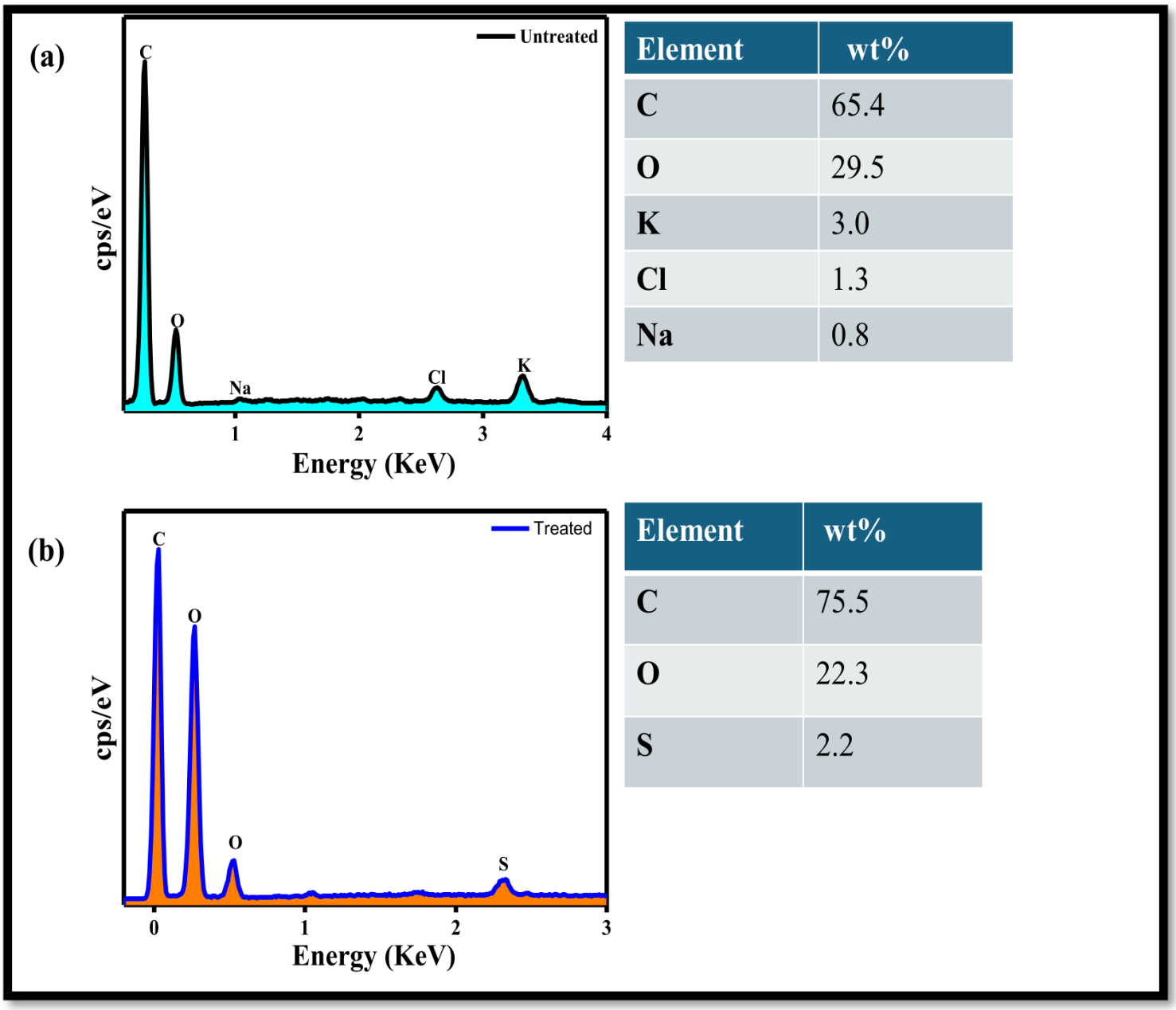


Figure 2

Scanning Electron Microscope images at different magnifications for (a) untreated (b) treated.



Element	wt%
C	65.4
O	29.5
K	3.0
Cl	1.3
Na	0.8

Element	wt%
C	75.5
O	22.3
S	2.2

Figure 3

EDS spectra for (a) untreated (b) treated samples.

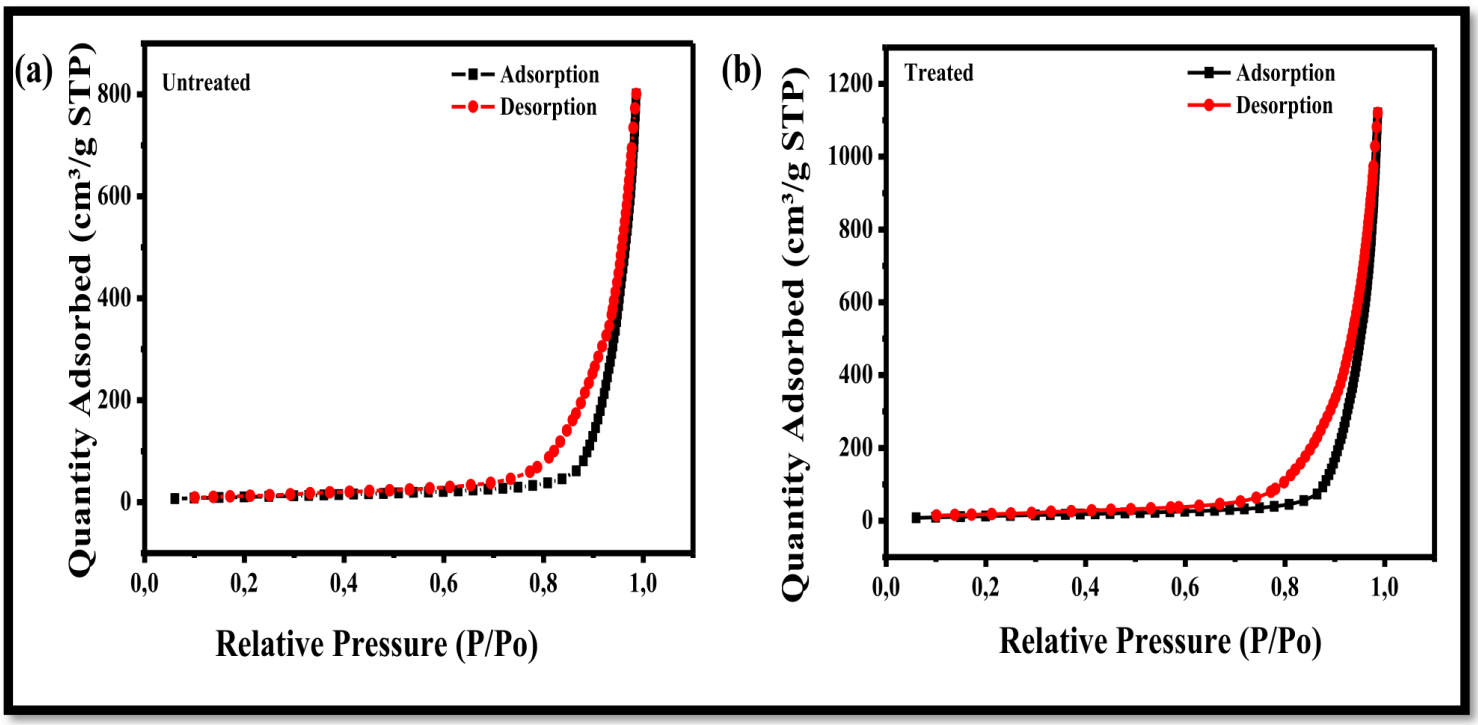


Figure 4

Error! No text of specified style in document.**: N2 adsorption -desorption spectra for (a) Untreated (b) treated**

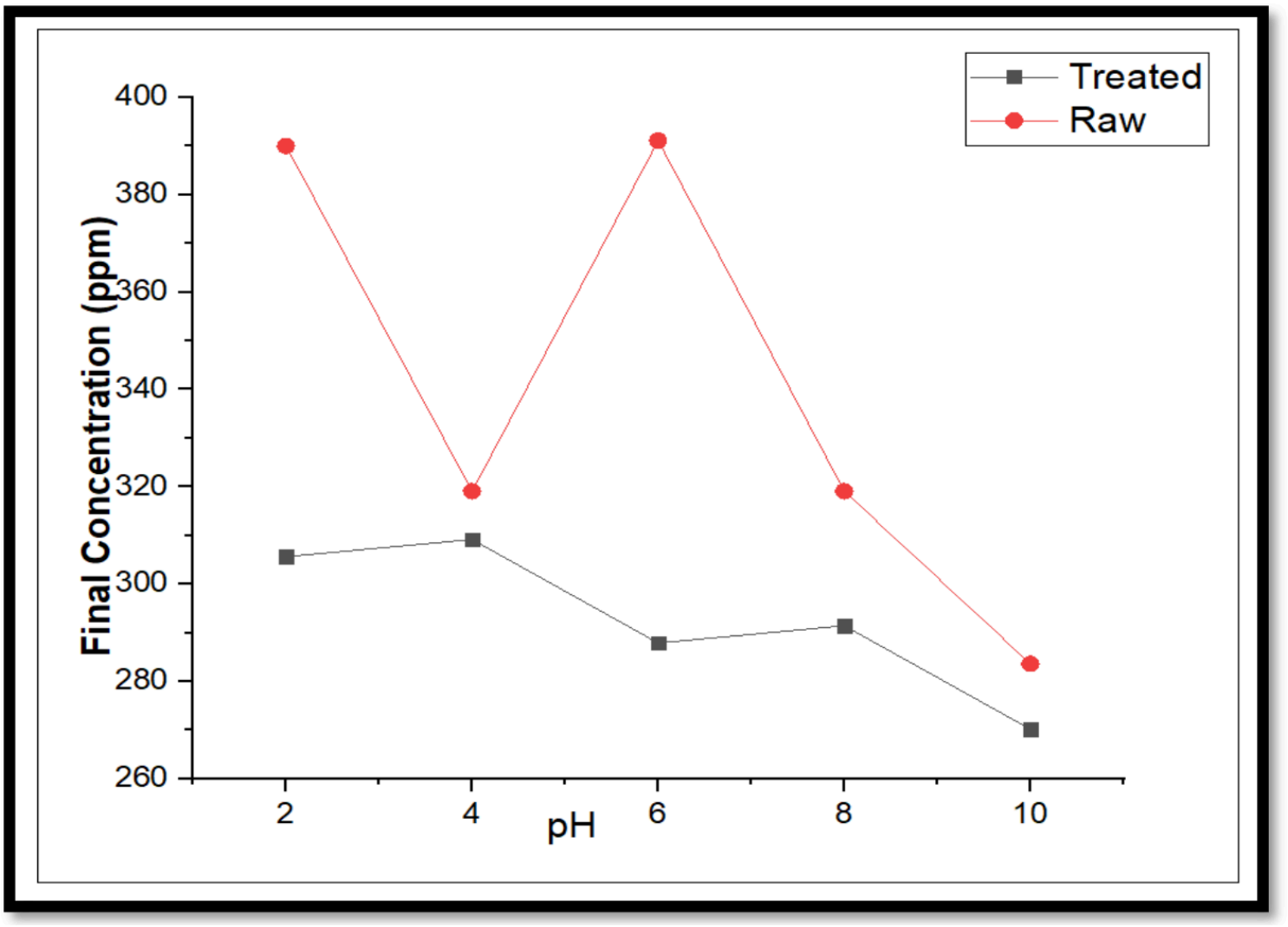


Figure 5

Effect of pH on removal of chloride ions

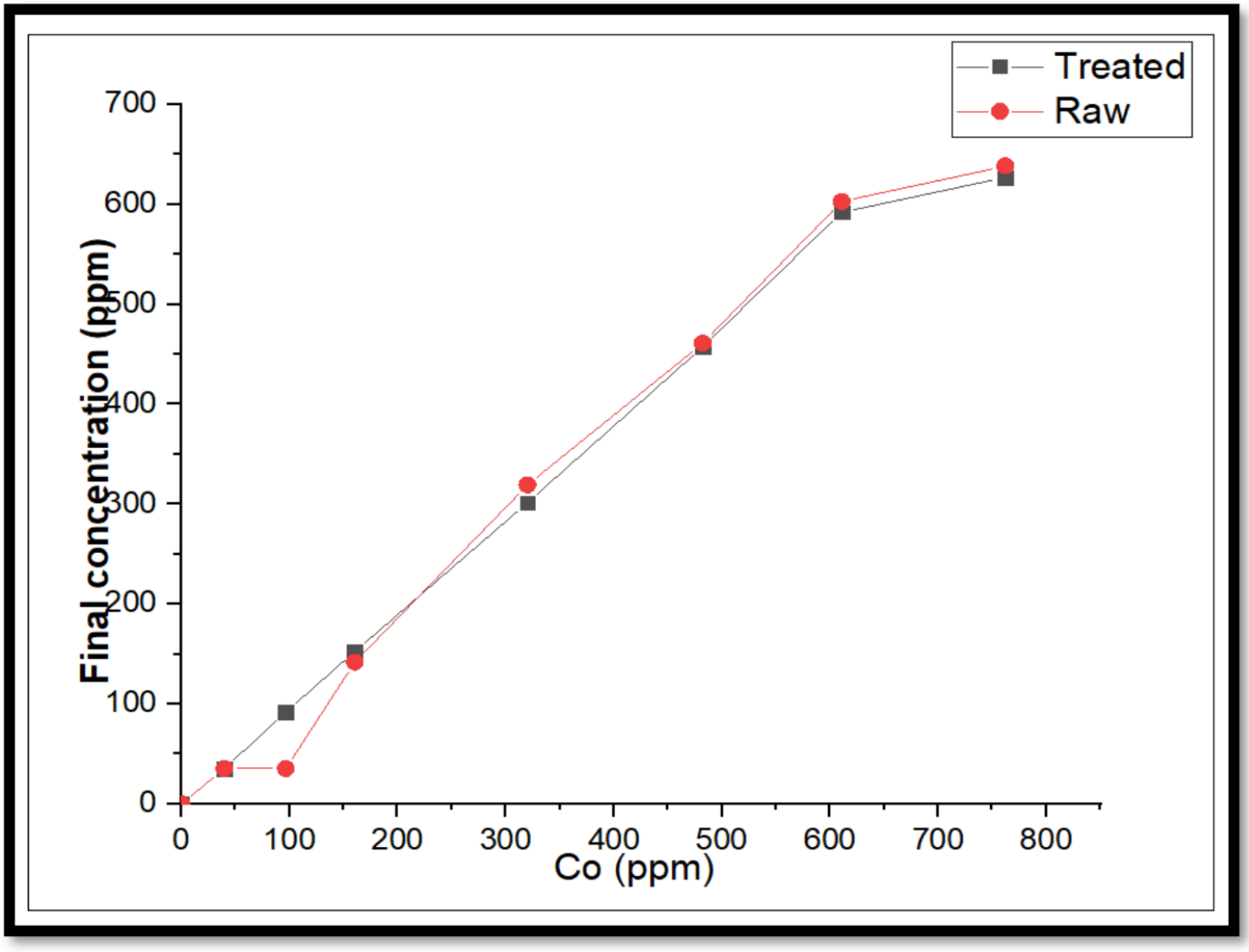


Figure 6

Effect of concentration.

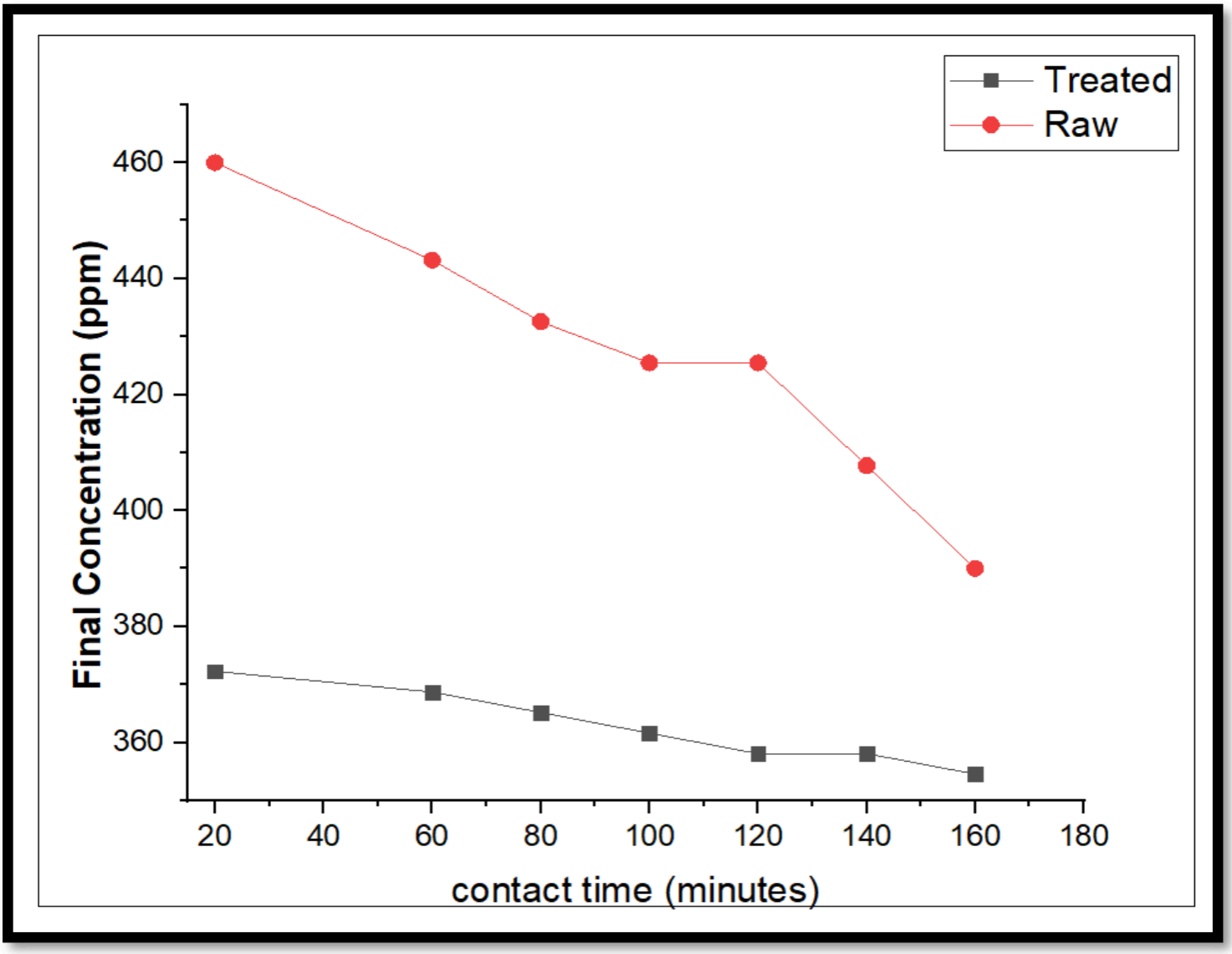


Figure 7

Effect of contact time.

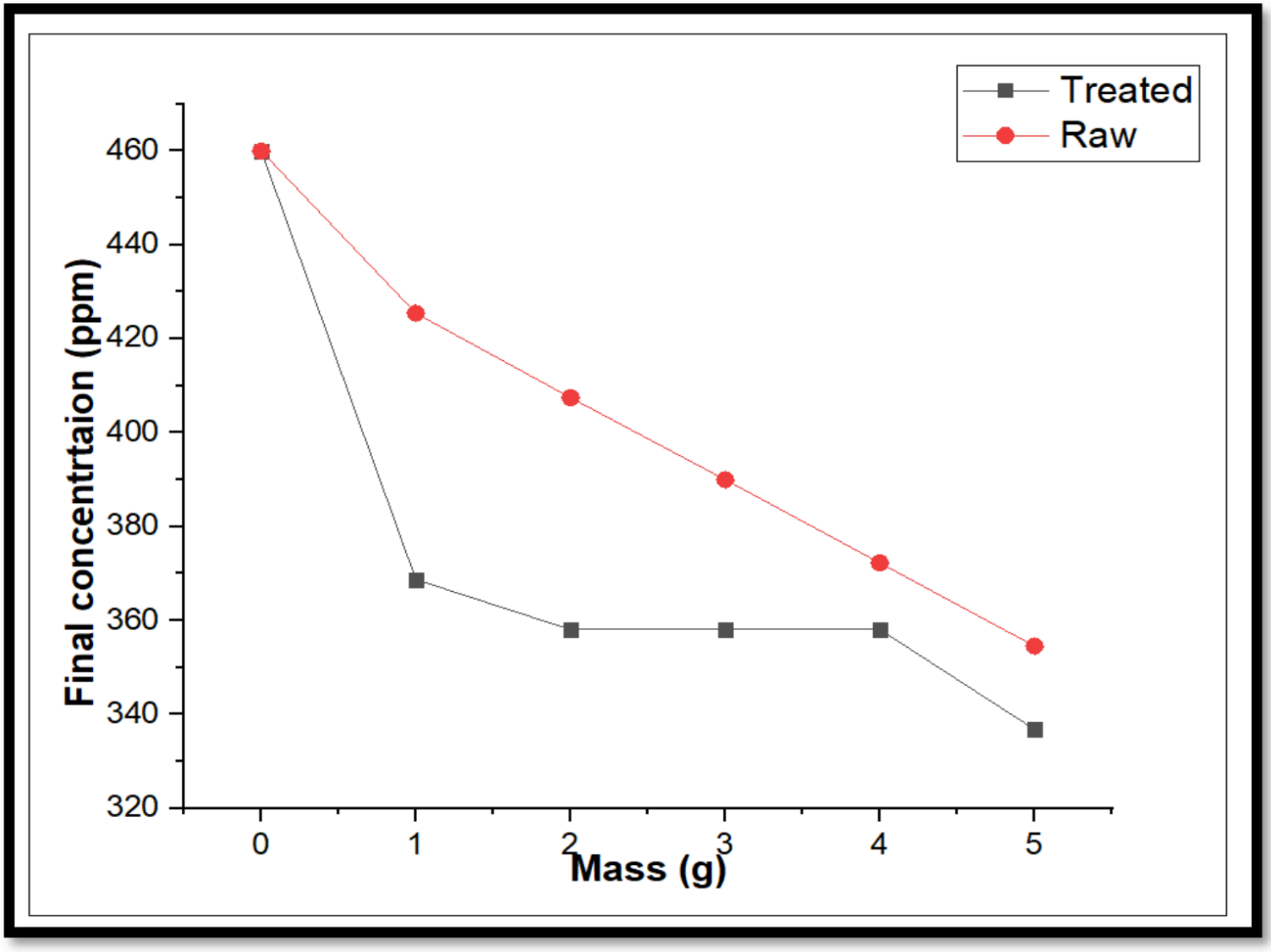


Figure 8

Effect of dosage.

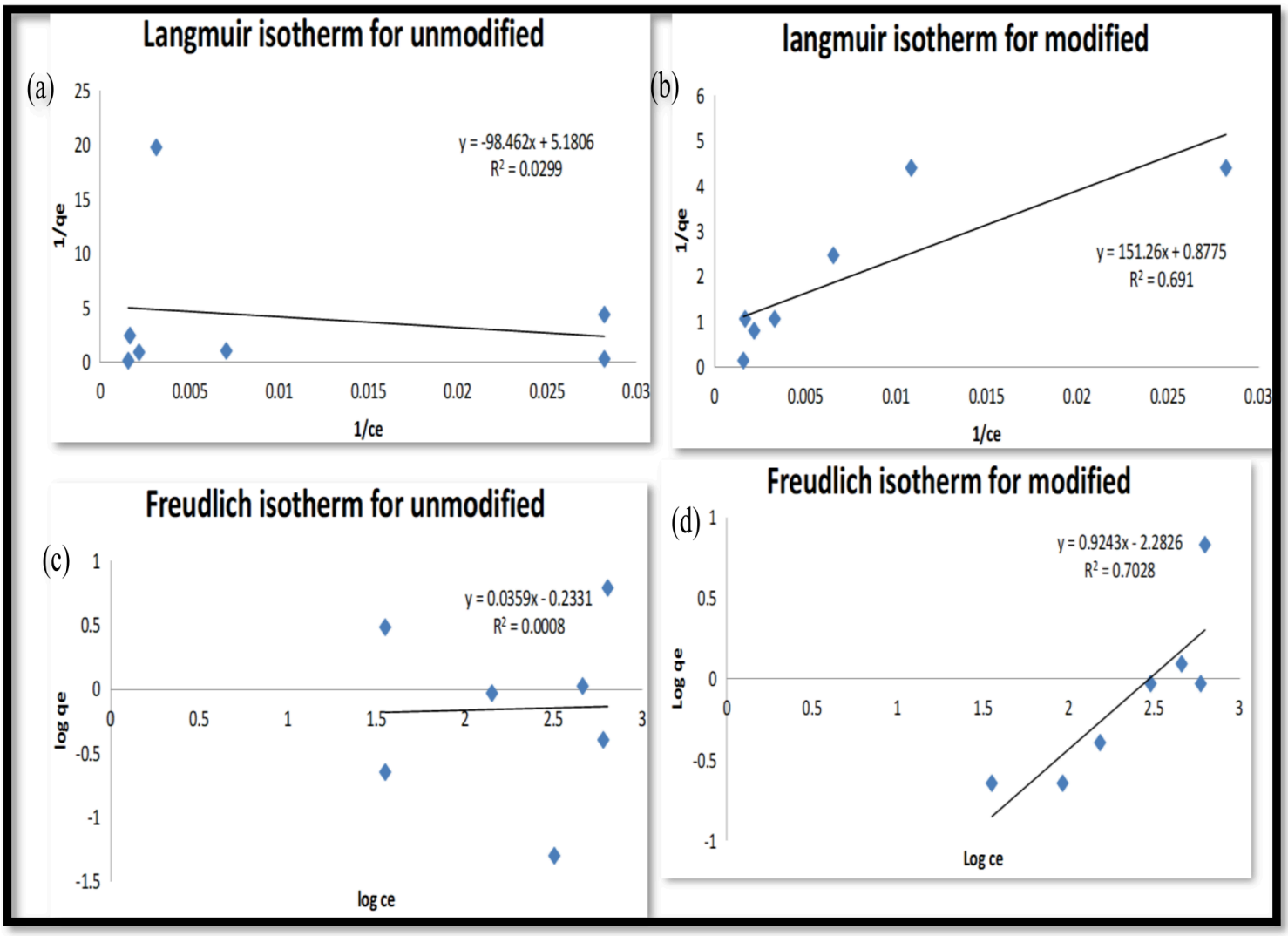


Figure 9

Adsorption Isotherms

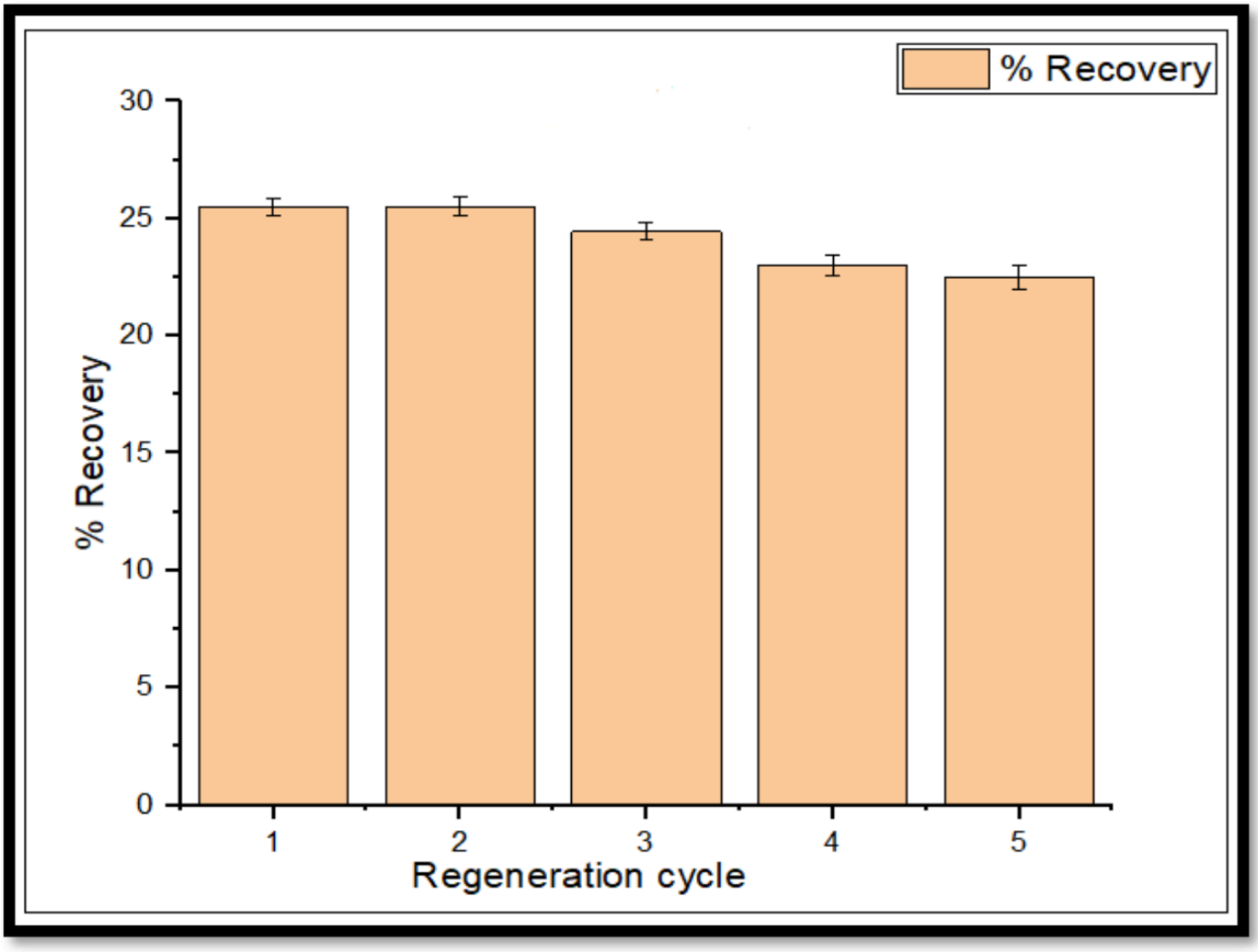


Figure 10

Regeneration study