



## Research Article

# Lead removal efficiency of various natural adsorbents (*Moringa oleifera*, *Prosopis juliflora*, peanut shell) from textile wastewater

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## Abstract

The present study deals with the class of natural adsorbents such as *Moringa oleifera*, *Prosopis juliflora* seeds and peanut shell for the removal of heavy metal (lead: Pb) from textile wastewater. The above adsorbents were characterized by Fourier transform infrared and scanning electron microscope to predict the functional groups and surface morphology. The effect of adsorbent dose, contact time, metal concentrations and pH on lead removal was studied in batch experiment and found that the maximum removal of lead was found to be 86.0%, 78.0% and 72.0% for *M. oleifera*, *P. juliflora* seeds and peanut shell, respectively. Langmuir isotherm best correlated to the experimental data for all three cases and 5.6 mg/g, 1.7 mg/g and 1.4 mg/g maximum adsorption capacity of lead was obtained for *M. oleifera*, peanut shell and *P. juliflora*, respectively. Pseudo-first-order and pseudo-second-order kinetics study revealed that pseudo-second-order kinetic model followed better correlation coefficient for *M. oleifera* ( $R^2 = 0.998$ ), peanut shell ( $R^2 = 0.978$ ) and *P. juliflora* ( $R^2 = 0.995$ ).

**Keywords** Textile wastewater · Lead · Adsorption · Isotherms and kinetic models

## 1 Introduction

Textile industry is known as one of the largest water-consuming industries that consumes  $1 \times 10^5$  L to  $1.5 \times 10^5$  L of water per tonne of textile material [1] thereby generating large amount of wastewater [2, 3]. According to Lim et al. [4], characteristics of textile wastewater shows high level of BOD, COD, pH, temperature and color. It also contains suspended solids, sulfide components, fats, oils, heavy metals (chromium, copper, arsenic, lead, cadmium, mercury, nickel, cobalt) and fibers [1]. Water bodies receiving untreated textile wastewater are prone to pollution and several toxic effects [5]. High BOD and COD indicate higher level of pollution that decreases dissolved oxygen which affects the aquatic flora and fauna of the receiving water body [6]. Color and suspended solids restrict the

penetration of light and gas solubility in the water body, which disturbs the biological activities of the aquatic plants and animals [7].

Heavy metals present in the textile wastewater produce negative ecological impact on the water body and also affect the human health when they enter the food chain. Although most of the heavy metals present in the textile wastewater are toxic, lead is recognized as one of the most toxic heavy metals for human health [8]. It causes numerous health effects such as persistent fatigue, loss of appetite, constipation, reduced attention span, mental retardation, insomnia, poor muscle coordination, increase blood pressure, hearing and vision impairment, less hemoglobin production, infertility, pregnancy problems, central nervous system syndrome, neuromuscular effects and abdominal pain. It is particularly more toxic to children [9].

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Therefore, it is necessary to remove the lead from textile wastewater before it is discharged into the water body.

It is reviewed that several methods of lead removal from textile wastewater have been proposed such as precipitation, coagulation/flocculation, ion exchange, reverse osmosis, electrochemical operations, ozonation and biological treatments [10]. Most of them have some limitations such as high sludge generation in precipitation, coagulation/flocculation and ionic exchange methods; huge pressure require in reverse osmosis; high cost of treatment in electrochemical operations, as short half-life of ozone in ozonation, formation of byproduct in photochemical degradation. These methods also require large amount of energy and reagents besides disposal problem of produced sludge and toxic by-products [11–13]. Adsorption is one of the best and effective methods used for removal of heavy metal from wastewater. Adsorption on activated carbon is expensive conventional process which provides affinity for many organic chemicals because of its vast surface area and micro pores [14]. Expensiveness of activated carbon prompted to find alternative low-cost effective natural or synthetic materials [15]. Materials such as papaya wood [16], maize leaf [17], rice husk ash and neem bark [18], chitosan composite beads [19], pomelo (*Citrus grandis*) peel [20], sawdust [21], tea leaves [22], sunflower seed shells [23], algal biomass based materials [24], wheat bran [25] and almond shells [26] can be used as a low-cost natural adsorbents.

*Moringa oleifera*, peanut shell and *Prosopis juliflora* [27, 28] have been reported having significant adsorbent characteristics for lead removal from textile wastewater. These naturally available bio-resources have got least attention among the researchers as adsorbent for the removal of lead from textile wastewater. In the present study, adsorption of lead onto *M. oleifera*, *P. juliflora* and peanut shell was investigated for the removal efficiency and adsorption mechanism. To achieve the objective of this study, characterizations of *M. oleifera*, *P. juliflora* and peanut shell are performed using Fourier transform infrared (FTIR) and scanning electron microscope (SEM) to confirm the functional group and surface morphology of the adsorbents. Adsorption study was done systematically with the variation in the parameters such as pH, dose, contact time, initial concentration of adsorbate along with Langmuir, Freundlich and Temkin isotherms to analyze the equilibrium data.

## 2 Materials and method

### 2.1 Chemical and reagents

All the chemicals and reagents of analytical grade were used in this study. Solutions were prepared in Milli-Q water.

### 2.2 Preparation of adsorbents

Fruits of *M. oleifera* and *P. juliflora* were collected from Ballia district of Uttar Pradesh, and peanut shells were collected from Lucknow district of Uttar Pradesh. These materials were washed thoroughly with distilled water and sundried for 7 days. The seeds and peanut shells were kept in oven 70 °C for 48 h. The dried samples were grounded to powder and sieved with sieve set containing 75 µm to 150 µm sieves. The powder passing sieve 150 µm and retained on 75 µm sieve was collected and stored in plastic bottle for further study [20].

### 2.3 Characterizations of *M. oleifera*, *P. juliflora* seeds and peanut shell

Fourier transform infrared (FTIR) spectra (Thermo Fischer: Nicolet, iS5, USA) was used to confirm the functional group on the adsorbents which have been recorded in the spectral range of 4000–550 cm<sup>-1</sup> with Thermo Fischer. The samples were placed, and spectra were recorded at a rate of 16 scans/min. The surface morphology of *M. oleifera*, *P. juliflora* and peanut shell was examined through scanning electron microscope (SEM, Quanta FEG 450, FEI, The Netherlands).

### 2.4 Preparation of textile wastewater

The commercially available reactive dye malachite green oxalate was used to simulate the synthetic textile wastewater sample. The reactive malachite green oxalate dye is frequently used in textile industries. Dye was then accompanied with the following chemicals such as sodium chloride 3 g/L, hydrolyzed starch 0.00556 g/L, ammonium sulfate 0.0174 g/L, disodium hydrogen phosphate 0.0174 g/L and detergent drops in order to correctly simulate the actual dye waste released from the textile industries [29]. Known concentration of lead was added in this synthetic textile wastewater [30] by using stock solution of lead, prepared as per standard method 1640 of USEPA. 0.1599 g of PbNO<sub>3</sub> was dissolved in 5 mL of nitric acid and diluted to 100 mL with Milli-Q water. The concentration of lead in stock solution contained 1000 µg of lead in 1 mL of the solution. When this simulated wastewater was compared

with textile effluent (Table 1), it showed almost similar characteristics as textile effluent [31].

## 2.5 Experiment

Batch studies were performed to optimize the process variables such as adsorbent dose, contact time, lead concentration and pH at room temperature  $27 \pm 4$  °C for the removal of lead using jar test apparatus (Model LBS-JTF1-6, Labsol Enterprises, New Delhi). The optimum values of process parameters thus obtained were used for adsorption studies.

All the experiments were conducted in triplicate forms, and sample mean was reported. Wastewater sample having 1 L of known initial lead concentration was taken in jars, and different dose of adsorbents were mixed in different jars. The mixing speed was set at 120 rpm, and contact time has been set using the knobs [32]. Jars were removed slowly from the platform at the end of the mixing period and were left for 2 min for settling. Settled contents were filtered through Whatman 42 no. filter paper and analyzed for residual lead by atomic adsorption spectroscopy (AAS 1909, Labman Scientific Instrument, USA).

The percent removal of the lead was calculated using formula given in Eq. 1:

$$\text{Percent removal} = \frac{(C_0 - C_t) \times 100}{C_0} \quad (1)$$

where  $C_0$  = initial concentration of lead ion (mg/L), and  $C_t$  = final concentration of lead ion (mg/L) at contact time  $t$  (min).

## 2.6 Isotherm analysis

Mass of metal adsorbed by per unit of adsorbent is called as adsorption capacity of the adsorbent. It also provides the information about the type of adsorption process and

**Table 1** Comparison between textile effluent and synthetic textile effluent

Characteristic	Textile industry effluent <sup>a</sup>	Synthetic textile wastewater
pH	5.5–11.0	7.1
BOD	160–600 mg/L	486 mg/L
COD	220–1400 mg/L	514 mg/L
Suspended solids	160–500 mg/L	430 mg/L
Chloride	300–1200 mg/L	630 mg/L
Temperature	Up to 40 (NEQS)	31 °C

NEQS national environmental quality standards

<sup>a</sup>Imtiazuddin et al. [46]

the capacity of adsorbent. For the analysis of adsorption process, various isotherms were tested, such as Langmuir, Freundlich and Temkin isotherms [12, 13].

### 2.6.1 Langmuir isotherm

Langmuir described the adsorption as a single layer on the surface of adsorbent with the formation of an ionic or covalent bond between metal and adsorbent molecules. Langmuir isotherm is used for monolayer adsorption [33]. It is expressed by Eq. (2):

$$\frac{C_e}{q_e} = \frac{1}{q_m K_{ads}} + \left( \frac{1}{q_m} \right) C_e \quad (2)$$

where  $q_e$  = adsorbed concentration at equilibrium (mg/g),  $C_e$  = concentration at equilibrium (mg/g),  $q_m$  = maximum capacity of adsorbent for adsorbate (mg/g), and  $K_{ads}$  = measure of affinity of adsorbate for adsorbent.

### 2.6.2 Freundlich isotherm

Freundlich and Heller [34] derived a model to describe non-ideal multilayer sorption on heterogeneous surface energy system. It assumes that the adsorption process took place layer by layer on the surface sites. Freundlich model can be expressed by Eq. (3):

$$\log q_e = \log K_F + \left( \frac{1}{n} \right) \times \log C_e \quad (3)$$

where  $C_e$  = concentration at equilibrium (mg/g),  $q_e$  = adsorbed concentration at equilibrium (mg/g),  $K_F$  = Freundlich constant related to adsorption intensity of adsorbents, and  $n$  = Freundlich constant related to adsorption capacity of adsorbents.

### 2.6.3 Temkin isotherm

Temkin isotherm follows the assumption that adsorption heat decreases linearly on interaction of adsorbent [35]. Temkin isotherm [36] is expressed by Eq. (4):

$$q_e = B_t \ln K_t + B_t \ln C_e \quad (4)$$

where  $K_t$  = equilibrium binding constant, and  $B_t$  = variation of adsorption energy.

## 2.7 Kinetic modeling

Kinetic modeling is important properties used to explain the adsorption process. The kinetics of adsorption has been studied to explain the lead uptake mechanism in the present materials. It was observed that the uptake of

lead increased with contact time. The pseudo-first-order Eq. (5) is generally expressed [37] as:

$$\frac{dq_t}{dt} = k_1(q_e - q_t) \quad (5)$$

where  $q_e$  = amount of lead adsorbed on adsorbent (mg/g) at equilibrium,  $q_t$  = amount of lead adsorbed on adsorbent (mg/g) at time  $t$  (min), and  $k_1$  = rate constant of pseudo-first-order kinetics.

On integrating Eq. (5) and applying boundary conditions ( $q_t=0$  to  $q_t=q_t$  at  $t=0$  to  $t=t$ ), the following equation was obtained as;

$$\log(q_e - q_t) = \log q_e - \frac{k_1}{2.303}t \quad (6)$$

Pseudo-second-order rate expression can be written [38] as:

$$\frac{dq_t}{dt} = k_2(q_e - q_t)^2 \quad (7)$$

On applying the boundary conditions ( $q_t=0$  to  $q_t=q_t$  at  $t=0$  to  $t=t$ ), Eq. (8) was obtained as:

$$\frac{t}{q_t} = \frac{1}{k_2q_e^2} + \frac{1}{q_e}t \quad (8)$$

where  $q_e$  = amount of lead adsorbed on adsorbent (mg/g) at equilibrium,  $q_t$  = amount of lead adsorbed on adsorbent (mg/g) at time  $t$  (min), and  $k_2$  = rate constant of pseudo-second-order kinetics.

### 3 Results and discussion

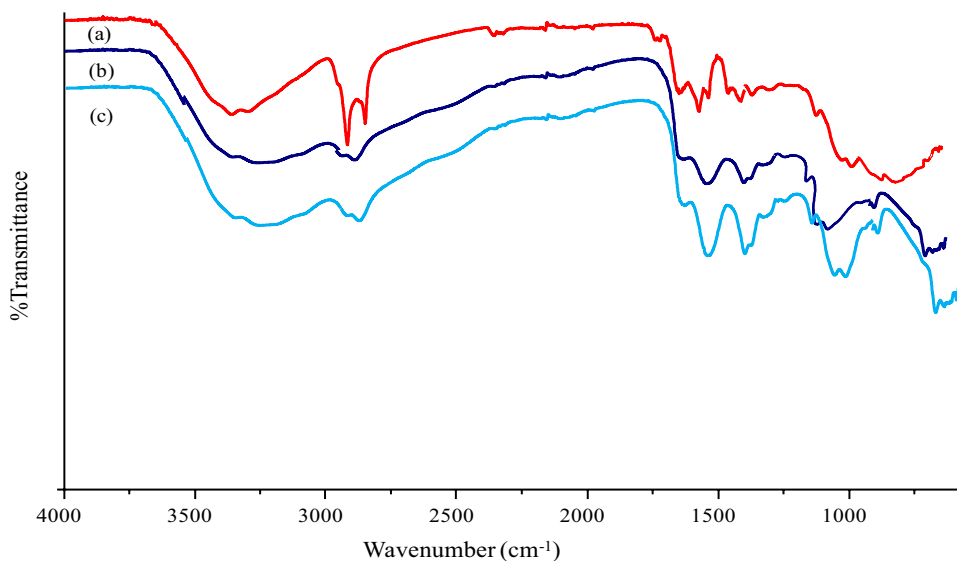
The confirmation of the functional groups on *M. oleifera*, *P. juliflora* and peanut shell was done using FTIR spectra as shown in Fig. 1. *Moringa oleifera* (a) displayed characteristic peaks at 1049 and 793  $\text{cm}^{-1}$  corresponding to the internal  $\text{SiO}_4$  tetrahedral (Si–O–Si chain structure stretching) and symmetric Si–O–Si stretching. Symmetric and asymmetric stretching vibrations of the  $-\text{CH}_2$  (2896  $\text{cm}^{-1}$ ) and  $-\text{CH}_3$  (2930  $\text{cm}^{-1}$ ) were found in *M. oleifera* (a). At the wave number of 1470  $\text{cm}^{-1}$ , C–OH deformation with contribution of O–C–O symmetric stretching and  $\text{CO}_3^{2-}$  groups was observed in *P. juliflora* (b) and peanut shell (c).

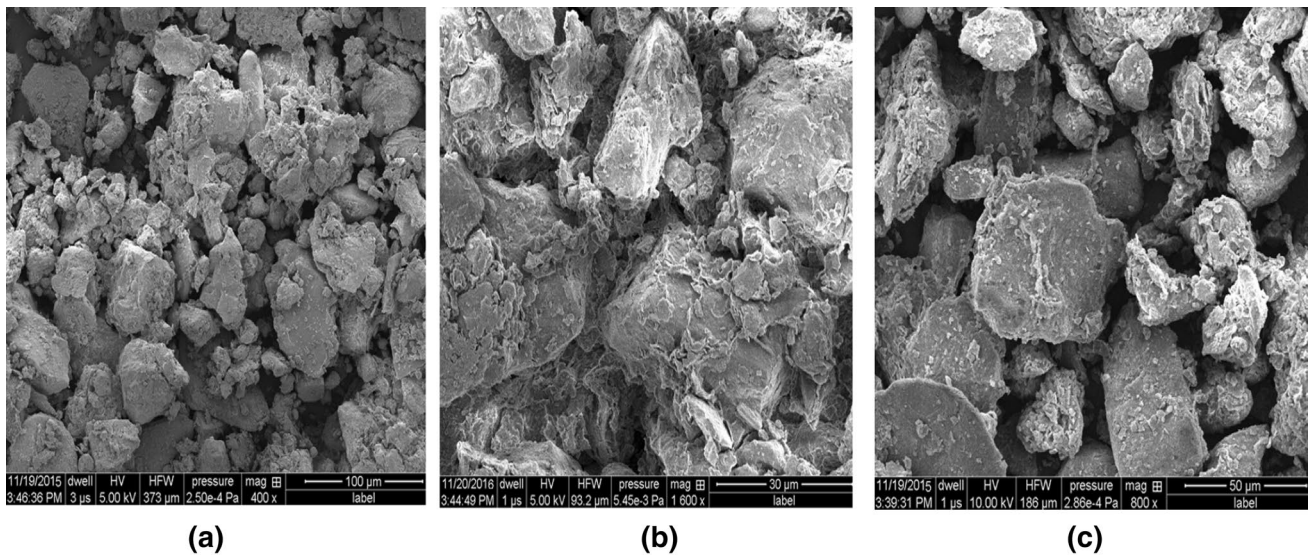
The surface morphology of *M. oleifera* (a), *P. juliflora* (b) and peanut shell (c) is elucidated in Fig. 2. *Moringa oleifera* (a) shows rough aggregates having smaller size, whereas in *P. juliflora* (b) the texture and particles are closely bound to each other. In the case of peanut shell (c), surface was observed to be globular and coarse in texture which provides high surface area to adsorb the lead.

#### 3.1 Effect of adsorbent dose

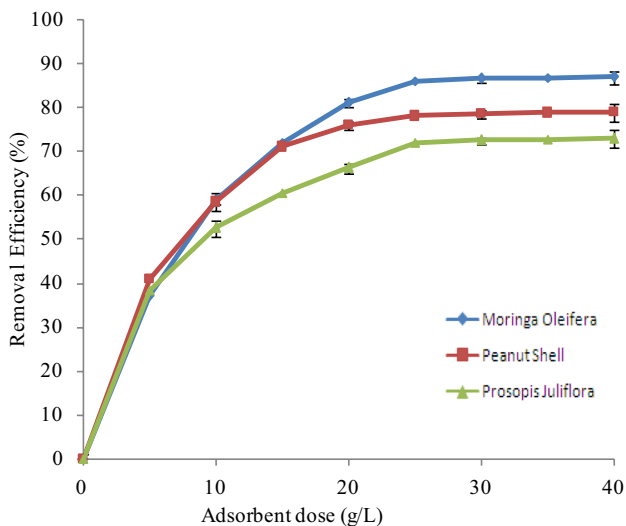
Adsorbent dose was varied from 5 to 40 g/L to assess its effect on lead removal. Variation of removal efficiency was observed to be 37.0–86.0% for *M. oleifera*, 41.0–78.0% for peanut shell and 38.4–72.0% for *P. juliflora* at 25 g/L as shown in Fig. 3. The rate of removal of lead increased when adsorbent dose varied from 5 to 15 g/L due to the availability of more active sites onto surface area of the adsorbents, thereby making penetration of metal (lead) easier to the adsorbent sites. With further increase in adsorbent dose up to 25 g/L, the rate of removal slowed down and

**Fig. 1** FTIR spectra of (a) *M. oleifera*, (b) *P. juliflora* and (c) peanut shell



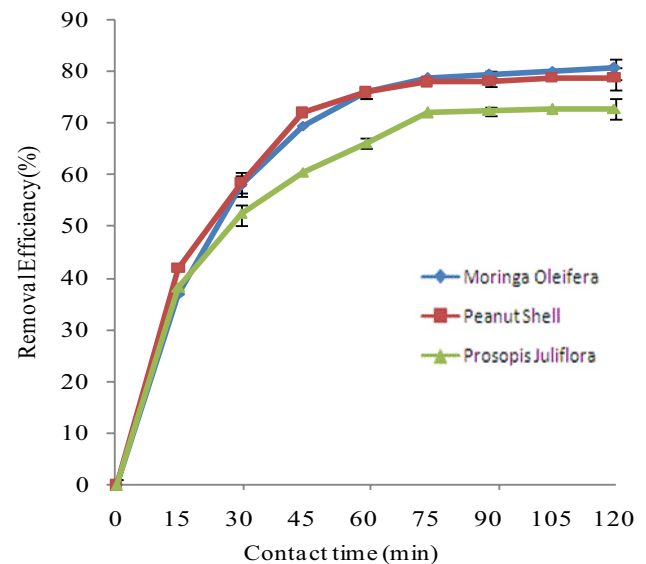


**Fig. 2** SEM images of **a** *M. oleifera*, **b** *P. juliflora* and **c** peanut shell



**Fig. 3** Effect of adsorbent dose on the lead removal

almost stagnant rate of removal was observed up to 40 g/L as manifested in Fig. 3. At higher adsorbent dose, the rate of lead removal is slowed down due to lack of surface area and over lapped active sites. The optimum dose is 25 g/L having lead removal efficiency 86.0%, 78.0% and 72.0% for *M. oleifera*, peanut shell and *P. juliflora*, respectively; indicating *M. oleifera* is better adsorbent among all the three tested adsorbents. Increase in lead removal efficiency from 46.0 to 60.0% with an increase in adsorbent dose from 10 to 50 g/L using modified *P. juliflora* has been reported by Sivakumar and Dheenadayalan [39]. Similar trend of increase in lead removal efficiency from 14.7 to 81.7% for



**Fig. 4** Effect of contact time on the lead removal

raw bamboo charcoal and 58.8–98.8% for activated bamboo charcoal at increase in 0.1–0.5 g/100 mL adsorbent dose was investigated by Lalhruaitluanga et al. [40] from aqueous solutions. Bhattacharyya and Sharma [9] also reported that the lead removal efficiency increased from 16.1 to 67.7% with an increase in 0.2–1.2 g/L adsorbent dose using neem leaf powder.

### 3.2 Effect of contact time

Contact time was varied from 15 to 120 min to assess its effect on lead removal as presented in Fig. 4. Initially, as

contact time increased, the efficiency of lead removal also increased. This might be due to the fact that binding time of metal increases on the active surface of adsorbent [3]. The maximum lead removal efficiency was found to be 86.0%, 78.0% and 72.0% at 90 min, 75 min and 75 min for *M. oleifera*, peanut shell and *P. juliflora*, respectively. Ghani et al. [41] reported that removal of lead from wastewater increased with increase in contact time and attained equilibrium at 90–120 min by adsorption onto rice husk, maize cobs and sawdust. OuYang et al. [28] studied the modified peanut shell as an adsorbent for removal of lead from aqueous solution and found that the trend of removal efficiency increased with respect to contact time and optimum contact time was found to be 100 min. Adelaja et al. [42] also found the maximum lead removal efficiency at the end of 180 min by using *M. oleifera* in aqueous solution.

### 3.3 Effect of initial lead concentration

Initial lead concentration was varied from 5 to 40 mg/L to assess its effect on lead removal. The percentage removal of lead decreased with increase in initial lead concentration as presented in Fig. 5. It may be due to that metal (lead) ions are higher as compared to available active sites at higher initial lead concentration [43]. The percentage removal of lead was observed to be 86.0% at 25 mg/L and 32.6% at 40 mg/L for *M. oleifera* and peanut shell showed 78.0% removal at 25 mg/L and 56.9% removal at 40 mg/L. The percentage removal was observed to be 72.0% at 25 mg/L and 28.6% at 40 mg/L for *P. juliflora*. Jayaram and Prasad [44] studied use of modified *P. juliflora* seeds as an adsorbent and reported that when the initial lead

concentrations were increased from 20 to 60 mg/L, the percentage of adsorption slightly decreased (88.3–67.2%). Bhattacharyya and Sharma [9] reported that lead removal efficiency decreased from 88.0 to 50.9% on the increment of initial lead concentration from 50 to 150 mg/L from aqueous solution by using neem leaf powder. Raju et al. [45] found that the lead removal efficiency from the aqueous solution decreased from 91.9 to 86.3% on the increment of initial lead concentration from 20 to 140 mg/L.

### 3.4 Effect of pH on lead removal

The pH of the wastewater was varied from 2 to 10 by adding 0.05 mol/L H<sub>2</sub>SO<sub>4</sub> or 0.1 mol/L NaOH to assess its effect on lead removal. In acidic pH (High H<sup>+</sup> concentration), the percent removal of lead from 13 to 86% (*M. oleifera*), 12 to 78% (peanut shell) and 13 to 72% (*P. juliflora*) at increasing rate when pH was raised from 2 to 6 was observed; only slight removal could take place in the pH range of 6–7. The lead removal efficiency of *M. oleifera*, peanut shell and *P. juliflora* was observed to be 86.0%, 78.0% and 72.0%, respectively, at pH 6 as shown in Fig. 6. It was found that the adsorption process for the removal of lead was effective in acidic condition. Further increase in pH beyond these values showed slight reduction in lead removal in alkaline condition (6–12 pH) in all the cases. At higher pH, this rivalry became weak and H<sup>+</sup> was replaced by lead bound to the adsorbent surface functional groups [20]. Nadeem et al. [43] found 79.3% of lead removal at pH 5.8 in a similar study by using modified *M. oleifera* pods. OuYang et al. [28] used the modified peanut shell as an adsorbent to remove lead from solution containing amino acid and

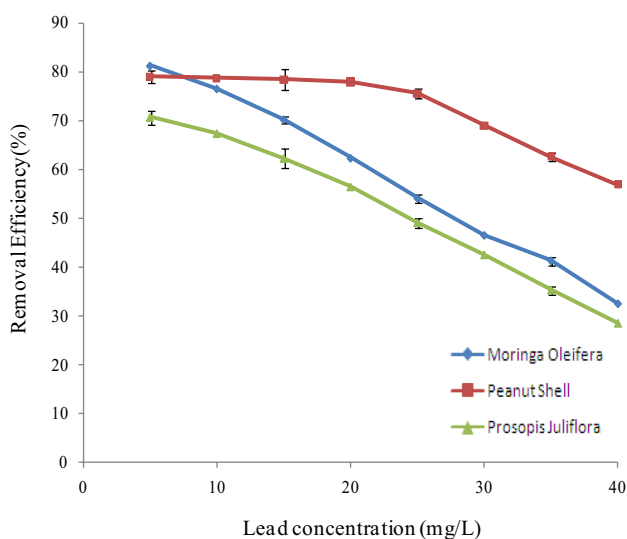


Fig. 5 Effect of lead concentration on the lead removal

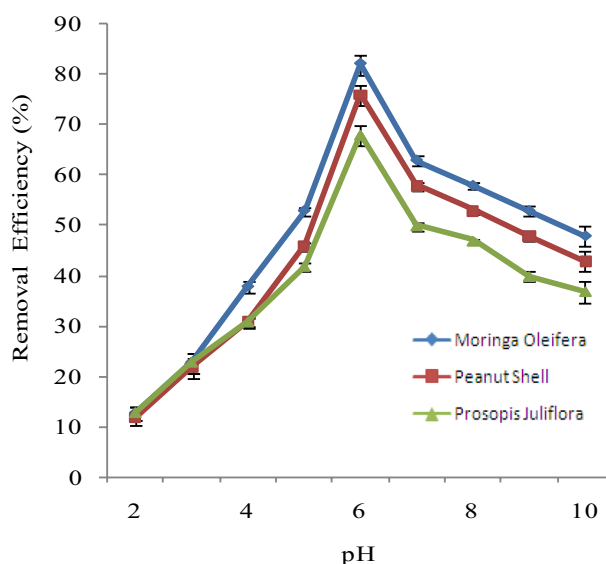


Fig. 6 Effect of pH on the lead removal

sodium chloride and reported that the maximum lead removal was observed at pH 5 and the removal efficiency decreased at higher pH values. Jayaram and Prasad [44] obtained maximum removal of lead at pH ranged from 4 to 6 in removal of lead from aqueous solution by modified *P. juliflora* seeds as an adsorbent.

### 3.5 Adsorption isotherm

#### 3.5.1 Langmuir isotherm

Langmuir isotherm is a plot of  $\log C_e/q_e$  versus  $\log C_e$  results in a straight line as shown in Fig. 7. The adsorption capacity,  $q_m$ , has higher value for peanut shell (5.617 mg/g) compared to the values for *M. oleifera* (1.780 mg/g) and *P. juliflora* (1.445 mg/g). From the results, it can be understood that peanut shell has more capacity to adsorb lead than that of *M. oleifera* and *P. juliflora* (Table 2). In order to check the applicability of the adsorption process, separation factor ( $R_L$ ) was evaluated by using the below equation [38];

$$R_L = \frac{1}{1 + bC_0} \tag{9}$$

where  $C_0$  = lowest initial concentration of metal ions, and  $b$  = Langmuir adsorption constant.

$R_L$  value also confirms whether the adsorption is linear ( $R_L = 1$ ), favorable ( $0 < R_L < 1$ ), unfavorable ( $R_L > 1$ ) or irreversible ( $R_L = 0$ ). In the present study, the  $R_L$  values given in Table 2 for lead were more than zero and less than unity which showed the favorable adsorption of lead onto all the adsorbents.

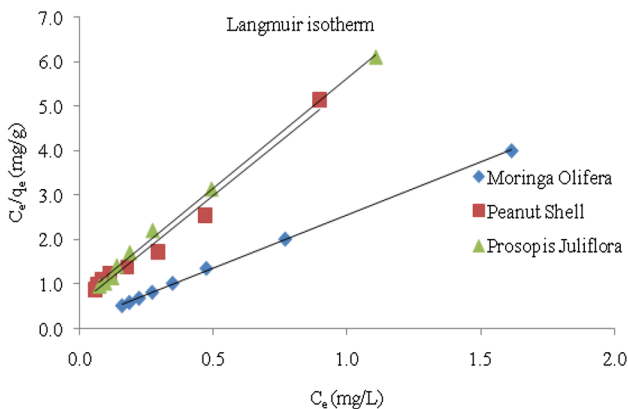


Fig. 7 Langmuir isotherm plots for lead adsorption

#### 3.5.2 Freundlich isotherm

Freundlich isotherm is a plot of  $\log q_e$  versus  $\log C_e$  and results in a straight line as shown in Fig. 8. The values of Freundlich constants ( $n$  and  $K_f$ ) were calculated from the slope ( $1/n$ ) and intercept ( $\log K_f$ ) of the plot of  $\log q_e$  versus  $\log C_e$ , respectively (Table 2). The parameter 'n' indicates the reactivity of the adsorbent's active sites, in the linearization by Freundlich. The value of  $n > 1$  shows the favorable nature of adsorption. The value of 'n' was greater than one, which showed the favorable adsorption of lead onto adsorbents at different concentrations.

#### 3.5.3 Temkin isotherm

The plot of  $q_e$  versus  $\log C_e$  gave a straight line as shown in Fig. 9. The values of slope and intercept were used to calculate the Temkin constants  $K_t$  and  $B_t$ . The values of Temkin adsorption potential,  $K_t$ , for *P. juliflora*, peanut shell

Table 2 Isotherms constant

	<i>Moringa oleifera</i>	Peanut shell	<i>Prosopis juliflora</i>
<i>Langmuir constants</i>			
$q_m$	5.617	1.780	1.445
$k_{ads}$	0.074	0.115	0.139
$R^2$	0.999	0.981	0.995
$R_L$	0.729	0.634	0.589
<i>Freundlich constants</i>			
$K_f$	0.386	0.231	0.184
$1/n$	0.874	0.576	0.686
$n$	1.144	1.736	1.457
$R^2$	0.969	0.939	0.952
<i>Temkin constants</i>			
$K_t$	0.720	0.880	0.910
$B_t$	1.290	3.200	3.150
$R^2$	0.926	0.962	0.954

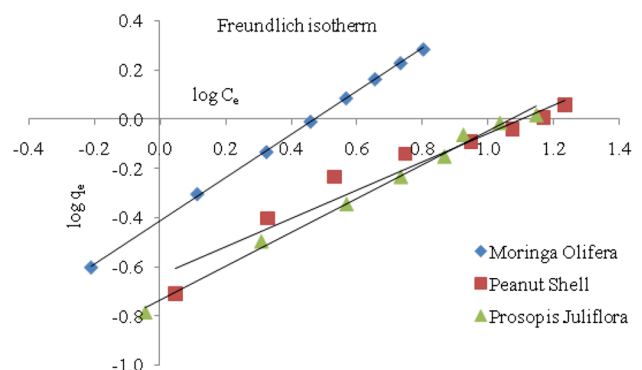


Fig. 8 Freundlich isotherm plot for lead adsorption

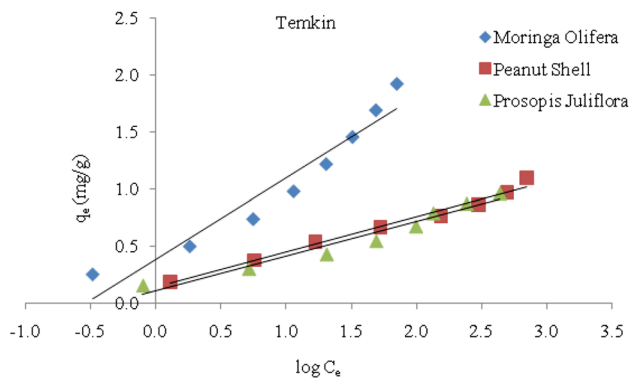


Fig. 9 Temkin isotherm plots for lead adsorption

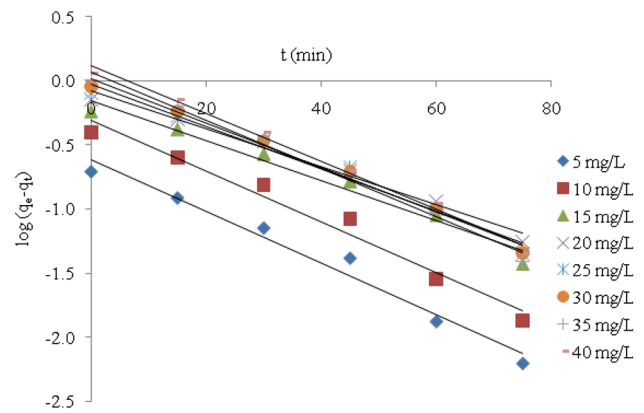


Fig. 11 Pseudo-first-order plots of lead adsorption for peanut shell

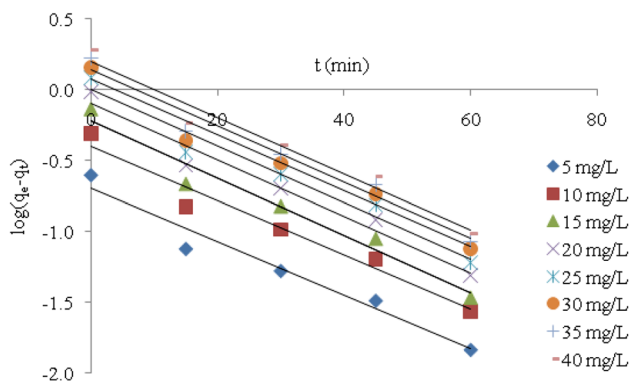


Fig. 10 Pseudo-first-order plots of lead adsorption for *M. oleifera*

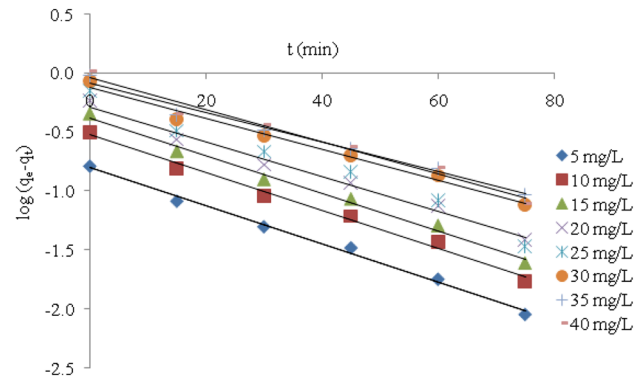


Fig. 12 Pseudo-first-order plots of lead adsorption for *P. juliflora*

and *M. oleifera* were found to be 0.910 L/mg, 0.880 L/mg and 0.720 L/mg, respectively. This indicates lowest adsorbent–lead potential of *M. oleifera* and highest for *P. juliflora* among the adsorbents. Among all three isotherms, the best correlation coefficient value ( $R^2$ ) in the Langmuir isotherm for each adsorbent presented in Table 2 was obtained, which manifest that it is best suited isotherm for this study. Jayaram and Prasad [44] studied adsorption of lead by modified *P. juliflora* seeds and observed that Langmuir isotherm better represented the adsorption process which is similar to the present study. Same result was obtained by Nadeem et al. [43] for sorption of lead from aqueous solution by chemically modified *M. oleifera* pods.

### 3.6 Kinetic modeling

The pseudo-first-order and pseudo-second-order kinetic models for the adsorption of lead onto adsorbents at different initial concentration of adsorbate are shown in Figs. 10, 11, 12, 13, 14 and 15.

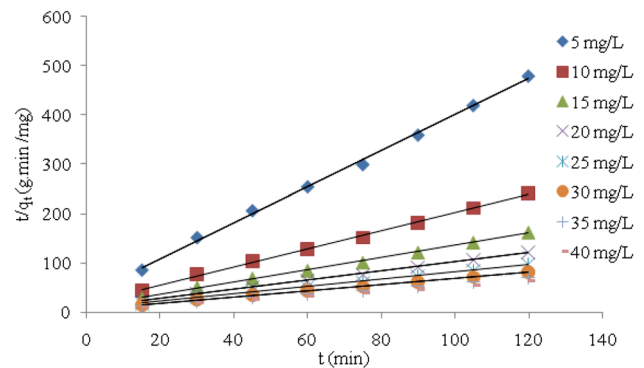
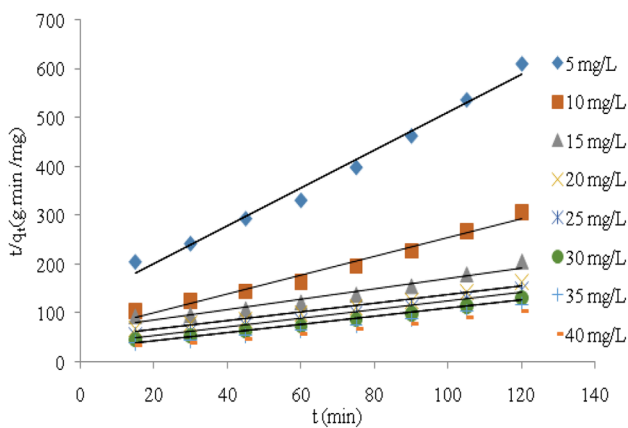


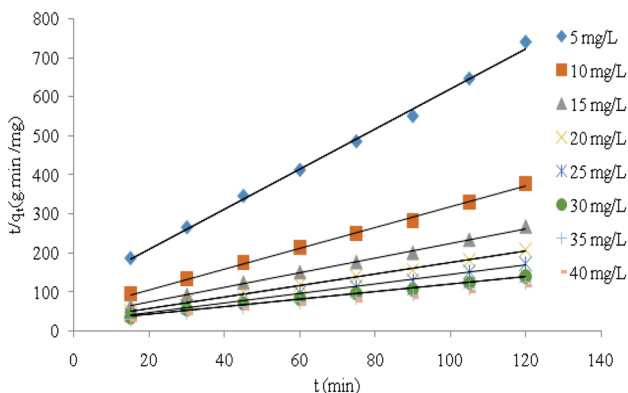
Fig. 13 Pseudo-second-order kinetic plot of adsorption of lead for *M. oleifera*

The values of rate constant  $k_1$  and  $k_2$  were obtained from the slope and intercepts of the plot  $\log(q_e - q_t)$  versus  $t$  and  $t/q_t$  versus  $t$ , respectively (Table 3). For the pseudo-first-order kinetic model, the values of correlation





**Fig. 14** Pseudo-second-order kinetic plot of adsorption of lead for peanut shell



**Fig. 15** Pseudo-second-order kinetic plot of adsorption of lead for *P. juliflora*

coefficients ( $R^2$ ) were low, which suggested that the adsorption of lead departed significantly from the pseudo-first-order kinetic model and could not explain the adsorption mechanism of lead. For pseudo-second-order kinetic model, the values of  $R^2$  (correlation coefficients) were greater than 0.958 which indicated that the adsorption process followed the pseudo-second-order kinetic model. Nadeem et al. [43] observed that pseudo-second-order kinetic model was better representing the kinetic isotherm which is similar to the present study.

### 4 Conclusions

Low-cost natural adsorbents such as *M. oleifera*, *P. juliflora* and peanut shell were used for lead removal from textile wastewater. As adsorbent dose increased gradually, it was observed that the lead removal efficiency also increased. The maximum removal of lead using *M. oleifera*, peanut shell and *P. juliflora* was found to be 86.0%, 78.0% and 72.0% at pH 6, adsorbent dose 25 g/L and contact time 90 min, 75 min and 75 min, respectively. At low initial lead concentration, removal capacity was found to be highest and decreased with increase in initial lead concentration. Adsorption of lead for adsorbents was better represented by the Langmuir isotherm as compared to the Freundlich and Temkin isotherms. It was concluded that pseudo-second-order model predicted better result for present study as compared to pseudo-first-order model.

**Table 3** Pseudo-first-order and pseudo-second-order adsorption kinetic constants

Lead conc. (mg/L)	<i>Moringa oleifera</i>				Peanut shell				<i>Prosopis juliflora</i>			
	Pseudo-first-order		Pseudo-second-order		Pseudo-first-order		Pseudo-second-order		Pseudo-first-order		Pseudo-second-order	
	$K_1$	$R^2$	$K_2$	$R^2$	$K_1$	$R^2$	$K_2$	$R^2$	$K_1$	$R^2$	$K_2$	$R^2$
5	0.041	0.961	0.370	0.997	0.046	0.974	0.121	0.985	0.013	0.317	0.250	0.996
10	0.044	0.961	0.189	0.998	0.438	0.974	0.059	0.978	0.017	0.438	0.133	0.997
15	0.046	0.964	0.133	0.998	0.035	0.971	0.017	0.958	0.019	0.484	0.100	0.998
20	0.044	0.964	0.098	0.998	0.032	0.982	0.016	0.978	0.016	0.493	0.076	0.997
25	0.044	0.962	0.079	0.998	0.037	0.979	0.021	0.984	0.017	0.521	0.062	0.996
30	0.044	0.963	0.056	0.998	0.039	0.989	0.023	0.988	0.019	0.553	0.415	0.993
35	0.044	0.963	0.056	0.998	0.415	0.990	0.025	0.986	0.017	0.557	0.037	0.992
40	0.044	0.964	0.048	0.998	0.415	0.991	0.022	0.986	0.019	0.573	0.037	0.991

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## Compliance with ethical standards

**Conflict of interest** There is no conflict of interest.

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