Investigation on the use of aluminium rich sandy soil as natural adsorbent in the removal of lead from water

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Abstract. The feasibility of aluminium rich sandy soil collected from Jeram as natural adsorbent in removing lead (Pb) from water was investigated without any surface modification. The investigation on the effect of initial concentration, solution pH, and soil:solution ratio was carried out using response surface methodology. The adsorption efficiency was increased at higher pH and soil:solution ratio, as well as lower initial concentration, as a result of higher availability of adsorption sites and less adsorbate competition. The adsorption followed Langmuir isotherm and monolayer chemisorption with an adsorption capacity of 10.64 mg g⁻¹. The process followed pseudo-second order kinetic model, with a rate constant of 0.011 g mg⁻¹ min⁻¹ at optimum adsorption pH of 4-5.

1. Introduction

Water is an irreplaceable natural resource that is essential for the survival of humanity and all species on the earth. However, one of the major environmental issues that the world is currently facing is the insufficient availability of clean water. The reported data shows that there are million of people have no access to clean drinking water in this world [1], as a result of water pollution.

Heavy metal contamination is one of the main contribution factors for water pollution problem. Among many types of heavy metals, lead (Pb) has been reported as a toxic metal element [2] whereby the maximum allowable concentration in wastewater has been set at 0.1-0.5 mg L⁻¹ in Malaysia [3]. Pb contamination can be attributed to different sources such as pipes and fittings, mining, smelting and milling processes [4–6], leading to high exposure risk of Pb for human. The overexposure and intake of Pb can cause several negative impacts to human such as damage to some elemental cellular processes, central nervous system, reproductive system, liver and kidney [4, 5]. Therefore, an effective counter measure is required urgently in order to ensure Pb is removed from water effectively before it is being consumed.

Many types of water treatment technologies have been reported for removing Pb from water such as adsorption, chemical precipitation, membrane filtration and etc. Among these water treatment technologies, adsorption emerges as a promising treatment method due to the advantages of resilience in design/operation, simple, low maintenance cost, ability to produce greater treated water quality and its ability to regenerate the adsorbent easily using proper desorption processes for future use [7, 8]. Recently, different types of natural adsorbents have been investigated to replace conventional activated carbons such as biosorbents [9–13], drinking water treatment sludge [14], mineral coated...
peats/sands/clays [15–17] and foams [18]. Positive results and significant Pb uptake capacity have been reported.

In this study, the ability of aluminium rich sandy soil as natural adsorbent in the adsorption of Pb from water was investigated. The effect of initial Pb concentration, solution pH and soil:solution ratio on the Pb removal efficiency were investigated. The adsorption isotherms and kinetic of the process were also evaluated.

2. Methodology

2.1. Materials

The Pb source in this study was lead (II) nitrate (Pb(NO3)2), which was purchased from R&M Chemicals (Malaysia). The pH adjustment for the Pb solution was carried out using hydrochloric acid and sodium hydroxide, which were purchased by R&M Chemicals (Malaysia). The soil samples, which were rich in aluminium content (11894 mg kg⁻¹) were originated from Jeram, Kuala Selangor. The soil was pre-treated by removing huge rocks and branches. Then, the soil was dried, grinded and sieved through 2 mm size mesh. The soil samples were then stored in desiccator prior to use for the experiments. The general characteristics study of the soil has been investigated by Mukhopadhyay et al. [19] and they are as shown in table 1.

| Soil characteristics [19] |
|----------------------------------------------------------|
| USDA soil classification | Soil distribution of soil particles | Size distribution, mm |
| Sand (Mainly medium and find sand) | 0.045 < x < 2 | 97.45 % |
| Silt + clay | <0.045 | 2.40 % |
| Physical characteristic of soil | Moisture content (% wt) | 3.60 |
| | Density (kg L⁻¹) | 2.52 |
| | Organic matter (Loss by ignition method, %wt) | 1.21 |
| | pH (USEPA SW-846 Method 9045D) | 3.45 |
| | Oxidation Reduction Potential (ASTM Method D 1498-93, mV) | 333 |
| | Electrical Conductivity (USEPA SW-846 Method 9045D, mS cm⁻¹) | 8.25 |
| Metal content of the soil, mg kg⁻¹ (USEPA Method 3050B) | Al | 11894 |
| | Ca | 221 |
| | Fe | 1000 |
| | Mg | 464 |
| | Mn | 42 |
| | Pb | 218 |
| | Zn | 10303 |

2.2. Experimental procedures

2.2.1. Effect of operating parameters. Response surface methodology (RSM) is a mathematical and statistical technique that is useful for the analysis and modelling of problems into a polynomial equation in which the response/outcome is influenced by several variables [20]. Three operating parameters were investigated using RSM in this study, namely: i) initial concentration (500 ppm to 1900 ppm), ii) solution pH (1 to 5), and iii) soil:solution ratio (0.067 to 0.2). The number and sequence of the experiments are planned using Box-Behnken Design, as shown in Table 2. The experiment was conducted by contacting a volume of 100 mL Pb solution at pre-determined concentration and pH with
a mass of soil. The mixture was homogenized at 300 rpm and 25°C for four hours. After the experiment, the aqueous sample was taken, filtered, diluted and analysed for Pb concentration using Inductively Coupled Plasma – Optical Emission Spectroscopy (ICP-OES).

2.2.2. Adsorption isotherms. Synthetic Pb contaminated water was prepared by dissolving Pb(NO₃)₂ into deionized water at different concentrations of 550 ppm to 1900 ppm at pH 5. A volume of 100 mL of the Pb solution was contacted with 10 g of soil and was homogenized using a shaker at 300 rpm and 25°C for four hours. Aqueous samples were taken after the experiment and they were filtered, diluted, and analysed using ICP-OES. The final Pb concentration in the aqueous phase and the Pb uptake were evaluated and were fitted into Langmuir isotherm and Freundlich isotherm.

2.2.3. Adsorption kinetics. The study was investigated by mixing 250 mL of 200 ppm Pb solution with 25 g of soil. The mixture was homogenized at 200 rpm and three hours contact time. Aqueous samples were taken from time to time and they were filtered, diluted and analyzed using ICP-OES. The experimental results were evaluated by different kinetic models.

2.3. Analytical methods
The removal efficiency can be calculated based on Pb concentration obtained from the sample, as shown in equation (1) where \( C_f \) is the Pb concentration (mg L \(^{-1} \)) after the experiment and \( C_i \) is the initial Pb concentration, (mg L \(^{-1} \)). The Pb uptake, \( q \) (mg g \(^{-1} \)) can be determined using equation (2), where \( m_s \) is the mass of soil used (g) and \( V \) is the volume of Pb solution (L).

\[
\text{Removal Efficiency, } \% = \frac{C_i - C_f}{C_i} \times 100 \quad (1)
\]

\[
Pb \text{ uptake, } q, \text{ mg/g} = \frac{(C_i - C_f)V}{m_s} \quad (2)
\]

### Table 2. Parameters studied and the results in Box-Behnken Design.

| Run | Initial concentration, ppm | Solution pH | Soil:solution ratio, g mL \(^{-1} \) | Pb uptake, mg g \(^{-1} \) | Removal efficiency, % | Ln (Removal efficiency) |
|-----|-----------------------------|-------------|--------------------------------------|--------------------------|------------------------|-------------------------|
| 1   | 1225                        | 3           | 0.135                                | 8.11                     | 88.42                  | 4.48                    |
| 2   | 1225                        | 3           | 0.135                                | 8.10                     | 88.32                  | 4.48                    |
| 3   | 1900                        | 3           | 0.067                                | 13.27                    | 46.79                  | 3.85                    |
| 4   | 1900                        | 5           | 0.135                                | 10.68                    | 75.06                  | 4.32                    |
| 5   | 1225                        | 3           | 0.135                                | 8.10                     | 88.3                   | 4.48                    |
| 6   | 1900                        | 3           | 0.2                                  | 8.47                     | 89.21                  | 4.49                    |
| 7   | 550                         | 3           | 0.067                                | 7.41                     | 90.31                  | 4.50                    |
| 8   | 1225                        | 1           | 0.067                                | 5.39                     | 29.48                  | 3.38                    |
| 9   | 550                         | 3           | 0.2                                  | 2.75                     | 99.84                  | 4.60                    |
| 10  | 1225                        | 3           | 0.135                                | 8.14                     | 88.67                  | 4.48                    |
| 11  | 1225                        | 3           | 0.135                                | 8.13                     | 88.62                  | 4.48                    |
| 12  | 1225                        | 5           | 0.067                                | 11.22                    | 61.37                  | 4.12                    |
| 13  | 1225                        | 5           | 0.2                                  | 5.96                     | 97.35                  | 4.58                    |
| 14  | 1225                        | 1           | 0.2                                  | 2.75                     | 99.84                  | 4.60                    |
| 15  | 1900                        | 1           | 0.135                                | 5.20                     | 36.53                  | 3.60                    |
| 16  | 550                         | 5           | 0.135                                | 4.04                     | 98.15                  | 4.59                    |
| 17  | 550                         | 5           | 0.135                                | 3.32                     | 80.67                  | 4.39                    |
3. Results and discussion

3.1. Soil characterization
According to the results as shown in table 1, the soil is acidic and is rich in aluminium and has significant magnesium and iron content. The X-Ray Diffraction (XRD) analysis on its mineralogical structure by Mukhopadhyay et al. [21] revealed that the minerals that are present in the soil are silicon oxide (SiO$_2$), aluminium silicate hydroxide (Al$_2$Si$_2$O$_5$(OH)$_4$), potassium magnesium iron aluminum silicate hydrate (K-Mg-Fe-Al-Si-O-H$_2$O), sodium aluminium silicate hydroxide hydrate (Na$_0.3$Al$_6$(Si, Al)$_8$O$_{20}$(OH)$_{10}$$\cdot$14H$_2$O), zeolite NdY (H$_{42}$Al$_{52.45}$Nd$_{18.25}$O$_{405}$Se$_{32}$Si$_{139.55}$), and magnesium silicate hydroxide hydrate (Mg$_4$Si$_6$O$_{15}$(OH)$_2$$\cdot$16H$_2$O). The presence of these minerals and organic matter content of 1.21% suggested that the soil has ability to retain Pb cation from water, as heavy metals are reported to be adsorbed on iron and aluminium based minerals [22, 23].

3.2 Effect of operating parameters

3.2.1. Analysis of Variance (ANOVA). In this study, the parameters are denoted as (A) for initial concentration, (B) for pH, and (C) for soil:solution ratio. The analysis of variance (ANOVA) as shown in table 3 shows that the model is significant with insignificant lack of fit. This is desirable and this shows that the experimental data fits well with the model.

| Source | Sum of Squares | DF  | Mean Square | F-Value | Prob> F |
|--------|----------------|-----|-------------|---------|---------|
| Model  | 2.078          | 11  | 0.19        | 29170.585 | < 0.0001 | significant |
| A      | 0.148          | 1   | 0.15        | 22892.639 | < 0.0001 |
| B      | 0.234          | 1   | 0.23        | 36153.715 | < 0.0001 |
| C      | 0.505          | 1   | 0.51        | 77973.203 | < 0.0001 |
| B$^2$  | 0.280          | 1   | 0.28        | 43174.919 | < 0.0001 |
| C$^2$  | 0.061          | 1   | 0.06        | 9357.397  | < 0.0001 |
| AB     | 0.069          | 1   | 0.07        | 10598.446 | < 0.0001 |
| AC     | 0.074          | 1   | 0.07        | 11464.045 | < 0.0001 |
| BC     | 0.062          | 1   | 0.06        | 9593.912  | < 0.0001 |
| A$^2$B | 3.32 x 10$^{-4}$ | 1   | 3.32 x 10$^{-4}$ | 51.306 | 0.0008 |
| A$^2$C | 0.057          | 1   | 0.057       | 8811.135  | < 0.0001 |
| AB$^2$ | 0.011          | 1   | 0.011       | 1626.174  | < 0.0001 |
| Residual | 3.24 x 10$^{-5}$ | 5   | 6.48 x 10$^{-6}$ | 4.720 | 0.0955 | not significant |
| Lack of Fit | 1.75 x 10$^{-5}$ | 1   | 1.75 x 10$^{-5}$ | 4.720 | 0.0955 | not significant |
| Pure Error | 1.49 x 10$^{-5}$ | 4   | 3.71 x 10$^{-6}$ | 4.720 | 0.0955 | not significant |
| Cor Total | 2.078          | 16  | 0.19        | 29170.585 | < 0.0001 |

The model shows that the terms A, B, C and the interaction effect between AB, AC and BC have significant impact on the removal efficiency. The high value of R$^2$ (0.9984-1) further confirm the model fits the data well. An adequate precision of 571.488, which is $>4$ further justify the adequacy of the model. The coded mathematical equation is as shown in equation (3) where the initial concentration, pH and soil:solution ratio, are represented by A, B, and C, respectively, and the range of the parameters are from -1 (lowest level) to 1 (highest level).
(3) 

\[ \ln(\text{Removal \ efficiency}) = 4.48 - 0.19A + 0.24B + 0.36C - 0.26B^2 - 0.12C^2 + 0.13AB \]
\[ + 0.14AC - 0.12BC - 0.013A^2B - 0.17A^2C - 0.073AB^2 \]

3.2.2. Interaction effect between pH and initial concentration. Figure 1 shows that, when the pH is increased, the removal efficiency is increased, regardless of initial concentration used. This was in line with the results for heavy metal adsorption in other reported literature [10, 15, 24]. The pH condition not only caused significant influence on the surface characteristics of the adsorbents, but also on the chemical speciation of Pb ion [13, 25]. Low adsorption rate occurring at low pH could be described by the competition between the adsorption of H\(^+\) and Pb\(^{2+}\) ions on the sorption sites [10]. Furthermore, the excessively acidic environment may also cause the protonation of the surface adsorption sites from negative to positive charge, which further induced electrostatic repulsion that restricted the adsorption of Pb ions on the soil surface [9, 11, 14–16, 24]. The concentration of H\(^+\) was decreased when the pH was increased to 5, and this reduced the competition for adsorption sites as well as the electrostatic repulsion mechanism via deprotonation of the adsorption sites for electrostatic interaction between Pb ions and the soil [11, 15–16, 24]. Thus, better Pb uptake was facilitated.

![Figure 1](image-url)  
**Figure 1.** 3D response surface on the effect of initial concentration and solution pH on the removal efficiency (soil:solution ratio: 0.135).

In contrast, the removal efficiency is inversely proportional to the initial concentration, as shown in figure 1. From the view of removal efficiency, the effect given by initial concentration has higher impact at low pH condition, as shown in figure 1 and table 2. When the initial concentration was increased from 550 ppm to 1900 ppm, the decrement in the removal efficiency at pH 1 was 44.15% (80.67% to 36.53%) in comparison to pH 5 at 23.10% (98.15% to 75.06%). This trend was also in line with the work of Karnib et al. [26] on the use of activated carbon for heavy metals adsorption. In general, high pH condition and low initial concentration will give higher removal efficiency, as a result of the abundance of adsorption sites due to: i) less competition between H\(^+\) and Pb\(^{2+}\), and ii) higher ratio of adsorption site to Pb. At low concentration, there was abundance of adsorption sites on the soil surface for Pb adsorption. With the increase of Pb concentration, the adsorption sites were filled and saturated [16, 26], resulting inadequacy of the number of adsorption sites. Thus, the removal efficiency was decreased. It was worth noting that the adsorption site was utilised effectively for Pb solution at higher concentration. In this study, Pb uptake by the soil was found to improve at higher initial concentration as more Pb ions were available for the adsorption. The increase in the initial
concentration from 550 ppm to 1900 ppm increased the Pb uptake from 3.32 mg g\(^{-1}\) to 5.2 mg g\(^{-1}\) and 4.04 mg g\(^{-1}\) to 10.68 mg g\(^{-1}\) when the system was operated at pH 1 and pH 5, respectively.

3.2.3. Interaction effect between pH and soil:solution ratio. Figure 2 illustrates that the use of higher soil:solution ratio increases the removal efficiency and this applies to all pH conditions in this study. This was due to the fact that at higher ratio, the number of available and accessible adsorption sites for Pb-adsorbent interaction was increased and this consequently caused easier access of Pb ion to the sorption sites [24]. Therefore, higher removal efficiency and adsorption rate could be achieved, as reported in the works of Hafsejani et al. [10], Chaudhry et al. [16] and Wen et al. [13]. Nevertheless, the enhancement given by higher soil:solution ratio was highly dependent on the pH condition. As shown in figure 2 and table 2, the enhancement in removal efficiency of 47.51% is observed at pH 1 when the soil:solution ratio is increased from 0.067 to 0.2. This was because at low pH condition, higher number of adsorption sites improved effective Pb adsorption, thereby reducing the effect of competition between Pb\(^{2+}\) and H\(^+\). In contrast, the increase in soil:solution ratio from 0.067 to 0.2 only increases the removal efficiency by 35.97% when the system was operated at pH 5, as shown in figure 2 and table 2. In this case, the competition between H\(^+\) and Pb\(^{2+}\) was less significant and thus, the requirement on the number of adsorption sites was less critical. However, the use of high soil:solution ratio was not feasible in terms of economical point of view. This argument was deduced from the experimental results which showed that the increase in soil:solution ratio from 0.067 to 0.2 reduced Pb uptake from 5.39 mg g\(^{-1}\) to 4.72 mg g\(^{-1}\) and from 11.22 mg g\(^{-1}\) to 5.96 mg g\(^{-1}\) when the system was operated at pH 1 and pH 5, respectively. The decrease in adsorption equilibrium at high soil:solution ratio was reported to be mainly caused by two mechanisms, namely i) unsaturation of adsorption sites [11, 13, 15], and ii) particles aggregation [11]. In addition, the higher decrement in Pb uptake per mass of soil at pH 5 can be attributed to the presence of excess adsorption sites due to the absence of competitive adsorption between hydrogen and Pb ions.

![Figure 2. 3D response surface on the effect of solution pH and soil:solution ratio on the removal efficiency (initial concentration: 1225 ppm).](Image)

3.3 Adsorption isotherms
The adsorption isotherm was investigated using Langmuir isotherm and Freundlich isotherm. Table 4 shows that the adsorption of Pb on soil is likely to follow Langmuir isotherm, as the curve fitting has highest R\(^2\) of 0.993 in comparison to Freundlich isotherm which only shows R\(^2\) of 0.867. Therefore, it was suggested that the adsorption was monolayer chemisorption [11] where the adsorption process
occurred due to the chemical bond between Pb and the finite number of adsorption sites which was mainly consisted of aluminium and iron as well as organic matter on soil surface and there was no transmigration of adsorbate on the soil surface [9, 27]. This adsorption isotherm was also observed for heavy metals adsorption on different types of adsorbent such as manganese coated sand [16], porous hydrogel adsorbents [25], carbonaceous based adsorbent [28], alginate-based attapulgite foams [18], ash biosorbents [9, 11, 13], suggesting that the adsorption process using the soil as adsorbent has similar mechanisms as other types of surface modified adsorbents. The maximum Pb adsorption capacity for the soil, Qmax was 10.64 mg g⁻¹.

### Table 4. Adsorption isotherms analysis at solution pH of 5.

| Isotherm   | Constant   | R²  |
|------------|------------|-----|
|            | Qmax,      | Kf  | n   | Kf  |
| Langmuir   | 10.64      | 0.03| -   | -   | 0.993 |
| Freundlich | -          | -   | 4.93| 2.74| 0.867 |

3.4 Adsorption kinetic study

Figure 3 illustrates the changes of Pb concentration in the aqueous solution with time at different pH conditions, in which equilibrium removal was achieved at 150 min. The remaining Pb concentration in the solution was found to be higher at pH 2 (51.87 ppm) and the concentration was stable at (21.22 ppm – 24.61 ppm) when the pH was increased from 3 to 5, suggesting that better Pb uptake by the soil. This revealed that at low pH, Pb²⁺ ion is competing with H⁺ for the adsorption site. Thus, the adsorption was lower in comparison to high pH condition, as discussed in Section 3.2.

![Figure 3. Changes of Pb concentration in aqueous solution with time.](image)

The adsorption kinetic study shows that Pb adsorption to the soil follows pseudo second order kinetic model as the R² obtained are the highest in comparison to other models for all pH conditions, as shown in table 5. The pseudo second order rate constant kₚ₂ and initial adsorption rate, V₀ are found to stabilize at 0.0110 g mg⁻¹ min⁻¹ and 0.056 mg g⁻¹ min⁻¹, respectively, at pH 4-5, as shown in table 6. The results are in line with the works of Bozbas and Boz [9], Lim and Lee [29] and Chaudhry et al. [16] which reported that the adsorption of heavy metals on anadara inaequivalvis shells, soil and manganese coated sand, respectively, followed pseudo second order kinetic model [24].
### Table 5. \( R^2 \) for the Pb adsorption on soil at different pHs using different kinetic models.

| Kinetic model                        | Linearized equation                                                                 | \( R^2 \) | pH 2 | pH 3 | pH 4 | pH 5 |
|-------------------------------------|-------------------------------------------------------------------------------------|-----------|------|------|------|------|
| Pseudo-first order kinetic model    | \( \log(q_e - q_t) = \log q_e - \frac{k_{pl}}{2.303} t \)                           | 0.836     | 0.96 | 0.956| 0.947|      |
| Pseudo-second order kinetic model   | \( \frac{t}{q_t} = \frac{1}{V_0} + \frac{1}{q_e} t; \quad V_0 = k_{ps} q_e^2 \)    | 0.994     | 0.987| 0.994| 0.981|      |
| Elovich model                       | \( q_t = \alpha \ln(\alpha q_e + \alpha \ln t) \)                                | 0.994     | 0.981| 0.982| 0.96  |      |
| Film diffusion mass transfer kinetic model | \( \ln \left(1 - \frac{q_t}{q_e} \right) = -R^1 t \)                         | 0.836     | 0.956| 0.956| 0.947|      |

### Table 6. Equilibrium Pb uptake, pseudo second order rate constant, and initial adsorption rate at different pH conditions.

| pH | Equilibrium Pb uptake \( q_e \), mg g\(^{-1}\) | Pseudo second order rate constant \( k_{ps} \), g mg\(^{-1}\) min\(^{-1}\) \( (V_0 = k_{ps} q_e^2) \) | Initial adsorption rate \( V_0 \), mg g\(^{-1}\) min\(^{-1}\) |
|----|---------------------------------------------|-------------------------------------------------|------------------------|
| 2  | 2.110                                       | 0.0065                                          | 0.029                  |
| 3  | 2.353                                       | 0.0080                                          | 0.044                  |
| 4  | 2.242                                       | 0.0111                                          | 0.056                  |
| 5  | 2.237                                       | 0.0109                                          | 0.055                  |

### 3.5 Comparison with other types of adsorbents

Table 7. Comparison on Pb adsorption capacity between different types of adsorbents.

| Type of adsorbents | Adsorbents                                      | Fe or Al content mg kg\(^{-1}\) | Adsorption capacity, mg g\(^{-1}\) | References |
|--------------------|------------------------------------------------|-------------------------------|------------------------------------|------------|
| Activated carbons  | • Activated carbon                             | -                             | 294.11                             | [26]       |
|                    | • Carbonaceous adsorbent                        | -                             | 130.54                             | [28]       |
| Biosorbents        | • Tomato waste and apple juice residue         | -                             | 108-152                            | [24]       |
|                    | • Nanostructured cedar leaf ash                | -                             | 7.23-8.05                          | [10]       |
|                    | • Exhausted coffee grounds                     | -                             | 61.6                               | [9]        |
|                    | • *anadara inaequivalvis* shells                | -                             | 621.1                              | [11]       |
| Soil               | • Manganese coated sand                        | -                             | 0.15                               | [16]       |
|                    | • Natural iron rich sandy soil                 | 3719 (Fe) 2400 (Al)           | 0.9-1.0                            | [30]       |
|                    | • Natural aluminium rich sandy soil           | 11894 (Al) 1000 (Fe)          | 10.64                               | Present study |

A comparison on the adsorption capacity between the soil used in this study and other adsorbents was conducted. The summary as shown in table 7 shows that in general, the activated carbons and biosorbents show relatively higher Pb adsorption capacity than the soil based adsorbents. Nevertheless, it is worth noting that the soil undergoes less surface modification or treatment for the adsorption process. Thus, it is expected that the adsorption capacity is lower. From the results, it was
found that the natural aluminium rich sandy soil has a much higher Pb adsorption capacity (10.64 mg g$^{-1}$) than natural iron rich sandy soil (0.9-1.0 mg g$^{-1}$), as a result of its relatively high total concentration in aluminium and iron content, as the aluminium and iron oxides serve as the main adsorption sites for removing Pb from water [22, 23].

4. Conclusions
The study investigated the use of aluminium rich sandy soil from Jeram as natural adsorbent in Pb removal from water. The soil was found to show promising ability as the adsorbent for removing Pb from water. The removal of Pb was mainly through the adsorption on the surface minerals of aluminium and ferric oxides and this mechanism was highly affected by the solution pH, initial Pb concentration, and soil: solution ratio. The adsorption efficiency was found to be increased at higher pH (4-5), higher soil:solution ratio and lower initial concentration, as a result of Pb exposure to higher number of adsorption surface area/sites at low competition with H$^+$ ion.

The Pb adsorption process followed Langmuir isotherm and pseudo-second order kinetic model, with the adsorption capacity of 10.64 mg g$^{-1}$ at optimum pH of 4-5. Even though the adsorption capacity is lower than typical commercial adsorbents, its highly abundance in Jeram area and its natural properties that does not require additional activation steps or surface modification make it suitable to be potential candidate as the adsorbent for water treatment in removing Pb.

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References
[1] Nahal S, 2014 Blue Revolution – global water primer. Retrieved 13 October 2019, from https://www.longfinance.net/media/documents/baml_bluerevolution_2014.pdf
[2] McCartor A and Becker D, 2010 Blacksmith institute’s world worst pollution problem report 2010. New York: Blacksmith Institute
[3] DoE-Malaysia, 2009 Contaminated land management and control guidelines No. 1: Malaysian recommended site screening levels for contaminated land. Retrieved 30 August 2019, from http://www.doe.gov.my/portal/wp-content/uploads/Contaminated-Land-Management-and-Control-Guidelines-No-1_Malaysian-Recommended-Site-Screening-Levels-for-Contaminated-Land.pdf
[4] Duruibe J O, Ogwuegbu M O C and Egwuruogwu J N 2007 Heavy metal pollution and human biotoxic effects Int. J. Phys. Sci. 2 112–8
[5] Wuana R A and Okieimen F E 2011 Heavy metals in contaminated soils: A review of sources, chemistry, risks and best available strategies for remediation. ISRN Ecology 2011 1–20
[6] Harvey P J, Handley H K and Taylor M P 2016 Widespread copper and lead contamination of household drinking water, New South Wales, Australia. Environ. Res. 151 275–85
[7] Mishra S P, Singh V K and Tiwari D 1996 Radiotracer technique in adsorption study part XV. Removal behaviour of barium titanate for mercury ions Radiochim. Acta 73 49–54
[8] Pan B, Pan B, Zhang W, Lv L, Zhang Q and Zheng S 2009 Development of polymeric and polymer-based hybrid adsorbents for pollutants removal from waters Chem. Eng. J. 151 19–29
[9] Babu A N, Reddy D S, Kumar G S, Ravindhranath K and Mohan G V K 2012 Removal of lead and fluoride from contaminated water using exhausted coffee grounds based biosorbent J. Environ. Manage. 218 602-12
[10] Hafshejani L D, Nasab S B, Gholami R M, Moradzadeh M, Izadpanah Z, Hafshejani S B, and Bhatnagar A 2015 Removal of zinc and lead from aqueous solution by nanostructured cedar leaf ash as biosorbent J. Mol. Liq. 211 448–56
[11] Bozbas S K and Boz Y 2016 Low-cost biosorbent: Anadara inaequivalvis shells for removal of Pb(II) and Cu(II) from aqueous solution Process Saf. Environ. Prot. 103 144–52
[12] Noor N M, Othman R, Mubarak N M and Abdullah E C 2017 Agricultural biomass-derived magnetic adsorbents: Preparation and application for heavy metals removal J. Taiwan Inst. Chem. Eng. 78 168–77
[13] Wen X, Du C, Zeng G, Huang D, Zhang J, Yin L, Tan S, Huang L, Chen H, Yu G, Hu X, Lai C, Xu P and Wan J 2018 A novel biosorbent prepared by immobilized bacillus licheniformis for lead removal from wastewater Chemosphere 200 173–9
[14] Abo-El-Enein S A, Shebl A and Abo El-Dahab S A 2017 Drinking water treatment sludge as an efficient adsorbent for heavy metals removal Appl. Clay Sci. 146 343–9
[15] Han R, Zou W, Zhang Z, Shi J and Yang J 2006 Removal of copper(II) and lead(II) from aqueous solution by manganese oxide coated sand I. Characterization and kinetic study J. Hazard. Mater. B137 384–95
[16] Chaudhry S A, Khan T. A and Ali I 2016 Adsorptive removal of Pb(II) and Zn(II) from water onto manganese oxide-coated sand: Isotherm, thermodynamic and kinetic studies Egypt. J. Basic Appl. Sci. 3 287–300
[17] Kasimliene A, Carabante I, Bhattacharya P, Caporale A G, Adamo P and Kumpiene J 2018 Removal of metal(oid)s from contaminated water using iron-coated peat sorbent, Chemosphere 198 290–6
[18] Wang Y, Feng Y, Zhang X-F, Zhang X, Jiang J and Yao J 2018 Alginic-based attapulgite foams as efficient and recyclable adsorbents for the removal of heavy metals J. Colloid Interface Sci. 514 190–8
[19] Mukhopadhyay S, Mukherjee S, Adnan N F, Hayyan A, Hayyan M, Hashim M A and Sen Gupta B 2016 Ammonium-based deep eutectic solvents as novel soil washing agent for lead removal Chem. Eng. J. 294 316–22
[20] Montgomery C D 2001 Design and analysis of experiments (5th ed.) (New York: John Wiley & Sons, Inc)
[21] Mukhopadhyay S, Mukherjee S, Hayyan A, Hayyan M, Hashim M A and Sen Gupta B 2016 Enhanced removal of lead from contaminated soil by polyol-based deep eutectic solvents and saponin J. Contam. Hydrol. 194 17–23
[22] Strawn D G, Scheidegger A M and Sparks D L 1998 Kinetics and mechanisms of Pb(II) sorption and desorption at the aluminum oxide-water interface Environ. Sci. Technol. 32 2596–601
[23] Jacukowicz-Sobala I, Ociński D and Kociołek-Balawejder E 2015 Iron and aluminium oxides containing industrial wastes as adsorbents of heavy metals: Application possibilities and limitations Waste Manag. Res. 33 612–29
[24] Heraldy E, Lestari W W, Permatasari D and Arimurti D D 2018 Biosorbent from tomato waste and apple juice residue for lead removal J. Environ. Chem. Eng. 6 1201–8
[25] Zhou G, Luo J, Liu C, Chu L and Crittenden J 2018 Efficient heavy metal removal from industrial melting effluent using fixed-bed process based on porous hydrogel adsorbents Water Res. 131 246–54
[26] Karnib M, Kabbani A, Holail H and Olama Z 2014 Heavy metals removal using activated carbon, silica and silica activated carbon composite Energy Procedia 50 113–20
[27] Dada A O, Olalekan A P, Olatunuya A M and Dada O 2012 Langmuir, Freundlich, Temkin and Dubinin-Radushkevich isotherms studies of equilibrium sorption of Zn2+ unto phosphoric acid modified rice husk IOSR J. Appl. Chem. 3 38–45
[28] Wajima T 2017 A new carbonaceous adsorbent for heavy metal removal from aqueous solution prepared from paper sludge by sulfur-impregnation and pyrolysis Process Saf. Environ. Prot. 112 342–52
[29] Lim S-F and Lee A Y W 2015 Kinetic study on removal of heavy metal ions from aqueous solution by using soil Environ. Sci. Pollut. R. 22 10144–58
[30] Ng Y S, Sen Gupta B and Hashim M A 2016 Performance evaluation of natural iron-rich sandysoil as a low-cost adsorbent for removal of lead from water *Desalin. Water Treat.* 57 5013–24