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Batch washing of lead contaminated and spiked soils using extracts of dried *Terminalia mantaly, Panicum maximum* and *Eleusine indica* plants

Effiong Ukorebi ETIM*

Department of Chemistry, University of Ibadan, Ibadan, Nigeria

Abstract. Application of dried plant water soluble extracts in soil Pb decontamination is rear, but advantageous due to their ecological biodegradability. Single batch laboratory scale suitability of *Terminalia mantaly, Panicum maximum, Eleusine indica* and water as washing solutions for Pb removal from contaminated and spiked soils at different soil pulp densities (3%, 6%, 9%, 12%, 15% and 18%) and washing time (1, 3, 6, 12, 24 and 96 h) was investigated. Washings of *Terminalia mantaly* and *Panicum maximum* proved more efficient comparatively for contaminated soil with Pb removal efficiency of 27.2±0.64% and 27.0±0.52% respectively at 3% soil pulp density and washing time of 96 h. Removal efficiency increased with increasing washing time but decreased with increasing of soil pulp density. Furthermore, water was found effective for removing Pb from spiked soils with maximum removal efficiency of 74.5±3.38% at 3% soil pulp density after 1 h washing. High exchangeable fraction of Pb (81.2%) in spiked soil makes water more suitable against other washing solutions. Statistical *t*-testing showed significant difference in Pb removal efficiency between contaminated and spiked soils for all four washing solutions, reflecting differences in geochemical phases of Pb in both soils. *Terminalia mantaly* and *Panicum maximum* showed promising result in soil washing and have potential for application in Pb removal from contaminated soils. However, chemical modifications are needed to enhance and improve on their efficiencies. Similarly, more information is needed to predict and model removal efficiencies when multiple washing steps are applied.

Keywords: heavy metals; plant extracts; removal efficiency; soils remediation; soil washing.

1. Introduction

Soil contamination is considered one significant environmental problem of the industrial age with greater footprints in developing countries [1]. Several contaminants such as heavy metals have been identified and classified of which lead is one with greater concern [2]. Lead contamination of soils could arise through emissions from rapidly expanding industrial areas, mining/smelting, shooting range and landfill activities among others [3-5]. The problem with lead in soils is their non-biodegradable nature, persistency, mobility and bio-accumulative potentials [6-8].

Lead constitutes an ill-defined group of inorganic chemicals which has been identified and considered one of the hazardous metals included in the US Environmental Protection Agency's (EPA) list of priority pollutants [9]. The presence of toxic lead in soils can severely inhibits soil ecology and contamination may pose direct risks and hazards to humans and animals [2, 10]. It's therefore of essence to adequately protect and possibly restore lead contaminated soil ecosystems through characterization and remediation. Soil washing offers the greatest advantage of highly effective removal efficiency of lead in contaminated soils and is among the best demonstrated available techniques listed for remediation [11, 12]. A range of applications, for strong acids [13, 14], weak organic acids [15-17], chelating agents [18], fluids or gases [19] and even water, have proven effective but with certain degree of limitations. For instance, strong acids decrease soil productivity while chelating agents are non-biodegradable [20-22].

The retention of the original soil ecology/chemistry after chemical washing has always been a priority due to the destructive actions of most washing solutions. These have caused increasing interest in research towards the use of soil friendly washing compounds, examples are the use of plant-derived compounds (such as biosurfactants) for soil remediation [23-28]. However, research in this area is still very limited. Furthermore, dried plant water-soluble extracts have found wide application in medicine, cosmetics and beverages. However, little or no scientific researches have reported the environmental applications of dried plant water-soluble extracts in metal contaminated soil remediation. Adaptation of dried plant derived water-soluble extracts as washing solution for soil remediation offers the advantage of biodegradability, availability, low cost, nontoxic and ecologically sustainable in restoring contaminated soils for agricultural purposes and enhanced food security [29].

This study solely investigates the use of naturally available water-soluble extracts from dried *Terminalia mantaly, Panicum maximum* and *Eleusine indica,* in enhancing solubilization and removal of lead from contaminated shooting range soils and laboratory spiked soils (artificially contaminated). The removal efficiency optimization was assessed by varying different factors such as soil pulp density (SPD) and washing time. Information obtained from this study will further aid in

**E-mail address*: etim242@yahoo.com

designing ecologically friendly natural plant-derived extracts for soil-metal remediation.

2. Experimental

2.1. Soil sampling, preparation and spiking

The washing experiment was conducted on two soil samples, i.e. field contaminated and artificially contaminated, collected from different locations. Field contaminated soil sample (depth 0 – 30 cm, about 5 kg) was collected within the impact berm of a major and active military shooting range, while soil for artificial contamination (depth 0 – 30 cm, about 5 kg) was collected from a remote location free from major pollutant derived activities. Sampling was carried out using stainless steel trowel after which air dried, homogenized and ground to pass through a 2 mm mesh sieve. The artificially contaminated soil (spiked soil) was spiked with 1000 mL $Pb(NO_3)_2$ at a concentration of 10,000 mg/L. The sample was homogenized by shaking for 48 h and left to dry at room temperature for three weeks, after which was dried at 103 - 105 ºC to a constant weight and further mixed.

2.2. Preparation of water soluble plant extract

Three locally available plant species, i.e. *Terminalia mantaly*, *Panicum maximum* and *Eleusine indica*, were chosen for the experiment. These plant species are locally abundant, cheap to asses, and are of no economic importance. The aerial parts of plants were collected, washed and air dried in the laboratory at room temperature. The dried plant samples were ground and sieved through a 4 mm sieve. 1 kg weight of each sieved dried plant sample was homogenized with 35 L deionized water for 24 h using a mechanical stirrer (Griffin and George Limited KQPS/34). The extracts were then filtered and stored below 20 ºC for the batch washing experiment.

2.3. Batch soil washing experiment

The single batch washing experiment was designed to assess the efficiency of water soluble plant extracts obtained from *Terminalia mantaly*, *Panicum maximum* and *Eleusine indica,* and water on Pb removal from contaminated and spike soil samples. The variables considered are SPD and washing time. The soil washing experiment was adapted from our previously published article [17].

For the contaminated soil, the washing experiments were conducted by weighing 3, 6, 9, 12, 15 and 18 g of soil into six plastic bottles, in which 100 mL washing solution obtained from *Terminalia mantaly* was added. This is equivalent to 3%, 6%, 9%, 12%, 15% and 18% soil pulp density, calculated as:

$$\text{SPD (\%)} = \frac{m_s}{V_{sol}} \times 100 \qquad (1)$$

where m_s = mass of soil (g), V_{sol} = volume of added solution, meaning aqueous extract or water (mL).

The bottles were placed on an end-to-end (Edmund Buhler SM 25) mechanical shaker and extracted for 1 h after which the mixtures were filtered using Whatman (Cat No 1001, 110 mm) filter paper.

The soil residue in the filter paper was then washed with deionized water sequentially twice and both supernatants from the initial leaching and washing were combined and stored for analysis. The agitation process was repeated for 3, 6, 12, 24 and 96 h intervals with same weight/volume of contaminated soil and *Terminalia mantaly* washing solutions.

A series of three other batch washing, using 100 mL of *Panicum maximum* and *Eleusine indica* extracts, and water, on the contaminated soil was repeated following the same procedure as for *Terminalia mantaly* washing solution.

The entire experiment was repeated using 100 mL *Terminalia mantaly*, *Panicum maximum*, *Eleusine indica*, and water following the same weight/volume and interval agitating of 1 to 96 h for the spiked soil sample.

The supernatants from each washing experiment were digested with 2 mL concentrated nitric acid, filtered and make to mark in 100 mL standard flasks and stored for Pb determination. The resulted solutions were analyzed for Pb using Varian SpectrAA 600 flame atomic absorption spectrophotometer.

The percentage removal efficiency of Pb from soil samples (either contaminated or spiked soil) was calculated using the following equation [17, 30, 31]:

$$\text{Removal efficiency (\%)} = \frac{C_1 \times V_1}{C_s \times m_s} \times 100 \qquad (2)$$

where C_1 and C_S are the concentrations of Pb in the supernatants (mg/L) and soil samples (mg/kg) determined using FAAS, V_1 is the volume of supernatants (L), and m_S is the weight of the soil (kg) used for the washing experiment.

Each batch washing experiment was performed in triplicate and the calculated standard deviation of triplicate analysis performed on extracts from each batch washing experiment ranged within 5%. These average values are shown in Tables 3 and 4.

2.4. Analytical methods

The soils' pH values were measured in deionized water using a solid : liquid ratio of 1:1 (w/v) following 1 h shaking and filtration through a Whatman (Cat No 1001, 110 mm) filter paper [32], while pH of the washing solutions were measured directly using a pH meter (Hanna Instruments). Particle size analysis was carried out using the hydrometric method [33]. Soil organic carbon content was determined by Walkley and Black method [34], available phosphate was determined by the Bray No. 1 method [35], and soil nitrate was determined by distillation method following extraction with 2 M KCl solution [36]. Cation exchange capacity was determined using 1 M ammonium acetate at pH 7 as the exchangeable base [37]. Total lead concentration in the contaminated and spike soils was determined using HCl : HNO_3 mixture on a hot plate. Procedurally, on 5.0 g of each soil were added 50 mL of HCl : HNO_3 mixture at 3:1 ratio (v/v) and heated on a hot plate for 3 h [38]. After cooling the extracts were filtered through Whatman (Cat No 1001, 110 mm) filter paper, made to a 50 mL standard volumetric flask and analyzed for total lead using Varian SpectrAA 600 flame atomic absorption spectrophotometer. Speciation of lead fractions was carried out by Tessier sequential extraction scheme [39] to obtain exchangeable, carbonate, reducible, oxidizable and residual fractions of lead in the soils.

2.5. Quality control and assurance

Supernatants from the washing experiment were analyzed in triplicates as stated above. Split samples were incorporated for instrument data validation. A *t*-test showed no significant differences in actual and slit results. Analar grade (Sigma-Aldrich) reagents were used for the experiment. The Varian SpectrAA 600 flame atomic absorption spectrophotometer was calibrated using 1, 3, 5, and 10 mg/L REHHGFT working standards.

3. Results and discussion

3.1. Soil and washing solution characterization

The characterization of the experimental soils and washing solutions is given in Tables 1 and 2.

Table 1. Characteristics of experimental soils and washing solutions (n = 3).

Parameter	Contaminated soil	Spiked soil	*Treminalia mantaly*	*Panicum maximum*	*Eleusine indica*	Water
pH	5.93	5.70	4.78	5.48	5.97	5.53
Sand content (%)	65.6	63.4	-	-	-	-
Silt content (%)	19.2	22.7	-	-	-	-
Clay content (%)	15.2	13.8	-	-	-	-
Organic carbon (%)	2.22	3.09	-	-	-	-
Organic matter (%)	3.84	5.34				-
CEC (cmol/kg)	112	103	-	-	-	-
Nitrate (mg/kg)	25.3	27.8	-	-	-	-
Phosphate (mg/kg)	15.7	16.2	-	-	-	-
Lead	15207 ± 8008 mg/kg	2441 ± 77 mg/kg	0.00 mg/L	0.00 mg/L	0.00 mg/L	0.00 mg/L

n - number of samples analyzed; CEC - cation exchange capacity.

The pH values of the contaminated (5.93) and spiked (5.70) soils were about the same, which is indicative of an oxidative soil. These soil types are known for their ability to chemically enhanced metal mobility depending on short-term fluctuations in moisture and redox potentials [40].

Table 2. Lead speciation (% geochemical phases) in experimental soils (n = 3).

Parameter	Pb [mg/kg]	
	Contaminated soil	**Spiked soil**
Exchangeable metal	3.02	81.2
Metal bound to carbonates	32.6	3.30
Metal bound to Fe-Mn oxides	18.4	5.74
Metal bound to organic matter	11.9	3.30
Residual metal	34.1	6.56

n - number of samples analyzed.

The organometric fractions of both soils showed a characteristic “sandy-loamy” property with high sand and silt contents and also low organic matter and cation exchange capacity. Nitrate and phosphate levels in both soils were also of about same values. The contaminated and spike soil samples are therefore of similar characteristics (sandy-loamy) with ability to enhance metal mobility and suitable for the washing experiment, to assess their ability to release adsorbed metals. Average lead level in contaminated soil (15207 ± 8008 mg/kg) is much higher than in spike soil (244 1 ± 77 mg/kg) due to contamination sources.

From speciation study shown in Table 2, average bioavailable (non-residual) fraction was lower in the contaminated soil (65.9%) as against the spike soil (93.4%), indications of the sources and treatment methods for both soil samples. The most mobile of the bioavailable fractions, the exchangeable fraction was similarly lower in the contaminated soil (3.11%) than in spiked soil (81.2%). The contaminated soil showed similar characteristics to previous studies [17, 41].

The pH values of the extracts (Table 1) were generally acidic in order of: *Eleusine indica* (5.97) > water (5.53) > *Panicum maximum* (5.48) > *Terminalia mantaly* (4.78), while lead levels were non-detectable in all extracts. A lower pH value of any washing solution is an important index in evaluating its solubilization potential for metals from contaminated soils. It can be inferred that lower pH may favor greater washing potential especially for *Terminalia mantaly* (4.78).

3.2. Removal efficiency of lead from contaminated soil

Table 3 shows percentage removal efficiency of Pb from contaminated soil using water soluble extracts and water as washing solutions.

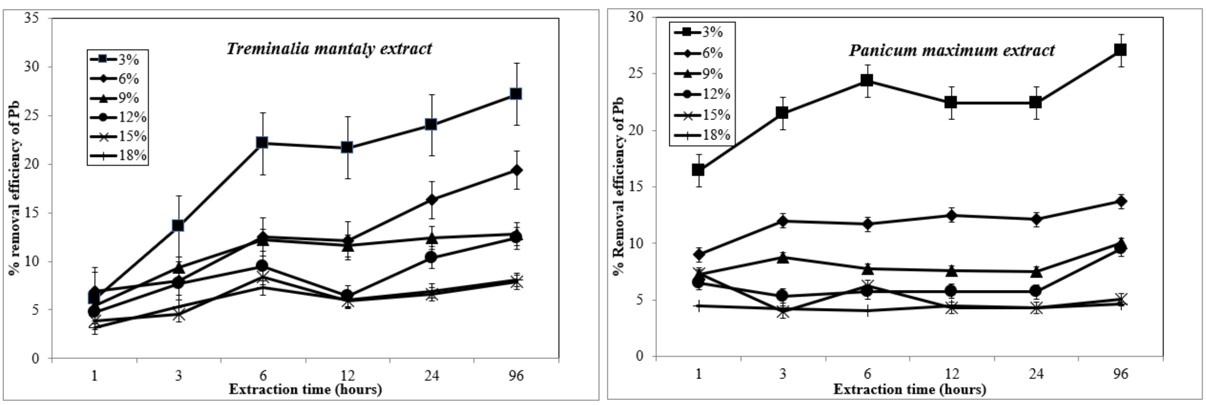
Table 3. Percentage removal efficiency of Pb from contaminated soil.

Washing time [h]	Soil pulp density [%]	*Treminalia mantaly*	*Panicum maximum*	*Eleusine indica*	Water
1	3	6.14±0.03	16.4±0.35	4.82±0.17	8.77±0.45
	6	6.91±0.11	8.99±0.12	3.84±0.11	4.82±0.21
	9	5.48±0.13	7.23±0.09	2.92±0.10	6.50±0.37
	12	4.71±0.12	6.52±0.12	0.00	1.92±0.10
	15	3.90±0.04	7.32±0.11	0.00	1.32±0.06
	18	3.18±0.10	4.46±0.10	2.48±0.11	2.30±0.12
3	3	13.6±0.26	21.5±0.22	16.0±0.46	12.1±0.41

Washing time [h]	Soil pulp density [%]	*Treminalia mantaly*	*Panicum maximum*	*Eleusine indica*	Water
	6	8.00±0.03	12.0±0.24	7.50±0.12	5.59±0.11
	9	9.35±0.02	8.77±0.16	2.48±0.04	4.10±0.10
	12	7.67±0.03	5.32±0.14	1.26±0.01	4.22±0.14
	15	4.52±0.03	3.95±0.14	0.48±0.03	1.97±0.03
	18	5.30±0.02	4.24±0.15	0.26±0.02	2.34±0.05
6	3	22.1±0.13	24.3±0.56	4.00±0.10	10.5±0.32
	6	12.5±0.11	11.7±0.26	3.51±0.12	5.26±0.12
	9	12.2±0.10	7.75±0.19	0.94±0.05	2.48±0.11
	12	9.43±0.07	5.70±0.10	0.00	2.63±0.11
	15	8.37±0.06	6.23±0.16	0.00	2.45±0.10
	18	7.27±0.05	4.02±0.10	0.00	1.68±0.06
12	3	21.7±0.10	22.4±0.36	0.00	11.4±0.38
	6	12.1±0.13	12.5±0.27	0.00	4.84±0.13
	9	11.6±0.14	7.60±0.31	0.00	2.85±0.06
	12	6.41±0.08	5.75±0.26	0.00	1.86±0.03
	15	5.92±0.11	4.30±0.11	0.00	1.84±0.05
	18	6.06±0.12	4.49±0.24	0.00	1.94±0.08
24	3	24.0±0.69	22.4±0.18	0.00	14.0±0.27
	6	16.3±0.77	12.1±0.23	0.00	3.29±0.16
	9	12.4±0.62	7.53±0.22	0.00	1.32±0.04
	12	10.4±0.31	5.70±0.19	0.00	0.26±0.03
	15	6.62±0.21	4.30±0.07	0.00	0.88±0.02
	18	6.94±0.11	4.31±0.05	0.00	0.80±0.04
96	3	27.2±0.64	27.0±0.52	0.00	6.80±0.15
	6	19.4±0.31	13.7±0.16	0.00	4.60±0.11
	9	12.8±0.27	10.0±0.15	0.00	2.56±0.10
	12	12.4±0.41	9.48±0.15	0.00	0.88±0.04
	15	7.85±0.08	5.04±0.12	0.00	1.40±0.03
	18	8.11±0.11	4.68±0.10	0.00	0.88±0.04

The removal efficiency of Pb was generally very low (< 28.0%) for all four washing solutions. Nevertheless, washings of *Terminalia mantaly* and *Panicum maximum* extracts showed promising high values of 27.2±0.64% and 27.0±0.52% respectively, for single batch washing at 3% SDP and washing time of 96 h. Meanwhile the highest of 16.0±0.46% was recorded for *Eleusine indica* and 12.1±0.41% for water, at 3% SPD and washing time of 3 h. Washings of *Terminalia mantaly* and *Panicum maximum* extracts showed relatively consistent Pb removal efficiency with values slightly greater than 20%, especially at 3% SPD. The pH values of these washing solutions may have played a significant role in Pb removal efficiency from the contaminated soil. *Eleusine indica* (pH = 5.97) recorded the poorest removal efficiency of Pb with well over 50% of soil washings having 0.00%, followed by water (pH = 5.53) with about 10% Pb removal efficiency at 3% SPD irrespective of washing time. Furthermore, from speciation studies of Table 2, low exchangeable fraction (3.02%) of Pb in the contaminated soil is another important factor that could explain the rather low washing potential of Pb by water and extracts of dried *Terminalia mantaly, Panicum maximum* and *Eleusine indica* plants. The other non-residual fractions (carbonate, reducible and organic) may be difficult to extract considering the pH of the washing solutions.

Figure 1 shows trend in Pb removal efficiency in relation to washing time and SPD.



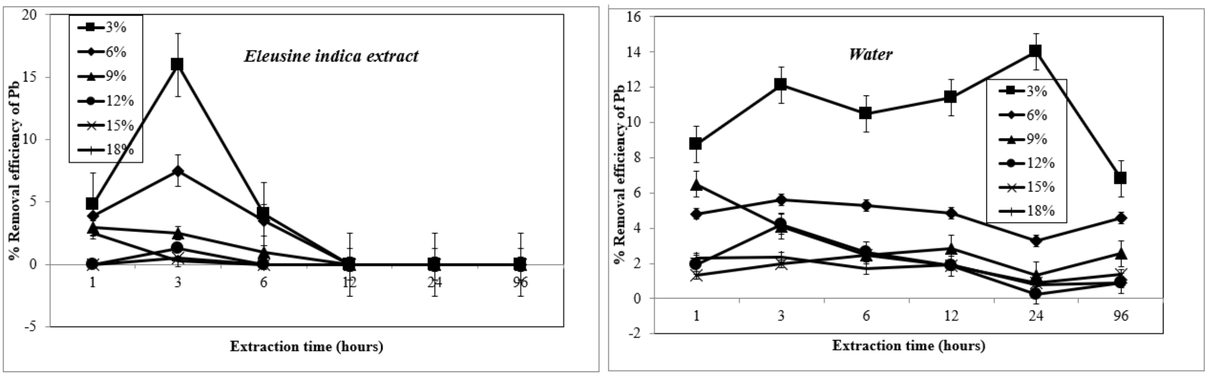


Figure 1. Removal efficiency (%) of Pb from contaminated soil.

The 3% SPD appears more favorable for Pb removal with removal efficiency significantly higher than for 6, 9, 12, 15 and 18% SPD across all four washing solutions. Removal efficiency of Pb increased with increasing washing time except for *Eleusine indica*. This trend is similar to previously report soil decontamination experiment with SPD = 3% at increasing washing time showing promising removal efficiencies for Pb [17]. Test of significance was carryout using single factor analysis of variance at p = 0.05. Percentage removal efficiency of Pb was significantly different among the four washing solutions factoring washing time and SPD.

3.3. Removal efficiency of lead from spike soil

The percentage removal efficiency of Pb from spike soil using extracts of *Terminalia mantaly*, *Panicum maximum* and *Eleusine indica*, and water as washing solutions is given in Table 4.

Table 4. Percentage removal efficiency of Pb from spiked soil.

Washing time [h]	Soil pulp density	*Treminalia mantaly*	*Panicum maximum*	*Eleusine indica*	Water
1	3	19.7±0.43	21.9±0.27	0.00	74.5±3.38
	6	9.75±0.19	10.5±0.23	0.00	65.8±2.64
	9	6.28±0.14	7.23±0.24	0.00	38.2±1.64
	12	4.71±0.15	5.59±0.18	0.00	48.8±1.55
	15	3.46±0.11	4.25±0.17	0.00	30.9±1.10
	18	3.47±0.16	3.76±0.14	0.00	14.8±0.22
3	3	19.7±0.32	22.1±0.38	0.00	63.4±2.17
	6	10.2±0.23	11.5±0.19	0.00	55.4±1.68
	9	7.09±0.17	7.09±0.21	0.00	45.5±2.34
	12	11.7±0.21	5.75±0.12	0.00	32.0±1.11
	15	4.34±0.06	4.56±0.11	0.00	12.8±0.63
	18	3.29±0.08	3.80±0.12	0.00	10.8±0.54
6	3	25.6±0.52	23.8±0.71	0.00	46.5±1.16
	6	3.07±0.07	11.7±0.22	0.00	33.3±1.21
	9	0.15±0.01	1.97±0.07	5.26±0.13	11.0±0.44
	12	0.05±0.02	1.64±0.06	0.60±0.02	12.7±0.21
	15	0.52±0.03	1.32±0.05	0.00	11.0±0.11
	18	2.01±0.01	1.39±0.05	1.31±0.03	5.89±0.26
12	3	18.6±0.37	8.55±0.11	0.00	39.0±2.10
	6	4.49±0.09	3.51±0.05	3.07±0.02	33.7±1.43
	9	2.63±0.06	2.85±0.06	1.53±0.02	22.8±1.19
	12	2.52±0.06	2.80±0.03	1.86±0.03	32.1±0.75
	15	1.67±0.03	2.15±0.03	0.04±0.01	33.3±0.48
	18	0.29±0.01	1.72±0.04	1.21±0.04	19.3±0.43
24	3	12.1±0.31	12.1±0.18	5.92±0.31	51.3±2.63
	6	8.44±0.10	5.70±0.12	5.26±0.22	50.5±1.85
	9	0.88±0.03	3.87±0.10	3.21±0.14	21.8±1.03
	12	3.73±0.10	2.31±0.09	2.08±0.11	30.7±0.86
	15	2.32±0.07	2.15±0.10	0.53±0.02	4.37±0.02
	18	1.46±0.01	1.97±0.10	2.05±0.07	13.2±0.03
96	3	9.43±0.11	10.3±0.20	8.54±0.18	28.9±1.57
	6	7.01±0.23	6.03±0.21	4.93±0.14	63.5±2.82
	9	3.14±0.15	3.95±0.13	1.10±0.05	58.3±0.77
	12	2.96±0.11	2.69±0.14	2.80±0.04	24.9±0.56
	15	2.10±0.06	2.32±0.10	1.80±0.03	18.8±0.32
	18	2.52±0.04	2.08±0.11	1.49±0.04	53.3±1.96

Spike soil was used for the washing experiment to assess removal efficiency of Pb in relation to contaminated soil, considering fractionated species of Pb in both soils. The use of water proved more efficient comparatively to other plant based washing solutions with removal efficiency ranging from 28.9±1.57% to 74.5±3.38% at 3% SPD, with highest value recorded in just 1 h washing time. This might be due to high exchangeable (81.2%) fraction of Pb in spiked soil comparatively to contaminated soil. The addition of water efficiently enhanced the dissolution of aqueous phase soluble Pb from the soil particles. It is believed that the fractions including exchangeable, carbonates and reducible forms are the species amenable to soil washing technique, whereas organic and residual forms are more stable not generally removed by soil washing [26, 42]. *Terminalia mantaly* had its highest removal efficiency of 25.6±0.52% followed by *Panicum maximum* of 23.8±0.71% at 3% SPD with 6 hours washing time. *Eleusine indica* washing solution reported the least of 8.54±0.18% at 3% SPD. The combine organic matter content of soil and washing *Terminalia mantaly*, *Panicum maximum*, and *Eleusine indica* solutions could make Pb removal quite difficult due to their high sportive capacity. Single factor analysis of variance at p = 0.05 showed significant difference in removal efficiency of Pb from spike soil among all four washing solutions.

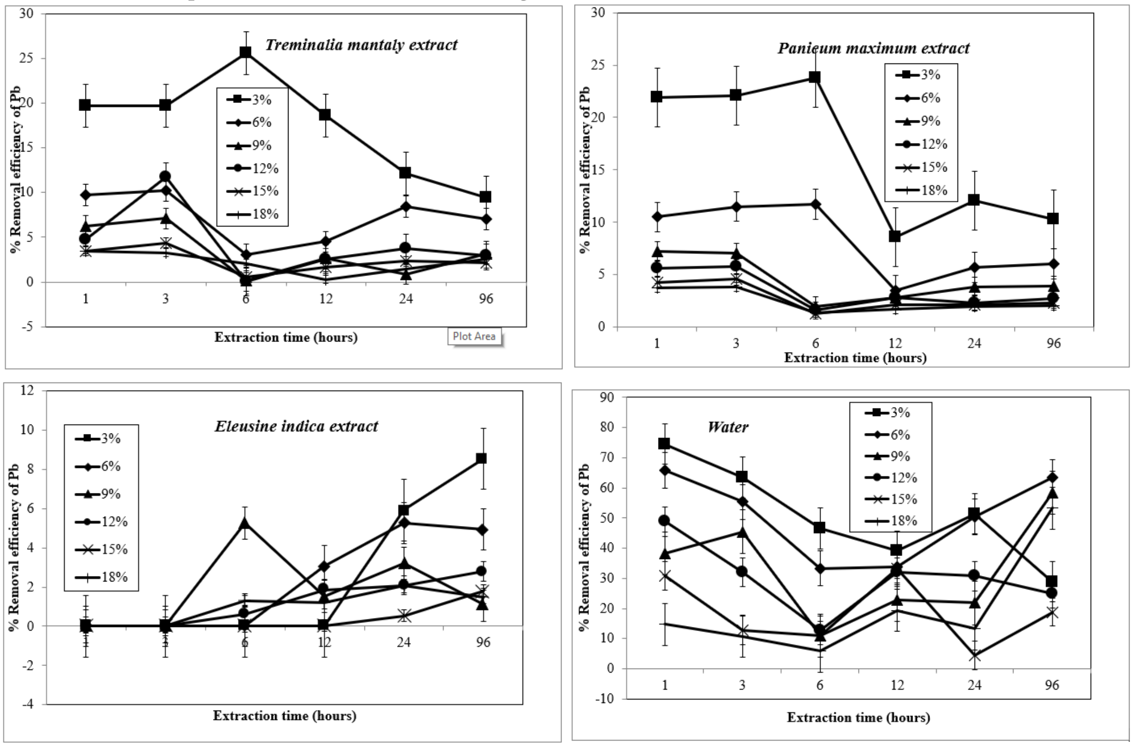


Figure 2. Removal efficiency (%) of Pb from spiked soil.

Figure 2 showed a decreasing removal efficiency of Pb from spiked soil relative to washing time for *Terminalia mantaly*, *Panicum maximum* and water, except for *Eleusine indica*. The relative oversaturation of the washing solutions with soil particles (more soil weight to washing solution volume) could account for this trend.

Table 5. Pearson's correlation coefficient (p = 0.05) of contaminated and spiked soils.

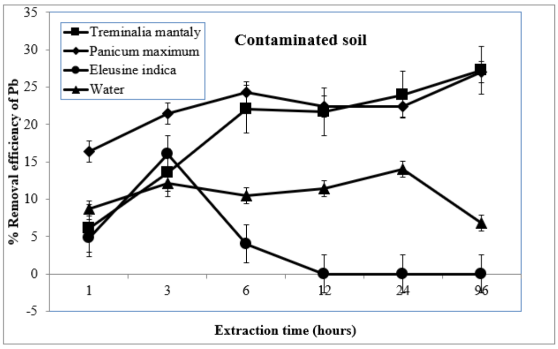
Extraction time [h]	*Treminalia mantaly*	*Panicum maximum*	Water
1	0.968	0.823	0.384
3	0.672	0.969	0.954
6	0.155	0.906	0.999
12	0.778	0.892	0.292
24	0.726	0.987	0.717
96	0.946	0.919	0.659

Statistical t-testing showed significant difference in Pb removal efficiency between contaminated and spiked soils for all four washing solutions, reflecting differences in geochemical phases of Pb in both soils.

Table 5 gives the correlation coefficients of Pb removal efficiency from contaminated and spiked soils.

Significant positive correlations were obtained for *Terminalia mantaly*, *Panicum maximum* and water for both soils. These suggest *Terminalia mantaly* and *Panicum maximum* extracts and water could apply to any soil type of varying degree of contamination.

Comparing Pb removal efficiency of the four washing solutions at 3% SPD (Figure 3), *Panicum maximum* and *Terminalia mantaly* extracts proved more efficient than other washing solutions for contaminated soil as against water for spiked soil. Consequently, removal efficiency was found to significantly increase for contaminated soil with washing time while water extract of spiked soil decreased with washing time. Therefore, longer contact time for contaminated soil and *Panicum maximum* and *Terminalia mantaly* washing solutions could relatively be efficient for Pb remediation. This efficiency could further be improved upon using double or multiple batch experimental washings.



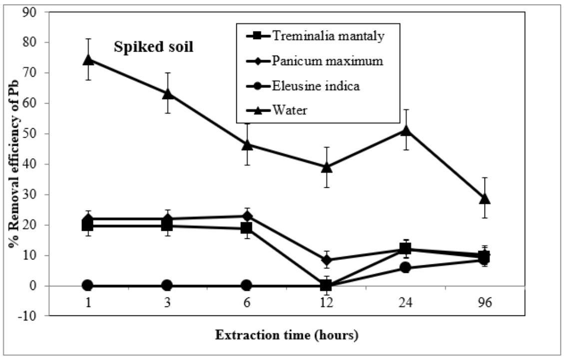


Figure 3. Removal efficiency (%) of Pb from contaminated and spiked soils with 3% SPD.

4. Conclusion

In conclusion, washing of *Terminalia mantaly, Panicum maximum* and *Eleusine indica* solutions for Pb contaminated and spiked soils was conducted with single batch equilibrium experiments, and the washing efficiencies expressed with percentage removal of Pb from both soils. Washings of *Terminalia mantaly* and *Panicum maximum* proved more promising and more effective for Pb removal in contaminated and spiked soils at 3% SPD. Influence of Pb species in soil form determined to a greater extent removal efficiency of Pb particularly in the contaminated soil. The eco-friendly biodegradable water soluble extract of dried *Terminalia mantaly* and *Panicum maximum* can be used for environmental cleanup of Pb contaminated soils. However, successive washing steps may be needed to further improved removal efficiency, predict and model removal efficiencies when multiple washing steps are applied.

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Conflict of interest

The author declares no conflict of interest.

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