



# Vermicompost-assisted phytoremediation of toxic trace element-contaminated soil in Madaka, Nigeria, using *Melissa officinalis* L and *Sida acuta*

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## Abstract

The aim of this study was to clean up toxic element polluted soil in Madaka, Niger State, Nigeria. Standard techniques were used to determine the soil physicochemical properties. To aid the plants (*Melissa officinalis* L and *Sida acuta*) during the remediation process, standard methods were used to make chicken dropping vermicompost and goat manure vermicompost. *M. officinalis* L mopped up toxic elements in the first location (Angwan Kawo), with concentrations of cadmium, arsenic, and lead ranging from 0.007 to 0.33 mg/kg, 0.09 to 4.39 mg/kg, and 0.07 to 10.35 mg/kg, respectively, while toxic elements, cadmium, arsenic, and lead in *S. acuta*, ranged from 0.002 to 0.43 mg/kg, 0.27 to 3.79 mg/kg, and 1.68 to 10.7 mg/kg, respectively. The two plants mopped up toxic elements at different rates in the second location of the polluted soil (Angwan Magiro). Cadmium, arsenic, and lead concentrations in *M. officinalis* L ranged from 0.03 to 0.41 mg/kg, 0.65 to 4.65 mg/kg, and 1.93 to 11.49 mg/kg, respectively, while toxic element concentrations in *S. acuta* ranged from 0.06 to 0.66 mg/kg, 0.68 to 4.64 mg/kg, and 1.53 to 11.53 mg/kg, respectively. *Melissa officinalis* L and *Sida acuta* were found to be the most suitable plants for phytoextraction of toxic element-contaminated sites because their bioconcentration factor, translocation factor, and biological accumulation coefficient were all greater than one ( $> 1$ ), and both plants had bioconcentration and translocation factor  $< 1$ ; they were also classified as phytostabilizers. As a result, the plants could be used to clean up Madaka soil polluted with toxic element.

**Keywords** Toxic element · Mining · Pollution · Remediation · Soil · Vermitechnology

## Introduction

Pollution is one of the most serious issues facing the world, with many people suffering from health problems as a result of mining, air pollution, and industrial activities (Martinez et al. 2004; Abioye et al. 2019). Human activities such as mining have been shown to have a significant negative impact on the environment overall quality (Donkor et al.

2005; Acosta et al. 2011). Anthropogenic activities such as mining, for example, devastate natural ecosystems by altering soil, vegetation, and soil microbes. The unintentional release of pollutants into the environment as a result of mining activities has reached an alarming level that requires attention (Ullah et al. 2015; Abioye et al. 2017; Abiya et al. 2019).

The presence of these toxic elements in soil and water bodies has been shown to degrade the quality of those soils and waters (Amarlal et al. 2006; Aransiola et al. 2021). State of Zamfara Lead poisoning is one of the most serious toxic element outbreaks in Nigerian history, killing over 500 children in just seven months. Between January and July 2010, illegal miners from seven villages in Zamfara State of Bukkuyum and Gummi Local Governments brought gold ore from small-scale mining operations into the villages; however, the villagers were unaware that the ore also contained extremely high levels of lead. The toxic element was

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crushed within village compounds, resulting in lead dust being spread throughout the community. Many villagers, mostly children, died as a result of these events (Galadima and Garba 2011; Aransiola et al. 2013). Because of their ability to cause harmful and toxic effects on plants and animals, toxic elements are a source of concern. Some metals (Cu, Fe, Mn, Zn, and Mo) are known to be important for growth in small amounts, but higher levels are harmful to growth and development (Alirzayeva et al. 2017; Ali et al. 2021). One of the most persistent pollutants in soil and water is toxic elements (Aransiola et al. 2021).

Vermicomposting is a green technique that uses specific earthworm species to produce vermicompost from various types of organic waste. It aids farmers in lowering their reliance on chemical fertilizers as well as their overall production costs. Vermicompost is a natural alternative to chemical additives in agricultural crop production that saves money while providing consumers with healthier organic products and improving the environment (Kaplan 2016). Some communities in Niger State, such as the Shikira community in the Rafi Local Government Area (RLGA), have their environment heavily polluted with lead (Pb) and other metals as a result of a series of mining activities (Ikhumetse et al. 2019; Aransiola et al. 2019). According to the Federal Ministry of Health FMH, 28 children died as a result of the lead poisoning in 2015. (FMH 2015). Excessive metal concentrations in soils pose a serious threat to humans and the environment in general. Uncontrolled human activities, particularly those related to mining, have often contaminated soils

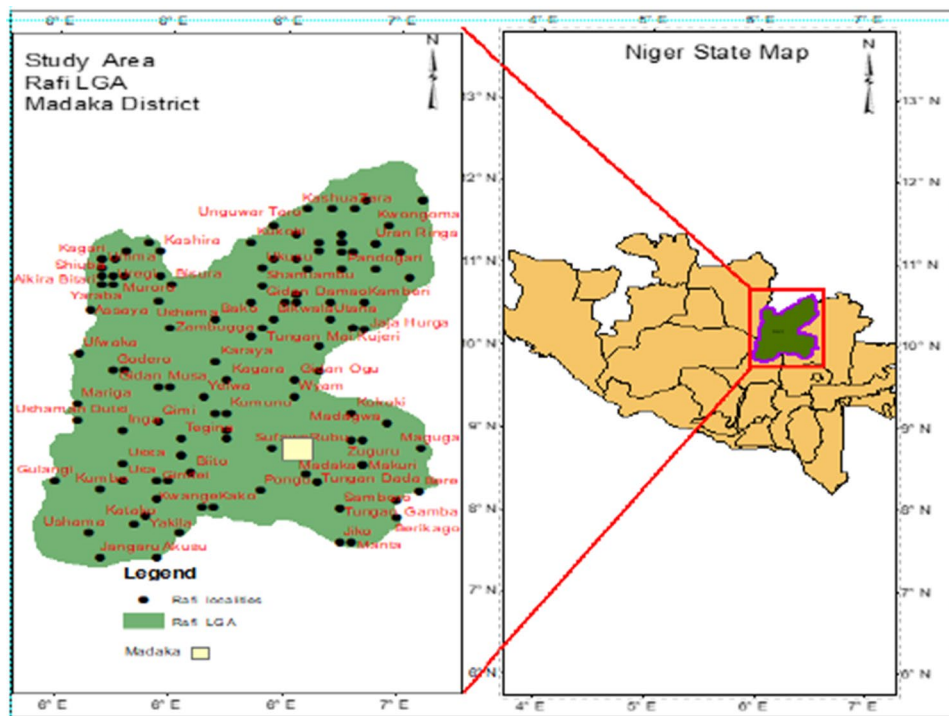
with toxic metals, as seen in the Madaka District, RLGA, Niger State, Nigeria (FMH 2015). There is a pressing need to develop an environmentally friendly remediation technology that can effectively remove contaminating metals from these communities' polluted soil. To achieve the aforementioned, this study used vermicomposts to aid in the restoration of polluted soil in Madaka, Niger State, Nigeria, for a period of seven months (April to October 2020), using *Sida acuta* and *Melissa officinalis* L.

## Materials and methods

### Study area

The research was conducted in Madaka District, Shikira community, which included two settlements: Angwan Magiro (AM) and Angwan Kawo (AK) (AK). Shikira is a town in Niger State, Nigeria, located in the eastern part of Kagara town, the headquarters of the Rafi Local Government Area (Fig. 1). Between longitudes 3° 30' E and 7° 30' E and latitudes 8° 10' N and 10° 30' N, lies Niger State (Fig. 1). The location was chosen after a report of lead poisoning in May 2015 as a result of artisanal mining activities (FMH, 2015). Madaka people are mostly farmers, with only a few nomads. For years, mining activities have been taking place in Madaka district, involving both locals and foreigners (Ikhumetse et al. 2019).

**Fig. 1** Study area (Madaka district, Shikira Community) Rafi LGA, Niger State, Nigeria



## Sample collection and processing

Plants and toxic element-polluted soil (50 kg each for the two locations) for this experiment were collected with a clean stainless steel shovel from a depth of 0–15 cm at the Shikira community comprising Angwan Magiro and Angwan Kawo, Rafi Local Government Area, Niger State, Nigeria, and transported in polythene bags to Federal University of Technology, Minna, for further analysis. These two major sites were chosen for this study because they have been contaminated with toxic elements and have had extensive mining activities. A 100 m by 100 m plot was demarcated in each of the sites, and the two most common herbaceous plant species thriving in the plots (*Sida acuta* and *Melissa officinalis* L) were chosen for this study. The stock culture of plant growth-promoting bacteria (PGPB) identified as *Bacillus safensis* obtained from the Microbiology Laboratory of the Federal University of Technology in Minna was used in the research.

## Determination of the soil's physicochemical properties

Standard methods described by various authors were used to determine the physicochemical properties of the soil. The pH of the soil was determined using the Eckerts and Sims (1995) method, the organic carbon and exchangeable cations were determined using the Walkley and Black (1934) method, and Agbenin was determined using the Agbenin method (1995). Total nitrogen was determined using the methods of Black (1965), Agbenin (1995), and Aransiola et al. (2013), while soil particle size was determined using the methods of Bouyoucos (1962) and USEPA (1996), and available phosphorus was determined using the methods of Bray and Kurtz (1945) and Nordberg et al (2007).

## Collection of vermicompost materials and preparation of chicken dropping vermicompost (CDV) and goat manure vermicompost (GMV)

Chicken droppings vermicompost (CDV) and goat manure vermicompost (GMV) materials were collected and prepared as follows: (a) Dried neem leaves for the bottom layer of the vermicompost were collected in a clean plastic container from environment of the Federal University of Technology, Minna, Niger State, Nigeria. (b) Rice straw was collected in the Sauka Kahuta area of Minna, Niger State, Nigeria, at a small rice mill factory. (c) Vegetable waste was collected in Minna, Niger State, Nigeria, at the Gwari vegetable market. (d) Goat dung was collected in Minna, Niger State, Nigeria, at the goat market in Gwari. (e) Chicken droppings were collected from Royal Splendour Integrated School farm, Mandela, Minna, Niger State,

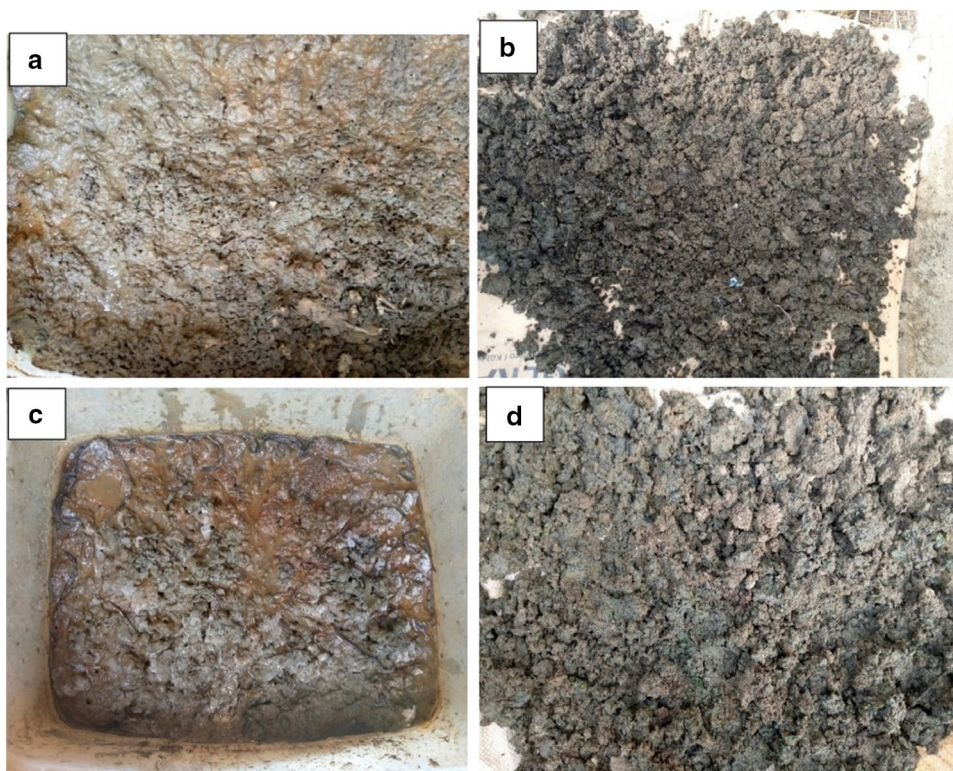
Nigeria. (f) Exotic varieties of earthworm (*Eisenia foetida*) were purchased from fishermen at the riverine village of Taji, Lokoja Local Government Area, Kogi State, Nigeria. About 2 kg of earthworms was used in vermicomposting.

Chicken droppings and vegetable wastes were used to create the vermicompost. To the five hundred grams (500 g) of vegetable wastes and 4 kg chicken droppings, dried neem leaves (1 kg) and chopped rice straw (2 kg) were added together in the plastic worm composter with two liters of water, and one kilogram of exotic earthworms (*Eisenia foetida*) was spread on the bedding materials. This setup was monitored for 90 days, with continuous addition of 2 L of water at 2-day intervals to keep the bed from drying out. Physicochemical parameters (pH, organic matter, total nitrogen, available nitrogen, total phosphorus, sodium, magnesium, iron, zinc, manganese, and copper) were determined during vermicomposting. Chicken vermicompost was collected after 90 days and air-dried, and a portion was taken for nutrient analysis (Jadia and Fulekar 2009). The nutrients in a dried sample of vermicompost were determined using an atomic absorption spectrophotometer after digestion with concentrated nitric acid and 30% hydrogen peroxide (AAS). For the second compost development, this setup was duplicated in another vermin composter, but goat dung was used instead of chicken droppings (APHA 1998; Jadia and Fulekar, 2009). The in-process and finished vermicasts for goat manure and chicken droppings are shown below (Fig. 2a–d).

## Phytoremediation studies: experimental design and layout

It was a pot experiment. Polluted soils were collected and transported from RLGA's Angwa Magiro and Angwa Kawo, and the experiment was set up at the Federal University of Technology Minna at the biological garden. Each treatment was replicated three times in a completely randomized design. 5 kg of polluted soils was placed in the experimental pots. For phytoremediation, seedlings of each plant (*S. acuta* and *M. officinalis* L) were grown and three seedlings transplanted to each pot containing polluted soil. *B. safensis* culture was prepared in nutrient broth, and 100 mL was sprayed on the plant leaves and stems. This was repeated every three weeks until the plants had fully matured. Vermicast (0.5 kg) was used as a fertilizer for the plants, which was applied directly to the plants surrounding the root. The application was completed twice, with two-monthly intervals between each application. For seven (7) months, the setup was monitored. Throughout the study period, the soil's physicochemical properties and microbial counts were determined at monthly intervals (Table 1).

**Fig. 2** **a** Production stage of goat manure vermicast. **b** Produced goat manure vermicast. **c** The production stage of chicken dropping vermicast. **d** Produced chicken dropping vermicast



### Determination of toxic elements in the harvested plants

Plant shoots and roots were carefully separated from soil after harvesting, washed with tap water and then distilled water until all dirt was removed. All samples were air-dried for seven days at the Microbiology Laboratory of the Federal University of Technology in Minna. The samples were oven-dried at 6000 °C until they reached constant weights. A horizontal grinder was used to grind the dried plant parts to powder (Kai et al. 2012). In microwave-assisted Kjeldahl digestion, the dried samples were digested with a 3:1 mixture of concentrated nitric acid and hydrofluoric acid. Each microwave extraction vessel was filled with 0.8 g of plant sample and six milliliters (6 mL) of nitric acid and two milliliters (2 mL) of hydrofluoric acid. Each microwave extraction vessel was filled with 0.8 g of plant sample and six milliliters (6 mL) of nitric acid and two milliliters (2 mL) of hydrofluoric acid. The vessels were capped and heated in a microwave unit at 800 W for 20 min at 1900 °C under 25 bar pressure. The digested samples were diluted to 50 mL and analyzed for metals using a flame atomization atomic absorption spectrophotometer. Each component's dry weight was used to calculate the results (Kai et al. 2012).

### Scanning electron microscope (SEM) analysis

The soil structural components were revealed with the help of a scanning electron microscope (SEM: JSM-7900F, JEOL, USA.). The soil sample was taped to an aluminum holder stub with double sticky carbon tape and then dried for at least 3 h at 60 degrees Celsius in an oven. The sample was placed on the sample holder stubs into the mounting holes, the door was gently closed, and the EVAC button was pressed after the "Vent" button on the Microscope table was clicked to release nitrogen into the chamber; 2 min after a sound of the rotary pump was heard which was evident with a visible green light. Thereafter, high vacuum at  $< 5 \times 10^{-5}$  Pa was achieved within 45 min. As the vacuum reached a proper level, filament and monitor light were switched on and the status of dial positions was checked at the acceleration voltage of 15 kV. With the lowest magnification (X10) selected, TV scan mode was chosen and samples were located using a trackball. Coarse focus switch was turned on using the focus knob with a working distance of 14 mm. The z-axis up key was pressed to slowly raise the sample stage, and the screen was examined to determine the z-position at which the image was in focus. This was noted down, and coarse focus was turned off. While the image setup icon was clicked, the scanning speed was set to S1 and the mapping



**Table 1** Design of the phytoremediation studies

Treatments	Treatment Code	Details of the Treatment
Angwa Kawo	Melissa officinalis L	
	A	Soil (5 kg) + <i>M. officinalis</i> L
	B	Soil (5 kg) + <i>M. officinalis</i> L + PGPB
	C	Soil (5 kg) + <i>M. officinalis</i> L + CDV + PGPB
	D	Soil (5 kg) + <i>M. officinalis</i> L + GMV + PGPB
	E	Soil (5 kg) + <i>M. officinalis</i> L + CDV
	F	Soil (5 kg) + <i>M. officinalis</i> L + GMV
	Sida acuta	
	G	Soil (5 kg) + <i>S. acuta</i>
	H	Soil (5 kg) + <i>S. acuta</i> + PGPB
	I	Soil (5 kg) + <i>S. acuta</i> + CDV + PGPB
	J	Soil (5 kg) + <i>S. acuta</i> + GMV + PGPB
	K	Soil (5 kg) + <i>S. acuta</i> + CDV
	L	Soil (5 kg) + <i>S. acuta</i> + GMV
Angwa Magiro	Melissa officinalis L	
	M	Soil (5 kg) + <i>M. officinalis</i> L
	N	Soil (5 kg) + <i>M. officinalis</i> L + PGPB
	O	Soil (5 kg) + <i>M. officinalis</i> L + CDV + PGPB
	P	Soil (5 kg) + <i>M. officinalis</i> L + GMV + PGPB
	Q	Soil (5 kg) + <i>M. officinalis</i> L + CDV
	R	Soil (5 kg) + <i>M. officinalis</i> L + GMV
	Sida acuta	
	S	Soil (5 kg) + <i>S. acuta</i>
	T	Soil (5 kg) + <i>S. acuta</i> + PGPB
	U	Soil (5 kg) + <i>S. acuta</i> + CDV + PGPB
	V	Soil (5 kg) + <i>S. acuta</i> + GMV + PGPB
	W	Soil (5 kg) + <i>S. acuta</i> + CDV
	X	Soil (5 kg) + <i>S. acuta</i> + GMV

**Keys;** PGPB = plant growth-promoting bacteria, CDV = chicken dropping vermicompost, GMV = goat manure vermicompost

option for 1024 normal resolution and frame 1 was selected to close the image set up window. To record the image, the image acquire icon was switched on. The software took control of SEM, freezing the monitor and saving the image (Auta et al. 2017).

### The toxic element removal efficiency

Adopting the method used by Emenike et al. (2017), the efficiency at which the metal contaminants were removed was determined (Eq. 1)

$$\% \text{ of toxic element removal} = \frac{CO(X) - CF(X)}{CO(X)} * 100 \quad (1)$$

Where,

$C_0(x)$  = initial concentration of metal, “x” = (Pb, Cd, As) in the soil at the beginning of the experiment.

$C_F(x)$  = final concentration of metal, “x” = (Pb, Cd, As) in the soil at the end of the experiment.

### Statistical analysis

The data generated from the study were analyzed in triplicates using SAS 9.0. All results of physicochemical experiments were subjected separately to the analysis of variance (ANOVA). Duncan multiple range test (at 5 and 1%) and Mean  $\pm$  SEM were used to test mean comparison for significant effects of the treatment. This was used to identify the significance of differences in the concentration of each element in the soil and plant samples. SAS version 9.0 was used to analyze the significant effects, and means were compared for the treatment, plant parts, and location effects with respective standard error of means. Canonical discriminant analysis was done with IBM statistics SPSS 20 to determine the combined distribution of the toxic elements as

influenced by treatments and assimilated by the plant parts in each location.

## Results and discussion

### Physicochemical properties of the vermicompost

Table 2 shows the results of physicochemical parameters of GMV and CDV vermicompost after 60 days of the vermicomposting process.

The toxic accumulation of toxic elements reduces soil structural quality, which has an impact on the overall ecosystem, which does not support plant growth and may also disrupt the activities of soil microbes (Daia et al. 2004; Sunitha et al. 2014). Organic matter amendments for soil enrichment enable the immobilization of toxic elements (for example, Pb, Ni, Cd, As, and Co) while also increasing plant growth rates in the phytoremediation process, potentially increasing plant removal efficacy (Basta and McGowen 2004). (Wang et al. 2012). Vermicomposting differs from traditional composting in that it requires a thermophilic phase, whereas traditional composting requires a mesophilic phase.

When vermicompost is made, it has a fine texture and a peat-like material, which reinforces its structural characteristics in terms of water retention and aeration (Belliturk et al. 2015). This increases the cation exchange capacity (CEC) of soils, allowing positive ions, including toxic elements, to be absorbed (Herwijnen et al. 2007).

### pH

After 60 days of vermicomposting, the results of physicochemical parameters of GMV and CDV vermicompost, as shown in Table 2, revealed that the CDV had a slightly higher pH (6.91) than the GMV (6.65). Earlier research studies on the vermicomposting of various wastes had similar findings (Garg and Gupta 2011; Mousavi et al. 2019). The mineralization of nitrogen and phosphorus into nitrites/nitrates and orthophosphates, as well as the transformation of organic waste into organic acids, could be the cause of pH decreases and the transformation of organic waste into organic acids (Ndegwa et al. 2000).

### Electrical conductivity (EC)

The EC results revealed that in both setups, the EC was higher in GMV than CDV with value of 166  $\mu\text{cm}$  and 126  $\mu\text{cm}$ , respectively (Table 2). Decomposition of organic material and release of minerals in the form of cations during vermicomposting may have increased EC (Tognetti et al. 2005; Khwairakpam and Bhargava 2009).

**Table 2** Physicochemical properties of the vermicomposts

Parameters	GMV	CDV
pH	6.65 $\pm$ 0.58	6.91 $\pm$ 1.16
Nitrogen (%)	2.47 $\pm$ 0.27	1.29 $\pm$ 0.58
Phosphorus (ppm)	33.87 $\pm$ 0.57	35.26 $\pm$ 2.88
Organic Matter	7.32 $\pm$ 1.7	9.06 $\pm$ 0.01
Organic Carbon	8.15 $\pm$ 0.58	12.64 $\pm$ 0.02
C:N	3.30 $\pm$ 0.56	9.80 $\pm$ 0.01
Sand (%)	53.87 $\pm$ 1.73	55.05 $\pm$ 0.57
Silt (%)	15.41 $\pm$ 0.005	10.06 $\pm$ 0.58
Clay (%)	29.15 $\pm$ 0.09	34.17 $\pm$ 1.15
Na <sup>+</sup> (Mmol/kg)	1.741 $\pm$ 0.57	1.062 $\pm$ 0.01
K <sup>+</sup> (Mmol/kg)	2.62 $\pm$ 0.58	2.47 $\pm$ 0.57
Mg <sup>2+</sup> (Mmol/kg)	12.05 $\pm$ 0.03	9.38 $\pm$ 1.15
Ca <sup>2+</sup> (Mmol/kg)	11.35 $\pm$ 0.02	13.30 $\pm$ 0.57
Moisture	10.8 $\pm$ 0.12	11.5 $\pm$ 0.28
Texture	Granular	Fine
Structure	Sand	Sand
Color	Yellowish-brown	Yellowish-brown
Electrical conductivity ( $\mu\text{cm}$ )	166 $\pm$ 0.57	126 $\pm$ 2.31
Exchangeable acidity (Mmol/kg)	4.28 $\pm$ 0.58	3.57 $\pm$ 0.57
Cation exchange capacity (Mmol/kg)	9.40 $\pm$ 1.15	6.30 $\pm$ 0.58

Values are means of three replicates  $\pm$  standard errors

**KEY:** GMV, goat manure vermicompost; CDV, chicken dropping vermicompost

ppm: parts per million, Mmol/kg: millimoles per kilogram

### Organic carbon (OC)

The OC result revealed that CDV (12.64) was higher than the GMV (8.15%) (Table 2). According to some researchers, earthworms adjusted the feed mixture condition, assisting carbon losses from the feed mixture via microbial respiration in the form of CO<sub>2</sub> (Elvira et al. 1996; Aira et al. 2007; Hait and Tare 2011). Wani and Rao (2013) used the earthworm *Eisenia fetida* to investigate vermicomposting of garden, cow dung, and kitchen wastes. The reduction in OC was confirmed by their findings at the end of the study. Sharma (2003) also discovered that during the vermicomposting of municipal solid waste, a significant amount of OC can be converted to CO<sub>2</sub>. The following are the nutrient compositions commonly found in vermicompost: N 0.5–1.50%, P 0.1–0.30%, Ca and Mg 22.67–47.60 meq/100 g, OC 9.5–17.98%, K 0.15–0.56%, Na 0.06–0.30%, Zn 5.70–11.50 mg/kg, Sulfur 128–548 mg/kg, Cu 2–9.50 mg/kg, Fe 2–9.30 mg/kg (Mousavi et al. 2019). Vermicomposting, on the other hand, allows waste to be biologically transformed into a valuable organic fertilizer.



## Nitrogen

When comparing CDV and GMV, there was a noticeable difference in nitrogen content. After 60 days of vermicomposting, the GMV had 2.47% as against 1.29% nitrogen content of CDV (Table 2). After 150 days of vermicomposting, nitrogen concentrations in tomato-fruit wastes increased by 35%, according to Mousavi et al. (2019). The nitrogen content differences observed could be due to the mineralization of Carbon-rich matter in GMV and the activities of N-fixing bacteria present in the feed mixtures (Plaza et al. 2008). The nitrogen content of kitchen waste compost, rotting foliage, and cow dung was 2.16% higher than that of the initial waste mixtures, according to Mousavi et al. (2019). This result is similar to the value obtained in this study, which could be due to GMV content being similar to the cow dung used by the researcher. Vermicomposting also causes a significant increase in total nitrogen content after worm activity, according to studies (Garg and Gupta 2011; Soobhany et al. 2015).

## C/N ratio

The carbon/nitrogen ratio, which is one of the main conventional indicators of compost maturation (Mousavi et al. 2019), is the stabilization and mineralization of organic wastes during the process of vermicompost. The carbon/nitrogen ratio of CDV had a higher value of 9.80 compared to 3.30 of GMV. These represented the results obtained in the organic carbon and nitrogen content of the research. This difference may be due to changes in the OC and N relative concentration as shown in Table 2. This is consistent with the findings of Kaur et al. (2010) that the carbon/nitrogen ratio decreased due to a higher loss of carbon. To show compost maturation, studies also showed that C: N ratio is one of the main indicators used (Malafaia et al. 2015).

## Phosphorous

The results for phosphorus concentration in vermicompost revealed that GMV and CDV had relative values of 33.87 ppm and 35.26 ppm, respectively. It is possible that processing time, raw materials, worm-digested materials, worm species, and test condition all play a role in these results (Ndegwa et al. 2000). While some phosphorous was added to the compost, the passage of organic matter through the intestines of earthworms could be a reason. This may increase the amount of phosphorus available to plants, which could explain why the phosphorus content of the treatments in this study increased. Microorganisms have also been reported to produce acids that solubilize insoluble phosphorus during the decomposition of organic material,

resulting in an increase in the phosphorus concentration of vermicompost (Vig et al. 2011).

## Macronutrient (Na, K, Mg, and Ca)

The macronutrient (Na, K, Mg and Ca) content of the two vermicasts GMV and CDV had 1.741, 2.62, 12.05, 11.35 mmol/kg and 1.062, 2.47, 9.38 13.30 mmol/kg, respectively. Of all treatments, Ca showed the highest value for both GMV (11.35 mmol/kg) and CDV (13.30 mmol/kg) (Table 2). Yadav and Garg (2011) reported a similar outcome in the vermicomposting of mixed feed consisting of cow dung, poultry droppings, and food industry sludge using *Eisenia fetida*.

## Physicochemical properties of soil during Phytoremediation study

### Mean comparison of the physicochemical properties for the months of experiments across the parameters measured

The pH values increased progressively, with no significant differences in values in the month of May, June, and July (Table 3). The pH values in August, September, and October were all higher than those previously mentioned; metal mobility was likely low, as evidenced by the pH of 7.14 in October, which was the highest and most significantly different from other values. All of the significant differences (Table 3) revealed followed a similar pattern, indicating that the values obtained in October were significantly different from those obtained in other months. This could be because the phytoremediation process has reached its peak and all nutrients have decreased.

Metal cations are the most mobile in acidic conditions, whereas oxide minerals are sorbed by anions in this pH range (Dzombak and Morel 1987). This follows a trend in which toxic element bioavailability rises as more metals are released into the soil solution due to competition with H<sup>+</sup> ions at low pH. (Dinev et al. 2008). When the pH is high, however, cations precipitate to minerals, causing metal anions to mobilize (Takac, et al. 2009). When the pH is neutral or alkaline, many toxic elements in the soil may not be available to plants, especially Cr and Pb, which are intrinsically immobile.

According to Singh and Kalamdhad, soil organic matter is one of the factors that determine metal behavior in the soil (2013). The presence of organic carbon boosts the soil's cation exchange capacity, which helps plants store nutrients (Yobouet et al. 2010). The metal uptake by plants is determined by soil edaphic factors and available nutrients (Afonne and Ifediba 2020; Maddela et al. 2020).



**Table 3** Mean Comparison of Physicochemical Properties across the Months of the Study

Months	pH	EC ( $\mu\text{cm}$ )	OC (%)	OM (%)	TN (%)	Ca (mg/kg)	Mg (mg/kg)	Na (mg/kg)	K (mg/kg)	ExA (Mmol/kg)	CEC (Mmol/kg)
May	6.06 $\pm$ 0.19 <sup>c</sup>	111 $\pm$ 13.26 <sup>b</sup>	0.45 $\pm$ 0.04 <sup>d</sup>	0.68 $\pm$ 0.08 <sup>d</sup>	0.12 $\pm$ 0.01 <sup>c</sup>	550 $\pm$ 37.90 <sup>d</sup>	110.23 $\pm$ 9.60 <sup>c</sup>	51.05 $\pm$ 4.11 <sup>c</sup>	61.35 $\pm$ 3.50 <sup>c</sup>	0.24 $\pm$ 0.05 <sup>d</sup>	2.13 $\pm$ 0.26 <sup>e</sup>
June	5.97 $\pm$ 0.19 <sup>c</sup>	107.17 $\pm$ 13.57 <sup>b</sup>	0.45 $\pm$ 0.04 <sup>d</sup>	0.62 $\pm$ 0.07 <sup>cd</sup>	0.13 $\pm$ 0.02 <sup>c</sup>	562.17 $\pm$ 37.09 <sup>d</sup>	115.08 $\pm$ 10.16 <sup>c</sup>	53.18 $\pm$ 4.51 <sup>c</sup>	63.78 $\pm$ 3.71 <sup>c</sup>	0.31 $\pm$ 0.06 <sup>d</sup>	2.24 $\pm$ 0.28 <sup>e</sup>
July	6.46 $\pm$ 0.13 <sup>c</sup>	112.75 $\pm$ 11.26 <sup>b</sup>	1.15 $\pm$ 0.18 <sup>cd</sup>	0.95 $\pm$ 0.14 <sup>c</sup>	0.19 $\pm$ 0.02 <sup>b</sup>	615 $\pm$ 42.36 <sup>cd</sup>	124.20 $\pm$ 13.02 <sup>bc</sup>	56.16 $\pm$ 4.11 <sup>b</sup>	68.01 $\pm$ 5.12 <sup>c</sup>	0.48 $\pm$ 0.09 <sup>c</sup>	3.32 $\pm$ 0.26 <sup>d</sup>
August	6.89 $\pm$ 0.18 <sup>b</sup>	122.42 $\pm$ 13.97 <sup>ab</sup>	1.47 $\pm$ 0.25 <sup>c</sup>	0.79 $\pm$ 0.07 <sup>cd</sup>	0.25 $\pm$ 0.03 <sup>b</sup>	645.83 $\pm$ 47.36 <sup>c</sup>	140.63 $\pm$ 15.59 <sup>b</sup>	58.63 $\pm$ 3.39 <sup>b</sup>	72.9 $\pm$ 5.89 <sup>c</sup>	0.66 $\pm$ 0.15 <sup>b</sup>	4.27 $\pm$ 0.44 <sup>c</sup>
September	6.81 $\pm$ 0.15 <sup>ab</sup>	152.08 $\pm$ 19.94 <sup>a</sup>	2.27 $\pm$ 0.26 <sup>b</sup>	1.31 $\pm$ 0.18 <sup>b</sup>	0.26 $\pm$ 0.04 <sup>a</sup>	740 $\pm$ 36.5 <sup>b</sup>	141.20 $\pm$ 14.94 <sup>b</sup>	62.9 $\pm$ 3.08 <sup>b</sup>	102.31 $\pm$ 10.67 <sup>b</sup>	0.84 $\pm$ 0.18 <sup>a</sup>	5.08 $\pm$ 0.57 <sup>b</sup>
October	7.14 $\pm$ 0.11 <sup>a</sup>	144.25 $\pm$ 20.02 <sup>a</sup>	4.19 $\pm$ 0.50 <sup>a</sup>	1.96 $\pm$ 0.39 <sup>a</sup>	0.36 $\pm$ 0.06 <sup>a</sup>	850.83 $\pm$ 67.14 <sup>a</sup>	200.71 $\pm$ 25.31 <sup>a</sup>	68.33 $\pm$ 4.51 <sup>a</sup>	147.97 $\pm$ 16.35 <sup>a</sup>	0.84 $\pm$ 0.15 <sup>a</sup>	6.43 $\pm$ 0.59 <sup>a</sup>

Values are measured at  $P \geq 95\%$

Down the column values with the same letter are not significantly different from the other

Key: EC = electrical conductivity, OC = organic carbon, OM = organic matter, exchangeable acidity, CEC = cations exchange capacity

Soil-to-plant transfer factors are another method for determining metal uptake by plants. This factor, on the other hand, will aid in the development of effective strategies to reduce metal entry into plant parts and, ultimately, into the food chain (Ramakrishnan et al. 2021).

### Canonical discriminant analysis of toxic element dispersion across the treatments and plants parts

The canonical discriminant analysis (CDA) of the toxic elements (Cd, As, and Pb) is revealed in Figs. 3 and 4. Ranges of toxic element interaction were used in all treatments at both locations to determine the toxic element dispersion rate, effectively identifying the element responsible for the CDA distribution. According to the results of a CDA analysis, the element concentrations in the root, stem, leaf, and seed showed a clear distinction between the two locations with different treatments and plant parts. Plants differ in their ability to extract, accumulate, and disperse toxic elements in their tissues (Kacalkova et al. 2015); as a result, plant selection for toxic element accumulation is largely based on their ability to tolerate and withstand the elements' toxic effect (Rezania et al. 2016). The findings revealed that the two plants studied contained more toxic elements in their stems than in their roots, leaves, or seeds (Fig. 4). For Pb, the metals were more evenly distributed throughout the plant parts. Plants will be able to remove more metal from polluted soil once their growth can withstand the metal tolerance. *B. napus* grown on cadmium-polluted soil produced less biomass, according to Selvam and Wong (2008). Both plants were graded on their ability to disperse and accumulate toxic elements:  $\text{Pb} > \text{As} > \text{Cd}$ . This indicated that lead concentrations were more widely distributed than As and Cd concentrations. All metal contents were strongly influenced by the assisted materials (Vermicast and PGPB) used for the study in the polluted soil from AK and AM, indicating that all metal contents were strongly influenced by the assisted materials (Vermicast and PGPB) used for the study (Manta et al. 2002). The distribution of Pb was more concentrated in the stems of the plants than in the roots and leaves. As a result, polluted soil from mining sites is likely to be the primary source of lead pollution, which may have an impact on the distribution of lead in the native plants used (Xiao et al. 2020).

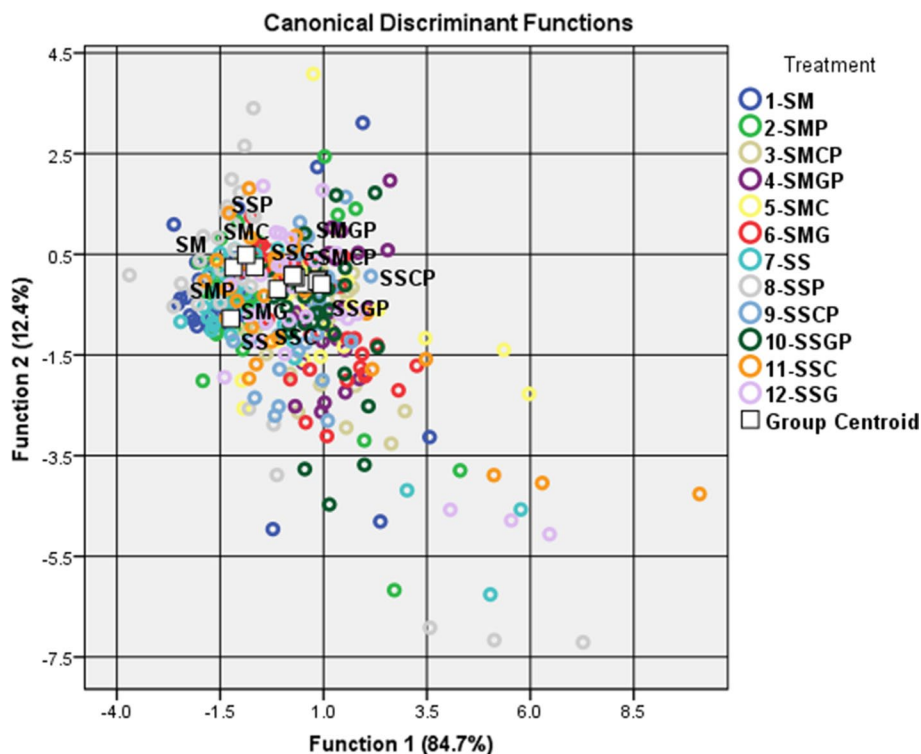
### The toxic element removal efficiency

The soil from Angwan Kawo with *M. officinalis* L (Fig. 5) was able to remediate and remove toxic metals of Cd, As, and Pb at the percentage range of 34.83–97.07%, 72.5–98.39%, and 78.02–89.55%, respectively. This soil

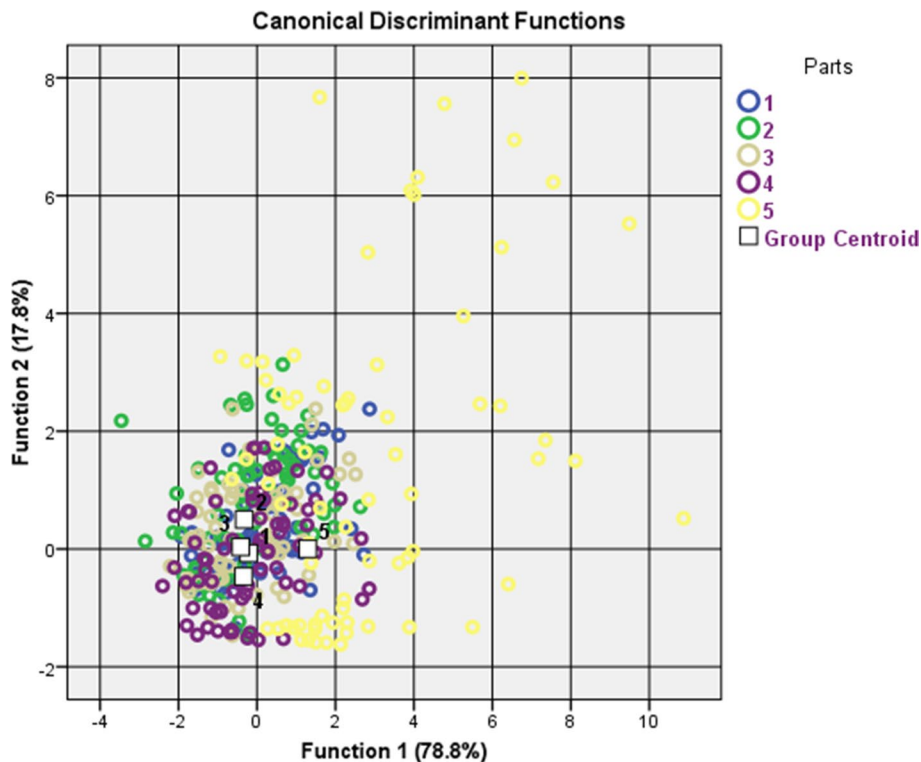




**Fig. 3** Canonical discriminant analysis (CDA) of toxic element for all treatment of AK- and AM-polluted soil remediated with *M. officinalis* L and *S. acuta* Key: 1(SM)=Soil (5 kg) + *M. officinalis* L, 2(SMP)=Soil (5 kg) + *M. officinalis* L + PGPB, 3(SMCP)=Soil (5 kg) + *M. officinalis* L + CDV + PGPB, 4(SMGP)=Soil (5 kg) + *M. officinalis* L + GMV + PGPB, 5(SMC)=Soil (5 kg) + *M. officinalis* L + CDV, 6(SMG)=Soil (5 kg) + *M. officinalis* L + GMV, 7(SS)=Soil (5 kg) + *S. acuta*, 8(SSP)=Soil (5 kg) + *S. acuta* + PGPB, 9(SSCP)=Soil (5 kg) + *S. acuta* + CDV + PGPB, 10(SSGP)=Soil (5 kg) + *S. acuta* + GMV + PGPB, 11(SSC)=Soil (5 kg) + *S. acuta* + CDV, 12(SSG)=Soil (5 kg) + *S. acuta* + GMV



**Fig. 4** Canonical discriminant analysis (CDA) of plant parts for Cd, As, and Pb in AK- and AM-polluted soil remediated with *M. officinalis* L and *S. acuta*. Key: Key: 1=Root, 2=Stem, 3=Leaf, 4=Seed, 5=Soil



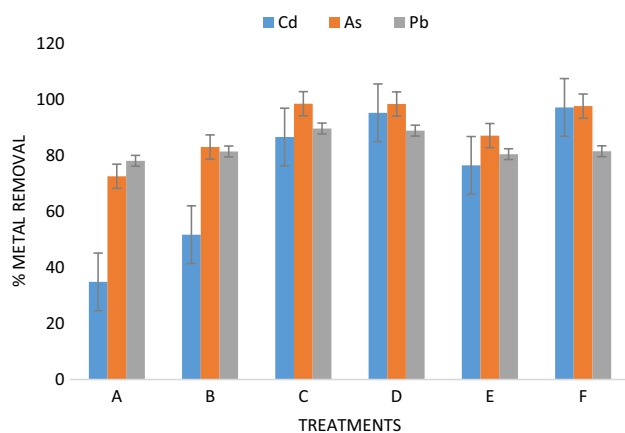
treated with *M. officinalis* L alone, without any amendments (control), had the lowest (34.83%) percentage removal for Cd while the Angwan Kawo soil remediated with *S. acuta* showed a similar pattern to the one remediated with *M.*

*officinalis* L. However, the highest and best bio-removal percentage obtained with *S. acuta* was observed with soil treated with CDV + PGPB which achieved 99.64% removal for As while the unamended soil with *S. acuta* all had low

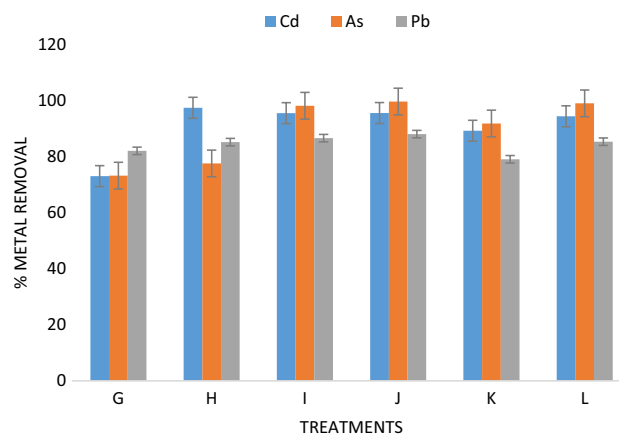
percentage removal (Fig. 8) for all the metals with Cd being the lowest (73.03%) (Fig. 8).

The result of the Angwan Magiro soil treated with *M. officinalis* L (Fig. 8) revealed the percentage removal of Cd, As and Pb at the range of 70.1–98.35%, 3.7–90.45%, and 53.36–81.95%, respectively. Of all the values obtained, As had the lowest percentage removal (3.7%) (Fig. 6) while Cd had the highest percentage removal when the soil was amended with GMV + PGPB. Generally, both locations after the remediation process had the best bio-removal of metals in the soil treated with vermicompost together with PGPB. However, among the treated soil, the least removal efficiency was recorded in the soil amended with PGPB or vermicompost alone. Likewise, all treatments were highly efficient and effective in the removal of Cd, As, and Pb.

The ability of the soil to remove toxic elements observed in conjunction with the vermicompost and PGPB in this study could be due to the presence of microbes that aided plant growth (Hassan et al. 2020). However, the rate of metal removal observed in this study is similar to that reported by Achal et al. (2011); they reported percentage metal removal of 94%; their result is lower than that observed in Angwan Magiro soil with *M. officinalis* L. The differences in the results obtained could be due to differences in the experimental conditions, location, or organisms used in the enhancement process. When comparing the extent of bio removal of toxic elements to metal pollutants, it was discovered that the removal order followed a trend of As (99.64%) > Cd (98.35%) > Pb (89.55%) (Figs. 5, 6, 7 and 8). The removal of metals from the polluted soil could have been aided by a number of mechanisms. The fact that the pH of the remediated soil was



**Fig. 5** Percentage of toxic element bio-removal efficiency with *M. officinalis* L in AM. A=Soil (5 kg)+*M. officinalis* L, B=Soil (5 kg)+*M. officinalis* L+PGPB, C=Soil (5 kg)+*M. officinalis* L+CDV+PGPB, D=Soil (5 kg)+*M. officinalis* L+GMV+PGPB, E=Soil (5 kg)+*M. officinalis* L+CDV, F=Soil (5 kg)+*M. officinalis* L+GMV

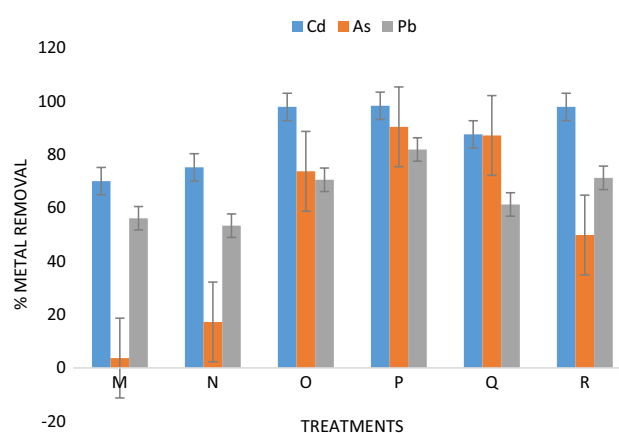


**Fig. 6** Percentage of toxic element bio-removal efficiency with *S. acuta* in AK. G=Soil (5 kg)+*S. acuta*, H=Soil (5 kg)+*S. acuta*+PGPB, I=Soil (5 kg)+*S. acuta*+CDV+PGPB, J=Soil (5 kg)+*S. acuta*+GMV+PGPB, K=Soil (5 kg)+*S. acuta*+CDV, L=Soil (5 kg)+*S. acuta*+GMV

initially acidic and then moved toward neutral indicated that immobilization and solubilization could have occurred (Turnau, and Kottke 2005).

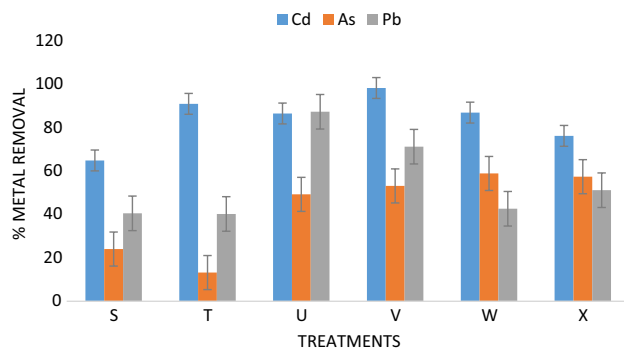
### SEM micrographs of polluted and remediated soil

The structural morphological changes within the soil samples were studied using SEM; this was done to validate the severity of the remediation carried out within seven (7) month (Figs. 9 and 10). Before the commencement of the remedial treatment, it was observed that all the polluted soils inoculated with *M. officinalis* L. and *S. acuta* exhibited a



**Fig. 7** Percentage of toxic element bio-removal efficiency with *M. officinalis* L in AM. M=Soil (5 kg)+*M. officinalis* L, N=Soil (5 kg)+*M. officinalis* L+PGPB, O=Soil (5 kg)+*M. officinalis* L+CDV+PGPB, P=Soil (5 kg)+*M. officinalis* L+GMV+PGPB, Q=Soil (5 kg)+*M. officinalis* L+CDV, R=Soil (5 kg)+*M. officinalis* L+GMV



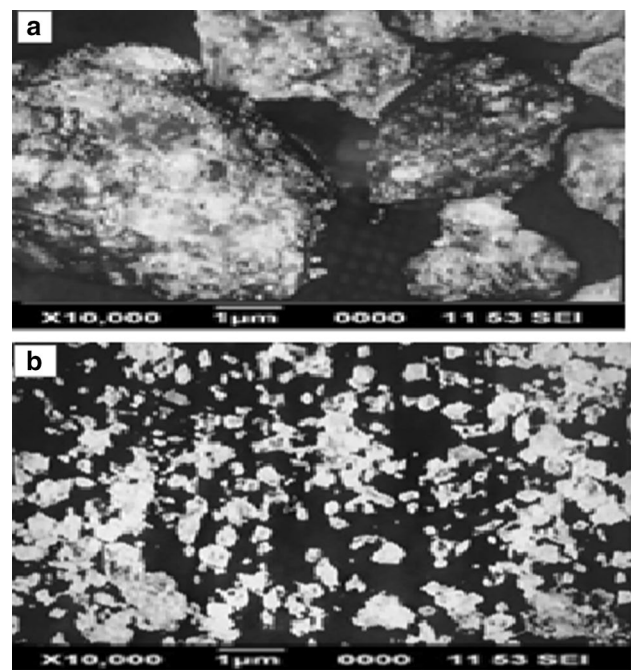


**Fig. 8** Percentage of toxic element bio-removal efficiency with *S. acuta* in AK. S=Soil (5 kg)+*S. acuta*, T=Soil (5 kg)+*S. acuta*+PGPB, U=Soil (5 kg)+*S. acuta*+CDV+PGPB, V=Soil (5 kg)+*S. acuta*+GMV+PGPB, W=Soil (5 kg)+*S. acuta*+CDV, X=Soil (5 kg)+*S. acuta*+GMV

smooth large compact structural surface which is an indication of metal pollution. After seven months of the remediation process, the remediated soil exhibited small rough structural surfaces validating and giving a clear evidence that remediation of the soil took place in the presence of the two plants used. The SEM micrographs of the soil from Angwan Kawo show more clarity of remediation and showed fine breakage of the soil structure. Various pores/pits and irregularities formed as a result of remediation activity (Figs. 9b and 10d). These surface changes observed in the SEM micrographs indicated changes in the soil structure of the remediated soil with the two plants. The structural changes of the soil imply that the plants enhanced by the vermicompost and PGPB were effective in the remediation of the soil. Although some toxic elements are required for growth by plants, extreme concentration of these metals could be toxic to plants. Plants accumulate some nonessential metals in the process where they uptake the necessary ones during their growth and development (Djingova and Kuleff 2000).

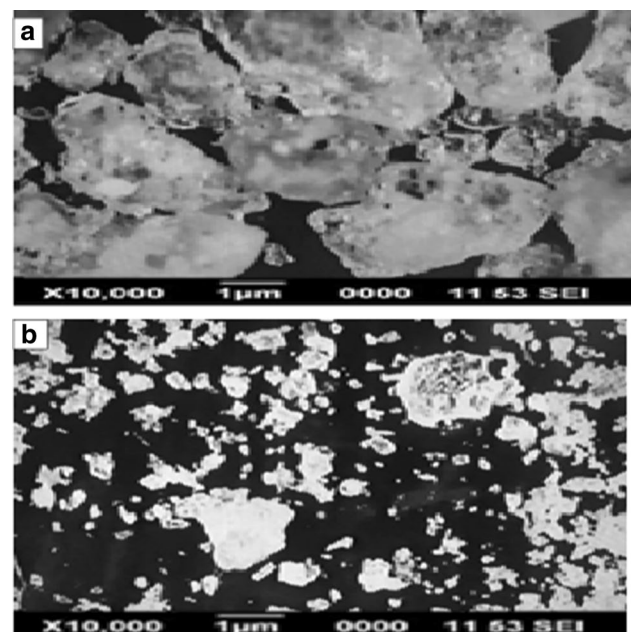
## Conclusion

Phytoremediation is a promising green technology that can be used to remediate toxic element present in the soils as contaminants. In developing countries like Nigeria, this technology can provide a low-cost solution to contaminated areas, especially abandoned industrial sites (mines and landfills). PGPB (*Bacillus safensis*) in combination with vermicompost produced from goat dung and chicken dropping manure has proved to be more effective than other combinations used. This study has revealed that the autochthonous plants (*M. officinalis* L. and *S. acuta*) around the polluted mining site when assisted with GMV and CDV had the ability to accumulate the toxic elements (Cd, As, and Pb) through phytoextraction and phytostabilizing mechanisms.



**Fig. 9** a SEM micrographs of the polluted soil before remediation with *M. officinalis* L. b SEM morphological appearance of the remediated soil with *M. officinalis* L.

There were no hyperaccumulators among the plants during this investigation; none exhibited phytovolatilization remediating mechanism. The results of this study had shown that



**Fig. 10** C. SEM micrographs of the polluted soil before remediation with *S. acuta*. D. SEM Morphological appearance of the remediated soil with *S. acuta*

plant species of *M. officinalis* L. and *S. acuta* can be used for containment, management, and remediation of soil polluted with toxic elements and hence reclaim it for agricultural purpose.

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**Authors Contributions** This work was carried out in collaboration with all authors. Author S.A. Aransiola anchored the field study, gathered the initial data, performed the preliminary data analysis, and designed the study. U.J.J. Ijah wrote the protocol and interpreted the data. Author O.P. Abioye and J.D. Bala managed the literature searches and produced the initial draft. All authors read and approved the final manuscript.

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**Availability of data and materials** Data are available on request from the authors. The data that support the findings of this study are available from the corresponding author upon reasonable request.

## Declarations

**Conflict of interest** The authors declare that there is no conflict of interest.

**Ethical Approval** Not applicable.

**Consent to Participate** Not applicable.

**Consent to Publish** All authors have approved the manuscript and agree with its submission to this journal.

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