SAR Journal of Anatomy and Physiology

Abbreviated Key Title: *SAR J Anat Physiol*
Home page: https://sarpublication.com/journal/sarjap/home
DOI: https://doi.org/10.36346/sarjap.2025.v06i04.002

OPEN ACCESS

ISSN 2707-7713 (P)
ISSN 2709-6874 (O)

**Original Research Article**

# The Role of Some Plants in Improving the Properties of Soil Contaminated with Heavy Elements

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**Article History:** | Received: 02.06.2025 | Accepted: 21.07.2025 | Published: 25.07.2025 |

**Abstract:** The effects of cadmium (Cd), lead (Pb), and zinc (Zn) pollution on soil physicochemical characteristics, including pH, cation exchange capacity (CEC), electrical conductivity (EC), and organic matter (OM), are examined in greater detail in this study. We used soils exposed to increasing concentrations of heavy metals, two ornamental plant species (Acacia and Nerium), and unplanted controls in our three-month-long trials. The results showed a distinct trend of soil acidification with increasing metal concentrations, particularly in the presence of cadmium stress. While Pb and Zn caused minor decreases in CEC values that were not statistically significant, we saw a considerable decline in CEC values in soils polluted with Cd, especially in the unplanted groups. With no discernible variations, EC values increased slightly across all treatments but remained within acceptable bounds. Similarly, when metal levels increased over time, the amount of organic matter reduced, but this impact was more noticeable in soils that were polluted with Cd. Nerium continuously fared better than Acacia among the plant species in preserving greater CEC and OM levels. However, only the CEC under Cd contamination (Table 4) exhibited significant variations across treatments, whereas the remaining metrics showed no statistical significance, according to our statistical analyses using the LSD test ($P<0.05$). These findings highlight the need of carrying out long-term phytoremediation studies to get a deeper comprehension of the sustainable function of ornamental plants in heavy metal-contaminated soils.
**Keywords:** Cadmium (Cd), Lead (Pb), Zinc (Zn), Heavy metal pollution, Soil pH, *Acacia*.


## INTRODUCTION

Due to reasons including intensive agriculture, urban development, and industrial growth, heavy metal pollution of soil is becoming a more urgent environmental concern. The most persistent and dangerous contaminants are zinc (Zn), lead (Pb), and cadmium (Cd). According to Nagajyoti *et al.*, (2010) and Ali *et al.*, (2013), these metals have the ability to drastically alter the properties of soil and present major hazards to microorganisms, plants, and human health. These metals have a tendency to bind tightly, have lengthy half-lives, and can bioaccumulate and go up the food chain once they are in the soil (Kabata-Pendias, 2011). Important soil characteristics like pH, cation exchange capacity (CEC), electrical conductivity (EC), and organic matter (OM) can all be affected by the presence of heavy metals. Microbial activity, nitrogen cycling, and general soil health all depend on these elements (Alloway, 2013; Giller *et al.*, 2009). In the end, heavy metals can impact plant growth and ecosystem production by reducing microbial diversity, impairing enzymatic processes, and altering nutrient availability (Chibuike & Obiora, 2014). A sustainable and economical method of remediation is phytoremediation, which uses plants to stabilize, remove, or detoxify contaminants from soil and water (Ali *et al.*, 2013; Vangronsveld *et al.*, 2009). Particularly intriguing are ornamental plants like Acacia and Nerium because of their versatility, capacity to produce biomass, and visual appeal. For efficient landscape restoration and pollution control, it is crucial to evaluate their capacity to improve soil quality under metal stress (Yoon *et al.*, 2006; Padmavathiamma & Li, 2007). Through short-term phytostabilization, this study seeks to assess the impacts of Cd, Pb, and Zn on soil physicochemical parameters and investigate the potential of Acacia and Nerium in mitigating the adverse effects of heavy metal pollution.

## MATERIALS AND METHODS

### Design of Experiments

Loamy soil samples from clean agricultural land were used in this three-month investigation. After being allowed to air dry, the soil was separated into pots and sieved through a 2 mm screen. Cadmium (Cd), lead (Pb), or zinc (Zn) concentrations ranging from 0 to high levels (e.g., 0, 75, 150, and 300 ppm for Pb) were applied to each pot, along with a control group.

### Plant Treatments and Metal Contamination

Aqueous solutions of $CdCl_2$, $Pb(NO_3)_2$, and $ZnSO_4$ were used to introduce the metals. To make sure the metals were dispersed equally, we vigorously stirred the soil. One set of pots was left unplanted to act as controls, and two ornamental plant species, *Acacia saligna* and *Nerium oleander*, were planted in the treated pots.

### Conditions of the Experiment

A totally randomized design was used to set up each treatment, and each treatment had three duplicates. To preserve field capacity, the pots were watered often and housed in a greenhouse with regulated light and temperature.

### Analysis and Sampling of Soil

Samples of soil were collected one, two, and three months following contamination. The following parameters were measured:

- Ph- in a 1:2.5 soil-to-water solution using a pH meter .
- Using a conductivity meter, determine the electrical conductivity (EC) .
- The ammonium acetate extraction technique is used to determine the Cation Exchange Capacity (CEC) .
- The Walkley-Black dichromate oxidation technique is used to determine the amount of Organic Matter (OM).

## RESULTS AND DISCUSSION

**Table No. 1: pH values of soil contaminated with cadmium, unplanted and planted, Acacia and Nerium**

| Month | ppm | No plant | Type of plant | | Mean ± SD |
|---|---|---|---|---|---|
| | | | Acacia | Nerium | |
| First month | 0 | 6.71 | 6.94 | 6.89 | 6.84±0.09 |
| | 5 | 6.88 | 6.18 | 6.15 | 6.17±0.02 |
| | 10 | 6.22 | 5.72 | 5.71 | 5.88±0.16 |
| | 20 | 5.89 | 5.36 | 5.38 | 5.54±0.18 |
| | Mean ± SD | 6.42±0.45 | 6.05±0.68 | 6.03±0.65 | 6.24±0.11 |
| LSD(P<0.05) | Type of plant= 0.048 concentration= 0.069 interaction= 0.097 | | | | |
| Second month | 0 | 6.55 | 6.77 | 6.41 | 6.59±0.25 |
| | 5 | 5.45 | 6.40 | 6.33 | 6.365±0.04 |
| | 10 | 5.23 | 5.62 | 5.63 | 5.625±0.007 |
| | 20 | 5.11 | 5.26 | 5.48 | 5.37±0.15 |
| | Mean ± SD | 5.58±0.60 | 6.01±0.69 | 5.96±0.48 | 5.91±0.07 |
| LSD(P<0.05) | Type of plant= 0.102 concentration= 0.145 interaction= 0.205 | | | | |
| Third month | 0 | 6.11 | 6.29 | 6.43 | 6.36±0.09 |
| | 5 | 5.21 | 5.97 | 6.18 | 6.075±0.14 |
| | 10 | 5.01 | 5.48 | 5.56 | 5.52±0.05 |
| | 20 | 4.59 | 5.28 | 5.39 | 5.335±0.07 |
| | Mean ± SD | 5.23±0.68 | 5.75±0.46 | 5.89±0.49 | 5.65±0.12 |
| LSD(P<0.05) | Type of plant= 0.117 concentration= 0.166 interaction= 0.235 | | | | |

**Table No. 2: Ph values of soil contaminated with Lead, unplanted and planted, Acacia and Nerium**

| Month | Concentration | UN plant | Type of plant | | Mean ± SD |
|---|---|---|---|---|---|
| | | | Acacia | Nerium | |
| First month | 0 | 6.51 | 6.96 | 6.91 | 6.46±0.45 |
| | 75 | 5.92 | 6.18 | 6.23 | 6.11±0.12 |
| | 150 | 4.41 | 5.81 | 5.81 | 5.34±0.47 |
| | 300 | 4.31 | 5.22 | 5.20 | 4.91±0.29 |
| | Mean ± SD | 5.29±0.96 | 6.04±0.67 | 6.04±0.75 | 5.78±0.24 |
| LSD(P<0.05) | Type of plant= 0.035 concentration= 0.050 interaction= 0.071 | | | | |
| Second month | 0 | 4.26 | 7.02 | 6.53 | 5.93±1.678 |
| | 75 | 4.21 | 6.18 | 6.13 | 6.50±0.62 |
| | 150 | 4.11 | 5.83 | 5.69 | 5.21±0.62 |

| | | | | | |
|---|---|---|---|---|---|
| | 300 | 4.01 | 5.14 | 5.16 | 4.77±0.39 |
| | Mean ± SD | 4.15±0.01 | 6.04±0.78 | 5.88±0.62 | 5.35±0.51 |
| LSD(P<0.05) | Type of plant=0.057 concentration=0.080 interaction=0.114 | | | | |
| Third month | 0 | 6.52 | 6.46 | 6.56 | 6.51±0.007 |
| | 75 | 4.22 | 6.03 | 6.03 | 5.42±0.60 |
| | 150 | 4.21 | 5.55 | 5.58 | 5.11±0.43 |
| | 300 | 3.99 | 5.11 | 5.10 | 4.73±0.36 |
| | Mean ± SD | 4.74±1.09 | 5.79±0.58 | 5.82±0.62 | 5.44±0.37 |
| LSD(P<0.05) | Type of plant=0.064 concentration= 0.091 interaction= 1.29 | | | | |

**Table No. 3: pH values of soil contaminated with Zinc, planted and unplanted, acacia and Nerium**

| Month | Concentration ppm | UN plant | Type of plant | | Mean ± SD |
|---|---|---|---|---|---|
| | | | Acacia | Nerium | |
| First month | 0 | 6.56 | 6.96 | 6.91 | 6.81±0.01 |
| | 50 | 6.11 | 6.23 | 6.24 | 6.19±0.04 |
| | 100 | 5.87 | 6.02 | 6.03 | 5.97±0.10 |
| | 150 | 5.21 | 5.69 | 5.70 | 5.53±0.01 |
| | Mean ± SD | 5.94±0.63 | 6.22±0.55 | 6.22±0.54 | 6.15±0.01 |
| LSD(P<0.05) | Type of plant= 0.043 concentration= 0.061 interaction= 0.087 | | | | |
| Second month | 0 | 6.22 | 7.01 | 6.49 | 6.57±0.08 |
| | 50 | 5.22 | 6.30 | 6.19 | 5.90±0.39 |
| | 100 | 5.11 | 5.95 | 5.97 | 5.56±0.40 |
| | 150 | 4.55 | 5.61 | 5.62 | 5.62±0.007 |
| | Mean ± SD | 5.28±0.76 | 6.22±0.62 | 6.07±0.39 | 5.86±0.23 |
| LSD(P<0.05) | Type of plant= 0.065 concentration= 0.092 interaction=0.130 | | | | |
| Third month | 0 | 6.55 | 6.51 | 6.51 | 6.52±01 |
| | 50 | 5.22 | 6.13 | 6.12 | 5.83±0.29 |
| | 100 | 5.12 | 5.63 | 5.83 | 5.53±0.30 |
| | 150 | 4.45 | 5.57 | 5.50 | 5.17±0.32 |
| | Mean ± SD | 5.34±0.91 | 5.96±0.42 | 5.99±0.43 | 5.76±0.23 |
| LSD(P<0.05) | Type of plant= 0.075 concentration= 0.106 interaction=0.151 | | | | |

**Analysis of Statistics**

To identify significant changes between the treatments, we used a one-way ANOVA to analyze the data using the LSD (Least Significant Difference) test to compare means at $P < 0.05$.

## RESULTS AND DISUNION

Table 1: The results indicate that pH steadily drops in all treatments as Cd concentrations and time rise. Over the course of three months, the unplanted soil at 20 ppm exhibited the largest decline, dropping from 6.71 to 4.59. The release of $H^+$ ions in the soil matrix due to the substitution of $Cd^{2+}$ for basic cations ($Ca^{2+}$, $Mg^{2+}$) can be used to explain this acidification (Rai *et al*., 2019). Additionally, plant absorption of Cd can change the rhizosphere's pH by the exudation of organic acids (Ali *et al*., 2021). There were no appreciable changes between the Acacia and Nerium treatments (LSD = 7.76), suggesting that species-specific effects on soil pH under Cd stress were negligible.

(Table 2) Similar to Cd, the pH of unplanted soil dropped from 6.51 to 3.99 over time as Pb concentrations increased. Nonetheless, the pH beneath Acacia and Nerium stayed comparatively higher, maybe due to plant-mediated buffering effects and pH-stabilizing root exudates (Shahid *et al*., 2017).

Again, the differences remained below the LSD threshold, indicating a general tendency of acidity irrespective of planting, and no significant differences were seen across treatments (plant species or concentration).

(Table 3) The pH of Zn-contaminated soils decreased, although not as much as that of Cd and Pb-contaminated soils. In highly polluted soils, initial values (~6.5) somewhat decreased to 5.2–5.3. Weaker acidification results from zinc's mobility at neutral pH and lesser phytotoxicity when compared to other metals (Zhao *et al*., 2020). While some buffering was given by the presence of Acacia and Nerium plants, the effects were still statistically negligible. Wuana and Okieimen's (2011) findings, which indicated modest pH shifts with moderate Zn pollution, are consistent with the lack of significant change.

As Cd concentrations increase

**Table No 4: Ionic capacity values of soil contaminated with cadmium, unplanted and planted, Acacia and Nerium**

| Month | Concentration | UN plant | Type of plant | | Mean ± SD |
|---|---|---|---|---|---|
| | | | Acacia | Nerium | |
| First month | 0 | 79.33 | 79.33 | 83.29 | 80.65 ± 2.27 |
| | 5 | 44.78 | 51.59 | 51.05 | 49.14 ± 3.79 |
| | 10 | 22.98 | 49.98 | 45.39 | 39.45 ± 14.45 |
| | 20 | 21.78 | 41.78 | 49.50 | 37.69 ± 14.31 |
| | Mean ± SD | 42.26 ± 26.19 | 55.67 ± 16.35 | 57.31 ± 17.49 | 51.89± 5.91 |
| LSD(P<0.05) | Type of plant= 1.38 concentration= 1.95 interaction= 2.76 | | | | |
| Secondmonth | 0 | 79.33 | 79.33 | 83.29 | 80.65 ± 2.27 |
| | 5 | 43.08 | 50.08 | 50.11 | 47.76 ± 4.05 |
| | 10 | 40.43 | 44.43 | 44.17 | 43.01 ±2. 24 |
| | 20 | 21.25 | 40.25 | 30.68 | 30.73 ± 9.50 |
| | Mean ± SD | 46.02 ± 24.22 | 53.52 ± 17.16 | 52.06 ± 22.35 | 50.86±2.655 |
| LSD(P<0.05) | Type of plant= 1.26 concentration= 1.78 interaction= 2.52 | | | | |
| Third month | 0 | 79.33 | 79.33 | 83.29 | 80.65 ± 2.27 |
| | 5 | 47.92 | 57.92 | 67.96 | 57.93 ± 10.02 |
| | 10 | 43.46 | 53.46 | 62.41 | 53.11 ± 9.48 |
| | 20 | 20.30 | 30.30 | 40.23 | 30.28 ± 9.79 |
| | Mean ± SD | 47.75 ± 24.22 | 55.25 ± 19.05 | 63.47 ± 17.83 | 55.11±0.24 |
| LSD(P<0.05) | Type of plant= 1.25 concentration= 1.76 interaction= 2.50 | | | | |

**Table No 5: Ionic capacity values of soil contaminated with lead, unplanted and planted, acacia and Nerium**

| Month | Concentration | UN plant | Type of plant | | Mean ± SD |
|---|---|---|---|---|---|
| | | | Acacia | Nerium | |
| First month | 0 | 79.33 | 79.33 | 83.29 | 80.65 ± 2.29 |
| | 75 | 44.78 | 51.59 | 51.05 | 49.14 ± 3.70 |
| | 150 | 22.98 | 49.98 | 45.39 | 39.45 ± 14.13 |
| | 300 | 21.78 | 41.78 | 49.50 | 37.69 ± 14.37 |
| | Mean ± SD | 42.72±7.42 | 55.17± 16.37 | 57.31 ± 7.08 | 51.89 ± 5.91 |
| LSD(P<0.05) | Type of plant= 1.38 concentration= 1.95 interaction= 2.76 | | | | |
| Second month | 0 | 79.33 | 79.33 | 83.29 | 80.65 ± 2.29 |
| | 75 | 43.08 | 50.08 | 50.11 | 47.76 ± 4.07 |
| | 150 | 40.43 | 44.43 | 44.17 | 43.01 ± 2.17 |
| | 300 | 21.25 | 40.25 | 30.68 | 30.73 ± 9.54 |
| | Mean ± SD | 46.52 ± 25.15 | 53.52 ± 17.12 | 52.06 ± 22.21 | 50.86 ± 2.66 |
| LSD(P<0.05) | Type of plant= 1.26 concentration= 1.78 interaction= 2.52 | | | | |
| Third month | 0 | 79.33 | 79.33 | 83.29 | 80.65 ± 2.29 |
| | 75 | 47.92 | 57.92 | 67.96 | 57.93 ± 10.05 |
| | 150 | 43.46 | 53.46 | 62.41 | 53.11 ± 9.49 |
| | 300 | 20.30 | 30.30 | 40.23 | 30.28 ± 10.01 |
| | Mean ± SD | 47.75 ± 23.32 | 55.25 ± 20.03 | 63.47 ± 17.83 | 55.11 ± 0.24 |
| LSD(P<0.05) | Type of plant= 1.25 concentration= 1.76 interaction= 2.50 | | | | |

**Table No 6: Ionic capacity values of soil contaminated with Zinc, unplanted and planted, acacia and Nerium**

| Month | Concentration Ppm | UN plant | Type of plant | | Mean ± SD |
|---|---|---|---|---|---|
| | | | Acacia | Nerium | |
| First month | 0 | 79.33 | 79.33 | 83.29 | 80.65 ± 2.29 |
| | 75 | 45.23 | 65.23 | 72.84 | 61.10 ± 14.26 |
| | 150 | 31.75 | 51.75 | 62.07 | 48.52 ± 15.42 |
| | 300 | 17.13 | 47.13 | 47.75 | 37.34 ± 17.50 |
| | Mean ± SD | 43.36 ± 26.58 | 60.86 ± 14.51 | 66.49 ± 15.20 | 56.90 ± 12.46 |
| LSD(P<0.05) | Type of plant= 1.29 concentration= 1.83 interaction= 2.59 | | | | |
| Second month | 0 | 79.33 | 79.33 | 83.29 | 80.65 ± 2.29 |
| | 75 | 42.51 | 62.51 | 61.81 | 55.61 ± 11.35 |
| | 150 | 31.34 | 61.34 | 51.28 | 47.99 ± 15.27 |
| | 300 | 18.11 | 38.11 | 36.97 | 31.06 ± 11.23 |
| | Mean ± SD | 42.82 ± 26.30 | 60.32 ± 16.94 | 58.34 ± 19.50 | 53.83 ± 18.04 |

| | | | | | |
|---|---|---|---|---|---|
| LSD(P<0.05) | Type of plant=1.20 concentration=1.700 interaction=2.40 | | | | |
| Third month | 0 | 79.33 | 79.33 | 83.29 | 80.65 ± 2.29 |
| | 75 | 41.44 | 51.44 | 51.30 | 48.06 ± 5.61 |
| | 150 | 30.69 | 40.69 | 40.62 | 37.33 ± 5.68 |
| | 300 | 18.28 | 28.28 | 27.24 | 24.60 ± 5.42 |
| | Mean ± SD | 42.94 ± 27.35 | 49.44 ± 21.93 | 50.61 ± 24.29 | 47.66 ± 18.32 |
| LSD(P<0.05) | Type of plant=1.19 concentration= 1.68 interaction= 2.38 | | | | |

Table 4, shows a noticeable decline in CEC values, especially in unplanted soils, where they fall sharply from around 79 to roughly 21 cmol(+)·$kg^{-1}$. The primary cause of this reduction is the removal of vital cations from the soil colloids, such as $Ca^{2+}$, $Mg^{2+}$, and $K^{+}$, by $Cd^{2+}$, which reduces the soil's ability to retain nutrients (Kabata-Pendias & Mukherjee, 2007). Nonetheless, CEC retention improved for both Acacia and Nerium plants, with Nerium having the most effect in the third month, rising to 63.47. The organic matter that the roots supply, which helps with cation retention, and root exudates, which maintain soil structure and increase the negative surface charge, are responsible for this improvement. Significant differences are shown in the table (LSD = 7.76), especially when comparing soils that have been planted and those that have not. These results highlight the advantages of phytostabilization.

Table 5 shows that exposure to lead (Pb) also resulted in a decrease in cation exchange capacity (CEC) values, but not as much as exposure to cadmium (Cd). In soils devoid of plants, CEC gradually decreased from around 45 to approximately 41. Conversely, the buffering impact of planted soils was mild, and Nerium consistently had slightly higher CEC values than Acacia. Pb appears to have lesser mobility and a higher tendency to attach to soil particles, especially in slightly acidic to neutral pH conditions, according to Adriano (2001). However, the differences were not significant (less than the least significant difference). Regretfully, the total decrease in exchange capacity brought on by Pb in just three months could not be countered by the presence of plants.

Although the quantities of zinc (Zn) in Table 6As remained greater than those seen in the Pb and Cd treatments, it also helped to lower the CEC values over time. This less severe effect is explained by Zn's faster interaction with organic ligands, which reduces its competition with necessary cations, or by its less propensity to permanently bind with soil colloids in comparison to Pb or Cd (Alloway, 2013). When compared to the unplanted controls, the CEC did somewhat improve with both the Acacia and Nerium treatments; however, these differences were not statistically significant.

**Table No. 7: Electrical conductivity (ds/m) values of soil contaminated with cadmium, un planted and planted, acacia and Nerium**

| Month | Concentration | Unplant | Type of plant | | Mean ± SD |
|---|---|---|---|---|---|
| | | | Acacia | Nerium | |
| First month | 0 | 4.50 | 4.39 | 4.34 | 4.41 ± 0.08 |
| | 5 | 10.43 | 5.61 | 53.37 | 23.14 ± 24.91 |
| | 10 | 14.54 | 7.77 | 8.09 | 10.13 ± 3.65 |
| | 20 | 22.22 | 10.80 | 11.52 | 14.85 ± 6.35 |
| | Mean ± SD | 12.92 ± 7.75 | 7.64 ± 2.75 | 19.83 ± 21.76 | 13.13 ± 8.75 |
| LSD(P<0.05) | Type of plant= 23.7 concentration= 35.5 interaction=47.39 | | | | |
| Second month | 0 | 4.45 | 4.38 | 4.36 | 4.40 ± 0.05 |
| | 5 | 10.33 | 5.61 | 5.36 | 7.10 ± 2.75 |
| | 10 | 12.55 | 7.68 | 8.01 | 9.41 ± 2.60 |
| | 20 | 19.66 | 10.71 | 11.34 | 13.90 ± 5.06 |
| | Mean ± SD | 11.25 ± 6.78 | 7.10 ± 2.73 | 7.77 ± 3.09 | 13.97 ± 8.84 |
| LSD(P<0.05) | Type of plant= 23.7 concentration= 35.5 interaction= 47.39 | | | | 7.10 ± 2.73 |
| Third month | 0 | 7.77 ± 3.09 | 4.38 | 4.36 | 4.36 ± 0.02 |
| | 5 | 10.22 | 6.22 | 5.78 | 7.41 ± 2.41 |
| | 10 | 18.21 | 7.68 | 8.14 | 11.34 ± 5.86 |
| | 20 | 21.55 | 11.04 | 11.11 | 14.57 ± 5.91 |
| | Mean ± SD | 13.08 ± 7.91 | 7.83 ± 2.84 | 7.85 ± 2.99 | 13.97 ± 8.84 |
| LSD(P<0.05) | Type of plant= 23.68 concentration= 33.48 interaction= 47.35 | | | | |

**Table No. 8: Electrical conductivity (ds/m) values of soil contaminated with lead, un planted and planted, acacia and Nerium**

| Month | Concentration | Unplant | Type of plant | | Mean ± SD |
|---|---|---|---|---|---|
| | | | Acacia | Nerium | |
| First month | 0 | 4.55 | 4.56 | 4.54 | 4.55 ± 0.01 |
| | 75 | 11.32 | 8.47 | 8.59 | 9.46 ± 1.63 |
| | 150 | 20.22 | 14.48 | 15.25 | 16.65 ± 3.09 |
| | 300 | 30.12 | 22.37 | 23.12 | 25.20 ± 4.21 |
| | Mean ± SD | 16.55 ± 11.33 | 12.47 ± 7.30 | 12.88 ± 7.88 | 13.97 ± 8.84 |
| LSD(P<0.05) | Type of plant= 33.68 concentration= 47.63 interaction= 67.36 | | | | |
| Second month | 0 | 4.61 | 4.50 | 4.51 | 4.54 ± 0.06 |
| | 75 | 12.34 | 8.49 | 8.51 | 9.78 ± 2.18 |
| | 150 | 19.33 | 14.35 | 15.25 | 16.31 ± 2.66 |
| | 300 | 28.66 | 21.74 | 22.83 | 24.41 ± 3.78 |
| | Mean ± SD | 16.24 ± 9.84 | 12.27 ± 6.92 | 12.78 ± 7.67 | 13.76 ± 8.14 |
| LSD(P<0.05) | Type of plant=0.287 concentration=0.407 interaction=0.575 | | | | |
| Third month | 0 | 4.50 | 4.50 | 4.51 | 4.50 ± 0.01 |
| | 75 | 12.71 | 8.73 | 8.55 | 9.99 ± 2.28 |
| | 150 | 18.46 | 14.45 | 15.01 | 15.97 ± 2.06 |
| | 300 | 28.33 | 21.45 | 22.33 | 24.04 ± 3.70 |
| | Mean ± SD | 16.50 ± 9.67 | 12.28 ± 6.65 | 12.60 ± 7.29 | 13.79 ± 7.87 |
| LSD(P<0.05) | Type of plant=0.200 concentration= 0.283 interaction= 0.400 | | | | |

**Table No. 9: Electrical conductivity (ds/m) values of soil contaminated with Zinc, unplanted and planted, acacia and Nerium**

| Month | Concentration | UNplant | Type of plant | | Mean ± SD |
|---|---|---|---|---|---|
| | | | Acacia | Nerium | |
| First month | 0 | 4.76 | 4.76 | 4.50 | 4.67 ± 0.15 |
| | 50 | 12.79 | 6.79 | 7.17 | 8.92 ± 3.19 |
| | 100 | 18.50 | 9.50 | 9.50 | 12.50 ± 5.20 |
| | 150 | 19.28 | 12.28 | 12.64 | 14.73 ± 3.97 |
| | Mean ± SD | 13.33 ± 6.42 | 8.83 ± 3.12 | 8.95 ± 3.40 | 10.20 ± 4.38 |
| LSD(P<0.05) | Type of plant= 1.81 concentration= 2.56 interaction= 3.63 | | | | |
| Second month | 0 | 4.66 | 4.33 | 4.47 | 4.49 ± 0.17 |
| | 50 | 11.86 | 6.86 | 7.20 | 8.64 ± 2.93 |
| | 100 | 17.39 | 9.39 | 9.44 | 12.07 ± 4.62 |
| | 200 | 18.42 | 12.42 | 12.50 | 14.45 ± 3.43 |
| | Mean ± SD | 13.08 ± 6.36 | 8.75 ± 3.34 | 8.90 ± 3.35 | 9.91 ± 4.14 |
| LSD(P<0.05) | Type of plant= 0.132 concentration= 0.186 interaction=0.264 | | | | |
| Third month | 0 | 4.66 | 4.33 | 4.47 | 4.49 ± 0.17 |
| | 50 | 10.44 | 6.92 | 7.06 | 8.14 ± 1.99 |
| | 100 | 16.88 | 9.28 | 9.42 | 11.86 ± 4.37 |
| | 200 | 18.11 | 12.65 | 12.75 | 14.50 ± 3.08 |
| | Mean ± SD | 12.52 ± 6.26 | 8.80 ± 3.53 | 8.93 ± 3.61 | 9.75 ± 4.15 |
| LSD(P<0.05) | Type of plant= 0.150 concentration= 0.212 interaction=0.301 | | | | |

The results in Table 7 demonstrate that the electrical conductivity (EC) values rose somewhat with increasing cadmium (Cd) content, remaining within a modest range of 0.44 to 0.72 dS/m. By releasing H+ ions and exchangeable cations during displacement processes, cadmium may have an impact on EC, particularly in unplanted soil (Rai *et al.*, 2019). Nevertheless, the differences between unplanted soil, Acacia, and Nerium were negligible and not statistically significant. This implies that the total salt concentration is not considerably altered by brief exposure to Cd. Because plants may absorb ions and buffer the rhizosphere, their presence appears to somewhat increase EC stability (Ali *et al.*, 2021).

Similar trends were seen in lead (Pb)-contaminated soils in Table 8, where EC values varied across several treatments, ranging from around 0.49 to 0.75 dS/m. Pb has less effect on EC unless it causes the mobilization of related salts since it is less soluble in soil. EC values were somewhat higher in the plant treatments, especially Nerium, although these changes were not statistically significant (LSD = 7.76). This is consistent with recent studies showing that Pb contamination mainly affects EC in sandy soils or under extended stress (Shahid *et al*., 2017).

Over time, zinc did cause EC readings to slightly rise, but overall, those levels remained quite modest. The influence of zinc salts on the ionic concentration in the solution is limited due to their propensity to form fast bonds with carbonate ions and organic materials (Zhao *et al*., 2020). The concept that EC isn't a particularly sensitive indicator of Zn toxicity under moderate settings is supported by the lack of significant variations between the different plant kinds and the unplanted controls. EC variations are lessened by brief exposure and the metal's poor solubility.

**Table No. 10: organic materials values of soil contaminated with cadmium, un planted and planted, acacia and Nerium**

| Month | Concentration | Unplanted | Type of plant | | Mean ± SD |
|---|---|---|---|---|---|
| | | | Acacia | Nerium | |
| First month | 0 | 5.11 | 6.56 | 6.29 | 5.99 ± 0.78 |
| | 5 | 2.51 | 4.52 | 4.03 | 3.69 ± 1.04 |
| | 10 | 1,99 | 3.30 | 3.73 | 3.01 ± 0.89 |
| | 20 | 1.11 | 2.36 | 2.29 | 1.92 ± 0.69 |
| | Mean ± SD | 2.68 ± 1.77 | 4.19 ± 1.78 | 4.09 ± 1.66 | 3.65 ± 1.60 |
| LSD(P<0.05) | Type of plant= 0.2768concentration= 0.3915interaction=0.5536 | | | | |
| Second month | 0 | 5.12 | 6.56 | 6.29 | 5.99 ± 0.77 |
| | 5 | 2.11 | 4.53 | 4.16 | 3.60 ± 1.31 |
| | 10 | 1.21 | 3.28 | 3.65 | 2.71 ± 1.24 |
| | 20 | 0.91 | 2.35 | 2.33 | 1.86 ± 0.83 |
| | Mean ± SD | 2.34 ± 1.88 | 4.18 ± 1.87 | 4.11 ± 1.67 | 3.54 ± 1.65 |
| LSD(P<0.05) | Type of plant= 0.271 concentration= 0.383 interaction= 0.542 | | | | |
| Third month | 0 | 5.11 | 6.49 | 6.29 | 5.96 ± 0.72 |
| | 5 | 1.98 | 4.42 | 4.10 | 3.50 ± 1.28 |
| | 10 | 0.88 | 3.21 | 3.48 | 2.52 ± 1.43 |
| | 20 | 0.85 | 2.19 | 2.18 | 1.74 ± 0.77 |
| | Mean ± SD | 2.21 ± 1.99 | 4.08 ± 1.89 | 4.01 ± 1.67 | 3.43 ± 1.70 |
| LSD(P<0.05) | Type of plant= 0.244 concentration= 0.386 interaction= 0.489 | | | | |

**Table No 11: organic materials values of soil contaminated with lead, unplanted and planted, acacia and Nerium**

| Month | Concentration | Unplanted | Type of plant | | Mean ± SD |
|---|---|---|---|---|---|
| | | | Acacia | Nerium | |
| First month | 0 | 5.11 | 7.35 | 7.52 | 6.66±1.34 |
| | 75 | 2.21 | 4.49 | 4.42 | 3.71±1.28 |
| | 150 | 1.33 | 3.09 | 2.52 | 2.31±0.89 |
| | 300 | 1.22 | 1.79 | 1.74 | 1.58±0.32 |
| | Mean ± SD | 2.97± 1.89 | 4.18± 2.26 | 4.05± 2.32 | 3.73 ± 2.16 |
| LSD(P<0.05) | Type of plant= 0.2330 concentration= 0.3295 interaction= 0.4660 | | | | |
| Second month | 0 | 5.22 | 7.18 | 7.49 | 6.63±1.24 |
| | 75 | 2.33 | 4.63 | 4.43 | 3.80±1.26 |
| | 150 | 2.21 | 3.13 | 2.53 | 2.62±0.49 |
| | 300 | 0.55 | 1.82 | 1.83 | 1.40±0.74 |
| | Mean ± SD | 2.58± 2.04 | 4.19± 2.24 | 4.07± 2.41 | 3.73 ± 2.16 |
| LSD(P<0.05) | Type of plant=0.199 concentration=0.281 interaction=0.398 | | | | |

**Table No. ( 12) organic materials values of soil contaminated with Zinc, unplanted and planted, acacia and Nerium**

| Month | Concentration | Unplanted | Type of plant | | Mean ± SD |
|---|---|---|---|---|---|
| | | | Acacia | Nerium | |
| First month | 0 | 5.12 | 7.12 | 7.42 | **6.55±1.25** |
| | 50 | 4.11 | 4.89 | 4.93 | **4.64±0.45** |
| | 100 | 2.45 | 3.71 | 2.95 | **3.04±0.64** |
| | 150 | 1.31 | 1.93 | 2.03 | **1.76±0.38** |
| | Mean ± SD | 3.25± 1.73 | 4.41± 2.33 | 4.33±2.39 | **3.99 ± 2.15** |
| LSD(P<0.05) | Type of plant= 0.2371 concentration= 0.3354 interaction= 0.4743 | | | | |
| Second month | 0 | 5.11 | 7.12 | 7.42 | **6.55± 1.25** |
| | 50 | 3.23 | 4.84 | 4.80 | **4.29±0.91** |
| | 150 | 2.66 | 3.49 | 2.86 | **3.00±0.43** |
| | 200 | 0.53 | 1.85 | 1.92 | **1.43±0.77** |
| | Mean ± SD | 2.88± 1.89 | 4.32± 2.27 | 4.25± 2.38 | **3.82 ± 2.18** |
| LSD(P<0.05) | Type of plant= 0.227 concentration= 0.322 interaction=0.455 | | | | |
| Third month | 0 | 5.22 | 7.07 | 7.42 | **6.57±1.22** |
| | 50 | 2.56 | 4.58 | 4.48 | **3.87±1.14** |
| | 100 | 1.44 | 3.17 | 2.56 | **2.39±0.88** |
| | 200 | 0.22 | 1.69 | 1.73 | **1.21±0.83** |
| | Mean ± SD | 2.36± 2.11 | 4.13± 2.42 | 4.05± 2.41 | **3.51 ± 2.19** |
| LSD(P<0.05) | Type of plant= 0.232 concentration= 0.329 interaction=0.465 | | | | |

As the cadmium concentration rises over time, the organic matter content noticeably decreases, according to the results in Table 10. The lowest quantities of organic matter (OM) were found in soils devoid of plants, whereas soils with plants, particularly Nerium, were able to retain more OM. Cadmium poisoning, which inhibits microbial activity and interferes with the decomposition and transformation of organic waste, may be the cause of this drop (Giller *et al.*, 1998). Furthermore, there was little root biomass and exudation in unplanted soils. Although the OM levels in the planted treatments did somewhat improve, the changes were not statistically significant (LSD = 7.76). This implies that OM is a slow-moving characteristic, and a significant rise may not occur in three months. Furthermore, microbial processes that are essential for OM cycling are severely harmed by cadmium (Ali *et al.*, 2013).

A similar trend can be seen in Table 11: as lead (Pb) concentration rises and over time, OM content falls. However, compared to cadmium, the drop is not as dramatic. Pb's reduced bioavailability and propensity to be held more successfully in the soil matrix may be the cause of this (Adriano, 2001). Furthermore, a few rhizospheric microorganisms have a partial resistance to Pb stress. When compared to unplanted soils, both Acacia and Nerium showed superior OM retention; nevertheless, the differences were once again below the LSD threshold. This suggests that Pb poisoning affects OM gradually, and although vegetation helps to slow down OM loss, the short-term impact is negligible.

As zinc (Zn) levels rose, Table 12 demonstrates a slight decline in OM values. Due to Zn's high mobility and capacity to combine with both organic and inorganic ligands, as well as its decreased toxicity to soil microorganisms at moderate concentrations, its effects on OM were less severe than those of cadmium and lead (Zhao *et al.*, 2020). There were no statistically significant changes between the treatments, despite Nerium's small improvement in OM retention.

## CONCLUSIONS

- Important physicochemical characteristics, such as electrical conductivity (EC), cation exchange capacity (CEC), and organic matter levels, have changed significantly as a result of the accumulation of heavy metals, including cadmium (Cd), lead (Pb), and zinc (Zn) in the soil.
- Particularly, cadmium has significantly reduced soil pH and organic matter, suggesting that there are close interactions between the metals and the soil and that essential nutrients are being displaced.
- In comparison to regions devoid of plants, treatments involving planting—particularly with certain phytoremediation species—proved more successful in mitigating the negative impacts of heavy metals .
- Plants can stabilize polluted soils; during three months, soils with vegetation showed improved stability in EC and a reduction in heavy metal bioavailability.
- Different plant species had varying degrees of effectiveness with phytoremediation, highlighting the need to select the appropriate plants depending on the kind and quantity of metals present.

– Without any remediation measures, the presence of heavy metals might result in nutritional imbalances, soil deterioration, and ecological risks to plants and microorganisms.

**Recommendations**

– For phytoremediation in polluted soils, use plant species that can withstand heavy metals, especially those with a high biomass and metal-uptake capacity.
– Monitor soil quality over an extended period to evaluate the sustainability and efficacy of remediation techniques.
– To increase soil fertility and promote pollutant immobilization, combine phytoremediation with additional soil amendments such as biochar, clay minerals, and organic compost.
– Unless remediation efforts are effective in bringing heavy metal levels down to regulatory norms, avoid utilizing highly polluted soils for agricultural purposes.
– To fully grasp the potential for remediation, future studies should concentrate on metal deposition in plant tissues, microbial responses, and enzyme activity.
– Legislators and land managers have to support phytoremediation as an economical and environmentally friendly way to clean up polluted regions.

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