FJARD VOL. 37, NO. 1. PP. 63 - 81 (2023)

Fayoum Journal of Agricultural Research
and Development
ISSN:1110- 7790
On Line ISSN:2805-2528

Assessment of phytoremediation efficacy of *Amaranthus viridis* L. against cadmium and nickel

Mai Sayed Fouad[1], Manar A. Megahed[1*], Nabil A. Abo Hamed [1],
Hoda F. Zahran[2], Abdel-NasserA. Abdel-Hafeez[3]
[1] Botany Department, Faculty of Science, Fayoum University, 63514, Fayoum, Egypt
[2] Pollution Management Department, Environment and natural materials research institute, City of Scientific Research and Technological Applications (SRTA-City), New Borg Al-Arab City 21934, Alexandria, Egypt
[3] Soils and Water Department, Faculty of Agriculture, Fayoum University, 63514, Fayoum, Egypt

ABSTRACT:

Phytoremediation as an emerging advantageous technique may play a strong role in overcoming the issue of heavy metals accumulation in the soil. The main purpose of this work was to assess the efficiency of *Amaranthus viridis* as a phytoremediator weed to remove cadmium, Cd (0.0, 2.5, 5 ,20 ,80 and 200 ppm) and nickel, Ni (0.0, 60, 80, 160, 320 and 400 ppm) from soil. The experiment was held with seed cultivation in pots filled with sandy loam soil to apply phytoremediation process for 67 days. The obtained results prove the coinciding depression in root length, shoot length and number of leaves by about 85% with serial augmentation of Cd and of Ni. Bioconcentration Factor (BCF) and Translocation Factor (TF) values are indicator for high uptake and accumulation of Cd more than of Ni in roots rather than in shoots.

Statistical analyses included descriptive analyses, one way ANOVA and Pearson Coefficient variant ($p \leq 0.05$) proved highly positive significant effects. This study put the candidate species in the tilt of promising plants that would be effective in Cd and Ni phytostabilization.

KEY WORDS: *Amaranthus viridis*; phytoremediation; heavy metals; Bioconcentration Factor; metal hyperaccumulation.

---

*Corresponding author: ✉ mam41@fayoum.edu.eg
Received: 22/11/ 2022
Accepted:23/12/ 2022

1. INTRODUCTION:

Heavy metals (HMs) discrimination depends on their specific gravity which exceeds that of water by five folds and have an atomic number more than 20 (Ali et al., 2019). Classification of HMs depends on their needed quantity. Iron, copper, nickel, cobalt and zinc are essential when used in small quantities as nutrients for plants and humans but are toxic in higher quantities. Iron, copper and zinc are crucial in photosynthesis and in enzyme activity as cofactors. Cd , Pb and Cr are nonessential as they have no biological function *(Volland* et al., 2014).

Industry, volcanic emissions, pesticides, fertilizers, automobile exhausts and urban wastes are the main reasons of HMs spreading (Tchounwou et al., 2012) . The presence of HMs in soil and water bodies is known to significantly deteriorate the quality of such soil and water *(*Tan et al., 2021). HMs in the soil from anthropogenic sources tend to be more mobile, hence more bioavailable than pedogenic, or lithogenic ones (Wuana and Okieimen, 2011). Due to their movement through plants and subsequent accumulation via the food chain, HMs are discharged into the environment, posing a serious threat to plants, animals and people (Fan et al., 2017; Karahan et al., 2020; Rai et al., 2019)**.** The process of HMs uptake and transport by plants is known as phytoextraction which includes the ion entry to the root system and subsequent translocation to the aboveground organs through mass flow and diffusion (Yan et al., 2020)**.**

Among HMs, cadmium (Cd) and nickel (Ni) are commonly considered as toxic to both plants and humans (Tchounwou et al., 2012). Plant growth reduction and declined photosynthetic activity are the main symptoms of HMs toxicity (Yang et al., 2020).

Cadmium (Cd) is one of the most deleterious pollutants that easily absorbed by plants, then distributed to all plant organs, and thus freely transferred to the food chain. Due to its inhibitory effects on plant photosynthesis, enzyme activity and ion uptake, Cd may lower yield and quality of plant production (Haider et al., 2021)**.**

As a result of deposition through anthropogenic activities, the distribution of Ni in soil profile is uniform, with typical accumulation at the surface soil (Zhou et al., 2020). Some fertilizers and soil amendments, which are used in agriculture, are chief source of soil Ni (Khan et al., 2017)**. (**Yan et al., 2020) stated that, after absorption by the root, the formation of organic complexes is the route of Ni movement to the aboveground parts of plants.

Phytoremediation is a technology which makes use of plants (herbs, shrubs and trees) to remediate the contaminated medium and bring it to innocuous state while achieving the goal of sustainability (Nedjimi, 2021). Phytoremediation involves the use of HMs-accumulating plants to extract contaminants from the soil (Yan et al., 2020).

Plants were classified to be tolerant to HMs when they show rapid growth, high biomass and are capable to accumulate high amounts of HMs in their shoots, without signs of toxicity (Abdelkrim et al., 2019; Sarma, 2011). (Yan et al., 2020) stated That plants growing in contaminated soils exhibit several strategies while coping with the toxicity of heavy metals including preventing their accumulation, detoxification or metal excretion from the tissues.

The hyperaccumulator plant species can accumulate HMs 50 to 100 times higher and more efficiently compared to other non-accumulator plant species(Ao, 2019). Many plant species have been identified for their effectiveness in phytoremediation. (Assad et al., 2017) mentioned that *Amaranthus spp.* is a cosmopolitan annual or perennial plant, including restricted endemics and widespread weeds, which are commonly referred as 'Amaranths' or 'Pigweeds'. North and Central America is the native country of Amaranth. Nowadays pigweeds plants invasion become cosmopolitan in Europe, Asia, Africa, and Australia as a result of agriculture practicing (Vincent et al., 2019). The uptake of HMs by *Amaranthus* species has been recently studied in soils at refuse dump sites, animal waste dump sites and other forms of contaminated soils (Yap et al., 2022).

Amaranth was included in a list of plants that exhibit resistance to HMs and it has the potential to clean up toxic HMs (Iori et al., 2013). Some *Amaranthus* species are very resistant to HMs, this was concluded from assessing research related to the antioxidant system and the degree of damage to cell membranes and morphological response under HMs stress (Emamverdian et al., 2015). *Amaranthus viridis* particularly was recorded as good biomonitoring agent for Cd, Fe, Ni and Zn respectively (Yap et al., 2022).

The current study was elaborated to determine the capability of *Amaranthus viridis* in the newly emerged field of phytoremediation. The work is focusing on tackling the problem of soil contamination with Cd or Ni and their accumulation rates and mobility through the target plant body. The research is extended to measure some morphological changes in plant growth resulting from metal absorption by roots and their translocation to shoot.

2.MATERIALS AND ETHODS:

1. Plant material

Seeds of ***A. viridis*** were collected from Fayoum depression, Egypt.

2. Chemicals

Acids (HCl and HNO_3) as well as standards (for ICP) were of analytical grade and were obtained from Sigma-Aldrich Chemicals (Steinheim, Germany). Metal salts were gained from Fluka Chemicals (Munich, Germany).

3. Experimental design

Pot experiment was conducted to examine *A. viridis* efficiency toward Cd and Ni absorption and how they in turn affect ***A. viridis*** growth. Sixty plastic pots were cleaned, filled with 4 kg sandy loam soil (devoid of Ni and Cd) for each and then they were divided into two sets. The first and second sets were artificially contaminated with serial concentrations of Cd (0.0, 2.5, 5, 20, 80 and 200 ppm) and Ni (0.0, 60, 80, 160, 320 and 400 ppm), respectively. Heavy metals solutions were prepared by dissolving salts of $Cd(NO_3)_2.4H_2O$ and $Ni(NO_3)_2$ separately in deionized water.

The above-mentioned number of pots were prepared to guarantee four replicates for each concentration. Metals concentrations were chosen on the basis of a preliminary experiment and previous studies (figures S1 and S2).

Seeds were rinsed with water and then, twenty-five healthy seeds were sown in each pot and covered with a thin layer of soil. Soil was kept saturated with water until the seedling's emergence. Experiment was performed at 25 ± 2 °C and under16/8 h photoperiod.

Soil watering was standardized regularly when needed till the harvest time at sixty seventh day before entering flowering stage. Survival percentage and some growth criteria (root length, shoot length and number of leaves) were recorded at harvest time.

4. Determination of Metal Content

Candidate plant yield was harvested, washed with tap water followed by rinsing with 3% HCl and then with deionized water. The harvested individuals were subjected to separation of shoot system from root system and allowed to be air dried. Each part was pulverized and digested in triplicates with nitric acid and hydrogen peroxide, temperatures were raised to about 95°C until evolution of nitrous gas stopped and the digest became clear. After dilution the digest was analyzed for Cd and Ni. The total concentration of each metal was determined as ppm of D Wt. in plant and soil as well using inductively coupled plasma mass spectroscopy (Agilent 7500a, USA) (Liang et al., 2013).

5. Assessment of phytoremediation efficiency

Both the bioconcentration factor (BCF) and the translocation factor (TF) were utilized to calculate the plant's ability to uptake and withstand metals (Yap et al., 2022).

5.1. Bioconcentration factor (BCF)

The ability of candidate plant to uptake metal with respect to concentration in the surrounding soil is determined by the biological concentration factor (BCF) (Amin et al., 2018).

BCF = Metal concentration in plant tissues at harvest / Initial concentration of metal in the soil.

5.2. Translocation factor (TF)

The ratio of metal concentration in plant shoot to that in plant root was calculated as **TF= metal conc. in shoot/ metal conc. in root** (Amin et al., 2018).

6. Statistical analysis

All analyses and plots were done using the R programming language (version 4.0.2.) (R Core Team 2021). To plot the model predictions along with the raw data, we used different functions from the tidy verse (Wickham et al., 2016). One-way ANOVA was conducted using SPSS (George and Mallery, 2012).

3. RESULTS AND DISCUSSION:

1. Survival percentage

The ascending application of Cd or Ni is inversely proportional to the percentage of survived seeds as can be observed from Figure 1 (a and b) respectively.

The finding of seed survival percentage is confirmed from the clear variation in the number of growing individuals in pots with different metal concentrations (figures S1 and S2).

Statistically, the differences in survival percentage are more significantly obvious in case of Ni treatment rather than in case of Cd. Seed survival reached to more than 75% in case of Ni meanwhile it did not exceed 37% in case of Cd.

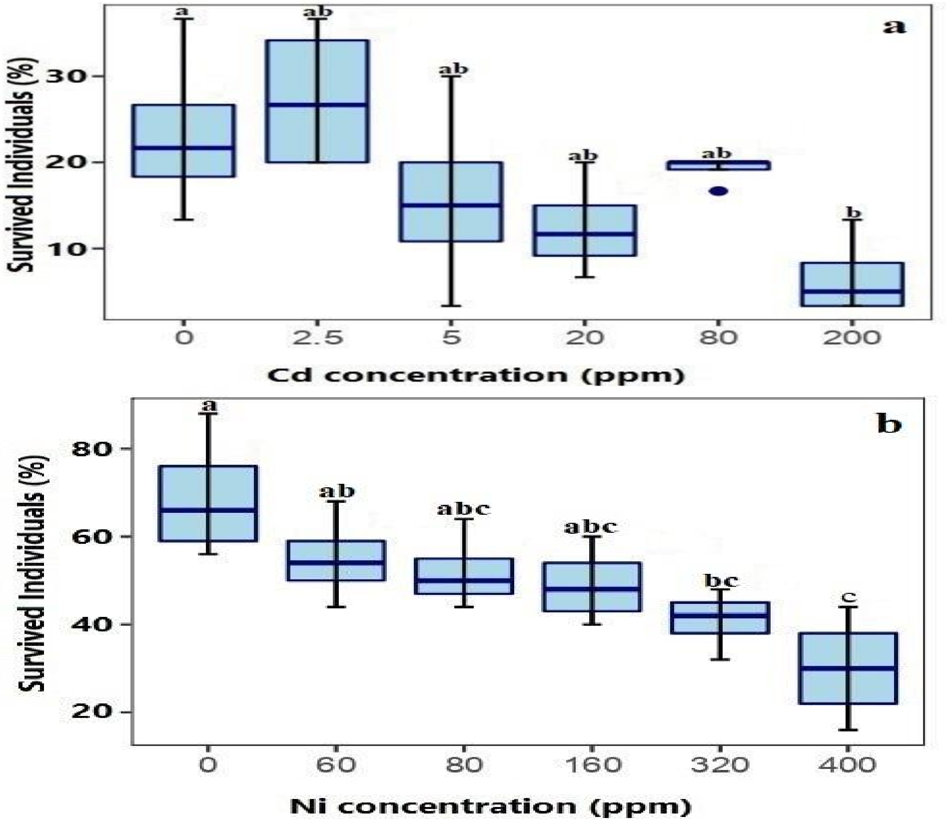
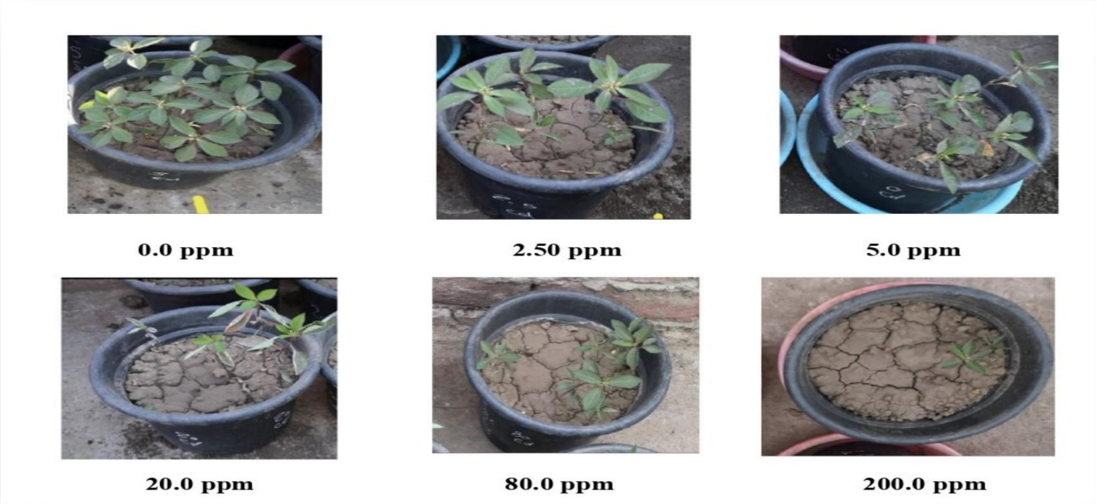
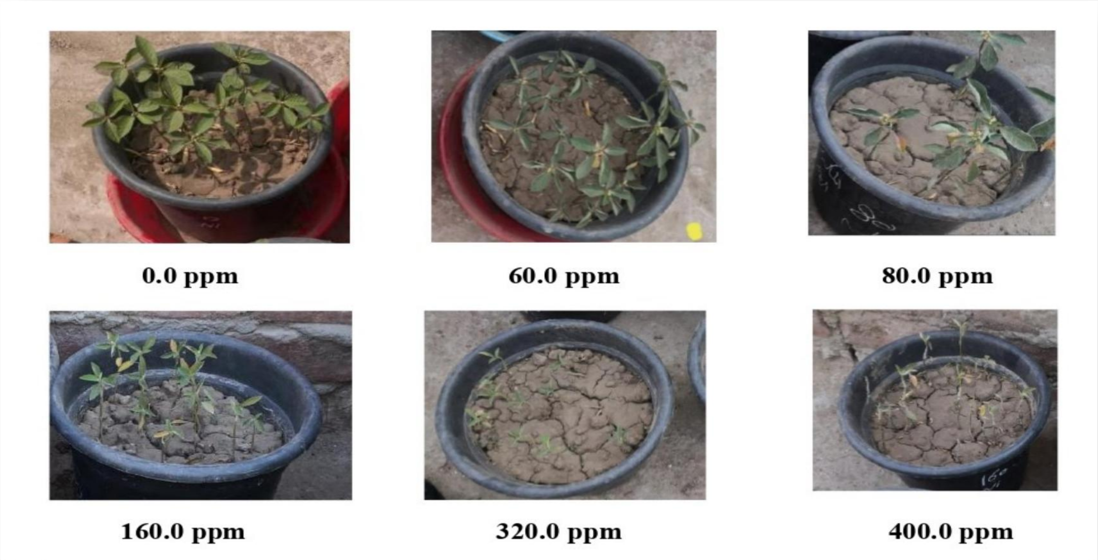


Fig. 1. Seed survival of *Amaranthus viridis* (mean ±SD) at different concentrations of (a) Cd and (b) Ni. Means followed by different letters are statistically significant ($P \leq 0.05$).



0.0 ppm
2.50 ppm
5.0 ppm
20.0 ppm
80.0 ppm
200.0 ppm

Fig. S1. Effect of different Cd concentration on *Amaranthus viridis* growth at harvest time.



0.0 ppm
60.0 ppm
80.0 ppm
160.0 ppm
320.0 ppm
400.0 ppm

Fig. S2. Effect of different Ni concentration on *Amaranthus viridis* growth at harvest time.

2. Measurements of *Amaranthus viridis* growth criteria

Root length, shoot length and number of leaves were measured for Cd and Ni treatments and plotted in figure 2 (a) and (b) respectively at harvest time. The obtained mean values of root length, shoot length and leaves number at 0.00 ppm and at 200 ppm Cd concentration were 10 cm, 11 cm, 8 leaves and were 5cm, 2.5 cm and one leaf respectively at the harvest time. The results explain the opposite relation between plant growth parameters and increasing Cd concentrations.

The same method was used to determine how Ni affected root length, shoot length, and leaf count, indicating a negative relationship between Ni concentration and plant growth.

3. Determination of heavy metal content

The results of inductively coupled plasma mass spectroscopy (ICP) presented in Figure 3 (a and b) revealed that the accumulation of Cd and Ni by *A. viridis* plant was found to be correlated to the concentration of the treatment. The content of Cd and Ni in plant increased significantly with the rise of Cd and Ni concentrations up to the maximum used level.

Roots were recorded for higher accumulating concentrations rather than shoots along the experiment. In case of 2.5 ppm Cd concentration, the recorded values for soil, roots and shoots were 2.16, 0.973 and 0.569 ppm, respectively. Rate of last recorded values increased to be (171.6, 22.45 and 2.04) ppm Cd respectively at 200 ppm Cd concentration. The obtained value of R^2 (0.6324) indicates the goodness of variables. At 60 ppm, soil, roots and shoots Ni concentration amounted to 51.2, 2.66 and 1.15 ppm respectively and then an obvious jump was reached at 400 ppm Ni. R^2 value (0.8427) evinced high fitness of variables but more than that in case of Cd.

4. Bioconcentration Factor (BCF) and Translocation Factor (TF) of *A. viridis*

Bioconcentration factor (BCF) of Cd and Ni decreased with increasing Cd and Ni levels. It was clear from tables 1 and 2 that BCF for *A. viridis* took the order of Cd > Ni. Regarding Cd, BCF of roots was 0.412 at 2.5 ppm Cd and increased to be 0.51 at 20 ppm Cd concentration. Then, they were decreased values to be 0.13 at 200 ppm Cd. On the other hand, TF values starts with 0.607 at 2.5 ppm Cd and decreased to be 0.09 at 200 ppm Cd. At 60 ppm of Ni, BCF of roots was 0.053 and increased to be 0.42 at 400 ppm. Consequently, at 60 ppm of Ni, BCF of shoots were 0.023 and increased to be 0.16 at 400 ppm of Ni concentration. On the contrary, TF values starts with 0.432 at 60 ppm of Ni and decreased to be 0.375 at 400 ppm of Ni.

Intuitively, Cd and Ni bioaccumulation showed their maximum intrinsic increase at low concentrations. At higher concentrations, *A. viridis* bioconcentration capacity came to constancy. It was clear from the recorded data that BCF of roots were higher than that in shoots which is concurring with the translocated amount of metal (TF) from root to shoot. When

BCF >1, it indicates that the plant accumulates a particular heavy metal (Huang *et al.,* 2019). BCF value of plant was > 1 at (2.5, 5, 20 mg / kg) Cd and BCF value of shoot < 1 at higher levels (80, 200 mg / kg). BCF values of roots were ranging from 0.132 to 0.520. BCF values vary by metal, plant species, tissue type and soil (Sharma *et al.,* 2018; Huang et al., 2019). BCF value of plant was > 1 at 400 mg / kg Ni and BCF value of shoot < 1 at 60, 80, 160, 320 mg / kg. BCF values of roots were ranging from 0.053 to 0.420. *A.viridis* accumulated Ni with a TF of 8.15 and BCF of 10.48 (Ramanlal et al., 2020).

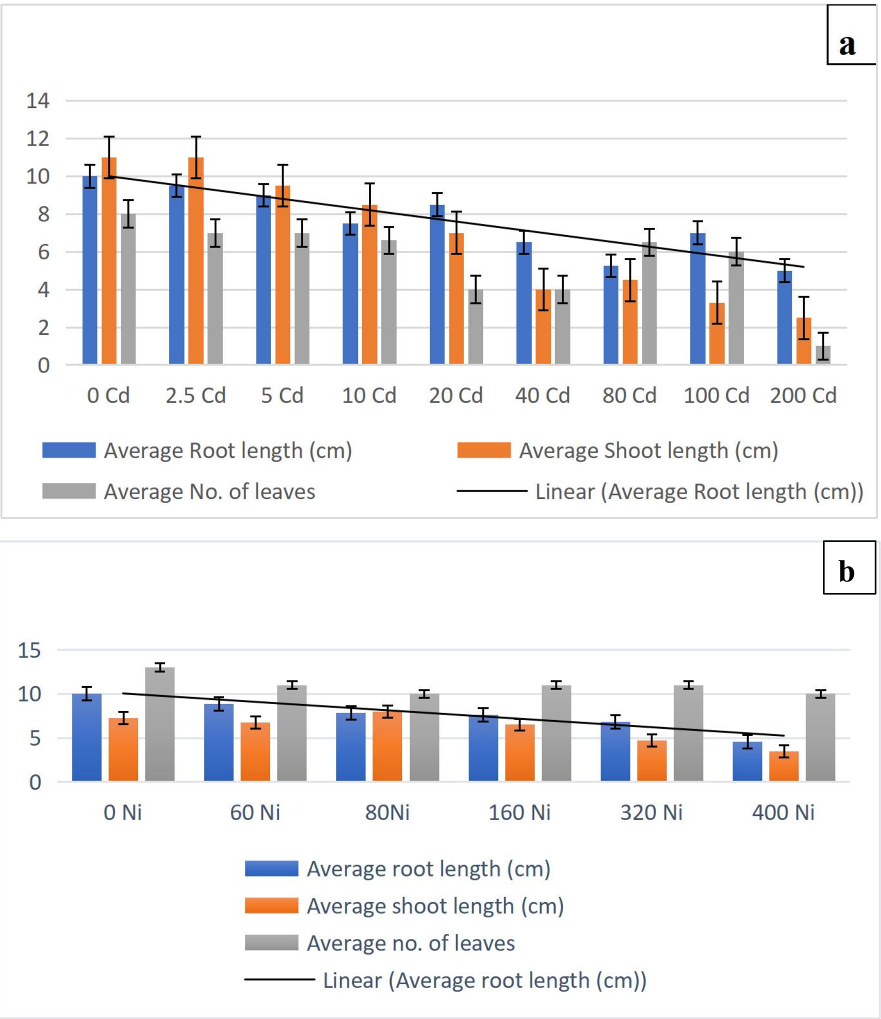


Fig. 2. Effect of different a) Cd concentration and b) Ni concentration on *Amaranthus viridis* growth at harvest time.

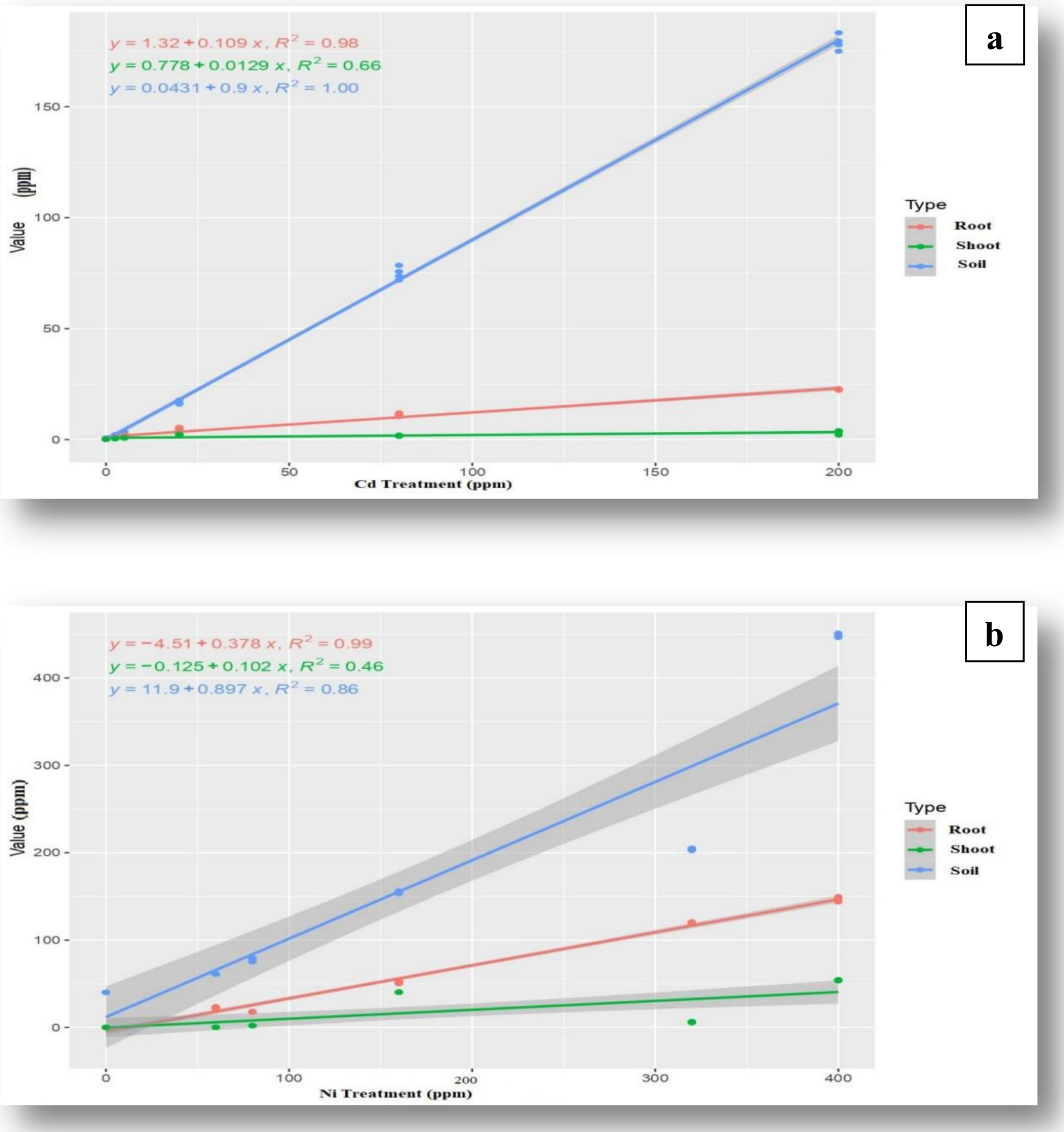


Fig. 3. Concentrations of (a) Cd and (b) Ni in *Amaranthus viridis* soils, roots and shoots after treatment with serial concentrations at harvest time.

Table 1. Bioconcentration factor and translocation factor of Cd of *Amaranthus viridis* using serial Cd concentrations after harvest.

Cd concentration(ppm)	0.0	2.5	5.0	20.0	80.0	200.0
BCF(Root)	-	0.412	0.520	0.510	0.180	0.132
BCF(Shoot)	-	0.233	0.411	0.301	0.031	0.013
BCF(Plant)	-	0.666	0.931	0.811	0.211	0.145
TF	-	0.607	0.4	0.418	0.153	0.09

Table 2. Bioconcentration factor and translocation factor of Ni of *Amaranthus viridis* using serial Ni concentrations after harvest.

Ni concentration(ppm)	0.0	60.0	80.0	160.0	320.0	400.0
BCF(Root)	-	0.053	0.340	0.416	0.410	0.420
BCF(Shoot)	-	0.023	0.044	0.034	0.015	0.160
BCF(Plant)	-	0.075	0.384	0.450	0.425	0.600
TF	-	0.432	0.115	0.080	0.376	0.375

roots and shoots. Figure (5 a and b) proves the positive strong significant relations between both Cd and Ni serial concentrations and the residual amount of Cd and Ni in *A. viridis* soils, roots and shoots after 67 days. Values of R^2 in Cd concentrations were equal to 0.983 while in Ni concentrations was 0.848 which strongly emphasizes the fitting and significance of variables. The one-way analysis of variance (ANOVA) test favored Pearson correlation. Tables S7 and S8 demonstrated a substantial correlation between the accumulation processes of Cd and Ni into the soil, roots, and shoots of *A. viridis*, but Ni is more significant than Cd at $p \leq 0.05$.

5. Correlations among Cd oncentrations and Ni concentrations in *A. viridis* soils, roots and shoots

Figure (4 a and b) shows Pearson correlation coefficients that demonstrates the relationships between; (a) applied Cd concentrations and measured Cd concentrations in *A. viridis* soils, roots and shoots and

(b) applied Ni concentrations and measured Ni concentrations in *A. viridis* soils, roots and shoots at the end of experiment (Aihemaiti et al., 2017); (Liu et al., 2018);(Laerd Statistics, 2020). The results indicated that the increased Cd and Ni concentrations in treatment had positive significant correlations with measured Cd and Ni concentrations in *A. viridis* soils,

Table S7. One-way ANOVA for Cd concentrations in soil, roots and shoots of *Amaranthus viridis.*

Cd concentration		Sum of Squares	Df	Mean Square	F	Sig.
Soil (ppm)	**Between Groups**	100728.441	5	20145.688	5833.714	0.000
	Within Groups	62.160	18	3.453		
	Total	100790.601	23			
Root (ppm)	**Between Groups**	1503.542	5	300.708	1940.131	0.000
	Within Groups	2.790	18	0.155		
	Total	1506.332	23			
Shoot (ppm)	**Between Groups**	29.050	5	5.810	41.633	0.000
	Within Groups	2.512	18	0.140		
	Total	31.562	23			

Table S8. One-way ANOVA for Ni concentrations in soil, roots and shoots of *Amaranthus viridis*

Ni concentration		Sum of Squares	df	Mean Square	F	Sig.
Soil (ppm)	**Between Groups**	465139.461	5	93027.892	50256.521	0.000
	Within Groups	33.319	18	1.851		
	Total	465172.780	23			
Root (ppm)	**Between Groups**	71759.054	5	14351.811	8202.246	0.000
	Within Groups	31.495	18	1.750		
	Total	71790.550	23			
Shoot (ppm)	**Between Groups**	11312.905	5	2262.581	22197.658	0.000
	Within Groups	1.835	18	0.102		
	Total	11314.740	23			

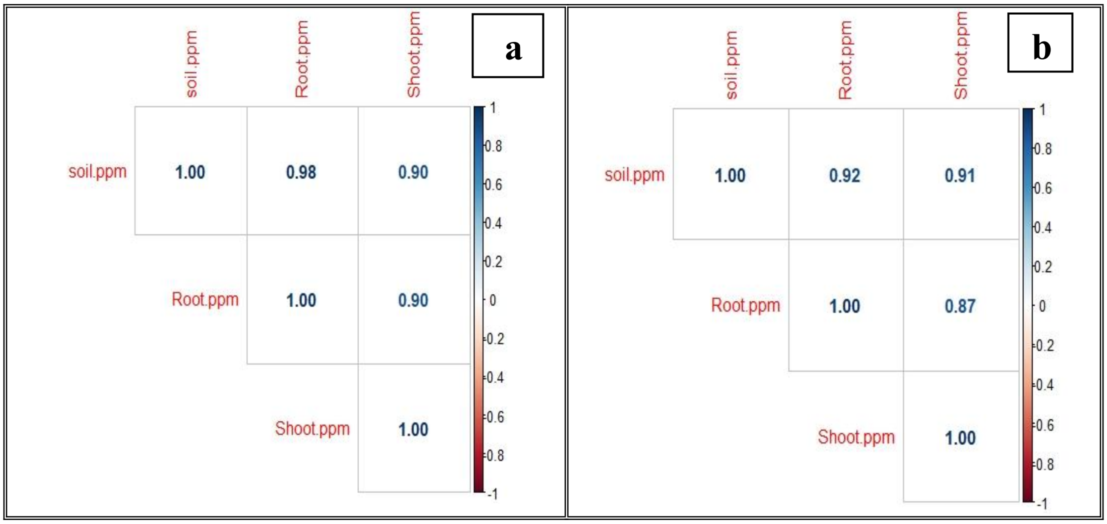


Fig. 4. Correlation coefficients of (a) Cd and (b) Ni in *Amaranthus viridis* soils, roots and shoots at harvest time.

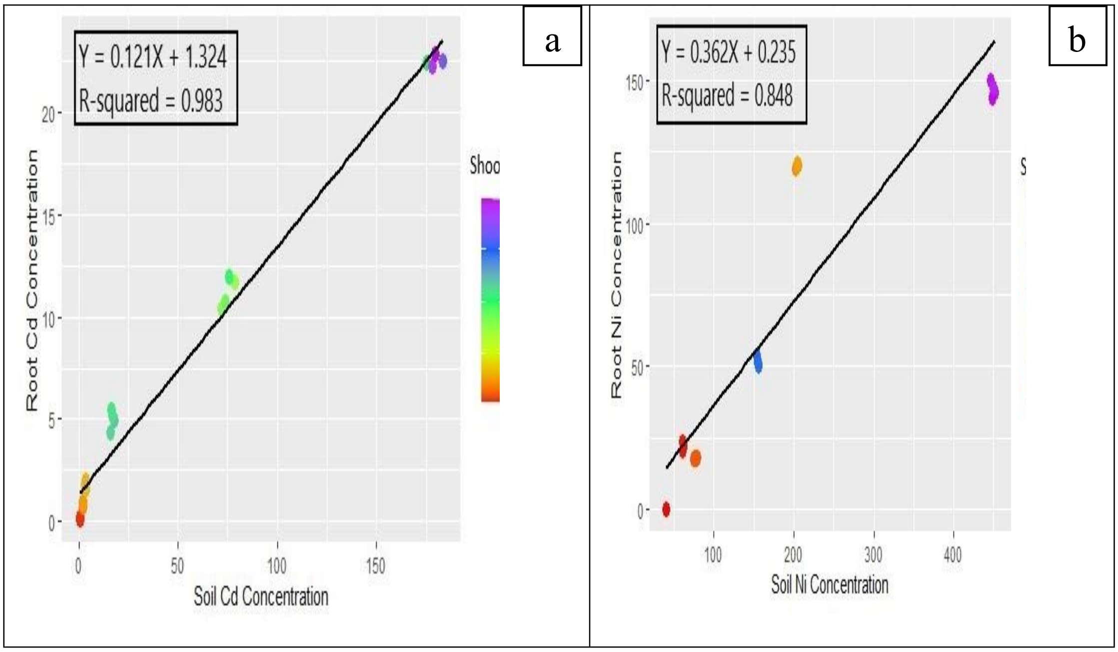


Fig. 5. Linear relations between (a) Cd concentrations in *Amaranthus viridis* soils, roots and shoots and (b) Ni concentrations in *Amaranthus viridis* soils, roots and shoots at harvest time.

preventing its uptake by most of the plant species (Liu et al., 2019). Ni uptake decrease root length, plant height and number of leaves in *A. viridis* beyond threshold concentration which may reach to toxic dose for the candidate species (Joseph et al., 2018).

Concerning metal uptake, results proved an increment of metal concentration absolute value in soil, roots and shoots of *A. viridis* at high levels of metal augmentation. Actually, Cd and Ni are belonging to the group of metals showing a tendency to interact with low molecular weight organic matter with an order of affinity as follows: Cu > Cd > Fe > Pb > Ni (Wuana and Okieimen, 2011);(Bolan et al., 2003). Metallothionein's and photoheating are low molecular weight peptides and responsible for metal binding. After binding, the previously mentioned peptides sequestered metals in the vacuoles of the plants leading to metal detoxification and give hyperaccumulation privilege to the plant species. (Leitenmaier and Küpper, 2013).

The resulting data of BCF and TF for Cd and Ni is indicator for uptake and accumulation of Cd more than Ni as a ratio and in roots rather than in shoots. In general, HMs stimulate root uptake at low soil concentrations but at high concentrations, root tolerance level is broken and the transport cells are inhibited and the passageway may be destroyed (Koźmińska et al., 2018). In particular, existence of some anions like Cl^{-} and NO_4^{-} in the soils influences sorption behavior of Cd, which enhance Cd sorption due to surface precipitation. The lower concentrations of Cd and Ni in shoots might have been attributed to the

Phytoremediation is considered as an eco-friendly potent technique of HMs decontamination to reduce the associated risks and maintain ecological restoration. This technique adopts different approaches to apply in HMs removal, One of them is plants' investment in cleaning up the soil (Subašić et al., 2022).

This research is focusing on the capability of *A. viridis* in removing Ni and Cd from soil. When testing seed traits in front of ascending concentrations of Ni and Cd, the behavior varied between viability and mortality during and after germination. Survival percentage while using Ni exceeds that of Cd. The findings of (Moreira et al., 2020) may interpret ours, he discussed the reasons beyond tolerance of Lettuce seeds for all metals during germination and concluded that the barrier effect of seed coat prevented the metals to come in contact with the developing embryo. In addition, not all HMs have the same impact and that is why while low Ni concentrations stimulated the growth of green leaves of Lettuce seedlings were sensitive to low Cd concentrations.

Output data, when plant growth parameters were indicators of stress conditions, showed a depression in values of root length, shoot length and leaves number of *A. viridis*. These results indicating the inverse relation between Cd and Ni uptake from one side and growth criteria from the other side. The exposure of plants to excess levels of metals inhibits active enzymes, inactivates photosystems, and destruct mineral metabolism thereby lowering plant growth (Füzy et al., 2019). It was proved that Cd as an example of HMs could stand as an obstacle in chlorophyll production mechanism thereby accumulation of Cd in roots more than in shoots. Other researchers suggested that when values of BCF is > 1.0 and TF is < 1.0, *A. viridis* may have a good pathway to be used in phytostabilisation. (Yap et al., 2022).

activity of a protective mechanism that limits HMs transportation to above-ground tissues of the plants by their accumulation in the root vacuoles. (Leitenmaier and Küpper, 2013). Some researchers proved that Cd transfer to the shoots from the roots was not efficient; this could explain

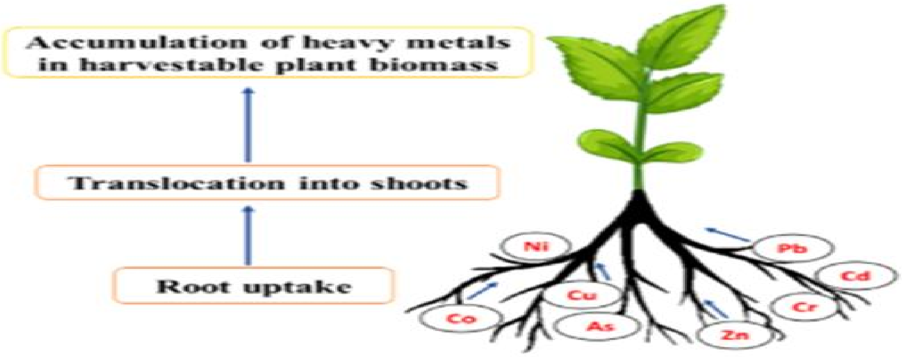


Fig. 6. Fate of heavy metals through roots to shoots and other parts of plant (Ashraf et al., 2019).

Herein, all statistical analyses for this study which included descriptive analyses, one way ANOVA and Pearson Coefficient variant, supported a highly positive significance between externally added Cd concentrations and determined Cd concentration and the same in case of Ni. According to Fan et al., 2017), these metals were readily and potentially bioavailable to the vegetables in the environmental soil and it could be a proof for a correlation between Ni and Cd from one side and their surroundings from the other side In general, Cd and Ni levels in vegetables could be expected as a result of higher levels of metals in soils. Ni bioaccumulation in *Amaranthus* leaves and shoots could be influenced by the Ni levels in the geochemical safe parts. Many researchers reported a positive and significant correlations for Cd and Ni between plant and their geochemical groups in the habitat topsoil's, this hypothesis is in agreement with that of (Yap et al., 2022).

CONCLUSION:

Presence of HMs in soil should be controlled form their point sources and non- point sources.

More efforts should be done to check HMs spreading. Application of *A. Viridis* in the phytoremediation process could be used to remove HMs from the soil. Although the results of the present work manifest some morphological detrimental impacts on the studied plant as a result of

HMs stress but a remarkable absorption and mobility of Cd and Ni through plant root and shoot were apparent. The investigation of *A. viridis* efficiency in Cd and Ni removal was achieved using various concentrations. *A. viridis* was proved to be a promising phytoextraction factor as well as Phyto stabilizing agent for Cd and Ni. The candidate plant was more effective at sequestering metal by its roots than it was

at moving it to its shoots. Usage of *A. viridis* to eliminate HMs from soil is considered as an economically and environmentall ysafe technique.

4. REFERENCES:

Abdelkrim, S., Jebara, S.H., Saadani, O., Chiboub, M., Abid, G., Mannai, K., Jebara, M., 2019. Heavy metal accumulation in Lathyrus sativus growing in contaminated soils and identification of symbiotic resistant bacteria. Arch. Microbiol. 201, 107–121. https://doi.org/10.1007/s00203-018-1581-4.

Aihemaiti, A., Jiang, J., Li, D., Li, T., Zhang, W., Ding, X., 2017. Toxic metal tolerance in native plant species grown in a vanadium mining area. Environ Sci pollut Res.24:26839-26850. DOI 10.1007/s11356-017-0250-5.

Ali, H., Khan, E., Ilahi, I., 2019. Environmental chemistry and ecotoxicology of hazardous heavy metals: Environmental persistence, toxicity, and bioaccumulation. J. Chem . https://doi.org/10.1155/2019/6730305.

Amin, H., Arain, B.A., Jahangir, T.M., Abbasi, M.S., Amin, F., 2018. Accumulation and distribution of lead (Pb) in plant tissues of guar (Cyamopsis tetragonoloba L.) and sesame (Sesamum indicum L.): profitable phytoremediation with biofuel crops. Geol. Ecol. Landscapes. 2, 51–60 https://doi.org/10.1080/24749508.2018.1452464.

Ao, A., 2019. Biodiversity Index. Transgenic Plant Technol. Remediat. Toxic Met. Met. 523–527. https://doi.org/10.1016/b978-0-12-814389-6.00034-1.

Ashraf, S., Ali, Q., Zahir, Z.A., Ashraf, S., Asghar, H.N., 2019. Phytoremediation: Environmentally sustainable way for reclamation of heavy metal polluted soils. Ecotoxicol. Environ. Saf. 174, 714 – 727. https://doi.org/10.1016/j.ecoenv.2019.02.068.

Assad, R., Reshi, Z.A., Jan, S., Rashid, I., 2017. Biology of Amaranths, Botanical Review. The Bot. Rev. https://doi.org/10.1007/s12229-017-9194-1.

Emamverdian, A., Ding, Y., Mokhberdoran, F., Xie, Y., 2015. Heavy metal stress and some mechanisms of plant defense response.

Sci. World J. 7–9. https://doi.org/10.1155/2015/756120.

Fan, Y., Li, H., Xue, Z., Zhang, Q., Cheng, F., 2017. Accumulation characteristics and potential risk of heavy metals in soil-vegetable system under greenhouse cultivation condition in Northern China. Ecol. Eng. 102, 367–373. https://doi.org/10.1016/j.ecoleng.2017.02.032.

Füzy, A., Kovács, R., Cseresnyés, I., Parádi, I., Szili-Kovács, T., Kelemen, B., Rajkai, K., Takács, T., 2019. Selection of plant physiological parameters to detect stress effects in pot experiments using principal component analysis. Acta Physiol. Plant.41,1–10. https://doi.org/10.1007/s11738-019-2842-9.

George, D., Mallery, P., 2012. IBM SPSS Statistics 19 Step by Step: A Simple Guide and Reference (12th Edition) ISBN 9780205255887.

Haider, F.U., Liqun, C., Coulter, J.A., Cheema, S.A., Wu, J., Zhang, R., Wenjun, M., Farooq, M., 2021. Cadmium toxicity in plants: Impacts and remediation strategies. Ecotoxicol. Environ. Saf. 211, 111887. https://doi.org/10.1016/j.ecoenv.2020.111887.

Huang, Y., Xi, Y., Gan, L., Johnson, D., Wu, Y., Ren, D. and Liu, H. (2019): Effects of lead and cadmium on photosynthesis in Amaranthus spinosus and assessment of phytoremediation potential. *International Journal of Phytoremediation*, *21*(10), 1041–1049. https://doi.org/10.1080/15226514.2019.1594686.

Iori, V., Pietrini, F., Cheremisina, A., Shevyakova, N.I., Radyukina, N., Kuznetsov, V. V., Zacchini, M., 2013. Growth responses, metal accumulation and phytoremoval capability in amaranthus plants exposed to nickel under hydroponics. Water. Air. Soil Pollut. 224. https://doi.org/10.1007/s11270-013-1450-3.

Joseph, J., Reddy, J., Sayantan, D., 2018. Effect of nickel uptake on selected growth parameters of Amaranthus viridis L. J. Appl. Nat. Sci. 10, 1011–1017. https://doi.org/10.31018/jans.v10i3.1838.

Karahan, F., Ozyigit, I.I., Saracoglu, I.A., Yalcin, I.E., Ozyigit, A.H., Ilcim, A., 2020. Heavy Metal Levels and Mineral Nutrient Status in Different Parts of Various Medicinal Plants Collected from Eastern Mediterranean Region of Turkey. Biol. Trace Elem. Res. 197, 316–329. https://doi.org/10.1007/s12011-019-01974-2.

Khan, M.N., Mobin, M., Abbas, Z.K., Alamri, S.A., 2017. Fertilizers and their contaminants in soils, surface and groundwater, Encyclo of the Anthropo. Elsevier Inc. https://doi.org/10.1016/B978-0-12-809665-9.09888-8.

Koźmińska, A., Wiszniewska, A., Hanus-Fajerska, E., Muszyńska, E., 2018. Recent strategies of increasing metal tolerance and phytoremediation potential using genetic transformation of plants. Plant Biotechnol. Rep. 12, 1–14. https://doi.org/10.1007/s11816-017-0467-2.

Laerd Statistics. (2020). Pearson's product moment correlation. Statistical tutorials and software guides. Retrieved July 3, 2021 from https://statistics.laerd.com/statistical-guides/pearsoncorrelation-coefficient-statistical.gov.php.

Leitenmaier, B., Küpper, H., 2013. Compartmentation and complexation of metals in hyperaccumulator plants. Front. Plant Sci. 4, 1–13. https://doi.org/10.3389/fpls.2013.00374.

Liang, Z., Ding, Q., Wei, D., Li, J., Chen, S., Ma, Y., 2013. Major controlling factors and predictions for cadmium transfer from the soil into spinach plants. Ecotoxicol. Environ. Saf. 93, 180–185. https://doi.org/10.1016/j.ecoenv.2013.04.003.

Liu,Y.,Yang,Y.,Li,Ch.,Ni,X.,Ma,W.,Wei,H.,2018. Assessing soil metal levels in an industrial environment of northwestern china and the phytoremediation potential of its native plants. Sustainability . MDPI. 10, 2686.http://dx.doi.org/10.3390/su10082686.WWW.mdpi.com.journal.sustainability.

Liu, H., Wang, H., Gao, W., Liang, H., Gao, D., 2019. Phytoremediation of Three Herbaceous Plants to Remove Metals from Urban Runoff. Bull. Environ. Contam. Toxicol. 103, 336–341. https://doi.org/10.1007/s00128-019-02677-z.

Moreira, I.N., Martins, L.L., Mourato, M.P., 2020. Effect of Cd, Cr, Cu, Mn, Ni, Pb and Zn on seed germination and seedling growth of two lettuce cultivars (Lactuca sativa L.). Plant Physiol. Reports 25, 347–358. https://doi.org/10.1007/s40502-020-00509-5.

Nedjimi, B., 2021. Phytoremediation: a sustainable environmental technology for heavy metals decontamination. SN Appl. Sci. 3, 1–19. https://doi.org/10.1007/s42452-021-04301-4.

Rai, P.K., Lee, S.S., Zhang, M., Tsang, Y.F., Kim, K.H., 2019. Heavy metals in food crops: Health risks, fate, mechanisms, and management. Environ. Int. 125, 365–385. https://doi.org/10.1016/j.envint.2019.01.067.

Ramanlal,D.B.,Kumar,R.N.,NirmalKumar,J.I.,Thakkar,R.,2020. Assessment of phytoremedial potential of invasive weeds Acalypha indica and Amaranthus viridis: Environmental Sustainability.) 3:415–425. https://doi.org/10.1007/s42398-020-00129-7.

Sarma, H., 2011. Metal hyperaccumulation in plants: A review focusing on phytoremediation technology. J. Environ. Sci. Technol. https://doi.org/10.3923/jest.2011.118.138.

Sharma, S., Nagpal ,A.K. and Kaur, I. (2018): Heavy metal contamination in soil, food crops and associated health risks for residents of Ropar wetland, Punjab, India and its environs. Food Chem. 255:15–22. doi: 10.1016/j.foodchem.2018.02.037.

Subašić, M., Šamec, D., Selović, A., Karalija, E., 2022. Phytoremediation of Cadmium Polluted Soils: Current Status and Approaches for Enhancing. Soil Syst. 6, 1–21. https://doi.org/10.3390/soilsystems6010003.

Tan, L., Yang, B., Xue, Z., Wang, Z., 2021. Assessing heavy metal contamination risk in soil and water in the core water source area of the middle route of the south-to-north water diversion project, China. Land 10. https://doi.org/10.3390/land10090934.

Tchounwou, P.B., Yedjou, C.G., Patlolla, A.K., Sutton, D.J., 2012. Molecular, clinical and environmental toxicicology Volume 3: Environmental Toxicology. Mol. Clin. Environ. Toxicol. 101, 133–164. https://doi.org/10.1007/978-3-7643-8340-4.

Vincent, L., Sivaraj, N., Anushma, P., Ganeshan, S., Rajasekharan, P.E., 2019. Diversity, distribution, collection and conservation of amaranth germplasm from Andhra Pradesh. Acta Hortic. 1241, 99–104. https://doi.org/10.17660/ActaHortic.2019.1241.16.

Volland, S., Bayer, E., Baumgartner, V., Andosch, A., Lütz, C., Sima, E., Lütz-Meindl, U., 2014. Rescue of heavy metal effects on cell physiology of the algal model system Micrasterias by divalent ions. J. Plant Physiol. 171, 154–163. https://doi.org/10.1016/j.jplph.2013.10.002.

Wickham, H., 2016. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York. ISBN 978-3-319-24277-4, https://ggplot2.tidyverse.org.

Wuana, R.A., Okieimen, F.E., 2011. Heavy Metals in Contaminated Soils: A Review of Sources, Chemistry, Risks and Best Available Strategies for Remediation. ISRN Ecol. 2011, 1–20. https://doi.org/10.5402/2011/402647.

Yan, A., Wang, Y., Tan, S.N., Mohd Yusof, M.L., Ghosh, S., Chen, Z., 2020. Phytoremediation: A Promising Approach for Revegetation of Heavy Metal-Polluted Land. Front. Plant Sci. 11, 1–15. https://doi.org/10.3389/fpls.2020.00359.

Yang, Y., Zhang, L., Huang, X., Zhou, Y., Quan, Q., Li, Y., Zhu, X., 2020. Response of photosynthesis to different concentrations of heavy metals in Davidia involucrata. PLoS One 15, 1–16. https://doi.org/10.1371/journal.pone.0228563.

Yap, C.K., Yaacob, A., Tan, W.S., Al-Mutairi, K.A., Cheng, W.H., Wong, K.W., Edward, F.B., Ismail, M.S., You, C.F., Chew, W., Nulit, R., Ibrahim, M.H., Amin, B., Sharifinia, M., 2022. Potentially Toxic Metals in the High-Biomass Non-Hyperaccumulating Plant Amaranthus viridis: Human Health Risks and Phytoremediation Potentials. Biology (Basel).11. https://doi.org/10.3390/biology11030389.

Yoon, J., Cao, X., Zhou, Q., Ma, L.Q., 2006. Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site. Sci. Total Environ. 368, 456–464. https://doi.org/10.1016/j.scitotenv.2006.01.016.

Zhou, W., Han, G., Liu, M., Song, C., Li, X., Malem, F., 2020. Vertical distribution and controlling factors exploration of Sc, V, Co, Ni, Mo and Ba in six soil profiles of the mun river basin, northeast Thailand. Int. J. Environ. Res. Public Health 17. https://doi.org/10.3390/ijerph17051745.

الملخص العربي

تقييم فعالية نبات الأمارانتس في معالجه الكادميوم والنيكل

المعالجة النباتية ظهرت كتقنيه مميزه وتلعب دورًا هاما في التغلب على مشكلة تراكم العناصر الثقيلة في التربة. الغرض الرئيسي من هذا العمل هو تقييم كفاءه عشبه نبات الأمارانتس في إزاله عنصر الكادميوم عندما يضاف الى التربة بهذه التركيزات (0.0 , 2.5 , 5 , 20 , 80 and 200) وعنصر النيكل عندما يضاف إلى التربة بهذه التركيزات (0.0 , 60 , 80 , 160 , 320 and 400 ppm) حيث أجريت التجربة بزراعه البذور في أواني مملوءه بالتربة الطينية الرملية لتطبيق عمليه المعالجة النباتية لمده 67 يوم حيث أثبتت النتائج انخفاض متزامن في طول المجموع الجذري والمجموع الخضري وعدد الأوراق بنسبه 85% مع الزيادة التسلسلية في الكادميوم والنيكل.

حيث تعد قيم عامل التركيز الحيوي وعامل النقل مؤشرا على ارتفاع وامتصاص وتراكم الكادميوم أكثر من النيكل وفى المجموع الجذري أكثر من المجموع الخضري. حيث تضمنت التحليلات الإحصائية تحليلات وصفيه. أثبت متغير (ANOVA) ذو الاتجاه الواحد ومعامل بيرسون (P 0.05) تأثيرات مهمه إيجابيه للغاية. وضعت هذه الدراسة عشبه نبات الأمارانتس من ضمن النباتات الواعدة والقوية التي ستكون فعاله في إزالة عنصري الكادميوم والنيكل واستقرار النبات.

الكلمات الدالة: عشبه الأمارانتس, المعالجة النباتية, العناصر الثقيلة, عامل التركيز الحيوي, تراكم المعدن.