مجلة سوزوسا العلمية المحكمة
Sozusa Peer-Reviewed Scientific Journal
ISSN: 3078 – 2767
المجلد الثاني، العدد الثاني، مارس 2025م
DOI: https://doi.org/10.66358/sozusa.v2i2.005

Cumulative Ability of *Juniperus phoenicea* Trees for Some Heavy Metals in Shahat Forest, Libya.

Khaled S. Al-mokhtar[1] **Younes Hamad-Sheip**[2]

[1-2]Derna University, Natural Resources & ecology Fac., Ecology Dept., Al-Goba Branch

[1]*khaledalmokhtar@gmail.com*

الاستلام: 3-1-2025، القبول: 18-2-2025، النشر: 1-3-2025.

Abstract:

This study was carried out in Shahat Forest to evaluate the capacity of *J. phoenicea* to absorb and store heavy metals in its tissues. Concentration of heavy metals, including (Zn), (Fe), (Cd) and (Pb), were measured in both aerial parts and root parts of the plant, as well as in the soil at a depth of 0-40 cm beneath the trees. Importantly, the concentrations of these heavy metals were found to be within the acceptable limits set by (WHO). The findings indicated that *J. phoenicea* exhibited notable efficiency in the uptake and accumulation of heavy metals, with (BAF) for Zn, Fe, Cd, and Pb recorded at 12, 6, 2.9, and 2.2, respectively. Additionally, the (BCF) were greater in the aerial parts than in the root parts, and the (TF) was greater than 1 for all heavy metals. As a result, *J. phoenicea* can be regarded as a promising candidate for bioaccumulation with phytoextraction strategy. Statistical analysis indicated significant differences ($p < 0.05$) in heavy metal concentrations among the different parts of the plant.

Keywords: Juniperus phoenicea, Cumulative, Ability, Heavy Metals, Shahat.

القدرة التراكمية لأشجار العرعر الفينيقي *Juniperus phoenicea* لبعض المعادن الثقيلة في غابة شحات، ليبيا

خالد سعد المختار[1] **يونس حمد سليمان**[2]

[1،2]جامعة درنة، كلية الموارد الطبيعية، قسم علوم البيئة، فرع القبة

الملخص:

أجريت هذه الدراسة في غابة شحات لتقييم قدرة نبات العرعر الفينيقي على امتصاص وتراكم المعادن الثقيلة داخل أنسجته. تم قياس تركيزات المعادن الثقيلة، (Zn)، (Fe)، (Cd)، (Pb)، في كل من الأنسجة الخضرية والجذرية لنبات العرعر الفينيقي وكذلك في التربة على عمق (0– 40 سم) تحت الأشجار. ومن الجدير بالذكر أن التركيزات المقاسة لهذه المعادن الثقيلة ظلت ضمن الحدود المسموح بها لمنظمة الصحة العالمية. أشارت النتائج إلى أن العرعر الفينيقي أظهر كفاءة ملحوظة في امتصاص وتراكم المعادن الثقيلة، حيث كان معامل التراكم الحيوي Bio Accumulation Factor(BAF) . Zn، وFe، وCd، وPb (12، 6، 2.9، و2.2) على التوالي. أيضا كانت قيمة معامل التركيز الحيوي (BCF) أعلى في الأجزاء الخضرية مقارنة بالأجزاء الجذرية وكذلك قيمة معامل انتقال العناصر Translocation Factor (TF) كانت أكبر من 1 لكل العناصر. وبناءً على ذلك، يمكن اعتبار ان العرعر الفينيقي مراكماً حيوياً يتبع استراتيجية الاستخلاص الحيوي phytoextraction. كما أظهر التحليل الإحصائي وجود اختلافات معنوية ($P<0.05$) في تركيزات العناصر الثقيلة بين أجزاء النبات المختلفة.

الكلمات المفتاحية: العرعر الفينيقي، *Juniperus phoenice*، القدرة التراكمية، التلوث بالمعادن الثقيلة، شحات.

1.Introduction

The concentration of heavy metals in the environment has been increasing each year (Ali *et al.*, 2013). The presence of heavy metals in agricultural soils presents considerable environmental challenges and poses a significant threat to life on Earth. The presence of heavy metals into the food chain is associated with various health risks for humans (Ghosh & Singh, 2005; Sarwar *et al.*, 2017; Bahiru & Yegrem, 2021). In natural ecosystems, heavy metals are recognized for their carcinogenic and mutagenic properties (Gola *et al.*, 2016). Additionally, their non-biodegradable nature contributes to their persistence in the environment, facilitating the rapid accumulation of dangerous levels (Chandrajith *et al.,* 2005; Taghipour & Mosaferi, 2013; Suman *et al.*, 2018; Khan *et al.*, 2023).Plants have been recognized as effective biomonitors for evaluating the rise in heavy metal levels in the atmosphere (Cesur *et al.*, 2021).Plants possess the capability to absorb heavy metals from their surroundings, often accumulating these metals at concentrations that surpass those present in the soil. However, the extent of toxic metal accumulation varies significantly among different plant species (Zhao *et al.*, 2014). Additionally, plants are integral to ecosystems, as they facilitate the transfer of elements from the abiotic environment to the biotic one (Hu *et al.,* 2014). Urban vegetation plays a vital role in environmental assessment and remediation by extracting heavy metals from the ecosystem (Young *et al.,* 2014). To counteract heavy metal toxicity, plants generally utilize two primary defense strategies: avoidance and tolerance. These strategies enable them to maintain intracellular heavy metal concentrations at levels that are not harmful (Hall, 2002; Dalvi & Bhalerao, 2013; Yu et al., 2022; Kraj *et al.,* 2021). The existence of a metal exclusion mechanism creates a barrier between the root and shoot systems, thereby restricting the uptake of heavy metals from the soil into the roots. This mechanism is essential for protecting the aerial portions of the plant from the adverse effects of heavy metals by limiting their absorption and subsequent transport from the roots to the shoots (Raskin *et al.*, 1994; Hall, 2002; Dalvi & Bhalerao, 2013). Plants can be categorized based on their capacity for metal accumulation into three distinct groups: heavy-metal accumulators, heavy-metal excluders (or non-accumulators), and indicator species. Heavy-metal-accumulating plants demonstrate a concentration ratio of metals within their tissues that exceeds 1 when compared to the soil concentration. Conversely, non-accumulating plants exhibit a markedly lower ratio, while indicator plants maintain a ratio that approximates 1 (Cunningham & Ow, 1996; Gleba *et al.,* 1999; McIntyre, 2003; Ghosh & Singh, 2005; Rascio & Navari-Izzo, 2011; Yan *et al.*, 2020; Khan *et al.,* 2023; Chitimus *et al.*, 2023; Kord *et al.*, 2024). The efficacy of phytoremediation is closely linked to a plant's ability to absorb metals, transport them from the roots to aerial parts, and sequester them within specific cellular compartments. As a result, a common approach to enhance metal accumulation involves the introduction of genes that code for metal transporters (Venegas-Rioseco *et al.,* 2021). In the realm of phytoremediation, plants utilize a variety of strategies, including (i) phytostabilization—using plants to reduce heavy metal bioavailability in soil, (ii) phytoextraction—using plants to extract and remove heavy metals from soil, (iii) phytovolatilization—using plants to absorb heavy metal from soil and release into the atmosphere as volatile compounds, and (iv) phytofiltration—using hydroponically cultured plants to absorb or adsorb heavy metal ions from groundwater and aqueous waste (Tangahu *et al.,* 2001; Yan *et al.,* 2020; Chitimus *et al.,* 2023). Phytostabilization and phytoextraction represent the two principal methodologies employed by plants for the remediation of heavy metal contamination (Ali *et al.,* 2013; Hao *et al.,* 2014; Yan *et al.,* 2020). Phytostabilization is characterized by the ability of metal-tolerant plant species to immobilize heavy metals within the soil matrix, thereby reducing their bioavailability and inhibiting their migration into surrounding ecosystems. This process effectively diminishes the potential for heavy metals to enter the food chain. Mechanisms facilitating phytostabilization include precipitation or reduction of metal valence in the rhizosphere, uptake and sequestration within root tissues, and adsorption onto the cell walls of roots (Gerhardt *et al.,* 2017). A notable advantage of phytostabilization, in contrast to phytoextraction, is that it does not require the removal of toxic biomass (Marques *et al.,* 2009; Wuana & Okueimen, 2011; Yan *et al.,* 2020). Conversely, phytoextraction involves the absorption of pollutants from soil or water by plants, which then transport and accumulate these contaminants in their aboveground biomass (Jacob *et al*., 2018). Recently, phytoextraction has gained prominence as a crucial technique in phytoremediation for the extraction of heavy metals and metalloids from contaminated soils (Sarwar *et al*., 2017). Unlike phytostabilization, which retains heavy metals within the root zone without their permanent removal, phytoextraction provides a conclusive method for the elimination of heavy metals from polluted environments, thus rendering it suitable for commercial applications (Yan *et al*., 2020; Siyar *et al.,* 2022).

The Cupressaceae family exhibits a remarkable efficiency in the translocation of nutrients, particularly heavy metals, from the shoot to the plant's aerial parts. Transfer factor (TF) values greater than 1 for this family signify a robust ability for metal accumulation. Within the Cupressaceae, the genus Juniperus encompasses around 75 to 80 species, rendering it the second largest genus among conifers. Species of Juniperus are commonly found in semiarid regions and are widely employed in landscaping, timber production, and medicinal uses. Juniperus phoenicea L. is native to various regions of the Mediterranean basin, the Canary Islands, and North Africa (Abu-Darwish & Ofir, 2014; Angelova, 2022; Asbabou *et al.,* 2024). Juniperus acts as a significant bioindicator for heavy metal pollution, as the concentration of heavy metals in its tissues is directly related to the levels of these metals in the surrounding soil (Binxhija & Ylli, 2021). Studies have shown that Juniperus species can effectively absorb and accumulate toxic heavy metals from contaminated sites, thereby positioning them as potential biomonitors or accumulators of environmental pollutants (Achak *et al.,* 2009; Diaconu *et al*., 2009; Farahat & Linderholm, 2015; Cesur *et al.*, 2021; Siyar *et al.,* 2022; Kord *et al.,* 2024).

This study was conducted in the Shahat Forest to assess the capacity of J. phoenicea to accumulate heavy metals from contaminated soil. Additionally, what strategies and mechanisms will J. phoenicea employ to manage heavy metal exposure?

2.Material and methods

2.1. Study aria: The study was conducted during 2023, in a site exposed to sewage in a forest inside Shahat city, located (32°49′40″N 21°51′44″E) which has a mild climate that tends to be warm and rainy in winter and hot in summer; where maximum temperature in the studied area varies from 35.3ºC in summer to 20.1ºC in winter. Minimum temperature ranges from 20.2ºC in summer and 7.5ºC in winter. (Othman & Al-Habbat, 2023).

2.2. Sample collection: Five mature J. *phoenicea* trees were selected to conduct this study, fresh samples of *J. phoenicea* trees from both aerial and root part, soil parts at depth (0 cm - 40 cm) were collected in polyethylene bags and transported to the laboratory for analysis. Five macro elements including total Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca) and Sodium (Na), four heavy metals including zinc (Zn), Iron (Fe), cadmium (Cd) and lead (Pb) were analyzed in the samples of tree and soil parts.

2.3. Sample Preparation: The Collected samples were homogenized and crushed into small particles, decomposed by dry digestion method for the determination of various metals. First of all, the crucibles and the glass wares used in the experiment were washed with distilled water and then dried in oven. Weight of each crucible was made constant by keeping it in muffle furnace at 750 °c for one hour. Then transferred it to desiccator and weighted it. The purpose was to remove all the moisture. This action was repeated till the weight became constant. A known quantity, 2g of each sample (aerial part, root part of trees and soil parts) was introduced into the Porcelain crucible. The crucibles were burned at around 200 °C until the end of organic matter smoke generation, then crucibles kept in muffle furnace at 600 °C for 5 hours, cooled to the room temperature in the desiccator for 40 minutes. The obtained white ash is moistened with a few drops of de-ionized water, an aliquot of 2.0 mL of concentrated HCl are added, left in contact for 10 minutes and filtered into 100 ml volumetric flasks, the volume was made up to the mark with de-ionized water, all samples were performed in triplicates (Ahmad *et al.,* 2018; Huang *et al.,* 2020).

2.4. Elemental analysis of samples: Determination of element concentrations in all the samples were made directly on each of the final solution by using the appropriate Instrumentation and methods.

1-Total Nitrogen (TN) and total phosphorus (TP) in soil samples were determined using an automatic elemental analyzer (Elemetar Vario Max CN, Germany) and the Olsen method, respectively (Iatrou *et al*., 2014; Zhao *et al*., 2022).

2-Total potassium (TK), Sodium (Na) and Calcium (Ca) were determined using an inductively coupled plasma mass spectrometer (ICP-MS) (Agilent 7500ce) (Nogueira *et al*., 2013; Zhao *et al.,* 2022).

3-Trace elements (Iron, Zinc, Cadmium & lead) were determined by atomic absorption spectrophotometer (AAS) (Oumlouki *et al.,* 2021; Cardoso-Silva *et al.,* 2013).

2.5. biological factors:

2.5.1. Bioconcentration factor (BCF) is described as the ability of plants for elemental accumulation from the substrate. It can be measured for each plant part, such as roots, stems, and leaves using the equation:

$$BCF= C_{plant\ part}\backslash C_{soil}$$

where C_{plant} shows the accumulation of heavy metals in plant part (aerial or roots) and C_{soil} denoted the concentration of heavy metals in soil. BCF values more than 1 demonstrate the potential success of a plant species for phytoremediation (Nouha *et al*., 2024)

2.5.2.Translocation factor (TF) is an important tool used to assess a plant's potential for phytoremediation purposes. It is calculated from the ratio of the element's presence in the plant's aerial parts compared to that in the plant's roots parts using the equation (Nouha *et al*., 2024; Wu *et al*., 2011).

$$TF = Metal\ (aerial\ parts)\ \backslash Metal\ (roots\ parts)$$

A (TF) value greater than 1 in the metal phytoextactors and less than 1 in the metal phytosabilizer species was observed (Mellem *et al*., 2012; Pandey *et al*., 2012; Mishra and Pandey, 2019; Khermandar *et al*., 2016).

2.5.3. Bioaccumulation factor (BAF) is used to calculate metals transfer from soil to various plant parts (total biomass) used the following equation:

$$BAF= C_{plant} \backslash C_{soil}$$

where C_{plant} shows the accumulation of heavy metals in plant (total biomass) and C_{soil} denoted the amount of heavy metals in soil. (BAF) values more than 1 demonstrate the potential success of a plant species for bioaccumulation. (Zhuang *et al.,* 2009; Khermandar *et al.,* 2016; He *et al*.,2021; Hussain *et al*., 2022;). Plants having both (TF) and (BAF) >1 can be employed as phytoremediators. (BAF) values greater than two are regarded as high values (Usman *et al*., 2013). If a plant has (BAF) >1 and (TF) <1, it can be used as a phytostabilizer; if it has (BAF) < 1 and (TF) >1, it can be used as a phytoextractor (Sopyan *et al.,* 2014; Takarina & Pin, 2017).

6.Statistical analysis

The obtained data were subjected to the statistical analysis of variance ANOVA of the combined analysis in completely randomized design (CRD) and least significant difference (LSD) at 0.05% was used to compare between the means of treatments using COSTAT software (pacific Grove, CA, USA) (Ott and Longnecker, 2015).

3.Results:

Table (1) showed an increase in the concentration of macro elements, with the aerial parts exhibiting concentrations of 1.17%, 0.030, 1.01, 3.1, and 0.559 g kg^{-1}for (N), (P), (K), (Ca), and (Na), respectively. In contrast, the root parts displayed concentrations of 0.74%, 0.012, 0.287, 2.05, and 0.286 g kg^{-1}for the same elements. The soil revealed concentrations of 0.71%, 0.060, 0.123, 3.1, and 0.140 g kg^{-1} for N, P, K, Ca, and Na, respectively.

Table (1) The macro elements in J. phoenicea and soil

Parts	**N%**	**P** g kg^{-1}	**K** g kg^{-1}	**Ca** g kg^{-1}	**Na** g kg^{-1}

Aerial	1.17	0.030	1.01	3.1	0.559
Roots	0.74	0.012	0.287	2.05	0.286
Soils	0.71	0.060	0.123	3.1	0.140

***Results resource: field & lab. Study 2023**

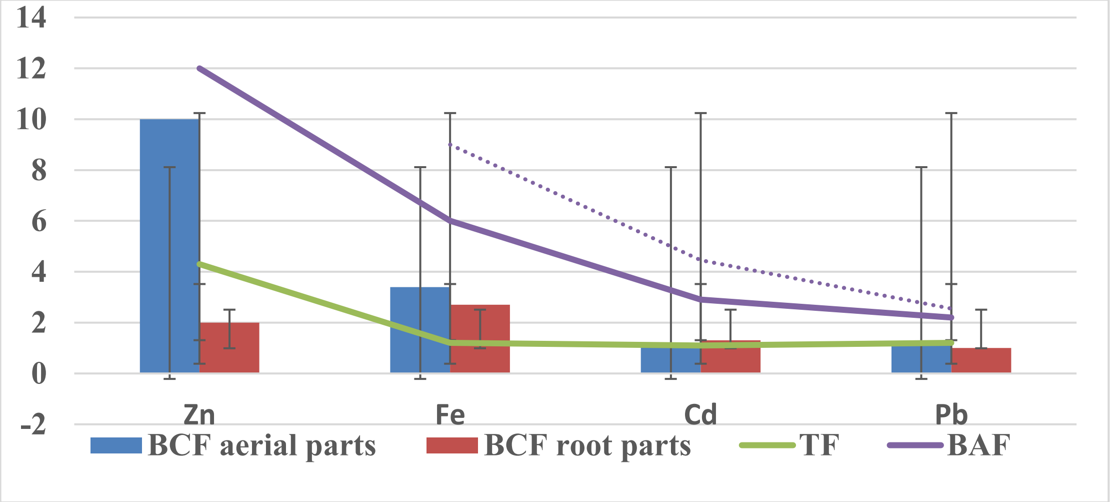
Table (2) We note that there are significant differences at ($p < 0.05$) between plant`s parts and soils parts, where were the concentrations of heavy metals in the aerial parts, 1.124, 1.328, 0.069, and 0.116 mg kg^{-1} for (Zn), (Fe), (Cd), and (Pb), respectively ,More than the roots parts which were 0.26, 1.055, 0.061, and 0.099 mg kg^{-1} for Zn, Fe, Cd, and Pb, respectively, Followed by Soils parts were 0.112, 0.382, 0.50, and 0.097 mg kg^{-1} for these heavy metals. The data indicate that the aerial parts accumulate a greater quantity of heavy metals compared to the roots, with the accumulation being aerial parts > roots parts > soil. Furthermore, Table (2) suggests that *J. phoneacae* has a tendency to accumulate heavy metals in its aerial parts.

Table (2) concentration of heavy metals in J. phoenicea and soil

Parts	**Zn** mg kg^{-1}	**Fe** mg kg^{-1}	**Cd** mg kg^{-1}	**Pb** mg kg^{-1}
Aerial	1.124^{A}	1.328^{A}	$0,069^{A}$	0.116^{A}
Roots	0.26^{B}	1.055^{B}	0.061^{B}	$0,099^{A}$
Soils	0.112^{C}	0.382^{C}	0.050^{C}	0.097^{A}
LSD	**0,035**	**0.058**	**0.005**	**0.022**

***Results resource: field & lab. Study 2023**

According to figure (1) (BCF) for the aerial parts was greater than that for the root parts across all heavy metals, with values of 10, 3.4, 1.5, and 1.2 for Zn, Fe, Cd, and Pb, respectively. In comparison, (BCF) for the roots parts was 2, 2.7, 1.3, and 1 for the same metals. (TF) values exceeded (1) for all heavy metals, where was 4.3, 1.2, 1.1, and 1.2 for Zn, Fe, Cd, and Pb, respectively. Conversely, (BAF) exceeded (1) for all heavy metals where (12, 6, 2.9 and 2.2) for (Zn, Fe, Cd and Pb) respectively, on other hand figure (1) showed that all indicators (BCF aerial parts, BCF root parts, TF, and BAF) indices that *J. phoneacea* trend to absorb heavy metals from the soil parts to the biomass parts, but transfer it by Phytoextraction strategy from roots parts to aerial parts.



***Results resource: field & lab. Study 2023**

Figure (1) Comparing biological factors

4.Discussion:

The elevated concentrations of (N), (P), (K), and s (Na) can be attributed to the influx of sewage water, as noted by Smith and Giller (1992), Farahat and Linderholm (2015), and Yu *et al.* (2022). The significant levels of (K) are linked to the presence of various minerals, including feldspar, mica, and illite, which are known to contain this element (Ben Mahmoud, 1995). The increase (Ca) concentration is primarily due to the soil's parent material, which is characterized by a high content of calcium carbonate (Ben Mahmoud, 1995).

Importantly, the concentrations of heavy metals remained within the permissible limits established by the World Health Organization WHO, 1997. The aerial parts of the plants exhibited the highest accumulation of heavy metals, with a greater concentration observed in the aerial parts compared to the root systems. This finding accord with the observations of Zhao *et al.* (2014), Farahat and Linderholm (2015), Cesur *et al.* (2021), Siyar *et al.* (2022), and Kord *et al.* (2024), who reported a higher absorption of heavy metals in the aerial parts of certain Cupressaceae species than in their roots . Furthermore, (TF) values exceeded (1) for all heavy metals, indicating that Juniperus phoenicea effectively accumulates these metals in its aerial parts. Similar findings were reported by Farahat and Linderholm (2015) and Kord *et al.* (2024). (BAF) also suggests that Juniperus phoenicea can be classified as a bioaccumulator, as the (BAF) of heavy metals exceed 1, its according to Achak *et al*. (2009) and Diaconu *et al*. (2009). Additionally, figure (1) explain that Juniperus phoenicea tends to transfer heavy metals from its roots to its aerial parts, corroborating the findings of Farahat and Linderholm (2015) and Siyar *et al*. (2022). According to the findings of Usman et al. (2013), Mishra and Pandey (2019), Venegas-Rioseco *et al*. (2021), Siyar *et al*. (2022), Kord *et al*. (2024), and Nouha *et al*. (2024), *Juniperus phoenicea* demonstrates a significant capacity for phytoextraction, enabling it to accumulate heavy metals in its above-ground structures. This species plays a crucial role in phytoremediation efforts, as it effectively sequesters heavy metals in the aerial portions of the plant, which is essential for the successful harvesting of these contaminants, as the process necessitates accumulation in the above-ground parts rather than the root system.

5.References:

Abu-Darwish, M. S., & Ofir, R. (2014). Heavy metals content and essential oil yield of Juniperus phoenicea L. in different origins in Jordan. Environmental Engineering & Management Journal (EEMJ), 13(12). https://doi.org/10.30638/eemj.2014.339

Achak, N., Romane, A., & Dahbi, A. (2009). Metals contents and organic composition in the leaf of three species of Cupressaceaes from the Atlas Mountains, Marrakech (Morocco). Physical & chemical news, (47), 98-102.

Ahmad, M., Usman, A. R., Al-Faraj, A. S., Ahmad, M., Sallam, A., & Al-Wabel, M. I. (2018). Phosphorus-loaded biochar changes soil heavy metals availability and uptake potential of maize (Zea mays L.) plants. Chemosphere, 194, 327-339. https://doi.org/10.1016/j.chemosphere.2017.11.156

Ali, H., Khan, E., & Sajad, M. A. (2013). Phytoremediation of heavy metals-concepts and applications. Chemosphere, 91(7), 869-881. https://doi.org/10.1016/j.chemosphere.2013.01.075

Angelova, V. (2022). Heavy metal accumulation and chemical composition of essential oil of Juniperus oxycedrus L.(Cupressaceae) grown on serpentine soils in Bulgaria. Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering, 11.

Anum, S., Khan, S. M., Chaudhary, H. J., Ahmad, Z., & Afza, R. (2019). Phytoremediation of nickel polluted ecosystem through selected ornamental plant species in the presence of bacterium Kocuria rhizophila. Bioremediation Journal, 23(3), 215-226. https://doi.org/10.1080/10889868.2019.1639610
Asbabou, A., Hanane, T., Gourich, A. A., Siddique, F., Drioiche, A., Remok, F., ... & Zair, T. (2024). Phytochemical profile, physicochemical, antioxidant and antimicrobial properties of Juniperus phoenicea and Tetraclinis articulate: in vitro and in silico approaches. Frontiers in Chemistry, 12, 1397961. https://doi.org/10.3389/fchem.2024.1397961

Bahiru, D. B., & Yegrem, L. (2021). Levels of heavy metal in vegetable, fruits and cereals crops in Ethiopia: A review. International Journal of Environmental Monitoring and Analysis, 9(4), 96. https://doi.org/10.11648/j.ijema.20210904.11

Ben Mahmoud, K. R. (1995). Libyan soils (Their Genesis, Classification, Properties and Agricultural potentials) NASR. Tripoli, Libya, 615.

Binxhija, L., & Ylli, A. (2021). Study of Heavy Metals in Wild Juniperus Plants from Kosovo. Appl Veg Sci, 20: 397-409.

Cardoso-Silva, C. B., Melo, J., Pereira, A., & Cerqueira-Silva, C. B. (2013). Aoac. 1997. Official Methods of Analysis Of The Association Of Official Analytical. Caracterização, Propagação E Melhoramento Genético De Pitaya Comercial E Nativa Do Cerrado, 29(1), 48.

Cesur, A., Zeren Cetin, I., Abo Aisha, A. E. S., Alrabiti, O. B. M., Aljama, A. M. O., Jawed, A. A., ... & Ozel, H. B. (2021). The usability of Cupressus arizonica annual rings in monitoring the changes in heavy metal concentration in air. Environmental Science and Pollution Research, 28(27), 35642-35648. https://doi.org/10.1007/s11356-021-13166-4

Chandrajith, R., Dissanayake, C. B., & Tobschall, H. J. (2005). The abundances of rarer trace elements in paddy (rice) soils of Sri Lanka. Chemosphere, 58(10), 1415-1420. https://doi.org/10.1016/j.chemosphere.2004.09.090

Chitimus, D., Nedeff, V., Mosnegutu, E., Barsan, N., Irimia, O., & Nedeff, F. (2023). Studies on the accumulation, translocation, and enrichment capacity of soils and the plant species phragmites australis (common reed) with heavy metals. Sustainability, 15(11), 8729. https://doi.org/10.3390/su15118729

Cunningham,S.D., and Ow, D.W.(1996):Promises and prospects of phytoremediation. - Plant Physiol. 110; 715-719. https://doi.org/10.1104/pp.110.3.715

Dalvi, A. A., & Bhalerao, S. A. (2013). Response of plants towards heavy metal toxicity: an overview of avoidance, tolerance and uptake mechanism. Ann Plant Sci, 2(9), 362-368.
Diaconu, D., Nastase, V., Nănău, M. M., Nechifor, O., & Nechifor, E. (2009). Assessment of some heavy metals in soils, drinking water, medicinal plants and their liquid extracts. Environmental Engineering & Management Journal (EEMJ), 8(3). https://doi.org/10.30638/eemj.2009.078

Farahat, E., & Linderholm, H. W. (2015). The effect of long-term wastewater irrigation on accumulation and transfer of heavy metals in Cupressus sempervirens leaves and adjacent soils. Science of the Total Environment, 512, 1-7. https://doi.org/10.1016/j.scitotenv.2015.01.032

Gerhardt, K. E., Gerwing, P. D., & Greenberg, B. M. (2017). Opinion: Taking phytoremediation from proven technology to accepted practice. Plant Science, 256, 170-185. https://doi.org/10.1016/j.plantsci.2016.11.016
Ghosh, M., & Singh, S. P. (2005). A review on phytoremediation of heavy metals and utilization of it's by products. Asian J Energy Environ, 6(4), 18.

Gola, D., Malik, A., Shaikh, Z. A., & Sreekrishnan, T. R. (2016). Impact of heavy metal containing wastewater on agricultural soil and produce: relevance of biological treatment. Environmental Processes, 3, 1063-1080. https://doi.org/10.1007/s40710-016-0176-9

Hall, J. Á. (2002). Cellular mechanisms for heavy metal detoxification and tolerance. Journal of experimental botany, 53(366), 1-11. https://doi.org/10.1093/jexbot/53.366.1

Hao, X., Taghavi, S., Xie, P., Orbach, M. J., Alwathnani, H. A., Rensing, C., & Wei, G. (2014). Phytoremediation of heavy and transition metals aided by legume-rhizobia symbiosis. International Journal of Phytoremediation, 16(2), 179-202. https://doi.org/10.1080/15226514.2013.773273

He, Y., Su, S., Cheng, J., Tang, Z., Ren, S., & Lyu, Y. (2021). Bioaccumulation and trophodynamics of cyclic methylsiloxanes in the food web of a large subtropical lake in China. Journal of Hazardous Materials, 413, 125354. https://doi.org/10.1016/j.jhazmat.2021.125354

Hu, Y., Wang, D., Wei, L., Zhang, X., & Song, B. (2014). Bioaccumulation of heavy metals in plant leaves from Yan′ an city of the Loess Plateau, China. Ecotoxicology and environmental safety, 110, 82-88. https://doi.org/10.1016/j.ecoenv.2014.08.021

Huang, J., Wang, C., Qi, L., Zhang, X., Tang, G., Li, L., ... & Lu, M. (2020). Phosphorus is more effective than nitrogen in restoring plant communities of heavy metals polluted soils. Environmental Pollution, 266, 115259. https://doi.org/10.1016/j.envpol.2020.115259

Hussain, B., Abbas, Y., Ali, H., Zafar, M., Ali, S., Ashraf, M. N., ... & Valderrama, J. R. D. (2022). Metal and metalloids speciation, fractionation, bioavailability, and transfer toward plants. In Metals metalloids soil plant water systems (pp. 29-50). Academic Press. https://doi.org/10.1016/B978-0-323-91675-2.00026-3

Iatrou, M., Papadopoulos, A., Papadopoulos, F., Dichala, O., Psoma, P., & Bountla, A. (2014). Determination of soil available phosphorus using the Olsen and Mehlich 3 methods for Greek soils having variable amounts of calcium carbonate. Communications in Soil Science and Plant Analysis, 45(16), 2207-2214. https://doi.org/10.1080/00103624.2014.911304

Jacob, J. M., Karthik, C., Saratale, R. G., Kumar, S. S., Prabakar, D., Kadirvelu, K., & Pugazhendhi, A. (2018). Biological approaches to tackle heavy metal pollution: a survey of literature. Journal of environmental management, 217, 56-70. https://doi.org/10.1016/j.jenvman.2018.03.077

Khan, S. N., Nafees, M., & Imtiaz, M. (2023). Assessment of industrial effluents for heavy metals concentration and evaluation of grass (Phalaris minor) as a pollution indicator. Heliyon, 9(9). https://doi.org/10.1016/j.heliyon.2023.e20299

Khermandar, K., Mahdavi, A., & Ahmady Asbchin, S. (2016). Differential expression of Lead accumulation during two growing seasons by desert shrub Acacia victoriae L. Desert, 21(2), 143-154.

Kord, B., Khademi, A., Madanipour Kermanshahi, M., Pourabbasi, S., & Hashemi, S. A. (2024). Phytoremediation potential of tree species in soil contaminated with lead and cadmium. Caspian Journal of Environmental Sciences, 1-9.

Kraj, W., Pietrzykowski, M., & Warczyk, A. (2021). The antioxidant defense system and bioremediation. In Handbook of Bioremediation (pp. 205-220). Academic Press. https://doi.org/10.1016/B978-0-12-819382-2.00012-0

Manohara, B., & Belagali, S. L. (2014). Characterization of essential nutrients and heavy metals during municipal solid waste composting. International Journal of Innovative Research in Science, Engineering and Technology, 3(2), 9664-9672.

Marques, A. P., Rangel, A. O., & Castro, P. M. (2009). Remediation of heavy metal contaminated soils: phytoremediation as a potentially promising clean-up technology. Critical Reviews in Environmental Science and Technology, 39(8), 622-654. https://doi.org/10.1080/10643380701798272

McIntyre, T., 2003. Phytoremediation of heavy metals from soils. Advances in Biochemical Engineering/ Biotechnology 78, 97-123. https://doi.org/10.1007/3-540-45991-X_4

Mellem, J. J., Baijnath, H., & Odhav, B. (2012). Bioaccumulation of Cr, Hg, As, Pb, Cu and Ni with the ability for hyperaccumulation by Amaranthus dubius. African Journal of Agricultural Research, 7(4), 591-596. https://doi.org/10.5897/AJAR11.1486

Mishra, T., & Pandey, V. C. (2019). Phytoremediation of red mud deposits through natural succession. In Phytomanagement of polluted sites (pp. 409-424). https://doi.org/10.1016/B978-0-12-813912-7.00016-8

Nogueira, T. A. R., Franco, A., He, Z., Braga, V. S., Firme, L. P., & Abreu-Junior, C. H. (2013). Short-term usage of sewage sludge as organic fertilizer to sugarcane in a tropical soil bears little threat of heavy metal contamination. Journal of Environmental Management, 114, 168-177. https://doi.org/10.1016/j.jenvman.2012.09.012

Nouha, k., Mounira, g. M., Lamia, h., Shahhat, i., Mehrez, r., & Arbi, g. (2024). Physiological and biochemical responses in mediterranean saltbush (atriplex halimus l., amaranthaceae juss.) To heavy metal pollution in arid environment. Pak. J. Bot, 56(5), 1717-1726. https://doi.org/10.30848/PJB2024-5(25)

Othman, A., & Al-Habbat, N. (2023). Modeling Trends in Rainfall Rates at Shahat Meteorological Station (1961-2050) Using Statistical Techniques. Journal of Humanitarian and Applied Sciences, 8(16), 176-188. https://doi.org/10.65137/jhas.v8i16.446

Ott, R. L. and Longnecker M. T. (2015) An introduction to statistical methods and data analysis: Nelson Education. 1296.

Oumlouki, K. E., Salih, G., Jilal, A., Dakak, H., Amrani, M. E., & Zouahri, A. (2021). Comparative study of the mineral composition of carob pulp (Ceratonia siliqua L.) from various regions in Morocco. Moroccan Journal of Chemistry, 9(4), 9-4.

Pandey, R., Shubhashish, K., & Pandey, J. (2012). Dietary intake of pollutant aerosols via vegetables influenced by atmospheric deposition and wastewater irrigation. Ecotoxicology and environmental safety, 76, 200-208. https://doi.org/10.1016/j.ecoenv.2011.10.004

Rascio, N., & Navari-Izzo, F. (2011). Heavy metal hyperaccumulating plants: how and why do they do it? And what makes them so interesting?. Plant science, 180(2), 169-181. https://doi.org/10.1016/j.plantsci.2010.08.016

Raskin, I, Kumar, P.B.A.N., Dushenkov, S. and Salt, D. (1994): Bioconcentration of heavy metals by plants. - Current Opinion Biotechnology 5; 285-290. https://doi.org/10.1016/0958-1669(94)90030-2

Sarwar, N., Imran, M., Shaheen, M. R., Ishaque, W., Kamran, M. A., Matloob, A., ... & Hussain, S. (2017). Phytoremediation strategies for soils contaminated with heavy metals: modifications and future perspectives. Chemosphere, 171, 710-721. https://doi.org/10.1016/j.chemosphere.2016.12.116

Siyar, R., Doulati Ardejani, F., Norouzi, P., Maghsoudy, S., Yavarzadeh, M., Taherdangkoo, R., & Butscher, C. (2022). Phytoremediation potential of native hyperaccumulator plants growing on heavy metal-contaminated soil of Khatunabad copper smelter and refinery, Iran. Water, 14(22), 3597. https://doi.org/10.3390/w14223597

Smith, S. R., & Giller, K. E. (1992). Effective Rhizobium leguminosarum biovar trifolii present in five soils contaminated with heavy metals from long-term applications of sewage sludge or metal mine spoil. Soil Biology and Biochemistry, 24(8), 781-788. https://doi.org/10.1016/0038-0717(92)90253-T

Taghipour, H., & Mosaferi, M. (2013). Heavy metals in the vegetables collected from production sites. Health promotion perspectives, 3(2), 185.

Takarina, N. D., & Pin, T. G. (2017). Bioconcentration factor (BCF) and translocation factor (TF) of heavy metals in mangrove trees of Blanakan fish farm. Makara Journal of Science, 77-81. https://doi.org/10.7454/mss.v21i2.7308

Usman, A.R.A., R.S., Alkredaa and M.I. Al-Wabel (2013) Heavy metal contamination in sediments and mangroves from the coast of Red Sea: Avicennia sp. marina as potential metal bioaccumulator.Ecotoxicol. Environ. Saf. 97: 263-270. https://doi.org/10.1016/j.ecoenv.2013.08.009

Van der Ent, A., Baker, A. J., Reeves, R. D., Pollard, A. J., & Schat, H. (2013). Hyperaccumulators of metal and metalloid trace elements: facts and fiction. Plant and soil, 362, 319-334. https://doi.org/10.1007/s11104-012-1287-3

Venegas-Rioseco, J., Ginocchio, R., & Ortiz-Calderón, C. (2021). Increase in phytoextraction potential by genome editing and transformation: a review. Plants, 11(1), 86. https://doi.org/10.3390/plants11010086

Wu, Q., Wang, S., Thangavel, P., Li, Q., Zheng, H., Bai, J., & Qiu, R. (2011). Phytostabilization potential of Jatropha curcas L. in polymetallic acid mine tailings. International Journal of phytoremediation, 13(8), 788-804.

https://doi.org/10.1080/15226514.2010.525562
Wuana, R. A., & Okieimen, F. E. (2011). Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation. International Scholarly Research Notices, 2011(1), 402647. 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. Frontiers in plant science, 11, 359. https://doi.org/10.3389/fpls.2020.00359
Youning, Hu., W. Dexiang, W. Lijing, Z. Xinping and S. Bin (2014). Bioaccumulation of heavy metals in plant leaves from Yan'an city of the Loess Plateau, China. Ecotoxicology and Environmental Safety, 110: 82-88. https://doi.org/10.1016/j.ecoenv.2014.08.021

Yu, H., Xiao, H., Cui, Y., Liu, Y., & Tan, W. (2022). High nitrogen addition after the application of sewage sludge compost decreased the bioavailability of heavy metals in soil. Environmental Research, 215, 114351. https://doi.org/10.1016/j.envres.2022.114351
Zhang, M., Cui, L., Sheng, L., & Wang, Y. (2009). Distribution and enrichment of heavy metals among sediments, water body and plants in Hengshuihu Wetland of Northern China. Ecological engineering, 35(4), 563-569. https://doi.org/10.1016/j.ecoleng.2008.05.012
Zhao, Q., Thompson, A. M., Callister, S. J., Tfaily, M. M., Bell, S. L., Hobbie, S. E., & Hofmockel, K. S. (2022). Dynamics of organic matter molecular composition under aerobic decomposition and their response to the nitrogen addition in grassland soils. Science of the Total Environment, 806, 150514. https://doi.org/10.1016/j.scitotenv.2021.150514
Zhao, X., Liu, J., Xia, X., Chu, J., Wei, Y., Shi, S., ... & Jiang, Z. (2014). The evaluation of heavy metal accumulation and application of a comprehensive bio-concentration index for woody species on contaminated sites in Hunan, China. Environmental Science and Pollution Research, 21, 5076-5085. https://doi.org/10.1007/s11356-013-2393-3