

Estimation of Cadmium, Copper, Nickel, Lead and Zinc in Five Medicinal Plants Collected from Musa Khail area in Baluchistan

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ABSTRACT

This study achieved a employed methodology to find out the level of Cadmium, Copper, Nickel, Lead, and Zinc in five medicinal plants, including Hertia intermedia, Cardariachalepense, Scorzoneraammophila, Tamarixkarelinii and Astragalus auganus, collected from Musa Khail area of Baluchistan, Pakistan. The plant samples were treated with the necessary acids to digest the material, ensuring the thorough extraction of heavy metals. The contents of heavy metals were then estimated by flame atomic absorption spectroscopy, a highly reliable method for heavy metal analysis. The study's findings indicated that all the studied plants contained Cd, Cu, Ni, and Zn concentrations below the recommended limit by Food Agriculture Organization (FAO), World Health Organization (WHO) and other international organizations. However, the Pb concentrations identified in Hertia intermedia and Tamarix karelinii were slightly higher than the FAO/WHO limit of 0.43 ppm but complied with the WHO limit for medicinal plants of up to 10 ppm. This article thus re-emphasizes the need for constant detection and identification of the levels of heavy metals in plants used in traditional medication.

INTRODUCTION

Herbal treatments have been a safe and readily available method of treating disease for thousands of years. Reportedly, throughout the last several decades, both developed and developing countries have increased their use of these goods because of their inexpensive prices and, most significantly, the general confidence that they are safe (Rai et al.,2005). In some parts of the world, like Ethiopia, where more than 85 percent of the population depends on traditional medicine, it is the primary option for primary healthcare (Baye& Hymete,2010).

Medicinal plants in primary healthcare are essential for preventing and treating disease for millions worldwide, in developed and developing nations. Much of what we use in modern medicine comes from plants with medicinal properties, such as vitamins, glycosides, essential oils, and other unique organic components. Essential physiological processes and therapeutic uses in living beings rely on these pharmacologically active components (Devi et al.,2008).

To achieve the desired medicinal benefits, it is essential to maintain the quality of the final products and the plant's raw materials. The high heavy metal concentration in herbal cures is a prevalent issue, according to research from multiple countries, and it can cause significant health concerns. Pollution of the environments that sustain the cultivation of medicinal plants to extract their active components (Barthwal et al.,2008). An evaluation and monitoring program for heavy metal contamination is necessary to improve the overall safety and quality of medicinal plants that are regularly utilized. This will protect the customer.

Thus, experts increasingly recommend plant-based remedies, including herbal teas, extracts, and medications, as a substitute for conventional medical care for often-encountered health problems (Ernst,1998). However, are medicinal plants risk-free to use? Despite herbal treatments' typical portrayal as safe and natural, they do contain specific potentially dangerous characteristics (Gomez M.R.,et al.,2007). Consistent or excessive use of medicinal herbs has long been known to cause the accumulation of various substances in the body, which can harm health (Sharma et al.,2009). Serious health hazards, such as prolonged poisoning symptoms, liver harm, kidney disappointment, and further unfamiliar toxic or allergic responses, might occur if medicinal herbs containing heavy metals were to be employed for pharmacological activity (Andrew et al.,2003). Many herbal therapeutic blends contain hazardous metals such as Cd, Hg, Pb, Al, and Cr in significant absorptions and oxidation number, which can harm human health (Lekouch et al.,2001). The risks of substantial metal exposure to people have been known for a long time, but exposure continues to occur in some areas and even it increases (Kaushik et al.,2009).

The World Health Organization (WHO) states that heavy metals such as lead, cadmium, and mercury must be thoroughly controlled in treatment programs to guarantee safety. Consequently, a continuing dispute is whether the herbal pharmaceuticals would be subject to suitable permitting procedures that include superiority, safety, and value criteria. In these cases, it is crucial to analyze medicinal plants' elemental concentrations to ensure their purity (Arczeus,A.et al.,2010). Unlike organic chemicals, which decompose into carbon oxide (IV) microbes, most heavy metal



contaminants do not undergo chemical breakdown. Heavy metal contamination, however, tends to stay in the soil for quite some time once it is introduced.

The biodegradation of organic waste is significantly slowed when toxic trace metals are present in the soil (Adriano et al, 2001). Due to plants toxicity, reduced food quality, the soil-plant-animal-human food chain, contaminated drinking water, and a decrease in the amount of land available for agricultural production, which could lead to issues with land tenure and food insecurity, both humans and the ecosystem are at risk from this soil contamination (McLaughlin, M. et al., 2000). Fertilizers, pesticides, pollution from vehicles and industries, and polluted irrigation water are only a few sources of copper and iron contamination in medicinal plants. In its list of thirteen substances causing the greatest alarm, the European Union has included the metals in question. Some of these are micronutrients that the body needs for normal function. However, they can build up in organisms and cause serious harm, especially to vital organs, if taken persistently with food and medicine. Ni, Co, Cr, and as concentrations need to be ascertained before using medicinal plants to prepare herbal remedies (Khan, Z.I. et al., 2021).

Lead is a bluish-gray mineral that occurs in group IV and the sixth period of natural mineralogy. It has an atomic number of 82 and a mass of 207.2. Lead, usually found in compounds with oxygen or Sulphur, is present in the Earth's crust in amounts ranging from 10-30 mg/kg. Lead can be converted into a wide variety of organic compounds, essential salts such as 2PbCO_3 and $\text{Pb}(\text{OH})_2$, and potent oxidant molecules like PbO_2 (Baldwin & Marshal, 1999).

LITERATURE REVIEW

The introduction of heavy metals into the ecosystem can be happened by the both natural and human activities (Amini et al., 2024). These metals can be assembled in plants, sediments water and soil. The extent of hazardous of heavy metals is not only limited in medicinal plants but also in several species of fishes (Rind et al., 2023).

Cd II ions containing cadmium are among the most poisonous heavy metals, alongside lead and mercury. It is a micronutrient essential for plant and animal metabolism, and its replacement by zinc renders metabolic processes useless. Cadmium inhibits the most catalytic action of biocatalysts such as arylsulfatase, liquor or lipoamide by a dehydrogenase, and others; this also has a long half-life in the body (Campbell, 2006). Copper is the third most used metal in the world, and it is essential for the development of all living things. Plants must resist diseases, produce seeds, and regulate water levels; humans also use it to make hemoglobin. Adverse side effects, such as anemia, gastrointestinal distress, liver and renal damage, and others, might occur at high dosages (Hussain et al., 2019).

The heavy metal nickel has the atomic numbers 58.69 and 28, making it a transition metal. It is the unchanging $\text{Ni}(\text{OH})_2$ molecule in solutions with impartial to marginally acidic pH and as the Ni II ion in places with low pH. In very acidic conditions, it forms the soluble nickel ate ion, HNiO_2 , and dissolves in water (Khodadoust et al., 2004). A small shrub with yellow blossoms, *Hertia*

intermedia (or *Othonnopsis intermedia*), belongs to the Asteraceae or Composite family. Vern, Central Asia, and Buski are their native habitats, as are the sandy gravel slopes and the banks of wastewater streams. Twelve species of *Hertiaca* can be found in the southwestern Asian region and southern and northern Africa. Its native Pakistani habitats include Baluchistan, Kurram, and the districts below Parachinar (Jakupovic *et al.*, 1989). In addition to be a popular green vegetable and livestock feed, this plant is well-known for the spicy oil that its seeds produce. This herb contains antioxidants and is beneficial for gastrointestinal motility (Germam & Chen, 2009). The therophyteruderal herb *Cardaria chalepense*, which has left the size of a microphyll, is native to central Asia and Pakistan. Notable for its peppery-flavored oil-producing seeds, this green vegetable and fodder crop is also well-known. Antioxidants and improved gastrointestinal motility are two benefits of this plant.

Chromium when enters into soil and water then it leads to a significant warning to plants which consequently affect productivity of agricultures. It can also has marked effects of toxicity which disturb biochemical and physiological phenomena in plants (Ali *et al.*, 2023). The angiosperm genus *Astragalus auganus* includes 1600 species distributed over Afghanistan, Iran, Pakistan, and India. It is a plant that lives in geophytes and has nanophyll-sized leaves (Lindon *et al.*, 2015).

RESEARCH METHODOLOGY

Study Design

People in the MusaKhail region depend on homeopathic medicines for therapy, so determining the concentration of heavy metals in medicinal plants is a crucial subject of study. Thus, knowing how polluted these plants are with heavy metals can benefit quality standards, laws, and public health preventative strategies. Environmental contamination has far-reaching consequences for human health, and this study adds to what is already known about the topic because of this, we will conduct this study to determine how much heavy metal is in the medicinal plants we gathered in the MusaKhail region of Baluchistan province, Pakistan. In this context, we intend to use techniques like atomic absorption spectroscopy (AAS) and inductively coupled plasma mass spectroscopy (ICP-MS) to determine the concentrations of particular heavy metals in selected medicinal plant samples. In addition to offering valuable information on potential health hazards linked to the use of plants from this region, the results of this research will help provide empirical support for nursing practices that outline sustainable strategies.

The primary objective of this research is to examine the medicinal plants of Pakistan's Baluchistan and MusaKhail areas for the presence of various heavy metals. In addition to exposing the extent to which medicinal plants are contaminated with heavy metals, this study will also help develop consistent regulations and laws for the proper use of natural plants in traditional medicine.



In addition to highlighting the importance of protecting plants for their medicinal properties, the study stresses the need to preserve the ecosystem to stop the decline in human health.

Sampling Collection

The samples of the medicinal plants were collected from the different sites of Musa Khail. During plants collections, many places were visited in which the help of the natives of the concerned areas was very helpful. We collected random samples using sterile plastic bags from each location and sent them to UOB's Laboratory of Chemistry for analysis. Based on the flora of Pakistan, these plants were recognized, and their names were determined. The following data show the sample collection's places.

Table 1: Medicinal plants with their life forms, parts used, treatment properties and collection sites

Medicinal Plants	Life Form	Part used	Treatment	Collection site
<i>Hertia intermedia</i>	Herbaceous	Leaves or roots	Dermal inflammation and insects sting	Rocky ground and mountainous areas
<i>Cardaria chalepense</i>	Herbaceous	Leaves and seeds	Eczema	Arid regions, disturbed habitats
<i>Scorzonera ammophila</i>	Perennial	Roots and leaves	Anticancer	Coastal and sandy areas
<i>Tamarix karelini</i>	Shrub	Barks and leaves	Jaundice	Desert regions and saline soil
<i>Astragalus auganus</i>	Perennial	Roots	Adapt genic	Temperate forest

Research Analysis Tool

The tools and techniques Chemicals and analytical reagents of various kinds were employed. Merck (Darmstadt, Germany) supplied the HNO_3 , $\text{Pb}(\text{NO}_3)_2$, HgSO_4 , $\text{Zn}(\text{NO}_3)_2$, CdCl_2 , $\text{Ni}(\text{NO}_3)_2$, HCl , and deionized water. We utilized a West Point 1844 Juicer/Blender/Mincer homogenizer for sample homogenizing, a JEN-WAY thousand warm bowl magnetic stirrer for removal, and a type S4 AA atomic absorption spectrometer. The experimental research used the System of thermo Electron Cooperation China for the absorbency measurements. Gathering samples from March to April of 2018, three field trips were planned in the Musa Khail district to collect samples of plants that have been shown to have therapeutic value in the past. The information about the five researched plants can be found in **Table 1**.

Sample preparation

All plant samples were washed with deionized water. After washing, we dried the samples in an oven at 80°C for two days and ground the dried plant material into a powder. Each sample was carefully

measured at 0.5 g and then transferred to a 100 ml PTFE beaker. The samples were acid-digested using the procedure described beneath to regulate the amounts of Cd, Cu, Ni, Pb, and Zn in the sections.

Digestion

Each herbal residue sample weighed 2 grams. After soaking in a solution of 9 ml each of HNO₃ (65%) and HCl (37%), the samples were heated gently at 95 degrees Celsius for 5 hours until completely dissolved. Deionized water was then added to the mixture to reach the final volume of 50 ml.

Atomic absorption spectrophotometry

Flame atomic absorption spectroscopy was used to determine the concentrations of heavy metals in the samples. Five solutions were created, each with a different concentration of heavy metals in ppm. Standard solutions for Cd, Cu, and Ni were as follows: 0.001, 0.010, 0.020, 0.030, and 0.040 ppm for Cd, 0.10, 1.0, 10.0, 20.0, and 30.0 ppm for Cu, and 0.1, 1.0, 5.0, 10.0, and 20.0 ppm for Ni. As for lead, the standard solutions were 0.01–0.2–0.5–1.0–2.0 ppm, while zinc had 0.1–30.0 ppm concentrations. Next, about 3 ml of plant sample solutions were used to determine the heavy metal concentration. Due to limitations in laboratory resources, all heavy elements other than Cd, Cu, Ni, Pb, and Zn were excluded.

RESULTS AND DISCUSSION

Public safety is greatly concerned when necessary along with unnecessary rare heavy element concentrations in healing sages exceed permissible limits worldwide. The lack of effective management and control over eminence guarantee characteristics of floras, which serve as the underdone resources for final beneficial goods, makes this situation even more significant and concerning in Pakistan.

Copper

The Copper levels taken in ppm of the floras tested were as follows: 2.1026 for *Hertia intermedia*, 1.0153 for *Carderia chalapense*, 1.0296 for *Scotzonera ammophila*, 1.6789 for *Tamarix karelini*, and 0.7558 for *Astragalus auganus* (see to Table 2 and Figure 7b for reference). According to FAO/WHO, the maximum allowable concentration of Cu in plants that can be eaten is 3.00 ppm. Based on our comparisons with the metal limit indicated by FAO/WHO and the permissible limits for copper set by Singapore and China (World Health Organization,.1998). It appears that the medicinal plants we researched accumulate Cu far below these limitations. The copper concentration in various plants in Iran's copper mining area varied greatly, with the lowest concentration found in therophytes (*Erodium* sp.) and the highest in geophytes (*Epilobiumhirsutum* L.), as reported by Ghaderian SM &Ravandi AAG (Ghaderian& Ravandi,.2012). This indicates that the therophytes in this area tend to have lower



Cu content than geophytes. In contrast to the majority of the plants studied by our therophytes (*H. intermedia*, *C. cheapens*, and *S. ammophila*) had a relatively low range of Cu content. This could indicate that therophytes do not accumulate Cu. On the other hand, our lone geophyte, *Astragalus auganus*, displayed a highly contrasting Cu content. The high Cu content in the Iran mining area permits most geophytes to collect more Cu concentration, which explains the high level of unfamiliarity in both investigations. In other countries, such as Bangladesh, reports of therapeutic plants with Cu levels ranging from 0.38 to 3.1 ppm have also been made (Wendland et al., 2001) and in Ethiopia (Dagnew et al., 2024) This is proof that these plants do not hyper-accumulate copper.

Cadmium

From the plants that were tested, the highest concentration of Cd in parts per million was found in *Scorzonera ammophila* (0.0429), next in *Cardaria achalepense* (0.0233), *Tamarix karelini* (0.0217), in *Hertia intermedia* (0.0070), and finally in *Astragalus auganus* (0.00749) (Table 2 & Figure 7a). For edible plants to be considered safe, the World Health Organization/Food and Agriculture Organization has established a maximum of 0.21 ppm for Cd. Nevertheless, according to WHO Canada and China, 0.3 ppm is the permitted limit for Cd. According to Canadian regulations, raw therapeutic plant material in finished herbal products cannot exceed 0.006 mg/day (Ang & Lee, 2005). Based on our findings, all plants from the area can be safely utilized in herbal treatments, as their Cd levels are below the allowed parameters specified by FAO/WHO and WHO. Possible explanations for the discrepancy between the study's findings and those of Jabeen S et al. include variations in plant species and geographical location; for example, less influenced by human activity than the densely populated Harripur region. There have been additional places where low Cd levels in therapeutic plants have been discovered, such as Saudi Arabia and 0.11–0.34 ppm in Ethiopia, indicating that these plants do not absorb or filter it (Alqahtani et al., 2020).

Nickel

Hertia intermedia had a Ni ppm concentration of 0.3152, whereas *Cardaria chalepense* had 0.4782, *Scorzonera ammophila* had 0.3061, *Tamarix karelini* had 0.2173, and *Astragalus auganus* had 0.0163 (Table 2 & Figure 7b). The FAO/WHO established a maximum of 1.63 ppm for Ni in edible plants. However, the World Health Organization has not yet established Ni limits for medicinal plants. The current study's plants exhibited Ni concentrations significantly lower than the FAO/WHO-recommended limits. The Ni concentration of our plants differs from that of all the plants analyzed by different researchers who found those whole plants tested accumulated Nickel over this boundary. Possible causes of this variation include soil Ni levels, plant species, and the capacity of plants to tolerate or accumulate Ni. The optimal Ni concentrations for medicinal plants require further investigation (Gautam et al., 2017).

Zinc

Here are the Zn concentrations in parts per million (ppm): *Hertia intermedia* had 4.4630, *Tamarix karelini* 3.825, *Scorzonera ammophila* 3.0174, *Astragalus auganus* 2.8225, and *Cardaria chalepense* 2.2771 (Table 2 & Figure 7b). The FAO/WHO established a maximum allowable value of zinc at 27.4 ppm. However, the WHO has no Zn content limitations for medicinal plants. Our investigation confirmed that all of the plants tested had safe zinc levels since they were compared to the permissible limits set by the FAO/WHO. Additionally, regarding Zn, our results directly contradict because some plant species store more zinc for metabolic use than others, this could result from species-specific differences. This study's findings suggest that certain plant species may naturally collect adequate levels of Zn for metabolic demands, which is not surprising given that Zn is an essential micronutrient. The observed differences show that different plant species and maybe soil variables affect Zn absorption capacities (Malinowska et al.,2015).

Lead

For the medicinal plants that were part of the study, the ones with the highest Pb concentrations were *Hertia intermedia* (0.2083 ppm), trailed by *Tamarix karelini* (0.1981 ppm), *Cardaria chalepense* (0.0864 ppm), *Astragalus auganus* (0.0312 ppm), and *Scorzonera auganus* (0.0187 ppm) (Table 2 & Figure 7a). The FAO/WHO established a maximum of 0.43 ppm for lead levels in edible plants. On the other hand, the World Health Organization (WHO), Chili, Thailand and Malaysia all increased such limitation to 10 ppm for healing herbal constituents. At the same time, Canada imposed a daily limit of 0.02 mg for completed herbal products. Results showed that the medicinal plants tested here had lead concentrations that were within the guidelines established by the World Health Organization. The different sections of *Wathena somniferous* revealed varied levels of Pb beyond the stated limit, indicating that *W. somniferous* can accumulate more Pb than the plants we investigated here. All the plants we tested had Pb levels within the acceptable limits, except *A. occidentalis* and *A. indicia*, which contradicted our results. The fact that even trace amounts of lead can be harmful to people owing to bioaccumulation over time makes constant monitoring all the more important (Hyder et al.,2022).

Table 2: Concentration (ppm) of heavy metals in medicinal Plants

No.	Name of plants	Cd	Cu	Ni	Pb	Zn
1	<i>Hertia intermedia</i>	0.0070	2.106	0.3153	0.2083	4.4630
2	<i>Cardaria chalepense</i>	0.0233	1.0153	0.4782	0.0864	2.2771
3	<i>ScorzoneraAmmophila</i>	0.0429	1.0296	0.3061	0.0187	3.0174
4	<i>Tamarix karelini</i>	0.0217	1.6789	0.2173	0.1918	3.825
5	<i>Astragalus auganus</i>	0.0049	0.7558	0.0163	0.0312	2.8225

CONCLUSION

The current study aims to determine the levels of heavy metals (Cd, Cu, Ni, Pb, and Zn) in five of the medicinal plants (*Hertia intermedia*, *Cardaria chalepense*, *Scorzonera ammophila*, *Tamarix karelini*, and *Astragalus auganus*) to be harvested from the Musakhail region in Baluchistan, Pakistan. All the investigated samples contained low concentrations of the stated metals: Cd, Cu, Ni, and Zn. They complied with the maximum limit set by the FAO/WHO and other international standards. These plants can, therefore, be safely used for the purpose of medicines. Nevertheless, the Pb content detected in *Hertia intermedia* (0.2083 ppm) and *Tamarix karelini* (0.1981 ppm) was slightly higher than the prescribed limit set by FAO/WHO of 0. The mean exposure level of processor gas was 43 ppm, while that of processor steam was 20 ppm, below the WHO limit of 10 ppm for medicinal plants. It also matters to note that any amount of lead is frowned upon in medicinal plants as it is known to cause significant health problems as levels accumulate in the body over time. The study further reveals the need for quality, safety, and efficacy that can be experienced when people take medicines containing medicinal plants by determining the number of heavy metals in them. It also points to the fact that standard procedures and policies should be adopted to identify the right channel to be followed when deploying natural plants for traditional medication. Furthermore, regarding the need to protect the environment from further pollution and guarantee people's health, the findings conclude with the need to accomplish that goal.

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AUTHOR'S CONTRIBUTION

This research was designed, conceptualized and conducted the study in which all the work related to research was reviewed and finalized. The final manuscript has read and approved by all authors.

REFERENCES

- Adriano, D. C. (2001). *Trace elements in terrestrial environments: Biogeochemistry, bioavailability, and risks of metals* (2nd ed.). Springer.
- Ali, S., Mir, R. A., Tyagi, A., Manzar, N., Kashyap, A. S., & Mushtaq, M. (2023). Chromium toxicity in plants: Signaling, mitigation, and future perspectives. *Plants*, 12(7), 1502. <https://doi.org/10.3390/plants12071502>



- Alqahtani, F. Z., ElTaher, A., Al Zahrani, J. H., & Abbady, A. G. E. (2020). Assessment of major and trace elements in drinking groundwater in Bisha Area, Saudi Arabia. *Journal of Chemistry*, 2020, 1–10. <https://doi.org/10.1155/2020/8818147>
- Amini, Z., Hatami, M., Aazami, J., & Savabieasfahani, M. (2024). Ecological risk assessment of heavy metals (Pb, Cd, Cr, Ni, Zn, Fe) and metalloid (As) in surface sediment of Anzali International Wetland, Iran. *Geology, Ecology, and Landscapes*, 1–19. <https://doi.org/10.1080/24749508.2024.2315833>
- Andrew, A. S., & Klein, L. R. (2003). Genomic and proteomic profiling of responses to toxic metals in human lung cells. *Environmental Health Perspectives*, 111(6), 825–835. <https://doi.org/10.1289/ehp.5831>
- Ang, H. H., & Lee, K. L. (2005). Analysis of mercury in Malaysian herbal preparations. *Journal of AOAC International*, 88(5), 1251–1255.
- Arceusz, A., Radecka, I., & Wesolowski, M. (2010). Identification of diversity in elements content in medicinal plants belonging to different plant families. *Food Chemistry*, 120(1), 52–58. <https://doi.org/10.1016/j.foodchem.2009.09.071>
- Baldwin, D. R., & Marshall, W. J. (1999). Heavy metal poisoning and its laboratory investigation. *Annals of Clinical Biochemistry*, 36(3), 267–300. <https://doi.org/10.1177/000456329903600301>
- Barthwal, J., Nair, S., & Kakkar, P. (2008). Heavy metal accumulation in medicinal plants collected from environmentally different sites. *Biomedical and Environmental Sciences*, 21(4), 319–324. [https://doi.org/10.1016/S0895-3988\(08\)60049-5](https://doi.org/10.1016/S0895-3988(08)60049-5)
- Baye, H., & Hymete, A. (2010). Lead and cadmium accumulation in medicinal plants collected from environmentally different sites. *Bulletin of Environmental Contamination and Toxicology*, 84(2), 197–201. <https://doi.org/10.1007/s00128-009-9916-0>
- Campbell, P. G. (2006). Cadmium—A priority pollutant. *Environmental Chemistry*, 3(6), 387–388. <https://doi.org/10.1071/EN06075>
- Dagnew, N., Ayalew, A., Fentahun, M., & Degu, G. (2024). Evaluation of carcinogenic and non-carcinogenic risks of heavy metals in selected medicinal plants. *Journal of Herbs, Spices & Medicinal Plants*, 30(2), 157–171. <https://doi.org/10.1080/10496475.2023.2244178>
- Devi, K. N., Sarma, H. N., & Kumar, S. (2008). Estimation of essential and trace elements in some medicinal plants by PIXE and PIGE techniques. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, 266(8), 1605–1610. <https://doi.org/10.1016/j.nimb.2007.12.083>
- Ernst, E. (1998). Harmless herbs? A review of the recent literature. *The American Journal of Medicine*, 104(2), 170–178. [https://doi.org/10.1016/S0002-9343\(97\)00397-5](https://doi.org/10.1016/S0002-9343(97)00397-5)
- Gautam, M., Pandey, D., & Agrawal, M. (2017). Phytoremediation of metals using lemongrass (*Cymbopogon citratus* (DC) Stapf.) grown under different levels of red mud in soil amended



- with biowastes. *International Journal of Phytoremediation*, 19(6), 555–562. <https://doi.org/10.1080/15226514.2016.1254155>
- German, D. A., & Chen, W. L. (2009). Notes on the family Brassicaceae in China. *Journal of Systematics and Evolution*, 47(3), 202–219. <https://doi.org/10.1111/j.1759-6831.2009.00024.x>
- Ghaderian, S. M., & Ravandi, A. A. G. (2012). Accumulation of copper and other heavy metals by plants growing on Sarcheshmeh copper mining area, Iran. *Journal of Geochemical Exploration*, 123, 25–32. <https://doi.org/10.1016/j.gexplo.2012.06.022>
- Gómez, M. R., Cerutti, S., Sombra, L. L., Silva, M. F., & Martínez, L. D. (2007). Determination of heavy metals for the quality control in Argentinian herbal medicines by ETAAS and ICP-OES. *Food and Chemical Toxicology*, 45(6), 1060–1064. <https://doi.org/10.1016/j.fct.2006.12.013>
- Hussain, M., Saeed, R., & Khan, M. A. (2019). Study of heavy metals (Cd, Cu, Ni, Pb & Zn) in some medicinal plant species (*Hertia intermedia*, *Cardaria chalepense*, *Scorzonera ammophila*, *Tamarix karelini*, *Astragalus auganus*) at Pishin area in Balochistan, Pakistan. *Pure and Applied Biology*, 8(1), 995–1007. <http://dx.doi.org/10.19045/bspab.2019.80042>
- Hyder, Z., Rizwani, G. H., Ahmed, I., Shareef, H., Azhar, I., & Aqeel, E. (2022). Determination of heavy metals content Lead (Pb), Mercury (Hg), Cadmium (Cd), Nickel (Ni), and Copper (Cu) with risk assessment to human consumption as food and medicine in herbal species through Atomic Absorption Spectroscopy. *Pakistan Journal of Pharmaceutical Sciences*, 35(1), 251–258.
- Jakupovic, J., Bohlmann, F., & Grenz, M. (1989). Furoeremophilanes from *Hertia pallens*. *Phytochemistry*, 28(11), 3231–3232. [https://doi.org/10.1016/0031-9422\(89\)80278-9](https://doi.org/10.1016/0031-9422(89)80278-9)
- Kaushik, A., Kansal, A., Santosh, Meena, Kumari, S., & Kaushik, C. P. (2009). Heavy metal contamination of river Yamuna, Haryana, India: Assessment by metal enrichment factor of the sediments. *Journal of Hazardous Materials*, 164(1), 265–270. <https://doi.org/10.1016/j.jhazmat.2008.08.031>
- Khan, Z. I., Ugulu, I., Nazir, R., Mehmood, N., Bashir, H., Rehman, M. U., & Ahmad, K. (2021). Biomonitoring of heavy metals accumulation in wild plants growing at Soon Valley, Khushab, Pakistan. *Pakistan Journal of Botany*, 53(1), 247–252. [http://dx.doi.org/10.30848/PJB2021-1\(22\)](http://dx.doi.org/10.30848/PJB2021-1(22))
- Khodadoust, A. P., Reddy, K. R., & Maturi, K. (2004). Removal of nickel and phenanthrene from kaolin soil using different extractants. *Environmental Engineering Science*, 21(6), 691–704. <https://doi.org/10.1089/ees.2004.21.691>
- Lekouch, N., Sedki, A., Nejmeddine, A., & Gamon, S. (2001). Lead and traditional Moroccan pharmacopoeia. *Science of the Total Environment*, 280(1–3), 39–43. [https://doi.org/10.1016/S0048-9697\(01\)00801-4](https://doi.org/10.1016/S0048-9697(01)00801-4)

- Lindon, H. L., Gardiner, L. M., Brady, A., & Vorontsova, M. S. (2015). Fewer than three percent of land plant species named by women: Author gender over 270 years. *Taxon*, 64(2), 209–215. <https://doi.org/10.12705/642.4>
- Malinowska, E., Jankowski, K., Sosnowski, J., & Wiśniewska-Kadżajan, B. (2015). Pesticide residues in cereal crop grains in Poland in 2013. *Environmental Monitoring and Assessment*, 187(6), 329. <https://doi.org/10.1007/s10661-015-4560-0>
- McLaughlin, M. J., Zarcinas, B. A., Stevens, D. P., & Cook, N. (2000). Soil testing for heavy metals. *Communications in Soil Science and Plant Analysis*, 31(11-14), 1661–1700. <https://doi.org/10.1080/00103620009370531>
- Rai, V., Agnihotri, A., Khatoon, S., Rawat, A. K. S., Mehrotra, S., & Rai, A. K. (2005). Chromium in some herbal drugs. *Bulletin of Environmental Contamination and Toxicology*, 74(3), 464–469. <https://doi.org/10.1007/s00128-005-0607-1>
- Rind, K. H., Aslam, S., Memon, N. H., Raza, A., Saeed, M. Q., Mushtaq, A., Ujan, J. A., Habib, S. F., Al-Rejaie, S. S., & Mohany, M. (2025). Heavy metal concentrations in water, sediment, and fish species in Chashma Barrage, Indus River: A comprehensive health risk assessment. *Biological Trace Element Research*, 203, 2226–2239. <https://doi.org/10.1007/s12011-024-04210-w>
- Sharma, R. K., Agrawal, M., & Marshall, F. M. (2009). Heavy metals in vegetables collected from production and market sites of a tropical urban area of India. *Food and Chemical Toxicology*, 47(3), 583–591. <https://doi.org/10.1016/j.fct.2008.12.016>
- Wendland, B. E. (2001). *Oxidative stress and plasma antioxidant vitamins in patients with Crohn's disease compared with healthy volunteers* [Master's thesis, University of Alberta].
- World Health Organization (WHO). (1998). *Quality control methods for medicinal plant materials*. World Health Organization.