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Effects of heavy metals in soil and plants on ecosystems and the economy

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ABSTRACT

Organisms need very small amounts of heavy metals to continue to grow and survive, so-called trace elements. Heavy metals are the main pollutants found in industrial effluents. Changes in ecosystems due to the increasing number of industrial activities and consequently the extraction, treatment and application of heavy elements have caused the density of these elements in the structural factors of ecosystems (especially water and soil resources) to exceed the self-purification capacity of the environment. On the other hand, the rapid population growth and more production of materials along with increasing demand for agricultural products, as well as the application of compost fertilizers and sewage sludge due to their richness of some elements, have been considered the other reasons for the heavy metal pollutions. Because these elements have very dangerous consequences for life, including humans, so it is necessary to pay attention to their pollutions. Heavy metals are dangerous environmental pollutants that pose a danger to humans, plants and other living organisms by entering the food chain. In soils contaminated with heavy metals, the use of plants that have the ability to grow, adapt and absorb metals is considered as one of the methods of cleaning these soils. In this study, phytoremediation is presented as one of the bioremediation methods for soils contaminated with organic and inorganic compounds. The results show that in order to reduce soil contamination and subsequent food and human poisoning, it is better to identify the factors causing heavy element elevations in the environment of each area, and consequently selecting plants that are not consumed as food before planting crops.

Keywords: Heavy metals, Phytoremediation, Ecosystem, Food chain, Economy.
Article type: Review Article.

INTRODUCTION

The main sources of heavy metal pollution include man-made and natural sources. One of the main problems with heavy metals is that they are not metabolized in the body. In fact, heavy metals are not excreted after entering the body, but have been deposited in tissues such as fat, muscles, bones and joints, which causes various diseases and complications in the body (Hu *et al.* 2020; Okhotnikova *et al.* 2021; Sesin *et al.* 2021). Heavy metals also replace other salts and minerals needed by the body. For example, in case of zinc deficiency in food, cadmium replaces it. In general, neurological disorders (Parkinson's, Alzheimer's, depression, schizophrenia), various cancers, nutritional deficiencies, hormonal imbalance, obesity, abortion, respiratory and cardiovascular disorders, weakened immune system, premature gene destruction, dermatitis, memory loss, anorexia, arthritis, hair loss, osteoporosis and in acute cases death are the results of the effects of heavy metals entering the human body. On the other hand, the accumulation of heavy metals in plants and their entry into the food chain doubles the risks caused by them. By the development of industries and increased consumption of chemicals, their discharges into the water, soil and has increased the likelihood of humans facing the dangers posed by them (Alizadeh & Mirarab-Razi 2016; Yabanli *et al.* 2016; Janbakhsh *et al.* 2018; Sattari *et al.* 2019a,b,c,d; Khan *et al.* 2020; Sun *et al.* 2020; Zhung *et al.* 2020, Sattari *et al.* 2020a,b,c,d; Forouhar Vajargah *et al.* 2020, 2021). Various studies have shown

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(Nguyen *et al.* 2021) that the presence of heavy metals in plants depends on their growing environment, plant species, drying conditions, storage, transportation and processing. Contamination of plant growth medium with heavy metals may cause significant changes in the quantity and quality of these metabolites by affecting the biological pathway of secondary metabolites. The World Health Organization has declared the maximum allowable amounts of cadmium, arsenic and lead for medicinal plants to be 0.3, 1 and 10 mg kg^{-1}, respectively. Even some other elements such as copper, zinc, manganese, molybdenum and nickel at high levels can be deleterious, but to date the World Health Organization has not imposed any specific restrictions on these elements. Due to the increasing use of chemical fertilizers and various pesticides to increase the yield of agricultural products on the one hand and the development of urbanization and industrial activities on the other hand as well as the unknown location of medicinal plants, lack of supervision and regulation on wild plants and the possibility of collecting from places contaminated with heavy metals, in some cases these elements may accumulate in plants. Nowadays, the problem of soil and water pollution with heavy metals is one of the factors threatening the sustainability of agricultural products and human life and other living organisms. Heavy metals are metals that have a density higher than 5 g cm^{-3}. This definition is biologically very useful because it includes a large number of elements found in nature, but only a small number of these elements are found in physiological conditions in solution and may therefore be available to living cells (Qayyum *et al.* 2020). Among them there are elements that are important for plant metabolism as micronutrients or trace elements (Fe, Mo, Mn, Zn, Ni, Cu, V, Co, W, Cr). There are also elements that once their amount in the plant growing environment is more than normal, they are poisonous to plants (Shenshan Zhan 2021). There are other elements that have unknown biological role and high toxicity to plants including As, Hg, Ag, Sb, Cd, Pb, and U. With the exception of natural environments, much attention is currently being paid to the destructive effects of the release of heavy metals into nature. Sources of these metals are: Urban traffic, household waste and industrial effluents, dust removal from factories, aerosols and ash from metal processing industries that have led to pollution in various areas.

Weiqing *et al.* (2016) worked onheavy metals in soil and plants after long-term irrigation with wastewater in Tianjin, China as a case study, reporting that the soil irrigated with wastewater had higher concentrations of cadmium, copper, lead, zinc, nickel, chromium, and mercury compared to the soil irrigated with clean water. Although trace elements are assumed to be retained in the soil, leaching a number of trace metals has been observed in sludge-treated soils. The cadmium and zinc concentrations in the effluent decreased over time, while copper and lead increased which may be due to the fact that lead and copper form strong bonds with organic matter and are released slowly due to the slow rate of decomposition of organic matter. Cadmium and zinc form weaker bonds with organic matter and therefore are not affected by sludge decomposition (Vigliotta *et al*. 2016). In agriculture, heavy metal contamination is an increasing problem due to soil treatment with contaminated effluents and excessive use of cadmium (Cd) phosphate fertilizers. Long-term biological durability and retention in the soil cause the accumulation of these metals in the food chain, resulting in potential negative effects on human health.

Lemtiri *et al.* (2015) worked on phytoremediation of zinc-contaminated soil using rapeseed (*Brassica napus* L.). reporting that soil pollution with heavy metals is one of the major environmental problems in the world. The amount of access to these metals depends on the type of plant and the amount they need as micronutrients and the ability of plants to efficiently regulate their metabolism through the secretion of organic acids or protons into the root environment. In addition, soil properties affect their mobility and thus regulate their release in soil solution. The ability of plants to absorb metals from the soil, their internal use, and their mechanisms for eliminating cellular toxicity are areas of the present research. Nowadays, phytoremediation, as a technology for cleaning soils and water systems from heavy metals, has received special attention. The results of th present study show that by phytoremediation, soil fertility does not change after the removal of heavy metals and even in some cases provides a bed for plant growth. Albeit, many of these engineering techniques are not feasible due to economic and rational constraints. Environmental clean-up of heavy metals and organic pollutants using their uptake by plants or phytoremediation has found a special place today that can be evaluated in further studies on various plants and substrates.

MATERIALS AND METHODS

Phytoremediation is an economic, environmental and scientific technique that is suitable for developing countries and is a valuable trade. Unfortunately, despite this potential, it is still not commercially used as a technology in

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some countries, such as Russia (Qayyum *et al.* 2020). Phytoremediation using green plant engineering, including herbaceous and woody species, is used to remove contaminants from water and soil or reduce the risks of environmental pollutants such as heavy metals, trace elements, organic compounds and radioactive materials (Thongyuan *et al.* 2021). The most important mineral compounds of pollutants are heavy metals. Soil microorganisms are able to decompose organic pollutants, however, in the case of microbial decomposition of metals there is a need for plant organisations to alter the metal that plants utilize (Annam & Singla 2021). Although another concern for experts is how to use plants that are contaminated in this way, the strategy of producing energy as one of the most essential parts of life has opened another window for scientists. From a global perspective, after the climate, the soil crust is the third major component of the human environment. In addition to being the base of terrestrial organisms, especially human societies, soil is a unique environment for all kinds of life, especially plants. In contrast to climate, soil pollution is not easily measurable in terms of chemical composition and a clean or pure soil is not definable. So we should study the potential issues of soil pollution in the context of predicting potential hazards and damage to soil function.

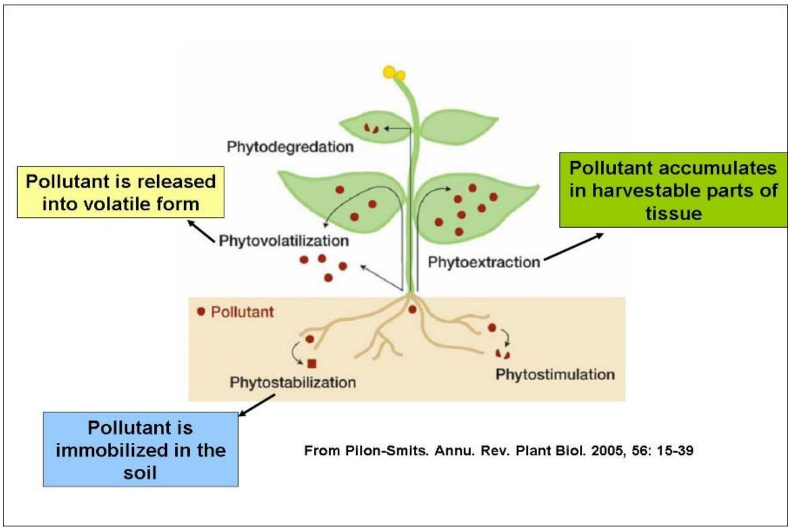

Fig. 1. Phytoremediation using green plant engineering.

With the development of man-made designs and soil contamination by heavy metals, soil structure becomes toxic and dangerous for plant growth and development, and soil biodiversity is disrupted. In phytoremediation method, plants are reduced based on the mechanism of adsorption of soil classification and soil contamination by heavy metals using chemical, physical and biological methods.

RESULTS

Phytoremediation methods can be used to decontaminate soils, climates contaminated with heavy metals and organic matter, including the following methods:

Phytostabilisation: This method is usually used to reduce pollution in soil, sediment and sludge. Depending on the strength of the roots, it limits the mobility and availability of contaminants in the soil and is done through adsorption, sedimentation, complexation or reduction of capacity.

Rhizofiltration: In this method, plants are used to purify pollution in dry and aquatic environments, and contaminants may be absorbed, concentrated or deposited. This method can be used to treat industrial wastewater, agricultural drains or acid mine drains for lead, cadmium, copper, nickel, zinc and chromium.

Phytoextraction: The best approach to phytoremediation is to absorb and transfer contaminants from soil to plant without destroying the soil structure and changing its fertility. By absorbing the plant, metals are concentrated, accumulated and deposited in the plant and added to the plant biomass and then harvested and the place of safety is transferred and if the amount of absorption is high, economic goals can also be considered.

Phytovolatilization: Plants absorb pollutants from the soil and then convert them into steam and transfer them to the atmosphere by transpiration. This method occurs in trees and other plants growing in water to absorb organic and inorganic pollutants.

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Destructive plant or plant decomposition: This method is the complete or partial destruction of organic pollutants by inactivating them by plant tissues. In this method, the plant helps to eliminate pollution from soil and groundwater through its metabolism by transferring, decomposing, stabilizing or sublimating contaminants.

Table 1. Strains of plants overgrown with metals.

Strain	Amount	Element (metal)
Matthiola longipetala	1	Cadmium
Diplacus aurantiacus	26	Cobalt
Diplacus aurantiacu, leaves grape planet	24	Copper
Aquifoliaceae, Nepenthes khasiana	11	Manganese
Violet	330	Nickel
Matthiola longipetala, Violet	19	Selenium
Matthiola longipetala	1	Thallium
Matthiola longipetala, Violet	16	Zinc

Reaction of plants against heavy metals

Plants have three basic strategies for growing in soils contaminated with heavy metals. These strategies include:

Metal excluder: These plants prevent metals from entering the aerial parts. They usually restrict the metal in their roots. These plants may do this by altering the permeability of their membranes, the ability of metals to attach to cell walls, or the secretion of chelating compounds.

Metal indicators: Species that actively accumulate metals in aerial tissues and generally reflect the surface of metals in the soil. These plants tolerate existing concentrations of metals by producing intracellular compounds that attach to metals (chelators) and by storing metals in insensitive parts (vacuoles).

Metal accumulators: These plants can concentrate metals in their aerial parts to levels higher than those in the soil. Most hyperaccumulators absorb high levels of contaminants and concentrate them in their roots, stems, or leaves. Approximately 400 plant species from 22 families have been identified that use this method. The Brassicacea family is the largest number of these plants, which includes 87 species of 11 genera.

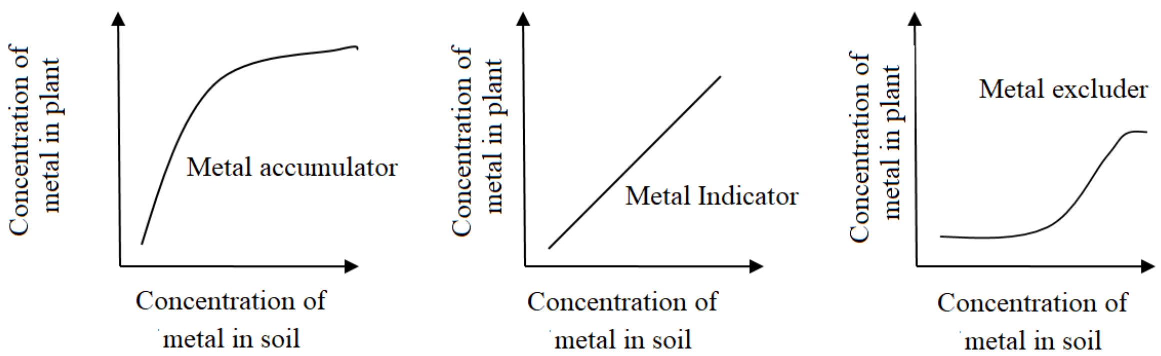

Fig. 2. Plant reaction in relation to increasing the concentration of total metals in the soil.

The ability to absorb cadmium from contaminated soils

According to the comparison of the mean of the data obtained from the interactions between the plant and different levels of cadmium, the highest shoot's cadmium content was related to corn at 400 ppm and 300 cadmium nitrate and the lowest shoot cadmium content was observed at Helianthus annuus and drought control plants at drought. The results showed that increasing the cadmium content in the studied two plants increased the amount of this element in the shoot. Cadmium and the lowest content of root cadmium in Helianthus annuus and corn were in control (zero concentration). The results showed that increasing the cadmium content in the studied plant increased the content of this element in the root (Fig. 3). According to the results, the higher the level of soil cadmium, the higher the concentration and content of cadmium in the roots and shoots, so that this increase in the roots was significantly compared to the shoots. In general, different plants differ in the absorption of elements and nutrients, and the main effect of the plant in the absorption of cadmium also follows this process. In various reports on the comparison of plants for use in phytotherapy, different plants show different responses in the absorption of

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elements. So that the concentration of these elements in the roots is significantly higher than the shoots, which probably shows the low mobility of this metal in the plant. Sunflower is one of the suitable crop options for extracting heavy metals such as cadmium. The biomass produced by sunflower is higher than rapeseed, so in general, it has a high phytoremediation efficiency. Due to its resilience and having more and deeper roots than dense plants, it can also be used to clean soils contaminated with heavy metals. It is also possible to create transgenic plants by transferring its resistance factors to non-economical plants with high biomass and use them in clearing contaminated soils.

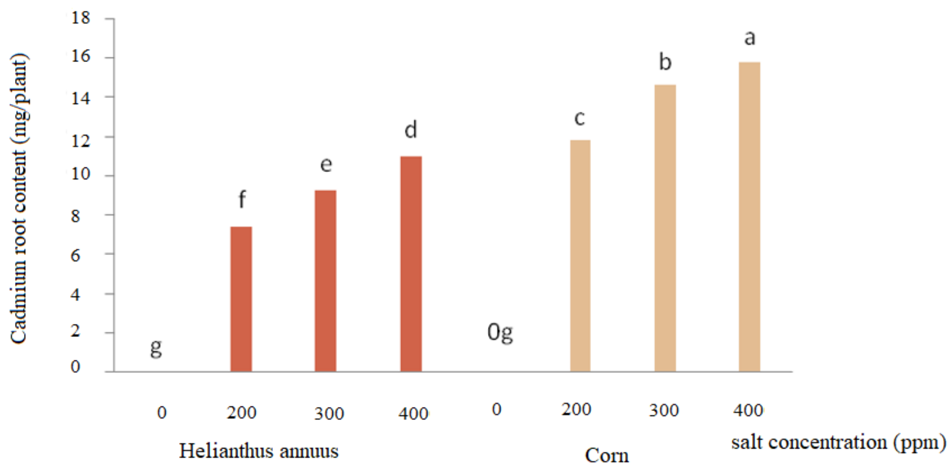

Fig. 3. Comparison of means of cadmium and cultivar interactions on root cadmium content.

CONCLUSION

Excessive and inappropriate use of fertilizers and pesticides in addition to increasing industrial and mining activities are the most important causes of soil, water resources and groundwater aquifers with a variety of toxic and heavy elements. The presence of some heavy elements in the soil, even in very small amounts, can be dangerous given that heavy metals are not biodegradable. Population growth has increased production demand, consumption of municipal wastewater and industrial effluents on the outskirts of large cities or factories. Phytoremediation is one of the green and environmentally friendly technologies, which is economically viable and low in energy. This technology involves the use of plants and their associated microorganisms to purify or stabilize toxic contaminants such as heavy metals. As mentioned, plants are not the same in terms of the ability to absorb and accumulate heavy elements. Therefore, it is recommended to avoid cultivation of medicinal and edible plants that have the ability to absorb and accumulate high heavy elements in soils contaminated with sludge, heavy metals, wastewater and chemicals.

REFERENCES

Alizadeh, S & Mirarab-Razi, J 2016, Growth and accumulation responses of *Populus nigra* L. exposed to hexavalent chromium excess. *Caspian Journal of Environmental Sciences*, 14: 253-261.

Annam, S & Singla, A 2021, A brief survey of assessment models to predict stress level of heavy metals in soil. *Recent Advances in Electrical & Electronic Engineering* (*Formerly Recent Patents on Electrical & Electronic Engineering*), 14: 276-289.

Forouhar Vajargah, M, Sattari, M, Imanpur, J & Bibak, M 2020. Length-weight relationship and some growth parameters of Rutilus kutum (Kaminski 1901) in the South Caspian Sea. *Experimental Animal Biology*, 9*:*11-20.

Forouhar Vajargah, M, Sattari, M, Imanpour Namin, J & Bibak, M 2020. Length-weight, length-length relationships and condition factor of *Rutilus kutum* (Actinopterygii: Cyprinidae) from the southern Caspian Sea, Iran. *Journal of Animal Diversity*, 2:56-61.

Forouhar Vajargah, M, Sattari, M, Imanpour Namin, J, Bibak, M 2021, Evaluation of trace elements contaminations in skin tissue of *Rutilus kutum* Kamensky 1901 from the south of the Caspian Sea. *Journal of Advances in Environmental Health Research*, DOI: 10.22102/jaehr.2021.259190.1201

Received: Aug. 10, 2021 Accepted: Nov. 10, 2021

Publisher: University of Guilan, Iran

Hu, B, Xue, J, Zhou, Y, Shao, S, Fu, Z, Li, Y & Shi, Z 2020, Modelling bioaccumulation of heavy metals in soil-crop ecosystems and identifying its controlling factors using machine learning. *Environmental Pollution*, 262: 114308.

Khan, MA, Wani, GA, Majid, H, Farooq, FU, Reshi, ZA, Husaini, AM, & Shah, MA 2020, Differential bioaccumulation of select heavy metals from wastewater by Lemna minor. *Bulletin of Environmental Contamination and Toxicology*, 105: 777-783.

Janbakhsh, S, Hosseini Shekarabi, S & Shamsaie Mergan, M 2018, Nutritional value and heavy metal content of fishmeal from the Southwest Caspian Sea. *Caspian Journal of Environmental Sciences*, 16: 307-317. DOI: 10.22124/cjes.2018.3200

Lemtiri, A, Liénard, T, Alabi, Y, Brostaux, D, Cluzeau, F, Francis, GC 2015, "Earthworms *Eisenia fetida* affect the uptake of heavy metals by plants *Vicia faba* and *Zea mays* in metal-contaminated soils. *Applied Soil Ecology,* 12 p.

Nguyen, MLT & Bui, TN 2021, The macroeconomy and the Real Estate market: Evidence from the global financial crisis and the COVID-19 pandemic crisis. *Industrial Engineering & Management Systems,* 20: 373-383.

Qayyum, S, Khan, I, Meng, K, Zhao, Y & Peng, C 2020, A review on remediation technologies for heavy metals contaminated soil. *Central Asian Journal of Environmental Science and Technology Innovation*, 1: 21-29.

Okhotnikova, O, Hlasov, P 2021, Clustering of the economy in a comprehensive system of the international economic security: organizational economic mechanism, *Economic Annals-XXI*, 189: 4-14,.

Sesin, IYu, Bolbakov, RG 2021, Comparative analysis of software optimization methods in context of branch predication on GPUs. *Russian Technological Journal*, 9: 7-15, [In Russian].

Sattari, M, Namin, JI, Bibak, M, Vajargah, MF, Bakhshalizadeh, S & Faggio, C 2019a, Determination of trace element accumulation in gonads of *Rutilus kutum* (Kamensky, 1901) from the south Caspian Sea trace element contaminations in gonads. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences,* pp.1-8. DOI: 10.1007/s40011-019-01150-5.

Sattari, M, Namin, JI, Bibak, M, Vajargah, MF, Faggio, C & Haddad, MS 2019b, Trace and macro elements bioaccumulation in the muscle and liver tissues of alburnus chalcoides from the south Caspian Sea and potential human health risk assessment. *Journal of Energy, Environmental & Chemical Engineering*, 1: 13- 20.

Sattari, M, Imanpour, J, Bibak, M, Forouhar Vajargah, M & Khosravi, A 2019c, Investigation of metal element concentrations in tissue of *Rutilus frisii* in the Southwest Caspian Sea. *Iranian Scientific Fisheries Journal,* 28: 149-161 (In Persian).

Sattari, M, Namin, JI, Bibak, M, Vajargah, MF, Hedayati, A, Khosravi, A & Mazareiy, MH 2019d, Morphological comparison of western and eastern populations of Caspian kutum, *Rutilus kutum* (Kamensky 1901) (Cyprinidae) in the southern Caspian Sea. *International Journal of Aquatic Biology*, 6: 242-247.

Sattari, M, Vajargah, MF, Bibak, M & Bakhshalizadeh, S 2020a, Relationship between trace element content in the brain of bony fish species and their food items in the southwest of the Caspian Sea due to anthropogenic activities. *Avicenna Journal of Environmental Health Engineering*, 7*:* 78-85.

Sattari, M, Bibak, M, Bakhshalizadeh, S & Forouhar Vajargah, M 2020b, Element accumulations in liver and kidney tissues of some bony fish species in the Southwest Caspian Sea. *Journal of Cell and Molecular Research*, 12: 33-40.

Sattari, M, Imanpour Namin, J, Bibak, M, Forouhar Vajargah, M and Mazareiy, MH 2020c, Trace elements contamination in Alosa braschnikowi of the southern basins of Caspian Sea-Guilan Province. *Journal of Animal Environment*, 12: 115-122.

Sattari, M, Bibak, M & Forouhar Vajargah, M 2020d, Evaluation of trace elements contaminations in muscles of Rutilus kutum (Pisces: Cyprinidae) from the Southern shores of the Caspian Sea. *Environmental Health Engineering and Management Journal*, 7: 89-96.

Shenshan Zhan, Yuangen Wu, Lumei Wang, Xuejia Zhan, Pei Zhou 2016, A mini-review on functional nucleic acids-based heavy metal ion detection, *Biosensors & Bioelectronics*, 86: 353-368.

Weiqing, M, Zuwei, W 2016, Heavy metals in soil and plants after long-term sewage irrigation atTianjin China: A case study assessment. *Agricultural Water Management*, 171: 153-161.

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DOI: 10.22124/CJES.2021.5331

Publisher: University of Guilan, Iran

Sun, M, Wang, T, Xu, X, Zhang, L, Li, J, & Shi, Y 2020, Ecological risk assessment of soil cadmium in China's coastal economic development zone: a meta-analysis. *Ecosystem Health and Sustainability*, 6: 1733921.

Thongyuan, S, Khantamoon, T, Aendo, P, Binot, A & Tulayakul, P 2021, Ecological and health risk assessment, carcinogenic and non-carcinogenic effects of heavy metals contamination in the soil from municipal solid waste landfill in Central Thailand. *Human and Ecological Risk Assessment: An International Journal*, 27: 876-897.

Vigliotta, G, Matrella, S, Cicatelli, A, Guarino, F, Castiglione, S 2016, Effects of heavy metals and chelants on phytoremediation capacity and on rhizobacterial communities of maize. *Journal of Environmental Management*, 179: 93-102.

Yabanli, M, Alparslan, Y, Hasanhocaoglu Yapici, H, Yapici, S, Yozukmaz, A 2016, Determination of heavy metal content in commercial marine fish hunted From Southeast Aegean Sea (Turkey) and their potential risk for public health. *Caspian Journal of Environmental Sciences,* 14: 1-13.

Zhang, Q & Wang, C 2020, Natural and human factors affect the distribution of soil heavy metal pollution: A review. *Water, Air & Soil Pollution*, 231: 1-13.

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