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Chapter

Ecological Risk Index, Implications, and its Bioconcentration Ratio in Soils Contaminated with Heavy Metals

Anahí C. Meza García and José G. Chan Quijano

Abstract

Soil contamination by heavy metals is a problem that is increasing worldwide due to human activities, and it is important to bear in mind that its toxicity and abundance in ecosystems can be serious. The remediation of these contaminated environments should be a priority in all countries, since the consequences that have been recorded are harmful to human and environmental health. In humans, it causes different diseases and even metals bioaccumulate in the human body, as well as in plants and animals, which come as food to the tables of many homes. Therefore, the objective of this chapter is to show the implications and consequences that heavy metals cause. In addition, show evaluation methods and techniques, such as the ecological risk index, to generate data that help investigations and possible alternatives for sustainable remediation. The impact that this theme must be relevant in the penta helix; because all the actors (government, society, business, academia, and civil associations) must cooperate and get involved for inclusive sustainability that provides solutions for the recovery of contaminated ecosystems, as well as for the care of human and environmental health.

Keywords: toxicology, bioaccumulation, acid soils, socio-environmental, remediation

1. Introduction

The impact of heavy metal pollution by urban growth, agricultural, mining, and oil activities has generated environmental problems in soil and aquatic systems, affecting biotic and abiotic components [1, 2]. In addition, anthropogenic activities increase the mobilization and distribution of heavy metals in ecosystems, if the standards allowed by international regulations are exceeded, they result in a serious problem for the health of living beings and the natural environment [3, 4].

Heavy metals are characterized by their high density, which is greater than 5 g ml\(^{-1}\) [5–7]. In the natural environment, heavy metals exist in a geogenic form, that is, they come from the parent rock, from volcanic activity, or from the leaching of mineralization [8]. Under normal conditions, most of the potentially toxic metals are found
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fixed by geological considerations and in very insoluble chemical forms, therefore, they do not represent a danger for the biota, but they become a toxic danger when there is bad management of these (anthropogenic activities) [1].

The introduction of these elements in large quantities to nature causes the breakdown of the balance of the ecosystem, causing the contamination of soils and aquifers; in aquifers, they reach the food web [1–3]. In the food web, heavy metals remain suspended in the water column and are deposited in the sediments [9, 10], which are absorbed by the benthic species, these, in turn, serve as food for the species of the pelagic system, for which create bioaccumulation routes between aquatic organisms [11–13].

The bioaccumulation of heavy metals in the soil is determined by internal factors (chemical characteristics of the element and compounds they form) and by external factors (edaphic processes and environmental conditions), as well as their dispersion in the soil (Table 1) [1, 14].


<table>
<thead>
<tr>
<th>Processes</th>
<th>Description</th>
<th>Soil unit</th>
<th>Accumulation of heavy metals</th>
<th>Heavy metal dispersion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Podzolization</td>
<td>This process encompasses the leaching of Al and Fe, together with organic matter, from the surface areas and its accumulation in the deep areas of the profile.</td>
<td>R, Q, Y</td>
<td>Co, Cu, Mn, Ni, Ti, V y Zr</td>
<td>B, Ba, Br, Mn, Cd, Cr, I, Li, Se, Sr, V, Zr</td>
</tr>
<tr>
<td>Alumination</td>
<td>This is a surface treatment, which belongs to the category of diffusion coatings, applied mainly to nickel- and/or cobalt-based superalloy components.</td>
<td>B, L, M, W, A</td>
<td>Co, Mn, Mo, V (gley)</td>
<td>B, Ba, Br, Cu, I, Se, Sr</td>
</tr>
<tr>
<td>Sialitization</td>
<td>Process that originates aluminum clays at the expense of silicates.</td>
<td>V, K</td>
<td>B, Ba, Cu, Mn, Se y Sr</td>
<td>—</td>
</tr>
<tr>
<td>Laterization</td>
<td>It consists of a process of generalized and deep chemical weathering in which silica and bases are extracted, by leaching, from the parent rock, in which iron and aluminum concretions are produced.</td>
<td>A, F, K</td>
<td>B, Ba, Cu, Mn, Se y Sr</td>
<td>—</td>
</tr>
<tr>
<td>Alkalization</td>
<td>It is the excess exchangeable sodium in the soil. As its concentration increases in the soil, it begins to replace other cations.</td>
<td>Z, S, X</td>
<td>B, Co, Cr, Ca, Mo, Ni, Se, Zn, V</td>
<td>—</td>
</tr>
<tr>
<td>Hydromorphy</td>
<td>Edaphic process in which the transformations caused by the presence of a permanent layer of water take place.</td>
<td>—</td>
<td>B, Ba, Co, Ca, I, Mn, Mo, Se, Sr, U</td>
<td>B, Br, Co, Ca, Mn, Ni, U, V</td>
</tr>
</tbody>
</table>

Table 1.
Accumulation and dispersion of some heavy metals according to some edaphic processes.
2. Implications and alternatives

Therefore, heavy metals cause poor soil quality and nutrient loss [17]. Similarly, despite these damages, poor physical soil structure, high concentrations of heavy metals, and nutrient deficiency, contaminated areas often contain unique microbial communities and plant species [18–20]. These act as phytoextractors and bioaccumulators of heavy metals; these characteristics will depend on the number of plant species in the affected area and the biomass of the plants [20, 21].

For example, the acute toxicity in *Agave tequilana* plants against metallic ions, such as Cu$^{2+}$, Cd$^{2+}$, and Co$^{2+}$. Among their results, they show that these metals bioaccumulated in the leaves of the seedlings, so these succulent plants have a remarkable tolerance to high concentrations of the different ionic metals tested, including both micronutrients and toxic metals, as well as the ability to transport these metals in high quantities to air tissue [22].

In aquatic plants, such as *Typha latifolia*, a study was carried out in search of removing heavy metals, such as Cu, Ni, and Zn. The number of metals removed by plants in the sediment was considerably lower (1%), mainly due to the small development of biomass. However, the contribution of these plants is that they can bioaccumulate pollutants in the roots, stems and leaves [23].

In crop plants, for example, with *Hordeum vulgare*, Cd was found, which may be causing toxic effects on the nucleolus of plant cells and affects the expression of nucleolar proteins, nucleolin, and fibrillarin [24]. In *Triticum aestivum*, high levels of Ni (29.3 μg g$^{-1}$) and Cd (0.22 μg g$^{-1}$) were found, which puts food safety at risk [25] due to the amounts of contaminants that may be present, bioaccumulating in plants and crop fruits.

*Portulaca grandiflora* was examined as a possible vegetation for green roofs. It was found that this plant has a hyperaccumulating potential of heavy metals, such as Al, Cd, Cr, Cu, Fe, Ni, Pb, and Zn, within its tissues 40 days after being exposed to the contaminated area, and it also has the ability of metal translocation (Al, Cu, Fe, and Zn) [26].

On the other hand, some metals, such as Co, Cu, Fe, Mn, Mo, Ni, and Zn, are essential micronutrients for plants but become toxic at high concentrations. Its role as an essential micronutrient may be as a cofactor or activator of specific enzymes or to stabilize organic molecules [7, 27].

Other heavy metals, such as Cd, Pb, Cr, Hg, Ag, U, and Au, are nonessential for plant operation. However, they are metals that cause damage to plant species and are bioaccumulated in roots, stems, leaves, fruits, and seeds [7, 28–32].

When there is a regeneration of plant species—mostly grasses—in the areas impacted by heavy metals, these plants can be induced or introduced by human actions [33]. In addition, there is a mutualistic relationship between soil particles and plant roots [34], creating a biotrophic interaction with the ecosystem affected by heavy metals, increasing the ability of plants to absorb these pollutants according to the physiological performance of the plants [35, 36].

3. Phytoremediation and ecological risk index

There are plants that could hyperaccumulate heavy metals from contaminated soils. During this bioaccumulation process, plants enter a state of stress under the different metals, for example, with Cd, the responses of hyperaccumulating plants differ in morphological responses and physiological processes, such as photosynthesis and respiration, uptake, transport, and assimilation of minerals, and nitrogen, and
absorption, and transport of water, which contributes to its ability to accumulate, and detoxify Cd [37]. In addition, it affects human health since it is quickly absorbed by plants and can affect crops.

The potential ecological risk index is the process of examining a hazard to avoid or reduce it, that is, it will focus on adverse events that affect environmental health caused by toxic chemical substances [38].

The three aspects that make up the triad of this potential ecological risk index in heavy metal contamination are chemical characterization (concentration of contaminants), toxicity (genetic and histopathological damage, enzymatic stress, and mortality), and ecological integration (richness and population distribution of species, Figure 1) [7, 27, 39–41].

This triad of potential ecological risk index in heavy metal contamination goes hand in hand with the basic strategies for plants to establish themselves in contaminated soils (Table 2) [1, 42].

The absorption that plants have is mainly through the roots; this absorption can be both passive (non-metabolic) and active (metabolic). Passive absorption occurs by the diffusion of ions from an external solution into the root endodermis. Instead, active absorption is carried out with metabolic energy down a chemical gradient; at the concentrations present in soil solutions, uptake of heavy metals by plant roots is controlled by metabolic processes [1, 52].

However, in the fauna, the damage is even more severe, since various diseases such as hepatitis, respiratory problems, cancer, and neurological disorders, among others, affect many parts of the body due to the different levels of toxicity, which also affects the cellular level [12, 13, 43]. Studies have been carried out at the level of muscle tissue and liver, mostly in fish and other aquatic species, finding medium and high toxic levels [13, 44–46], which means that these products are ingested as food (without knowing

Figure 1.
Descriptive scheme of the triad of integrity to evaluate soils contaminated with heavy metals. Source: own elaboration based on [38, 39].
Strategy | Characteristic
--- | ---
Exclusion | It consists in those plants that must avoid the accumulation of metals in their aerial parts, preferentially accumulating them in the root system.
Accumulation | It consists of the ability of plants to accumulate metals in their tissues proportionally to the concentrations present in the environment.
Hyperaccumulation | It consists of the ability of the plant to accumulate high concentrations of metals in its tissues (stems and leaves).

Source: own elaboration based on [42].

Table 2.
Strategies of multiple tolerance of terrestrial and aquatic plants for their establishment in soils contaminated with heavy metals.

<table>
<thead>
<tr>
<th>Heavy metal</th>
<th>Toxicokinetic</th>
<th>Distribution and storage in the body</th>
<th>Health effects</th>
<th>Bibliographic reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pb</td>
<td>It enters the human body through respiratory, oral, and skin routes.</td>
<td>After absorption, lead passes through the blood and is distributed throughout the body; a dynamic exchange is then established between the different tissues and organs.</td>
<td>It affects the cardiovascular system and damages the central and peripheral nervous system. In adults, 94% of the lead load is found in the skeleton, in children it is 73%. It can cause encephalopathy, memory loss, poor attention, irritability, headache, muscle tremors, clumsiness, hallucinations, fatigue, ataxia, seizures, and coma, among others.</td>
<td>[52]</td>
</tr>
<tr>
<td>Hg</td>
<td>Absorption is through respiratory, oral, and skin routes.</td>
<td>It is distributed in red blood cells and plasma in approximately equal proportions. It accumulates mainly in the kidney, as well as the gastrointestinal tract, the squamous epithelium of the hair and skin, and some glands, such as the thyroid, pancreas, sweat glands, testicles, and prostate.</td>
<td>Acute intoxication occurs causing tremors, paresthesia, memory loss, hyperexcitability, erethism, and reduction in reflexes. Also, it causes bronchitis, interstitial pneumonitis, pulmonary edema, metallic taste, increased salivation, stomatitis, gingivitis, cough, chest pain, diarrhea, vomiting, and hemorrhage.</td>
<td>[49]</td>
</tr>
<tr>
<td>Cd</td>
<td>It has entry through the respiratory and oral routes.</td>
<td>Once absorbed, it passes into the blood and is transported to all organs and tissues, mainly bound to hemoglobin inside erythrocytes.</td>
<td>Genetically affects the stages of development and functional status of the organism and affects the efficiency of nutrients. It has negative effects on the kidneys (renal efficiency), among others.</td>
<td>[48]</td>
</tr>
</tbody>
</table>
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what they contain pollutants), it would be participating in a bioaccumulation network in the human body, which would be presenting in acute or chronic diseases.

The bioaccumulation of heavy metals, such as Cd, Cr, Ni, Pb, V, and Zn, in suspended loads, sediments, primary producers, mollusks, crustaceans, and fish can sometimes be moderate, but even so they pose an ecological risk to the ecosystem [2]. Within the bioaccumulation of heavy metals, these can be ingested by consuming contaminated food and at the same time follow this accumulation process in humans [47]. In humans, the intake of food contaminated by heavy metals estimates serious health effects (Table 3).

<table>
<thead>
<tr>
<th>Heavy metal</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Cr</td>
<td>It enters the body by inhalation, ingestion, and to a lesser extent through the skin.</td>
<td>It reaches the intestine and passes into the blood, where it is distributed to the different organs.</td>
<td>The effects depend on the valence state of Cr exposure (Cr III or Cr VI), Cr VI crosses the cell membrane, causing conjunctivitis, tearing, and pain. Cr III damages the skin, causing ulcers and redness. They affect the respiratory system, the gastrointestinal tract, and cause cancer, among other symptoms.</td>
<td>[53, 54]</td>
</tr>
<tr>
<td>As</td>
<td>The main entry of As into the body is through the gastrointestinal tract, the respiratory tract, and through the skin is low.</td>
<td>It accumulates mainly in the liver, kidney, lung, and arm. They are also deposited by keratin in hair and nails.</td>
<td>Acute exposure alters the gastrointestinal, cardiovascular, nervous, renal, and hepatic systems. Also, it is possible to observe vasodilation, hyperemia, and edema due to capillary damage and a drop in blood pressure. It causes skin lesions, alterations in the cardiovascular system, alterations in the metabolism of the heme group, neurological effects, effects on the immune system, and on the endocrine system, it causes cancer and genotoxicity.</td>
<td>[51]</td>
</tr>
<tr>
<td>Be</td>
<td>The main route of absorption is the respiratory one, by the other routes it is difficult, in the cutaneous absorption it is insignificant.</td>
<td>It circulates through the blood (colloidal phosphate), a part of the absorbed dose is incorporated into the skeleton and in the lungs.</td>
<td>It has effects on the respiratory and skin systems. Causes chronic beryllium disease (it is an irreversible, long-lasting disease of progressive severity; it damages the liver, spleen, and heart).</td>
<td>[50]</td>
</tr>
</tbody>
</table>

Table 3. Toxic effects in humans due to the ingestion of food contaminated with some heavy metals.
Therefore, it is necessary to influence government policies and programs that promote the safety of human and environmental health within the gradients of food consumption from orchards, milpas, and production fields near the contaminated areas and due to the complexity of the risk that is run by the movements of pollutants in the soil and the atmosphere. Similarly, it is important to evaluate the perception of health benefits and risks due to the influence of contaminants [55].

4. Conclusions

Heavy metals are highly harmful to human and environmental health depending on their toxicity and abundance.

Ecosystems continue to be contaminated with heavy metals, which should be a red point and national security in several countries for the search for sustainable remediation.

The ecological risk index is a method that helps to evaluate the problem of heavy metal contamination, it is also an alternative to identify the level of contamination in the ecosystem or in human health.

The absorption and bioaccumulation of pollutants in plant, animal and human tissues cause diseases from the mildest to the most serious that can cause death.

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Conflict of interest

The authors declare no conflict of interest.

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