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Pollution by Heavy Metals: Environmental Implications and Key Strategies for Remediation

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ABSTRACT

Heavy metals in small amounts found in nature, are essential to the survival of animals and plants on the planet. However, is becoming worring the direct and indirect releases of the heavy metals in the environment, causing negative effects and the imbalance in the cycle of these chemicals. This activity is progressive increase in the face of population growth, agriculture and industrial sectors, the main dispersers of this pollutant for the production of goods and services. The influence of these environmental contaminants is considerably wide and can be found in air, water, soil and consequently in food, passing the necessary conditions for an ecological imbalance. The arrangement of these metals in nature affects, often irreversibly, the ecosystem as a whole, resulting in short- or long-term risk of living organisms and human health. This review reports the contamination caused by different heavy metals and their potential to cause damage to fauna, flora and humans. Thus, in order to minimize the impacts, it is necessary to highlight the problems about polluting activities as a subsidy for concentration of efforts in the development of innovative and sustainable methods for remediation.

Keywords: ecology, environment, degradation, toxicity, contamination

INTRODUCTION

Economic development has industries symbols of prosperity after the Industrial Revolution (ORTEGA-ORTIZ, 2009), causing the appearance of steam engines and the emergence of contamination problems in the mid-eighteenth century (GALVÁN RICO & REYES GIL, 2009). The process of development of production and technology results in environmental damage, where the physical and biological environment are the main scenario of these processes (Baggio & Horn, 2008). The degradation of the environment is deserving special attention, particularly with regard to the release of heavy metals on water resources and urban soil, causing several problems in environmental and human health. Environmental degradation, according to Viana et al. (2012), is characterized by the reduction of renewable resources derived from combinations of impacting actions acting on the environment.

Garbisu & Alkorta (2003) report that the quality of the environment is closely linked with the quality of life. Thus, the life can be significantly affected by human activities, for large scale production of chemical compounds from a variety of ways. Such practices are causing changes in the geochemical cycle, which is closely linked to environmental quality (ARAUJO PINTO & SON, 2010)

Heavy metals coming from various sources of pollution are harmful to plants, animals and human health. Some metals are added to the soil and water, causing serious problems to the environment and human health (LONE et al., 2008). Pine et al. (2014) mention that the soil and water systems polluted by heavy metals, are factors that contribute to the degradation of the quality of the environment, consisting of eminent risk of poisoning for humans.

To Sepúlveda et al. (2005) there are several definitions for heavy metals. One of them says the metals are elements that have higher density than 5 g / cm^3. Further define the heavy metal based on physicochemical properties, such as weight and atomic number and reactionn with other elements.

The metals are a group of chemicals that are not degradable, therefore, once released into the environment, are dispersed affecting water, air and soil, sometimes turning into its oxidation state, and others being incorporated into living beings (VULL, 2003).

Environmental damage may occur by digging mines, removing minerals and the metal extraction process, causing destruction of ecosystems through contamination by toxic elements such as arsenic (As), selenium (Se), lead (Pb), cadmium (Cd) and sulfur oxides (S), among others (SEPÚLVEDA et al., 2005). Also Chromium (Cr) and Mercury (Hg) are released by industrial and technological activities that generate high impact on the environment (Paisio et al., 2012).

In this context, the present work aimed to a wide literature review of the sources and consequences of the main heavy metals in the environment, showing strategies mentioned in the literature for their remediation.

REVIEW

Heavy metals are part of a group of chemical elements which are linked to the nature in small amounts, however, due to human activities, whether industrial or agricultural, there was a considerable increase in the concentration in various types of ecosystems (PINEDA & RODRIGUEZ, 2015).

The environmental impact on soils and sediments, originated from metal contaminants depends on the physical, chemical and biological conditions, influencing the complexation ability of these components in the environment (Vullo, 2003).

Certainly the plants require micronutrients that are essential for their development, such as boron, chlorine, copper, iron, manganese, molybdenum, zinc and nickel. Depending on the level of heavy metal contamination in a given area, there may be disruption of the natural vegetation, influencing the development of new plant species (Silva et al., 2014). In this context, the environmental impact of heavy metals, can be associated with various activities, whether economic or social, the possible sources can be identified, as well as find ways to change mitigation and pollution control.

Table 1 shows the main heavy metals that are discussed in this paper and cause environmental damage when exceeded their limits in the environment.

Table 1: Heavy metals in the soil and its limits.

Heavy metals	Limits Levels (Kg/ha)
Arsenic	30
Barium	265
Cadmium	4
Lead	41
Copper	137
Chrome	154
Mercury	1,2
Molybdenum	13
Nickel	74
Selenium	13
Zinc	445

Source: CONAMA, 2012

1. Pollution sources

Paz et al. (2015) state that it is necessary to analyze and understand the impacts associated with socio-economic activities and their implication in nature over time, realizing the influence that they have in production mode and environmental issues. Thus, they should be quantified and characterized the main sources of pollution and ways of release of heavy metals in the environment, developing methods that can directly influence the solution of the problem.

Depending on agricultural inputs and by-products used, agriculture is considered a source of contamination with heavy metals (Campos et al., 2005). Araújo & Pinto Filho (2010) mention the industrial and agricultural activities as potentially polluting activities because its facilities occur indiscriminately and cause changes in the properties of the area, through the increase of high amounts of toxic substances. According to Oliveira et al. (2009), the use of waste contaminated by heavy metals in agriculture is growing and getting more attention from researchers, particularly on the subject of mobility of these elements.

According Coutinho & Borges (2004), the biosolids is considered the final product of the treatment of domestic and industrial wastewater, a method used in order to minimize the pollution of rivers. However, the final disposal of biosolids is of concern because it contains high concentrations of heavy metals. Moreover, with its use in agriculture a profitable activity, it is necessary to consider the physical, chemical and biological soil characteristics (PEREIRA, 2015).

Mining for exploration of gold, silver and mercury, is one of the human activities that release mercury into the environment (Paisio et al., 2012). Oliveira et al. (2015) reported that the mining to obtain gold stimulates the inordinate use of mercury for the removal of fine gold particles. Successively, after the separation of gold, there is release of mercury in the form of gas and liquid, causing significant environmental pollution, and affect human health.

Pinho et al. (2014) point out that the mining activity, used for the extraction of essential materials to human activities, can cause changes in the environment causing a problem with high proportion, as the addition of 1.16 million tons of metal per year, both in terrestrial and aquatic ecosystems.

According to Santos & De Jesus (2014) anthropogenic sources that release lead (Pb) in the environment, causing enrichment, are similar to the sources of nickel (Ni). Thus, it is possible that explanations to Ni can be applied to Pb as the pollution sources.

Scaburri et al. (2013) features in their study that the areas with the highest concentration of heavy metals correspond to local traffic (compressed area) and movement of industrais solid waste.

Martins et al. (2014) claim that the basin of the São Francisco River is polluted by heavy metals and contamination is directly associated with the presence and operation of a metallurgical plant. There are contamination of the alluvium and sediments for arsenic (As), cadmium (Cd), copper (Cu), lead (Pb) and zinc (Zn).

Technological growth is a factor that should be highlighted on the subject of the release of heavy metals by anthropogenic activity. Almeida et al. (2015) report that the rapid exchange of electronic equipment, due to the large production, causes the elimination incorrectly, generating a major global problem. The authors emphasize that electronic waste, also known as e-waste, are composed of toxic and non-biodegradable materials.

Table 2: Different sources of heavy metals

Heavy Metals	Sources
As	Semiconductors, petroleum refining, wood preservatines, animal feed additives, coal power plants, herbicides, volcanoes, mining and smelting.
Cu	Electroplating industry, smelting and refining, mining, biosolids.
Cd	Geogenic sources, anthropogenic activities, metal smelting and refining, fossil fuel burning, application of phosphate fertilizers, sewage sludge.
Cr	Electroplating industry, sludge, solid waste, tanneries.
Pb	Mining and smelting of metalliferous ores, burning of leaded gasoline, municipal sewage, industrial wastes enriched in Pb, paints.
Hg	Volcano eruptions, forest fire, emissions from insdustries producing caustic soda, coal, peat and wood burning.
Se	Coal mining, oil refining, combustion of fossil fuels, glass manufacturing industry, chemical synthesis (e. g., varnish, pigment formulation).
Ni	Volcanic eruptions, land fill, forest fire, bubble bursting and gas exchange in ocean, weathering of soils and geological materials.
Zn	Electroplating industry, smelting and refining, mining, biosolids.

Source: Lone *et al.*, 2008.

2. Areas impacted by heavy metals

Among the various activities that trigger the release of heavy metals, are extractive and metallurgical industries. According to Martins et al. (2014), this fact is associated with poor waste management and the absence of adequate containment areas for these materials. According to the authors, in a study near an industrial unit producing metal alloys, high levels of heavy metals were obtained (Mn, Cu, Zn, Ni, Pb, Cd, Cr and As), through geochemical and mineralogical analysis of sediments, coming from a small tributary of the São Francisco river, the stream Consciência.

The problems in the stream Consciência are not new. Oliveira & Horn (2006) claim that results in high concentrations of some heavy metals, especially zinc, are frequent in the area since 1991, which was also observed in 2003-2006.

Baggio & Horn (2008) explain that the river Formoso, in the municipality of Buritizeiro / MG, concentrations of heavy metals were found in sediments, originated from natural contributions to anthropogenic activities. These authors found high levels of Cd and Cr that have exceeded the reference values of CONAMA Resolution 344/2004, compromising the compartments water and sediment. They also mention that the metals found are the result of metalorganic waste generated by commercial agriculture.

Study by Rangel Sanches & Son (2014) showed traces of metals in the sediment of the channel in the Avenue Bento Gonçalves - Pelotas/RS and, according to the results, concluded that it is highly impacted water body. It is a channel created for rainwater drainage purposes, with the passage of time and the disorderly growth of the surrounding population, has become body raw sewage receiver.

In sub basin of Pomba River in Minas Gerais - Brazil, Carvalho et al. (2009) obtained results which demonstrate pollutants values for Cr in sediment, Cu in water, and Cu and Cr in soils.

Oliveira et al. (2005) concluded that cadmium metal occurs in high concentrations in stream sediments in some parts of Itacolomi State Park area, Minas Gerais State - Brazil, featuring some locations with anomalous concentrations of this element.

Nammoura Neto et al. (2009) point out in their study the concentration of zinc and barium in soil adjacent to Marginal Pinheiros River, with values exceeding the recommended limits of intervention by the Environmental Sanitation Technology (CETESB). They point out that the zinc is of anthropogenic nature and for Barium can not say whether its origin is only anthropic.

3. Methods for mitigation

According to Resolution No. 420 of 2009 CONAMA, contamination is described as the presence of chemicals in air, water or soil provided with human activities that limit their use, defined based on risk assessment to human health. To mitigate the impact of the areas characterized as contaminated locals, are necessary the use of technological or biotechnological methods and for the reduction of environmental impacts. Viana (2012) specifies that these methods can be classified as thermal, physical, biological and chemical. Can be applied in situ or ex situ, depending on the effectiveness of the technique, associated with less environmental impact beyond the financial cost.

Beltran & Gomez (2015) emphasize the use of technologies to mitigate, for example, the use of organisms that are resistant or tolerant, and plants that have the capacity to accumulate heavy metals, with promising results, effective both in vitro and in the field. Coimbra et al. (2002) point out that some vegetables can accumulate heavy metals, as a function of the capacity they have to adapt to environmental chemical properties, and are considered intermediate reservoirs of these components.

According to Cunningham (1996) agronomic techniques such as the use of macrophytes, in the same way as the associated organisms and their enzymes, are being used to minimize non-toxic levels of environmental contaminants in order to recompose and try to stabilize the contaminants in the soil or groundwater. Jesus et al. (2015) state that the practice cited above defines the phytoremediation.

Several researchers have focused their interest on the potential of some species in phytoremediation that, according to Pereira et al. (2013), it is the field of biotechnology that is expressed as a technique of employing plant species to obtain the energy required to perform remediation from its own metabolism when performing photosynthesis. Among the studies focused on this technology, there is the work of Procopio et al. (2005) with the velvet bean (*Stizolobium aterrimum*), which showed efficiency in the remediation of the herbicide-sodium herbicide in the soil in the field, and stressed that the minimum population density of this plant should be 25 plants per square meter.

Jesus et al. (2015) studied the *Typha dominguensis* species, *Nymphaea lingulata*, *Eleocharis acutangula* and *Acroceras zizanioides* for environmental monitoring of the river basin Subaé. They observed that the increase of metals in organisms was proportional to the increase in metal concentrations in the environment, and concluded that the species showed satisfactory results with bioaccumulative potential, especially of zinc and copper elements. Ignatius et al. (2014) conceptualize the coefficient of bioaccumulation (BA) as "is a parameter used to assess the ability of the species to accumulate a certain element."

As described by Dias et al. (2014), some species endemic to Brazil or South America have the phytoextraction and phytostabilizing capacities, with the potential to support the physical and chemical conditions in tropical soils (Table 3). According to the author, factors may influence the use of phytoremediation method such as, the soil type, the concentration of heavy metals and local features to be implemented, as areas of difficult growing.

Table 3: Examples of plant species for use in phytoremediation.

	Species	
Metals	Phytoaccumulation	Phytostabilization
As	*Pteris vittata*	*Brassica* sp.
Cd	*Pfaffia sp.*	*C. rotundus*
As	*Stylosanthes humilis*; *Lolium multiflorum*	*C. fissilis*; *M.* caesalpiniaefolia
Cu	*Brachiaria decumbens*	*A. mangium*
Pb	*Canavalia ensiformis*	*P. gonoacantha*
Zn, Cd	*Gomphrena claussenii*; *Nicotiniana tabacum*	*E. camaldulenses*; *E. grandis*

Source: Adapted from Dias *et al.*, 2014

According to Silva et al. (2014), biotechnological processes favor the maintenance of the environment and that, among the various pollutants and mechanisms for the recovery of degraded areas, microorganisms and plant species have particular ways for removal, immobilization or transformation of specific pollutants.

Organisms, especially microbes, are being used as bioremediators for soil, aquifers, sludge, waste and air cleaning (GARBISU & Alkorta, 2003). The authors also point out that bioremediation is an area with rapid growth in the biotechnology industry, being more efficient and economically viable than conventional physicochemical methods currently in use.

Study by Santos et al. (2015) demonstrated that the electrodeposition technique, has shown considerable promise in the treatment of effluents with various contaminants, including heavy metals. They also state that the technique has advantages over conventional methods because chemical inputs are not necessary for its operation and there is reduction in the amount of generated sludge.

4. Final considerations

Heavy metals are known for their toxic effects, causing damage to the environment and human health, often irreversible. High concentrations of these substances are in water and soil and can cause extensive damage to living beings in these environments.

Water resources are the most affected by the release of heavy metals. This ease of contamination is due to the solubilization and transport for water resources, reaching the water table. The contamination can be observed by the adhering of heavy metals in sediment and accumulate in soils, in addition to being absorbed by some plants, such as lettuce, carrot and grasses. The consequences may be direct, or indirect and often irreversible damage to human health and the contaminated environment.

Monitoring of contamination by heavy metals, must be effected in the search for prevention and promotion of environmental and human health. In places with high interference of industries, there must be greater monitoring of effluents, as well as guidance and awareness of farmers regarding the use and disposal of fertilizers and pesticides.

The operators of mining activities cause changes in the environment, especially the water quality of the places where the projects are located. In this case, the monitoring should be routine to minimize social and environmental impacts arising from the exploitation of these resources, especially those that directly or indirectly affect water resources, vital source for the survival and quality of life of society.

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