FACTA UNIVERSITATIS
Series: **Working and Living Environmental Protection** Vol. 20, Nº 2, 2023, pp. 99 - 109
https://doi.org/10.22190/FUWLEP2302099I

Review Paper

HEAVY METALS: IMPACT ON THE ENVIRONMENT AND HUMAN HEALTH

UDC 546.4/.8:504:614.2

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Abstract. *Heavy metals are important environmental pollutants, and their toxicity is an issue of increasing concern regarding environmental and health reasons. Sources of heavy metals in the environment can be natural (metal-bearing rocks, volcanic eruptions, vegetation, etc.) and anthropogenic (mining, industrial and agricultural activities, traffic, etc.). Environmental pollution caused by heavy metals is long-term and persistent. The contamination of terrestrial and aquatic ecosystems with toxic heavy metals is a significant environmental concern that has consequences for public health. Certain metals affect biological functions, while other metals accumulate in one or more different organs causing numerous serious diseases.*

Key words: *environmental pollutants, heavy metals, health*

1. INTRODUCTION

There is no general agreement on chemical definition of heavy metals. These elements acquired the name *heavy metals* because they all have high densities, greater than 5 g/cm^3 [1]. Although heavy metals are naturally present in the earth crust, various anthropogenic activities can cause heavy metals contamination. The major anthropogenic sources of heavy metals are some industrial processes, mining, combustion of fossil fuel and gasoline, smelters and waste incinerators. Heavy metals are a considerable environmental threat to living organisms and habitats because of their bioaccumulation, environmental stability, non-biodegradability, and toxicity. Many factors (temperature, soil pH, soil aeration, Eh condition, etc.) influence the uptake of a metal by plants (lowest trophic level). Humans are exposed to a wide range of heavy metals (e.g., cadmium, lead, mercury) as well as metalloids (e.g., arsenic) in the environment, workplace, through food and water consumption. Exposure to metals can

Received November 21, 2023 / Accepted November 23, 2023
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occur through a variety of routes (inhalation, oral and dermal). The route and duration of exposure as well as the absorbed dose of metals cause metal toxicity [2].

2. Sources of Heavy Metals

Heavy metal pollution can originate from natural as well as anthropogenic sources. The most important natural source of heavy metals is the geologic parent material (rocks). The geologic parent materials commonly contain high concentrations of Cu, Zn, Cr, Mn, Co, Ni, Cd, Sn, Hg and Pb. However, the composition and concentration of heavy metals depend on the rock type and environmental conditions.

As regards volcanoes, there are data on the emission of high concentrations of some heavy metals (Al, Zn, Mn, Pb, Ni, Cu and Hg). For instance, Mount Etna (Sicily, Italy) is one of the most active volcanoes in the world and is in an almost constant state of activity. Some major eruptions emitted high amounts of Cd, Cr, Cu, Mn and Zn [3]. The eruptions of the Etna volcano also significantly enhanced the Hg content of plants and soil in the surrounding area [3].

Several studies showed that significant levels of toxic metals (cadmium, chromium, copper, iron, lead, manganese, nickel, silver, and zinc) are emitted into the environment during fires. It was estimated that the amount of lead and mercury from fires was comparable to emissions from anthropogenic sources such as industrial processes and city pollution [4,5].

Also, vegetation can be an important factor in heavy metals emission into the soil and atmosphere through decomposition, volatilization, and leaching from leaves and stems.

When it comes to anthropogenic sources of heavy metals, mining takes a significant place. Namely, mining operation emits different heavy metals depending on the type of mining. According to the global inventory of the United Nations Environmental Program (UNEP) in 2015, 2220 tons of Hg was emitted to the atmosphere from 17 key anthropogenic sources [6]. It should be emphasized that small anthropogenic sources were not possible to quantify in the detailed global inventory. Emissions from these additional sources are evaluated to total on the order of tens to hundreds of tonnes per year. They would therefore not significantly change the total global emissions inventory but may be of local or regional significance. Mercury-based artisanal and small-scale gold mining causes more mercury pollution than any other human activity. In this method, mercury metal is used to extract gold from ore as a stable amalgam [7]. Based on a systematic review of 16 research studies, Soe et al. concluded that mercury is widely used in artisanal and small-scale gold mining (ASGM) industries throughout Southeast Asia countries, including Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, and Thailand. Mercury concentrations exceeding the WHO and United States Environmental Protection Agency guideline values were reported in environmental (i.e., air, water, and soil) and biomonitoring samples (i.e., plants, fish, and human hair). ASGM-related health risks to miners and nonminers, specifically in Indonesia, the Philippines, and Myanmar, were also assessed. The findings indicated mercury contamination around the ASGM process, specifically the gold-amalgamation stage was significantly high. Mercury atmospheric concentrations from all observed studies were shown to be extremely high in the vicinity of gold operating areas [8]. Mercury delivered from tailings and evaporated mercury exceeds 1000 tons per year from artisanal and small-scale gold mining. Besides mercury, the characteristic features of gold mine tailings are the elevated concentrations of toxic heavy metals and metalloids such as arsenic, cadmium, nickel, lead, copper, zinc and cobalt [9,10]. Cadmium (Cd) contamination from mining and smelting operations has led to growing environmental health concerns. According to a study conducted in China, soil, surface water, drinking water, rice, vegetables, hair and urine were collected from local residents in the vicinity of an active lead-zinc mine and a copper smelter. The aim was to determine how nonferrous metal mining and smelting activities have influenced the health of local residents. It was found that the Cd concentrations in most soil and rice samples exceeded the national tolerance limits of China. Dietary intakes of rice and vegetables were the two major pathways of Cd exposure to local residents, accounting for >97% of the total probable daily intake. The excessive daily intake of Cd resulted in potential non-carcinogenic risks to the local residents, especially to children living in investigated areas [11]. With the rapid development of the mining industry, the pollution of heavy metal(loid)s in soils near copper (Cu) mining sites is a significant concern worldwide. In the research conducted by Chen et al., heavy metal(loid) pollution and ecological risk in soils near Cu mines were evaluated. The research has included literature data concerning concentrations in soil samples taken near 102 Cu mining sites worldwide. Most of the study sites exceeded the moderately to heavily polluted levels of Cu and Cd. These findings indicate that the control of Cu, Cd, and As should be prioritized because of their high incidence and significant risks in soils near Cu mines [12].

The most prevalent agricultural sources of heavy metals are sewage sludge, pesticides, and fertilizers. Regarding the agricultural sources of heavy metals, fertilizers, pesticides, and sewage sludge are the most common. Fertilizers, including organic and inorganic elements, are responsible for producing heavy metals in the soil. Excessive use of fertilizers for a long time resulting in heavy metals accumulation in agricultural soils reduces soil fertility and consequently decreases plant growth and productivity [13]. The research conducted in the rice farming area to the north of Albufera Natural Park (Valencia, Spain) has shown that superphosphate (compared to urea, iron sulphate, and copper sulphate) is the fertilizer that contains the highest concentrations of Cd, Co, Cu and Zn as impurities. Copper sulphate and iron sulphate have the most significant concentrations of Pb, and are the only fertilizers in which Ni was detected. Analysis of three groups of pesticides (two herbicides and one fungicide) shows similar Cd contents while the highest levels of Fe, Mn, Zn, Pb and Ni are found in the herbicides. The most significant additions of heavy metals as impurities that soil receives from agricultural practices, are Mn, Zn, Co and Pb [14]. Investigation of changes in peanut (*Arachis hypogaea* L.) yield and kernel quality, as well as changes in copper (Cu), zinc (Zn), lead (Pb), and cadmium (Cd) concentrations in soil and peanut kernels after 16 years of continuous cropping with different fertilization treatments, pointed to significantly increased peanut biomass, kernel yield, and crude protein and total amino acid contents in kernels, but led to higher amounts of Cu, Zn, and Cd in soil and higher amounts of Zn and Cd in peanut kernels when pig manure was used compared with that of chemical fertilizer [15].

Numerous studies have shown intense contamination of soil and vegetation with heavy metals near roads, but also a significant decrease in concentrations with distance from roads. Lead and cadmium levels in soils and vegetation mostly decrease with increasing distance from the roadside [16]. Studies also found that Pb amount in the environment is firmly related to vehicular traffic density. Generally, topsoil is characterized by the highest heavy metal concentration [17]. Heavy metals such as Cu, Zn, Pb and Cd contained in contaminated soils have a high potential bioavailability to soil biota, plants and humans.

The requirement for the collection and sanitary disposal of municipal solid waste was not recognized until recently. In other words, most of municipal solid waste was disposed of in open dumpsites, without planning and consideration for environmental and health standards [18, 19]. Municipal solid waste landfills pose a potential risk due to the migration of contaminated leachate, landfill gas, and landfill fires; thus, the environmental impacts of the landfills must not be ignored.

Leachates are complex mixtures of dissolved substances such as inorganic components including heavy metals and metalloids, organic matter, and a wide range of xenobiotic organic compounds. Landfill leachate is an important source of pollutants. A great content of these substances is hazardous and toxic to humans and the environment.

Landfill fires pose a threat to the environment as they cause the migration of pollutants to the atmosphere, soil and water. Some of the most significant polluting substances that arise during a fire are dioxins/furans, polycyclic aromatic hydrocarbons (PAHs), respirable particulates (PM) and heavy metals (HM), as well as other harmful compounds [20].

Landfill-induced heavy metal pollution of soils is a global and complex issue. A number of studies have provided data on quantities of heavy metals in soils near landfill sites. To evaluate the extent and possible hazards of heavy metal pollution at Shanghai Laogang Landfill, the largest landfill in China, surface soil samples were collected near the landfill and concentrations of Cu, Zn, Cd, Pb, and Cr were determined. The results revealed that the concentrations of heavy metals, except Pb, were higher in the surface soil near the landfill than in the background soil [21]. The research conducted in Tehran aimed to estimate the health and ecological risk associated with soil heavy metal in the Tehran landfill. A total of 48 soil samples were taken from the landfill and residential area and were analyzed. The results showed the following order for heavy metal levels in landfill soil: Al > Fe > Mn > Zn > Cr > Cu > Pb > Ni > Co > As > Cd. The investigated ecological indices showed moderate to high heavy metal pollution [22].

3. Environmental Impact of Heavy Metals

Heavy metals are important environmental pollutants because their concentrations in air, soil, water, and biota are constantly increasing as a result of anthropogenic activities.

After entering the environment, heavy metals may be modified into other substances. Transport of heavy metals can occur within a compartment (air, soil, water or biota) or between them.

Significant quantities of metals enter the atmosphere, resulting in serious harmful effects. Heavy metals of anthropogenic origin directly enter the atmosphere in the form of aerosols [23]. After that, they are transferred by atmospheric circulation and can be removed from the atmosphere by dry or wet deposition, as well as during direct air/water/soil exchange. The transmission distance of atmospheric metals is dependent on different factors, such as meteorological conditions (e.g., precipitation and wind), particle size, physicochemical properties of the aerosols, etc. The particle size of particulate matter (PM) is the major cause of atmospheric metal adsorption. Particle pollution includes PM_{10} (inhalable particles, with diameters that are generally 10 micrometers and smaller) and $PM_{2.5}$ (fine inhalable particles, with diameters that are generally 2.5 micrometers and smaller). The size of the particulate matter is in correlation with its specific surface area, and consequently with the adsorption effect on metals. Also, the migration capacity of fine particles is stronger than that of coarse particulate matter. Small particles are mainly removed from the air under conditions of wet deposition (rainfall and snowfall), while large particles are generally deposited in the process of dry deposition [24,25]. The lifespan of particulate matter (PM) in the atmosphere can vary depending on various factors. In general, larger particles (PM_{10}) tend to have a shorter lifespan compared to smaller particles ($PM_{2.5}$). Larger particles are more susceptible to gravitational settling and can be removed from the atmosphere relatively quickly, ranging from a few hours to several days. Wind and rain can also accelerate the removal of larger particles from the air. On the contrary, smaller particles can have a longer lifespan in the atmosphere. They are more affected by atmospheric dynamics and can be transported over longer distances before being removed. The lifespan of $PM_{2.5}$ can range from a few days to weeks, or even months in some cases. It is important to emphasize that these estimates are general, and the real lifespan of PM can vary depending on local conditions and specific particle characteristics. Additionally, certain chemical components of PM, such as sulfate or black carbon, may undergo atmospheric transformations that can affect their lifespan.

As previously mentioned, the emitted heavy metals do not deposit on surfaces right after the emission; rather, they disperse and are transported. During this retention period, heavy metals can cause direct and indirect harmful impacts on human and ecosystem health. Mostly, heavy metal emissions that have anthropogenic origins are known to cause notable surface depositions on the biosphere components such as water bodies and soil [26].

Metals from atmospheric precipitation enter water bodies and have a significant impact on them. Metals can enter water bodies via direct deposition or through surface runoff. The literature data point out that the trace metals in water bodies are in approximately the same order as the atmospheric metals concentrations, implying that the metals in the water bodies at the site are mainly derived from atmospheric deposition. Ahmed et al. reported the results of measurements of eight trace metal concentrations in lake water and atmospheric ambient air samples, collected before and after precipitation events during November and December 2015. The metal concentrations in the lake water samples showed the following trends: Zn > Al > Cr > As > Hg > Pb > Sn > Cd, while the metal concentrations in the atmospheric samples were Zn > Al > Pb > Cr > As > Sn > Hg > Cd [27].

Sediment is an integral and dynamic part of the aquatic system, with a diversity of habitats [28-30]. Contaminated sediment has a direct negative impact on the benthic organisms and is a potential long-term source of pollutants that can adversely affect the benthic organisms, as well as the human population through the food chain. Heavy metals have low solubility in water and are easily absorbed in sediment, making it a sink for heavy metals in aquatic environments. The accumulation and spatial distribution of heavy metals in aquatic sediments are primarily controlled by physical, chemical, hydrological, and hydraulic factors. Once contaminated sediment can become a source of secondary pollution. Namely, due to a change in conditions in the water system (flooding, acidification, etc.) sorbed heavy metals are desorbed and returned to the water phase where they again pose a risk. Metals that have a geochemical origin are usually found in sediment in less available or completely unavailable forms. On the other hand, metals that have reached the sediment from anthropogenic sources, are found in more bioavailable forms.

Soil is a main sink for most pollutants in the environment, including heavy metals. Excess heavy metals in the soil originate from many sources, which include atmospheric deposition, the use of pesticides and fertilizers, inappropriate deposition of industrial solid waste, mining activities, sewage irrigation, etc.

Heavy metals cause long-term hazardous effects on soil ecosystems and negatively influence soil biological processes. Soil enzyme activities are considered to be good bioindicators, reflecting natural and anthropogenic disturbances. Soil enzymes are inhibited by heavy metals to different ranges depending on the properties of the soil (pH value, clay, silt and organic matter contents) and enzyme factors (enzyme sensitivity, structural inhibition of the enzyme, etc,). Also, the inhibition of soil enzyme activities by heavy metals depends on concentration, chemical form and availability of the heavy metal. The reduction in soil microbes and consequently the inhibition of soil enzyme activities, caused by heavy metal contamination, negatively affect soil fertility [31-33].

The uptake of metals by plant roots is the main way of metal uptake. During the uptake of metals by plant roots, metal ions adsorbed to root hairs or root epidermal cells enter the root cell via the coplasmic or exosomal pathway, and most of the metal ions enter the root cell via specific or universal ion carriers or channel proteins. After entering the root cells, metals form complexes with chelating agents, which translocate to the aboveground part of the plant [34]. Also, absorption by the leaves is a significant way for toxic metals from atmospheric fallout to enter the plant body. Foliar uptake of metals depends on numerous factors. The physicochemical properties of cuticles, the morphology and surface area of plant leaves, the surface texture of leaves, the chemical and physical forms of adsorbed metals, exposure duration, and environmental conditions can affect the uptake of metals by foliage. Deposition and adsorption of atmospheric metals on plant leaves varies with the content of metals in atmospheric particulate matter.

Toxic metals have a different impact on plants. Metal toxicity reduces the uptake and translocation of nutrients and water, and enhances oxidative damage, thus inhibiting plant growth [35]. The manifestation of chromium (Cr) toxicity is reflected in different phenomena, decrease in seed germination, reduction of plant growth, inhibition of enzymatic activities, and impairment of photosynthetic machinery and oxidative balances [36]. Pb causes inhibition in ATP production and enhances ROS and DNA damage. In addition, it significantly affects plant germination, root and stem biomass growth, photosynthetic activity, and enzymatic activity. Toxic accumulation of Pb interferes with spindle formation and cell wall growth, decreases cell expansion and division, and leads to suppression of root volume [35, 36]. Among all the pollutants, Hg and As are known to be among the top five key dangerous metals/metalloids (Hg, As, Cu, Pb, Cd). Exposure of plants to As, even at very low concentration, can cause many morphological, physiological, and biochemical changes. Arsenic can induce oxidative stress via the enhanced production and/or inefficient elimination of ROS and consequently damage lipids, proteins, and nucleic acids, and interferes with various metabolic pathways. As is known to reduce and/or inhibit the process of seed germination, root growth, and various earlier developmental processes, that occurs during initial stages of seedling development. Plants have evolved several mechanisms to overcome the toxic effects of As. Hg affects the growth of roots and buds, and affects mitochondrial activity and photosynthesis.

4. IMPACT OF HEAVY METALS ON HUMAN HEALTH

Humans are exposed to a wide range of heavy metals (e.g., lead, mercury, cadmium) as well as metalloids (e.g., arsenic) in the environment, food and water consumption, and workplace. Exposure to metals can occur through a variety of routes (inhalation, oral and dermal). Regarding duration, exposure can be acute, subacute, chronic or subchronic. The route and duration of exposure as well as the absorbed dose of metals cause metal toxicity.

The general population is exposed to lead (Pb) from air and food, mainly via inhalation and ingestion of lead-bearing dusts and fumes, and ingestion of lead-contaminated food, water, and paints [37]. Workplace environments presenting the largest potential sources of occupational exposure to lead include battery manufacturing plants, steel welding or cutting operations, construction, rubber products and plastics industries, printing industries, firing ranges, lead smelting and refining industries, radiator repair shops, and other industries requiring flame soldering of lead solder [38]. Studies of lead workers suggest that chronic exposure to lead may be associated with increased mortality owing to cerebrovascular disease. The brain is the most sensitive organ to lead exposure. Lead poisoning induces loss of neuron myelin sheath, decreases the number of neurons, interferes with neurotransmission, and reduces neuronal growth. One of the main concerns in terms of lead toxicity is the cognitive and neurobehavioral deficits. Some investigations propose that there is an important relationship between bone-lead levels and hypertension. Blood lead levels have also been associated with small elevations in blood pressure. Also, some research on humans environmentally or occupationally exposed to lead found a link between blood lead levels and abortion and preterm delivery in women, as well as alterations in sperm and decreased fertility in men. One of the significant mechanisms by which lead pursues its toxic effect is through biochemical processes that involve lead's ability to inhibit or mimic the activity of calcium and to interact with proteins [39]. Within the skeleton, lead is incorporated into the mineral in place of calcium. Lead binds to sulfhydryl and amide groups of enzymes, modifying their configuration and activities. Its competition with essential metallic cations for binding sites inhibits enzyme activity, or modulates the transport of essential cations. Gastrointestinal indications of lead poisoning involve chronic or recurrent abdominal pain, nausea, vomiting, constipation, bloating, anorexia and weight loss. Some *in vitro* and *in vivo* studies indicated that lead compounds cause genetic damage through various indirect mechanisms that include inhibition of DNA synthesis and repair, oxidative damage, and interaction with DNA-binding proteins and tumor suppressor proteins.

Mercury (Hg) has no physiological function in humans, and hence exerts many toxic effects. The effect of Hg poisoning depends on its different forms [40]. There are many resemblances in the toxic effects of the various forms of mercury (elemental, mercurous and mercuric mercury) but there are also significant differences. Most of the studies on inhalation exposure concern exposure to metallic mercury vapor. Other species of inorganic mercury don't present an inhalation risk. The main target organs of metallic mercury-induced toxicity are the kidneys and the central nervous system. At high-exposure levels, respiratory, cardiovascular, and gastrointestinal effects also occur [40, 41]. Various studies have reported death in humans following accidental acute-duration exposure to high, but unspecified, concentrations of metallic mercury vapor. Death in all cases was attributed to respiratory failure. Gastrointestinal effects were reported after people were exposed to organomercurial compounds as well as metallic mercury vapor. Exposure to high concentrations of elemental mercury vapors manifests a syndrome like "metal fume fever," which is characterized by fatigue, fever, chills, and elevated leukocyte count. A number of studies have reported increases in tremors, muscle fasciculations, myoclonus, or muscle pains after acute, intermediate, or chronic exposure to metallic mercury vapor. The kidney is a sensitive target organ for toxicity following inhalation exposure to metallic mercury. This sensitivity may be explained by the relatively high accumulation of mercury in the kidneys. Exposure of individuals to elemental mercury vapors has resulted in erythematous and pruritic skin rashes. Ocular effects observed following acute exposure included red, burning eyes and conjunctivitis. The central nervous system is probably the most sensitive target organ for metallic mercury vapor exposure. Adverse neurological effects following acute inhalation of high concentrations of mercury vapor include cognitive, personality, sensory, and motor disturbances. The most prominent symptoms include tremors (initially affecting the hands and sometimes spreading to other parts of the body), emotional lability (characterized by irritability, excessive shyness, confidence loss, and nervousness), insomnia, memory loss, neuromuscular changes (weakness, muscle atrophy, muscle twitching), headaches, polyneuropathy (paresthesia, stocking-glove sensory loss, slowed sensory and motor nerve conduction velocities) [41].

Food and cigarette smoking are the most important sources of Cd apart from water. Workers are exposed occupationally to cadmium, particularly by inhalation of dust and fumes. Also, absorption from the gastrointestinal tract can be particularly important when a significant fraction of inhaled dust gets swallowed. Mostly, the different cadmium compounds have similar toxicological effects. However, differences in absorption and distribution can cause different responses, particularly for the less soluble cadmium pigments. There is very strong evidence that the kidney is one of the main target organs of cadmium toxicity following extended inhalation exposure. Long-term low-level exposure leads to cardiovascular disease and cancer [42].

Arsenic (As) is a potent toxicant that may occur in various oxidation states and in different inorganic and organic forms. Usually, arsenic-related toxicity is typically caused by inorganic arsenic exposure, and there is a comprehensive database on the human health effects. Even though there may be differences in the toxicity of diverse chemical forms, these differences are usually minor (the exception would be highly toxic arsine). Humans may be exposed to organic arsenicals that are used in agriculture and to organic arsenicals found in some food products (fish and shellfish). Although the toxicity of organic arsenicals has not been as extensively investigated as inorganic arsenicals, there is enough animal data to evaluate their toxicity. Inorganic arsenic enters the body primarily through inhalation of arsine gas or airborne arsenic fumes or dusts. The particle size of airborne arsenic determines whether arsenic will reach the lower respiratory tract or be deposited in the upper airways and swallowed after mucociliary clearance. In addition, soluble forms of inorganic arsenic compounds are well absorbed from the gastro-intestinal tract. Some arsenic compounds (arsenic acid and arsenic trichloride) may be absorbed percutaneously. Inorganic arsenic does not cross the blood-brain barrier but does cross the placenta. Acute clinical symptoms from arsenic exposure will vary widely. Acute effects are generally the result of short-term exposures to high concentrations of arsenic. The most common chronic effects due to arsenic exposure are: contact dermatitis, scaling, blistering of the skin, hyperpigmentation and hyperkeratotic lesions on the skin; conjunctivitis; mucous membrane irritation and perforation of the nasal septum; weakness, loss of appetite, gastro-intestinal disturbances; liver cirrhosis and portal hypertension; peripheral neuropathy initially of hands and feet; bone marrow depression with pancytopaenia, etc. [43, 44].

6. CONCLUSION

Heavy metals and metalloids are ubiquitous environmental pollutants. Heavy metals are considered hazardous due to their persistence, bioaccumulation, and toxicity. The trophic transfer of heavy metals in aquatic and terrestrial food chains has important implications for wildlife and human health. It is very important to assess and monitor the concentrations of potentially toxic heavy metals in different environmental segments with the purpose of minimizing the impact of these elements on human health and the environment.

Acknowledgement: *This research was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia - Agreements on the implementation and financing of scientific research in 2023 [number 451-03-47/2023-01/ 200148].*

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TEŠKI METALI: UTICAJ NA ŽIVOTNU SREDINU I ZDRAVLJE LJUDI

Teški metali su zagađujuće supstance životne sredine, i pitanje njihove toksičnosti sa aspekta životne sredine i zdravlja ljudi je od sve većeg značaja. Izvori teških metala u životnoj sredini mogu biti prirodni (matične stene, vulkanske erupcije, vegetacija, itd.) i antropogeni (rudarske, industrijske i poljoprivredne aktivnosti, saobraćaj, itd.). Zagađenje životne sredine prouzrokovano teškim metalima je dugotrajno i perzistentno. Zagađenje zemljišnih i vodenih ekosistema toksičnim metalima predstavlja glavnu zabrinutost sa aspekta zagađenja životne sredine, a posledično i sa aspekta zdravlja opšte populacije. Određeni metali utiču na biološke funkcije, dok se drugi akumuliraju u jednom ili više različitih organa prouzrokujući niz ozbiljnih oboljenja.

Ključne reči: *zagađenje životne sredine, teški metali, zdravlje*