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A Review on the Effect of Heavy Metal Contamination and its Impact on the Environment

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Abstract: Environmental pollution of heavy metals is increasingly becoming an alarming problem and has become of great concern around the world due to the adverse effects. These inorganic pollutants are widely distributed in the environment through water, soil and also into the atmosphere. Due to the rapidly growing agricultural, metal and Pharmaceutical industries, through improper waste disposal, fertilizers and pesticides, raising concerns over their potential effects on human health and the environment. Their toxicity depends on several factors including the dose, route of exposure, and chemical species, as well as the age, gender, genetics, and nutritional status of exposed individuals. Because of their high degree of toxicity, arsenic, cadmium, chromium, lead, and mercury rank among the priority metals that are of public health significance. They are also classified as human carcinogens (known or probable) according to the U.S. Environmental Protection Agency, and the International Agency for Research on Cancer. This review provides an analysis of their environmental occurrence, production and use, potential for human exposure, and molecular mechanisms of toxicity, genotoxicity, and carcinogenicity.

Keywords: Bio-accumulation, Pollution, Toxicity, Mercury, Cadmium, Lead, Environmental hazards

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Introduction

Environment is defined as the totality of circumstances surrounding an organism or group of organisms especially, the combination of external physical conditions that affect and influences the growth, development and survival of organisms. It consists of the flora, fauna and the abiotic which includes the aquatic, terrestrial and atmospheric habitats. The environment is considered in terms of the most tangible aspects like air, water and food (Gore, 1997). A pollutant is any substance in the environment, which causes objectionable effects, impairing the welfare of the environment, reducing the quality of life and may eventually cause death. Hence, environmental pollution is the presence of a pollutant in the environment (air, water and soil), which may be poisonous or toxic and will cause harm to living organisms (Ali *et al.*, 2013). Environmental contamination and pollution by heavy metals is a threat to the environment and is of serious concern, and is also one of the major challenges in the modern human society (Hashem *et al*., 2017). Rapid industrialization and urbanization have caused contamination of the environment by heavy metals, and their rates of mobilization and transport in the environment have greatly accelerated since 1940s.

Metals are having high malleability, electrical conductivity and they voluntarily lose their electrons for the formation of cations. Naturally they are found in the earth crust and their composition differs greatly among various localities, which result in spatial variations in the adjoining concentrations. Heavy metal refers to naturally occurring metal or metalloid having atomic number greater than 20, and elemental density exceeding 5g/cm^{-3} (Barbieri, 2016). Terms usually used in relation to metals in biological and environmental studies are metal, metalloid, semimetal, light metal, heavy metal, essential metal, beneficial metal, toxic metal, abundant metal, available metal, trace metal, and micronutrient (Muchuweti *et al*., 2006).

Heavy metals are persistent in the environment, contaminate the food chains, and cause different health problems due to their toxicity. Chronic exposure to heavy metals in the environment is a real threat to living organisms. Metal concentrations above threshold levels affect the microbiological balance of soils and can reduce their fertility (Malik and Maurya, 2014). Bioaccumulation of toxic heavy metals in biota of the riverine ecosystems may have adverse effects on animals and humans. Higher levels of heavy metals in biota can have negative effects on the ecological health of aquatic animal species and may contribute to declines in their populations. Globally the exposure to heavy metals is increasing day by day. They act as significant pollutants in environment and their toxicity is of concern for evolutionary, ecological, environmental and nutritional reasons (Shallari *et al*., 1998; Jaishankar *et al*., 2014). This article comprehensively reviews the different aspects of heavy metals as hazardous materials with a special focus on their environmental persistence, toxicity for living organisms, and bio-accumulative potential.

Sources of Heavy Metal Pollution:

The heavy metals are naturally occurring elements that are found throughout the earth's crust, Due to the astounding increase of the use of heavy metals, it has resulted in an imminent surge of metallic substances in both the terrestrial and aquatic environments. Most environmental contamination and human exposure has dramatically increased from anthropogenic activities such as mining the metals and smelting operations, industrial production, pharmaceutical, domestic and agricultural use of metals and metal-containing compounds (Nriagu, 1989; He *et al*., 2005). Environmental contamination can also occur through metal corrosion, atmospheric deposition, soil erosion of metal ions and leaching of heavy metals, sediment re-suspension and metal evaporation from water resources to soil and ground water (Arruti *et al.*, 2010). Natural phenomena such as weathering and volcanic eruptions have also been reported to significantly contribute to heavy metal pollution (Nriagu, 1989). Industrial sources such as metal processing in refineries, coal burning in power plants, petroleum combustion, nuclear power stations and high tension lines, plastics, textiles, microelectronics, wood preservation and paper processing plants (Hazrat *et al.*, 2019) are also responsible for environmental pollution.

Essential and Non-Essential Metals:

The heavy metals are classified into two major groups namely essential and nonessential heavy metals based on their roles in biological system (Turkmen *et al*., 2009). Essential heavy metals are important for living organisms and may be required in the body in quite low concentrations. Non-essential heavy metals have no known biological role in living organisms. Some metals like copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) are examples of essential heavy metals.

While the heavy metals cadmium (Cd), lead (Pb), and mercury (Hg) are toxic and are regarded as biologically nonessential (Martin and Johnson, 2012; Ramirez, 2013) and has no known biological role in living organisms (Williams *et al.*, 2000). Metals like cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), magnesium (Mg), nickel (Ni), zinc (Zn) and selenium (Se) are among essential micronutrients which are required for normal physiological and biochemical functions of living organisms (Sinha *et al.*, 2005; Kim *et al.*, 2015) and their insufficient supply may result in deficiencies diseases. Because of their presence in trace concentrations they are also known as trace elements but they become toxic when they exceed threshold concentration (Chalkiadaki *et al.*, 2014; Asati *et al.*, 2016). However, the lists of essential heavy metals may be different for different groups of organisms such as plants, animals, and microorganisms. It means a heavy metal may be essential for a given group of organisms but nonessential for another one (Rezania *et al.*, 2016).

Contamination of Soil, Water and Air by Heavy Metals:

Pollutants may enter the ecosystem in various ways and can enter into the hydrosphere, lithosphere and atmosphere. Apart from entering through natural ways as mentioned earlier (through volcanic activity and weathering of rocks), anthropogenic activity is a big cause of pollutants entering the ecosystem. Heavy metals released into the atmosphere in volcanic eruptions and in different industrial emissions also ultimately return to the land and cause contamination of waters, soils and air. Since heavy metals are persistent in the environment, they either accumulate in biota or leach down into ground waters. Contamination of biota and groundwater with potentially toxic heavy metals has important implications for human health (Turkmen *et al.*, 2009). It is important to evaluate the amount of heavy metal pollution in the ecosystems by investigating the concentration of these elements and their distribution.

(i) *Effects on Water*:

Water is the "life-blood of the biosphere." Since water is a universal solvent, it dissolves different organic and inorganic chemicals and environmental pollutants. Aquatic ecosystems, both freshwater and marine, are vulnerable to pollution. Contamination of water resources by heavy metals is a critical environmental issue which adversely affects plants, animals, and human health (Rajaei *et al.*, 2012). Pollution of water bodies with heavy metals is a world wide problem because of the environmental persistence, bioaccumulation, and bio-magnification in food chains and toxicity of these elements (Afzal *et al.*, 2018). Aquatic ecosystems are contaminated by heavy metals through different industrial effluents, domestic sewage, and agricultural run-off, whereas the release of industrial effluents without treatment into the aquatic bodies is a major source of pollution of surface and groundwater (Akif *et al.*, 2002). Heavy metals are extremely toxic to aquatic organisms even at very low concentrations and these elements can cause significant histopathological alterations in tissues of aquatic organisms such as fish (Matos *et al.*, 2017). Moreover, high bioaccumulation of heavy metals in the aquatic body can lead to genotoxic damage of aquatic species and high concentrations of heavy metals can have cytotoxic, mutagenic and genotoxic effects on fish species (Alloway, 2013). Consumption of fish having high level of heavy metal can be a serious health hazard (Arunakumara *et al.*, 2013) for the human population. To limit the risks for humans and the environment, many countries have legislated limits for each heavy metal. Specific limits have been defined in drinking water, and surface waters (lakes, rivers, seas). There are also limits in agricultural products, sea foods and animal feed.

(ii) *Effects on Soil*:

Heavy metals and metalloids are released into soils from the parent material (lithogenic source) and different anthropogenic sources (Arunakumara *et al.*, 2013). Factors affecting the presence and distribution of heavy metals in soils include composition of parent rock, degree of weathering, physical, chemical, and biological characteristics of soil and climatic conditions (Walker *et al.*, 2012). Since metals are non-biodegradable hence, remain persistent in the environment for a very long time. They cannot be broken down, moreover heavy metals present in soils and sediments remain present for an extended period until they are eluted to other compartments. They can also react with other elements in the soil or sediment and form or degrade to become more toxic. An example of this is the formation of poisonous methyl mercury from the inorganic mercury by the activity of bacteria found in water, sediment and soil (Semu and Singh, 1996). Significant enrichment of heavy metals has been reported in soils receiving more input of fertilizers and Cu fungicide compared to virgin soils and soils receiving low inputs (Mackay *et al.*, 2013). In urban areas, soils may be contaminated with heavy metals from heavy vehicular traffic on roads, soil samples in urban areas have elevated concentrations of Pb, out of which 45–85% is bio-accessible (Aronsson and Perttu, 2001). The bioavailability of heavy metals in soils is very important for their fate in the environment and for their uptake in plants. Different heavy metals have different bio-availabilities in soils, and this bioavailability is dependent on metal speciation and on different physicochemical properties of soils.

Farmers sometimes use sewage sludge and mix it in the soil, though this may contain heavy metals, primarily if the sludge has been produced by industries. Heavy metals, such as copper, zinc, lead, cadmium and chromium have been found in the soil of these agricultural lands at a high concentration (Gupta *et al.*, 2012). Smelting causes localised pollution through atmospheric pollution, which then deposits on the soil. Some areas were smelting occurs shows dead vegetation and absence of life such as earthworms and woodlice, which help in vegetation to be decomposed. Lead-contaminated gasoline was used with a high concentration of lead, lead shotgun pellets, and lead fishing weights all contributed to lead being found in our environment (Chibuike and Obiora, 2014). Some have been banned in certain parts of the world. Shotgun pellets have been taken up by birds, and then this moves through the food chain, the weights have caused lead to be found in wetlands also. Metals are bound more to the soil if the clay content, organic matter, and the pH are higher. The more acidic the soil, the less elements have been found as these become more soluble and leach lower in the ground where the roots do not reach causing nutrient deficiency to the plants (Semu and Singh, 1996; Soleimani *et al.*, 2018).

(iii) *Effects on Air*:

Increased industrialisation and urbanisation have recently made air pollution as a major environmental problem. The air pollution was reported to have been accelerated by dust and particulate matters (PMs) particularly fine particles such as PM2.5 and PM10 which are released through natural and anthropogenic processes. Natural processes which release particulate matters into air include dust storms, soil erosion, volcanic eruptions and rock weathering, while anthropogenic activities are more industrial and transportation related (Herawati *et al.*, 2000). Particulate matters are important and require special attention as they can lead to serious health problems such as skin and eye irritation, respiratory infections, premature mortality and cardiovascular diseases. These pollutants also cause deterioration of infrastructure corrosion, formation of acid rain, eutrophication and haze (WHO, 1987).

Heavy Metals:

(1) *Effects of Cadmium*:

Cadmium is a heavy metal of considerable environmental and occupational concern. The highest level of cadmium compounds in the environment is accumulated in sedimentary rocks, and marine phosphates contain about 15 mg cadmium/kg (Mohan *et al*., 2013). Cadmium is widely used in mining, metallurgical operations, electroplating industries, manufacturing vinyl plastics, electrical contacts, metallic and plastic pipes and also in pigment manufacturing, plastic stabilizer and batteries. Cadmium is bio-persistent and once absorbed by an organism remains for many years (over decades for humans) although it is eventually excreted. In humans long-term exposure to lower levels leads to a build-up in the kidneys and possible kidney disease, lung damage and fragile bones. Smokers get exposed to significantly higher cadmium levels than non-smokers (Perera, 2017). High exposure can lead to obstructive lung disease and has been linked to lung cancer, although data concerning the latter are difficult to interpret due to compounding factors. Cadmium may also produce bone defects (osteomalacia, osteoporosis) in humans and animals. In addition, the metal can be linked to increased blood pressure and effects on the myocardium in animals, although most human data do not support these findings. The average daily intake for humans is estimated as 0.15 µg from air and 1 µg from water. Regulatory limits of cadmium based on EPA are 5 ppb or 0.005 ppm of cadmium in drinking water. According to FDA, permission of concentration in bottled drinking water should not exceed 0.005 ppm (5 ppb) (Mohan *et al*., 2020).

(2) *Effects of Mercury*:

Mercury is one of the most toxic elements among the heavy metals and considered as hazardous environmental pollutant (Barone *et al*., 2018). Mercury has many industrial uses, such as in the manufacture of plastics and agricultural fungicides (Barone *et al*., 2018) and is also used in thermometers, dental fillings, switches, light bulbs and batteries (Mohan *et al*., 2020). Mercury has no known function in human biochemistry or physiology and does not occur naturally in living organisms. Inorganic mercury poisoning is associated with tremors, gingivitis and minor psychological changes, together with spontaneous abortion and congenital malformation. The potential toxic effects of mercury include damage to kidneys, reproductive systems, immune, hematologic, cardiovascular, respiratory systems and brain (Bernhoft, 2012).

Mercury also binds with a high affinity to T cell surfaces and sulfhydryl groups which influence the T cell function. Metallic mercury is excreted mostly as mercuric mercury (Habuer *et al*., 2016). Mercury in soil and water is converted by microorganisms to methyl mercury, a bio-accumulating toxin. They bio-accumulate over a million fold and concentrate in living organisms, especially fish. These forms of mercury, monomethylmercury and dimethylmercury, are highly toxic, causing neuro-toxicological disorders. The main pathway for mercury to humans is through the food chain and not by inhalation (CDC, 1991). Thus, more stringent regulatory controls have been imposed for mercury in many countries. The FDA level of concern for mercury concentration in fish is 1ppm. The fish with level higher than this concentration should probably be avoided for human consumption.

(3) *Effects of Lead*:

Lead is a naturally occurring metal present in small amount in the earth's crust. It is used in the production of lead-acid batteries, ammunitions, metal products (solder and pipes), and devices to shield X-rays. Lead exposure usually results from lead in deteriorating household paints, lead in the workplace, lead in crystals and ceramic containers that leach into water and food, lead use in hobbies, and lead use in some traditional medicines and cosmetics (ATSDR, 1992, 2019). In humans, exposure to lead can result in a wide range of biological effects depending on the level and duration of exposure. Lead is distributed mostly to the bones and can cause osteoporosis. Lead can be found primarily in the red blood cells, transferring of lead from mother to foetus and through breast feeding occurs (Bagul *et al*., 2015). High levels of exposure may result in toxic biochemical effects in humans which in turn cause problems in the synthesis of hemoglobin, effects on the kidneys, gastrointestinal tract, joints, reproductive system, and acute or chronic damage to the nervous system (Jessica *et al*., 2020). At intermediate concentrations, however, there is persuasive evidence that lead can have small, subtle, subclinical effects, particularly on neuropsychological developments in children. Some studies suggest that there may be a loss of up to2 IQ points for a rise in blood lead levels from 10 to 20 µg/dl in young children (Langard and Vigander, 1983).

(4) *Effects of Chromium*:

Chromium is used in metal alloys and pigments for paints, cement, rubber, and other materials. Non-occupational exposure occurs via ingestion of chromium containing food and water, whereas occupational exposure occurs via inhalation (Jacobs and Testa, 2005). Chromium concentrations range between 1 and 3000 mg/kg in soil, 5 to 800 µg/L in sea water and 26 µg/L to 5.2 mg/L in rivers and lakes (Shelnutt *et al*., 2007). Low-level exposure can irritate the skin and cause ulceration. Long-term exposure can cause kidney and liver damage, and damage to circulatory and nerve tissue. Even though the principal route of human exposure to chromium is through inhalation and the lung is the primary target organ, significant human exposure to chromium has also been reported to take place through the skin (Valko *et al*., 2005). For example, the widespread incidence of dermatitis noticed among construction workers is attributed to their exposure to chromium present in cement (Valko *et al*., 2005). The metal is excreted mostly through urine but is also eliminated by bile excretion, and smaller quantities in nails, hair, milk and sweat. Chromium often accumulates in aquatic organisms, adding to the danger of eating fish that may have been exposed to high levels of chromium. Regulatory limit by EPA is 0.1 ppm in drinking water and according to FDA limit should not exceed 1 mg/l (1 ppm) in bottled water.

(5) *Effects of Copper*:

Copper has a number of applications in industrial and agricultural processes and it can be released into the environment from many sources such as mining, metal piping, chemical industries and pesticides industry. Copper normally occurs in drinking water from copper pipes, as well as from additives designed to control algal growth (Ihsanullah *et al*., 2016). Copper is needed by many enzymes to function normally and is thus classified as an essential element. It can change states from $Cu^{2+}$to Cu^{+} by cuproenzymes which are involved in redox reactions. This change ofstate can also make it toxic as superoxide, and hydroxyl radicals can be formed (Chibuike and Obiora, 2014). The effects of high intake of copper in human body are increased blood pressure and respiratory rates, damage to kidney and liver, convulsions, cramps, vomiting or even death. People with Wilson's disease are at greater risk for health effects from overexposure to copper. Copper is eliminated mostly through the bile, but it can also be excreted in small amounts through the faeces, sweat and urine (Ihsanullah *et al*., 2016). Permissible limit of copper concentration by US EPA is 1.3 mg/L and 2 mg/L by World Health Organization for drinking water.

(6) *Effects of Zinc*:

The human activities and industrial sources of zinc include brass platting, wood pulp production, newsprint paper production, steel works with galvanizing lines and zinc and brass metal works (Mohan *et al*., 2020). Zinc is released into environment from sediment entrainment, agricultural activities, groundwater intrusion or from a combination of these sources (US EPA, 2005). Zinc is classified as an essential element where it is needed by over300 enzymes. Zinc function in these metalloenzymes is to participate in catalytic functions, regulatory functions, and maintenance of the stability of the structure. Zinc plays a vital role in regulating many biochemical processes and physiological functions of living tissues. Zinc is implicated in DNA and RNA synthesis, together with cell proliferation (Meche *et al*., 2010). The human body contains 2–3 g zinc, and nearly 90% is found in muscle and bone. Other organs containing estimable concentrations of zinc include prostate, liver, the gastrointestinal tract, kidney, skin, lung, brain, heart, and pancreas. Oral uptake of zinc leads to absorption throughout the small intestine and distribution subsequently occurs via the serum, where it predominately exists bound to several proteins such as albumin and α-microglobulin (Mackay *et al*., 2013). The presence of zinc in excess causes prominent health problems, for example, stomach nausea, skin irritations, cramps, vomiting and anaemia.

(7) *Effects of Nickel*:

Nickel is a non-biodegradable toxic heavy metal ion present in wastewater. The main source of nickel pollution in the water is from a number of industrial production processes such as battery manufacturing, production of some alloys, zinc base casting, printing, electroplating and silver refineries (Cempel and Nikel, 2006). Small amounts of Nickel are needed by the human body to produce red blood cells, however, in excessive amounts, can become mildly toxic. Short-term overexposure to nickel is not known to cause any health problems, but long-term exposure can cause decreased body weight, heart and liver damage, and skin irritation. The toxic effects of nickel include dry cough, bone, nose and lung cancer, cyanosis, rapid respiration, shortness of breath, tightness of the chest, chest pain and nausea. Nickel can accumulate in aquatic life, but its presence is not magnified along food chains (Freije, 2015).

(8) *Effects of Arsenic*:

Arsenic present in the water originates from natural resources and human activities and it is released into the surface ground water by means of geological formation that happens in sedimentary rocks, geothermal water and from weathered volcanic rocks. Human activities such as mining, manufacturing, metallurgy, wood preservation and use of pesticides also introduce arsenic into the water bodies (Allan *et al.*, 2000). Arsenic is toxic and can cause numerous health effects in humans including cancer. Lower levels of arsenic exposure can cause nausea and vomiting, reduced production of erythrocytes and leukocytes, abnormal heart beat, pricking sensation in hands and legs, and damage to blood vessels. Long-term exposure can lead to the formation of skin lesions, internal cancers, neurological problems, pulmonary disease, peripheral vascular disease, hypertension and cardiovascular disease and diabetes mellitus (Cooper and Harrison, 2009). Arsenic bio-accumulates in fish and shellfish. WHO guidelines for Arsenic permissible limit for drinking water is 0.01 mg/l.

(9) *Effects of Antimony*:

Antimony is a metal used in the compound antimony trioxide, a flame retardant. It can also be found in batteries, pigments, ceramics and glass. Exposure to high levels of antimony for short periods of time causes nausea, vomiting, and diarrhoea. There is little information on the effects of long-term antimony exposure, but it is a suspected human carcinogen (Obasi and Akudinobi, 2020). Most antimony compounds do not bio-accumulate in aquatic life.

(10) *Effects of Selenium*:

Selenium is needed by humans and other animals in small amounts, but in larger amounts can cause damage to the nervous system, fatigue, and irritability. Selenium accumulates in living tissue, causing high selenium content in fish and other organisms, and causing greater health problems in human over a lifetime of overexposure. Selenium can cause muscle tenderness, tremor, light headedness, facial flushing, blood clotting problems, liver and kidney problems, and other side effects. High doses of selenium can cause significant side effects including nausea, vomiting, nail changes, loss of energy and irritability (Preda *et al*., 2015). Poisoning from long-term use is similar to arsenic poisoning, with symptoms including hair loss, white horizontal streaking on fingernails, nail inflammation, fatigue, irritability, nausea, vomiting, garlic breath odour and a metallic taste (Preda *et al*., 2015). Drinking water standard for selenium as per WHO is 0.04 mg/l.

Conclusion

Heavy metals and metalloids are ubiquitous environmental pollutants in both aquatic and terrestrial ecosystems. The hazard of an environmental chemical is a function of its environmental persistence, toxicity, and bio-accumulative potential. Toxic environmental chemicals which are persistent and bio-accumulative are more hazardous. Heavy metals are considered hazardous due to these three characteristics-- persistence, bio-accumulation, and toxicity (PBT). Environmentally relevant most hazardous heavy metals and metalloids include Cr, Ni, Cu, Zn, Cd, Pb, Hg and As. The trophic transfer of these elements in aquatic and terrestrial food chains/webs has important implications for wildlife and human health. It is very important to assess and monitors the concentrations of potentially toxic heavy metals and metalloids in different environmental segments as well as in the resident biota. A comprehensive study of the environmental chemistry and ecotoxicology of hazardous heavy metals and metalloids shows that steps should be taken to minimize the impact of these elements on human health and the environment.

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