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Bioaccumulation of some heavy metals: An overview

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Abstract

The use of heavy metals has increased with rapid population and urbanization which in turn has both positive and negative impacts. As some of them are essential elements to living systems, many of them are being used in the manufacturing of products thereby fulfilling the physical demands of many products in our lives in a way heavy metals are good for us while their accumulation into the soil affects soil ecosystem, plants and ultimately to the human body has adverse effects in the human body with different concentration. As it has an adverse effect on the long run as well as in short durations, it becomes an emerging field to investigate the sources of heavy metal, its pathways through which it could enter the biological system including both the environment and the human body and its effect on the human body.

Keywords: Heavy metals, wastewater, phytoaccumulation, liver, kidney.

INTRODUCTION

Heavy metals comprise a group of metals and metalloids with an atomic density greater than 4g/cm³, including lead (Pb), cadmium (Cd), zinc (Zn), mercury (Hg), arsenic (As), silver (Ag), copper (Cu), iron (Fe), and the platinum group elements. These elements are naturally occurring in the earth's crust and are ubiquitous due to natural and anthropogenic activities. Being non-degradable, they function as environmental contaminants (Jarup, 2003; Mohammed, 2017; Srivastava, 2012). The human body is subjected to these heavy metals through various environmental mediums such as water, air, and soil, predominantly via the gastrointestinal, pulmonary, and dermal pathways. The impact of heavy metals on the human body varies based on their properties and affinity to different tissues (Beijer, 1986; Elinder, 1994; Friberg & Elinder, 1986; Isarael, 2003). Thus, studying the role of heavy metals in the human body with respect to their toxicity and association with diseases is imperative. While certain heavy metals are essential for animals and plants, with copper (Cu) and zinc (Zn) being crucial for plant growth, and zinc's role in balancing copper in the human body and its significance for male reproductive activity, not all heavy metals are essential, and some are known to be toxic due to their bioaccumulative nature and their severe impact on human health and environmental quality (Amuno, 2013; Davies, 2006).

In addition, heavy metals are capable of infiltrating the ecological environment as a result of anthropogenic activities, including but not limited to mining, smelting, sewage sludge disposal, use of pesticides and inorganic fertilizers, and atmospheric depositions (Ganesh, 2010; Stuanes, 2003). Irrigation using sewage water effluents is a primary factor contributing to heavy metal accumulation in vegetables. The trend of metal accumulation in soil irrigated with wastewater follows the order: Fe > Mn > Pb > Cr > Cd (Elinder, 1994; Ganesh, 2010; Mahmood, 2013). Soil contamination with heavy metals is a pervasive issue significantly influenced by anthropogenic activities (Alloway, 1995; Ganesh, 2010). Soil contamination represents the primary source of exposure as consumable vegetables are ultimately derived from such contaminated soil, given that plants tend to amass these heavy metals in both their edible and non-edible parts (Mahmood, 2013).

SOURCES OF HEAVY METALS

The utilization of heavy metals by humans spans millennia, primarily in the production of metal alloys and pigments for various industrial applications. Despite being prohibited in most countries, certain cosmetic companies incorporate heavy metals into their manufacturing processes (Oves M, 2016). Mercury exposure commonly occurs through disinfectants such as mercurochrome, antifungal agents, toiletries, creams, and organo-metallics, as well as through dietary intake, particularly from fish, which is a significant source of methyl mercury(McCluggage, 1991).

Furthermore, dental amalgam, a restorative treatment in dentistry for over 170 years, consists of a mixture of metals, including mercury as its primary component along with silver, tin, zinc, and copper; however, about 43–54% of the main component is mercury (Banuelos & Ajwa, 1999; Tibau, 2019). Cadmium exposure is attributed to a range of sources including wine bottle wraps, mirror coatings, batteries, old paints, tiles, and rechargeable nickel-cadmium batteries, with cigarette smoking being a major contributor. Occupational exposure to cadmium occurs predominantly in mining environments (Duruibe, 2007; Hutton, 1986; Jane, 1979).

OCCUPATIONAL EXPOSURE OF DIFFERENT HEAVY METALS

Cadmium poisoning in India occurs through the silver jewellery industry. Silver is mixed with cadmium and then used to make silver jewellery (Isarael, 2003). During this process, there is a formation of cadmium fumes and therefore the workers inhale those fumes continuously while working there. Use of Iron (Fe) and Chromium (Cr) as an alloying additive to chrome steel manufacturing industries, ferrous foundries and pigments and mordents for paints and dyes, contribute to the raised levels of Cr in chrome plating is among one of the sources of Fe and Cr(Aggarwal, 2014; Reddy, 2014; WHO, 1992).

Lead (Pb) was found to be significant in labours working in battery manufacturing units, fitter, blacksmith, welding workers and workers involved in gear fabrication. Also people involved in the manufacturing of bullets, hair dyes, ceramics, electric cable insulation, artificial flowers, calico painting, fly papers, fruit sprays have high chances of exposure. People who are involved in pest control activities like preserving timber against white ants, rat poison, sheep dips (liquid insecticide used by farmers to protect their sheep against ticks and lice) and weed killers are also directly exposed.

Toothpowder workers are exposed to Mn, Fe, Cu, Zn, Ca, Mg; Cr. Mn exposure is mainly seen in welders and workers involved in gear fabrication; Cu exposure is in lead battery workers and those working in gear making section; Zn exposure can be found in machineman, fitter, and welders; Mg in lead battery workers and Ni in welders (Reddy, 2014). Exposed workers are prone to illness on prolonged exposure (Nolan, 2003). Trivalent and pentavalent arsenic represent the two most prevalent forms discovered in soil. Arsenic trioxide and arsenic pentoxide are employed in the production of calcium, copper, and lead arsenate pesticides (Robson, 2003).

One of the foremost important sources of heavy metals within the environment is mining. In the absence of control or restoration measures, heavy metals present in the residue from mining and metallurgical operations are frequently dispersed by wind or water following disposal (Jiqiang, 2014). The soil used for waste disposal receives varying inputs of heavy metals from multiple sources, including domestic, industrial, construction, and demolition waste, which may serve as a significant contributor to soil pollution (Young, 2002).

PHYTOACCUMULATION OF HEAVY METALS

Long-term irrigation with wastewater may lead to the accumulation of heavy metals in agricultural soils and plants. The presence of heavy metals in vegetables poses a significant concern, as these metals can accumulate in both the edible and non-edible parts of the plants. While certain heavy metals such as zinc (Zn), manganese (Mn), nickel (Ni), and copper (Cu) serve as essential micronutrients at lower concentrations, their elevated levels can lead to toxicity. Research indicates that lettuce and radish are particularly implicated in the accumulation of heavy metals in the human body through the consumption of these vegetables.

Furthermore, studies have demonstrated that concentrations of heavy metals, including those found in radish, spinach, turnip, brinjal, cauliflower, and carrot, are notably higher when these vegetables are cultivated using wastewater irrigation compared to cultivation with clean water irrigation (Kumar, 2006; Singh, A., et al., 2010).Leafy vegetables were found to accumulate and uptake more of heavy metals than bulbs and tubers type of vegetables may be because of two reasons; either atmospheric deposition of heavy metal on the leafy surface vegetables or high rate of transpiration to sustain growth and moisture of the plant which leads to more uptake of heavy metals from the contaminated soil (Mahmood, 2013).

Sample	Standard	Cd	Cu	Pb	Zn	Mn	Ni	Cr
Soil (µg g^{-1})	Indian Standard (Awashthi 2000)	3-6	135-270	250-500	300-600	-	75- 150	-
	WHO/FAO(2007)	-	-	-	-	-	-	-
	European Union Standards(EU 2002)	3.0	140	300	300	-	75	150
Water (µg g^{-1})	Indian Standard (Awashthi 2000)	0.01	0.05	0.10	5.0	0.10	-	0.05
	WHO/FAO(2007)	0.01	0.20	5.0	2.0	0.20	0.20	0.10
	European Union Standards(EU 2002)	-	-	-	-	-	-	-
Plant (µg g^{-1})	Indian Standard (Awashthi 2000)	1.5	30.0	2.5	50.0	-	1.5	20.0
	WHO/FAO(2007)	0.2	40.0	5.0	60.0	-	-	-
	European Union Standards(EU 2002)	0.2	-	-	-	-	-	-

Table 1. Guideline for safe limits of heavy metals (Singh,A., et al., 2010)

According to a study of risk assessment of heavy metal toxicity through contaminated vegetable from wastewater irrigated area of Varanasi, India, Concentration of Zn was found highest in ladyfinger (1222.3 – 132.7 µg g^{-1}) among other fruits and vegetables, the concentration of Cu was found maximum (17.94 µg g^{-1}) in tomato, range of Cd concentration in brinjal (1.55 – 13.80 µg g^{-1}). Among leafy vegetables (Palak, Cabbage, and Amaranthus), the range of Ni concentration was highest in Palak (10.45 – 39.25 µg g^{-1}) (Singh, A., *et al*., 2010). Safe limit of different heavy metals is shown in Table 1.

THE CONCENTRATION OF HEAVY METALS IN THE HUMAN BODY

Investigation into the distribution of heavy metal in various body tissues was done in korean cadavers (Young, 2002) According to which;

Arsenic (As) was found to be higher in liver, bones, hairs, nails and evenly distributed in other tissues. The concentration of arsenic can be detected from urine and hair as the water arsenic concentrations increased. Arsenic levels in the blood did not show this trend until chronic toxicity was expected (Jarup, 2003). Arsenic can be absorbed through entry portals like oral, nasal, cutaneous, but it fails to cross the blood-brain barrier, therefore, the brain has the lowest level. It is also found in muscles for several days and in keratin containing tissues (skin, hair, nails) for years.

The normal level in hair – 2 ppm.

Normal level in urine - <0.03mg/L.

The level of Cadmium (Cd) was found to be significant in kidney (35 ± 18 µg/g) then in liver (2.8 ±1.8 µg/g) and then in other tissues (0.10 - 1.67 µg/g) (Young, 2002). Accumulation of Cd in the kidney is due to the smoking habit, whereas the concentration of Cd in non-smokers comes from the diet (Nolan, 2003). Cigarette contains generally 1-2 µg cadmium, of which about 10% is absorbed by the lung (Davies, 2006; Lauwerys, 1984; Livingston, 1972).

Chromium (Cr) was detected in large quantities in the lung, spleen, and liver compared with other tissues—the concentration of chromium in the lung increases according to the age and the period of smoking.

The concentration of copper (Cu) was found to be highest in the cerebrum, followed by the liver, heart, and kidney. Compared to other heavy metals, copper accumulates at a particularly high concentration in the cerebrum (Srivastava, 2012).

The level of Iron (Fe) was detected highest in the spleen which is the tissue of hematopoiesis, and it was also detected in the order of lung, liver and kidney(Young, 2002).

Mercury (Hg) was detected in a large amount in the kidney and liver compared to the other tissues. Hg accumulates in bones (Young, 2002).

Manganese (Mn) was detected significantly in the kidney and liver (Young, 2002).

Molybdenum (Mo) was detected at a high concentration in the liver then the kidney and then in the lung, but the difference in the concentration was not large in the lung, heart, spleen, cerebrum, and bone (Young, 2002).

Nickel (Ni) was detected to a great extent in the lung, but its level with a mean value of 0.12μg/g was similar in the other tissues, except in the nails (Young, 2002).

The concentration of Lead (Pb) was found to be in the decreasing order of the lung, heart, liver, kidney, and cerebrum and in the bone (Jiqiang, 2014).

Zinc (Zn) was highly detected in the liver and kidney (Young, 2002).

Aluminium (Al) was detected evenly in the liver, kidney, heart, and cerebrum (Young, 2002.In a study conducted on placental transfer of lead, mercury, cadmium, and carbon monoxide in women it was found that the placenta does not concentrate lead nor mercury but it concentrates cadmium to about 10–fold (Roels, 1978

A number of tissues in the human body such as the kidney and liver can be used for metal analysis, particularly for lead, but these are not easily accessible in living individuals, as they can only be taken from cadavers for their analysis.

Specimens readily available for analysis include blood, urine, nails, teeth, and hair. Blood metal levels reflect transient levels whereas hair metal levels show long-term retention (Reddy, 2014).

TOXIC EFFECTS OF HEAVY METALS

Prolonged ingestion of contaminated food may result in the gradual accumulation of toxic metals in the liver and kidneys of individuals, causing disruption to essential biochemical processes. These disturbances manifest as liver, kidney, cardiovascular, neurological, and skeletal disorders (Davies, 2006).

Metals exert biological effects primarily through the formation of stable complexes with sulfhydryl groups and other ligands. The biological reactivity of many metals results in the accumulation in several organs and tissues (Robson, 2003). General signs associated with cadmium, lead, arsenic, mercury, zinc, copper and aluminium poisoning; gastrointestinal(GI) disorder, diarrhoea, stomatitis, tremor, haemoglobinuria causing a rust-red colour to stool, ataxia, paralysis, vomiting, convulsion, depression and pneumonia when volatile vapours and fumes are inhaled.[9] Exposure to lead, cadmium, mercury, and arsenic are mainly associated with threats to human health (Banuelos, 1999).

Cadmium (Cd); inhalation of cadmium fumes will lead to shortness of breath, lung edema, renal dysfunction and effects on bone ultimately leading to fracture (Jarup, 1998; Johannes, 2006; WHO, 1992).

Arsenic (As); Population exposed to arsenic via drinking water, shows an excess risk of mortality due to lung, bladder and kidney cancer. There is also an increased risk of skin cancer and other skin lesions, such as hyperkeratosis and pigmentation changes as shown in Figure 1-6. In addition, the pollution of water by dissolved As and heavy metals has been mainly associated with acid mining drainage (AMD) (WHO, 2001).

Mercury(Hg) exposure in its acute form may lead to lung damage, spontaneous abortion, and congenital malformation. Chronic poisoning is characterized by neurological and psychological symptoms such as tremor, changes in personality, restlessness, anxiety, sleep disturbance, and depression.

Lead (Pb) poisoning causes inhibition of the synthesis of hemoglobin, dysfunctioning in the kidneys, joints and reproductive systems, cardiovascular system and acute and chronic damage to the CNS and PNS.

Skin lesions observed in patients due to arsenic contaminated drinking water (chaurasia,2015)

Figure 1. Keratotic Lesion

Figure 2. Mottled Depigmentation

Figure 3. Hyperpigmentation

Figure 4. Early stage Punctate Keratosis

Figure 5. Keratosis

Figure 6. Punctate keratosis

Zinc (Zn) is considered to be relatively non-toxic, especially if taken orally. The clinical sign includes bloody urine liver failure, kidney failure, and anemia.

Copper (Cu) excess concentration in the human body causes renal failure.

Manganese (Mn) excess concentration in the human body causes hyperirritability, mania. High Mn content causes skeletal abnormalities and brain damage (WHO, 2001).

Nickel (Ni) excess concentration causes dermatitis, respiratory disorder, and lung cancer.

Excess iron (Fe) can lead to haemorrhagic gastritis, intravascular clotting, acidosis, fatal shock, and skin discoloration.

CONCLUSION

Long term irrigation with waste water is one of the major source of heavy metal accumulation or pollution to both biotic as well as abiotic system. There are some other sources as well that contribute to the increase level of heavy metals in the environment which includes emissions from motor vehicles which is the second most important sources as it directly affects a large population, mining and manufacturing industries are another important contributor towards the pollution but it affects a limited number of people who are either working in those industries or residing at nearby places, lastly, the consumers of the product that are being manufactured with heavy metals are directly exposed to it.

To only a permissible limit these heavy metals are not harmful, even some of them are essential parts of the metabolism in plants and animals, otherwise, most of them are harmful depending on both of its association to the living system as well as its duration of exposure.

Due to their binding affinity, they do not tend to degrade, once they entered into the biological system, specifically into the human body, which lead to many harmful effects, majorly associated problems are breathing problem, different types of cancer, skin lesions, pigmentation , lung damage, liver failure, kidney failure, abortion, dysfunction of the reproductive system, anemia , bone fracture in chronic poisoning of cadmium and daily abnormality like nausea, vomiting, ingestion, restlessness, anxiety, sleep disturbance majorly seen in people working and living at or near the factories.

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