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Chapter 6

Human health risk assessment and mitigation of heavy metal pollution in agriculture and environment

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Chapter contents

Abstract

Heavy metals contamination in agricultural environment and its deleterious effects on the crops and human health is an issue of serious concern in the present time. Agricultural fields receive various heavy metals such as Zn, Ni, Mn, Cu, Cd, Cr, Pb, As and Hg etc. mainly from natural and anthropogenic sources. The greater concentration of heavy metals in the fields spoils the soil characteristics and has extreme consequences on both crops and human. Their persistence and non-degradable nature increases its accumulation in the agricultural field, crops and human body through various food chains. The present chapter highlights various sources of heavy metals in agricultural environment and its impacts on both crops and human health and gives various strategies to mitigate the heavy metal concentrations in agricultural environment.

Keywords: Agro-environment, Heavy metals, Human health, Risk assessment, Toxic effect

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Introduction

Heavy metals contamination in agricultural field is a serious concern in the present time due to their deleterious effects on both crop and human health. The establishment of industrial areas nears the villages and agricultural areas which releases tremendous amount of pollutants in the agricultural environment are alarming. Their abundance in agricultural environment is due to field irrigation with industrial and municipal waste water or heavily polluted river water, then subsequent soil erosion, weathering of rocks, use of various chemical fertilizers and pesticides which contaminants the agricultural fields with heavy metals such as Zn, Ni, Fe, Co, Cr, Cu, Cd, Pb, As and Hg etc (Morais *et al.*, 2012, Srivastava *et al.*, 2017a, Malik and Maurya, 2014; Kumar *et al.*, 2018). These metals are non-biodegradable and non-thermodegradable hence are persistent in the soil for longer duration and accumulated in the plant body (Wu *et al.*, 2010; Vodyanitskii, 2013; Yushu *et al.*, 2013; Kayastha, 2014).

Metals are essential and non-essential on the basis of their functions in the organisms. They act as co-factor in many enzymes and play important roles in various oxidation-reduction reactions (WHO, 1996). Essential heavy metals play important physiological and biochemical function in the organisms, however, their inadequate amounts causes a variety of deficiency diseases (WHO, 1996). The regulation and detoxification of heavy metals in organisms is done by metaloproteins such as metallothioneins, glutathione and phytochelatins. But metal concentration beyond the limit may alter the metal regulatory mechanism and initiate metal accumulation (Kumar *et al.*, 2017; Maurya and Malik, 2018). Heavy metals cause oxidative stress by the formation of free radicals and reactive oxygen species (ROS), resulting in cell and tissue damage (Dietz *et al.*, 1999; Leonard *et al.*, 2004).

During stress condition the level of ROS increases which causes cellular toxicity in the organisms while lower level is necessary for various physiological activity such as cell differentiation, cell proliferation, apoptosis and regulation of redox-sensitive signaling pathways (Shibanuma, 1988; Allen and Balon, 1989; Hockenbery *et al.*,1993; Lo *et al.*, 1996). The ROS induced damage in organisms are cell death, chromosomal aberrations, mutations and carcinogenesis (Cerutti, 1985). ROS also affect various biomolecules such as carbohydrates, amino acid chain, proteins, membrane lipids, nucleic acids and pigments (Gratao *et al.*, 2005; Manikandan *et al.*, 2015; Venkatachalam *et al.*, 2017). Several researchers have reported that heavy metals affect the cellular components such as cell organelles and plasma membrane (Squibb, 1981). Metal ions interact with DNA and proteins causing DNA damage and protein conformational changes which may lead to cell cycle modulation and carcinogenesis or apoptosis (Berg, 1986; Leonard, 1986; Shahid *et al.*, 2014).

Organisms have several antioxidants which protect the cells or repair the cellular damages caused by reactive oxygen species (ROS). The antioxidant activity is maintained by both enzymatic and non-enzymatic components. The enzymatic components are superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (AP_X), glutathione peroxidase (GP_X), glutathione-S transferase (GST) and the non-enzymatic components are reduced glutathione (GSH) and ascorbic acid (AA) (Gill and Tuteja, 2010; Miller *et al.*, 2010; Gill *et al.*, 2011). Both enzymatic and non-enzymatic antioxidant components are responsible for detoxification of ROS for cellular survival (Gill *et al.*, 2011; Das and Choudhury, 2014). High toxicity levels of heavy metals such as chromium (Cr), Lead (Pb), cadmium (Cd), mercury (Hg) and arsenic (As) are posing health hazards impact on crops and human health. This encouraged the researcher to develop several strategies to remove the metals from agro-environment.

Sources of heavy metals in agro-environment

Agriculture field receives heavy metals from both natural and anthropogenic sources that percolates into the soil layers (Kabata-Pendias and Pendias, 2001; Dembitsky and Rezanka, 2003; Sidhu, 2016). Weathering of rocks, volcanic eruptions, windblown dust particles, sea spray and aerosols etc are the natural sources by which heavy metals come into the agricultural environment (Nagajyoti *et al.*, 2010; Srivastava *et al.*, 2017b). The anthropogenic sources such as inorganic and organic fertilizers, pesticides and fungicides that have variable level of Zn, Ni, Pb, Cd and Cr etc; along with these, field irrigation through municipal and industrial waste water, organic manure, atmospheric pollution from motor vehicles and the combustion of fossil fuels (Nicholson *et al.*, 2003; Zhang, 2006; Kelepertzis, 2014; Toth *et al.*, 2016, Malik *et al.*, 2017). The repeated use of fertilizers and pesticides continuously making the agricultural soils enriched with heavy metals. Several study have reported that the irrigation of cultivated vegetables in wastewater and use of chicken manure, chemical fertilizers and pesticides are the source of metals in food (Modaihsh *et al.*, 2004, Kumar *et al.*, 2017a, Kumar *et al.*, 2017b, Kumar *et al.*, 2018). The sources of various heavy metals in the environment are shown in Figure 6.1 and the sources of heavy metals in the agricultural environment and their effect on crops health are shown in Figure 6.2.

Arsenic (As)	• Pesticides, fungicides, metal smelters
Cadmium (Cd)	• Welding, electroplating, pesticides, fertilizer, batteries, nuclear fission plant
Chromium (Cr)	• Mining, electroplating, textile, tannery industries
Copper (Cu)	• Electroplating, pesticides, mining
Lead (Pb)	• Paint, pesticides, batteries, automobile emission, mining, burning of coal
Manganese (Mn)	• Welding, fuel addition, ferromanganese production
Mercury (Hg)	• Pesticides, batteries, paper industries
Nickel (Ni)	• Electroplating, zinc base casting, battery industries
Zinc (Zn)	• Refineries, brass manufacture, metal plating, immersion of painted idols

Figure 6.1. *Sources of heavy metals in the environment (Adopted from Paul, 2017).*

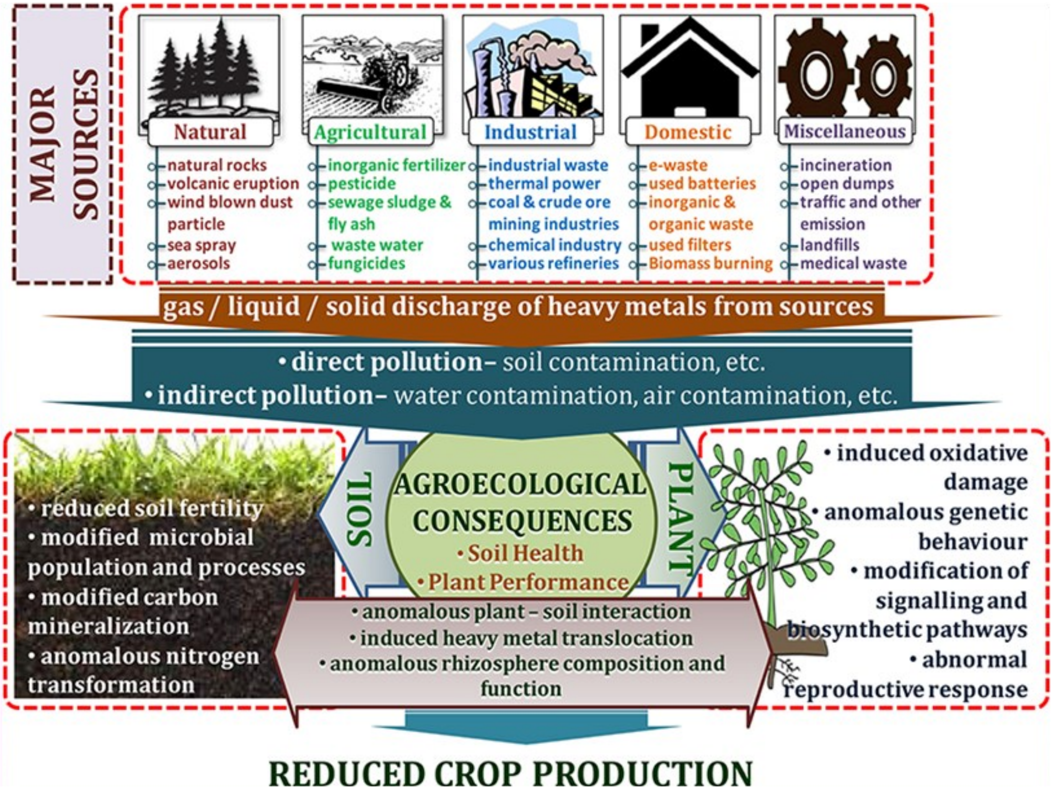

Figure 6.2. *Sources of heavy metals in agro-environment and their effects on soil and crops (Adopted from Srivastava et al., 2017c).*

Toxicity of heavy metals on human health

Heavy metal contamination in the agriculture environment and their bioaccumulation in human beings through the food chain and toxicity effect on crops and human health is one of the major problems in the present time.

Lead (Pb)

Lead is a non-essential metal for our body system; even its low concentration is harmful for human health. It enters in our body through contaminated food, water, air and also from beverages. EPA has reported that lead is a carcinogenic agent for human health. It has long biological half-life about 20-30 years and its accumulation takes place in teeth and bone from where it enters into bloodstream and binds with erythrocytes. It inhibits the function of enzymes that are necessary for hemoglobin synthesis thereby reduces the level of hemoglobin in the body and cause anemia (Landis *et al.*, 2003; Bradl, 2005). Pregnant women and young children are more susceptible to lead toxicity resulting in iron deficiency (Flora *et al*., 2006).

Chromium (Cr)

Chromium is an essential trace element for lipid and carbohydrates metabolism and its deficiency causes cardiovascular diseases and diabetes (Mertz, 1998). The trivalent form of chromium (Cr III) is an essential micro nutrient while its hexavalent (Cr VI) form is more dangerous for human health. People who work in leather and textile industries are mostly affected by allergic reactions such as skin rashes, nose irritation and bleeding (Karadede *et al*., 2004). A study has reported that the over concentration of chromium causes genetic defects in the body (Kherici *et al*., 2009). It has also been reported that exposure of high dose of Cr compounds in human beings may lead to lung cancer (Jordao *et al*., 2002).

Cadmium (Cd)

Cadmium enters into the human body through intake of contaminated foodstuffs such as mushrooms, liver and sea weeds (Jarup *et al*., 2000). It gets transported into liver through blood circulation where it binds with metal binding protein metallothionein that sequesters it and transports to the kidney. In kidney, it accumulates and interferes with blood purification mechanisms. It causes kidney and liver damage and deformation of bones (Abbas *et al*., 2008). Cadmium has been reported to be mutagenic, carcinogenic, teratogenic, embryo toxic, hyperglycemic agents and anemia inducing agents and has reduced immunopotency (Rehman and Sohail, 2010).

Copper (Cu)

Copper enters into the body through intake of foods, dietary supplements and drinking water. The tolerance limit of copper in the body recommended by Environmental protection Agency (EPA) is 1.3 mg/L while the WHO tolerance limits of copper in drinking water is 2.00 mg/L (World health organization, 2004). Long term exposure of Cu can cause irritation in mouth eyes and nose and also causes headaches, vomiting and diarrhoea. In India, Indian childhood cirrhosis is reported where large amount of copper are rapidly deposited in the liver (Tanner, 1998). Some visceral organs (liver, kidney) and some fruits and nuts have high copper contents (Pandit and Bhave, 2002). Copper accumulation in the liver is being reported in a variety of pediatric hepatic diseases like idiopathic copper toxicosis (ICT), Wilson's disease, and Indian childhood cirrhosis (Muller, 1998).

Mercury (Hg)

Mercury is a highly neurotoxic pollutant to animals and human and especially affects the central nerve system (Lebel *et al*., 1998). It enters in the body by food intake and in food it exists as inorganic and organic forms. The organic form is methylmercury (MeHg) which is more hazardous to health. The level of mercury in foods is inconsistent and reflects the level of pollution of the local environment (Dudka and Miller, 1999). It is the most toxic heavy metal in the environment and its poisoning is referred to as acrodynia or pink disease. Mercury is released into the environment by the activities of various industries such as pharmaceuticals, paper and pulp preservatives, agriculture industry, and chlorine and caustic soda production industry (Morais *et al*., 2012). Exposure to elevated levels of metallic, organic and inorganic mercury can damage the brain, kidneys and the developing fetus (Alina *et al*., 2012).

Arsenic (As)

The exposure of arsenic causes organ and skin diseases but it may also affects the immune system (Duker *et al*., 2005). It binds with sulfhydryl groups of enzymes and proteins and causes their denaturation within the cell (Gebel, 2004). It increases the formation of reactive oxygen species which damages cell and its components (Ahmad *et al*., 2000). The agricultural pesticides, herbicides, veterinary and human medicine contain arsenic (Tchounwou, 1999). Its therapeutic action induces programmed cell death (apoptosis) in leukemia cells (Yedjou and Tchounwou, 2007).

Human health risk assessment

The high concentration of heavy metal reduces the soil fertility. Their transfer into the food chain and results in their accumulation in the food stuffs which causes potential health risks to the consumers (Khan *et al*., 2008). Thus, it is important to determine their concentration in food stuffs and its amount transfer to the consumers during daily intake could be estimated by following formula (Wang *et al*., 2005; Mitra *et al*., 2012; Krishna *et al*., 2014, Gupta *et al*., 2017).

$$EDI = \frac{E_f \text{ x } E_d \text{ X } F_{ir} \text{ x } C_f \text{ x } C_m}{W_{ab} \text{ x } T_a} \text{ X } 10^{-3}$$

Where,

EDI: Estimated Daily Intake; Ef: Exposure frequency 365 days/year; Ed: Exposure duration, equivalent to average life time (65 years); Fir: Fresh food ingestion rate (g/person/day) which is considered to be India 55g/person/day; Cf: Conversion factor (= 0.208) (The content of fresh weight (fw) to dry weight (dw) considering 79% of moisture content); Cm: Concentration of heavy metal in food stuffs (mg/kg dw), Wab = Average body weight (60kg); Ta: Average exposure time for non-carcinogens (Ta = Ef×Ed).

Bioremediation as a tool to remove heavy metals from agro-environment

The approach of bioremediation is related to the use of biological strategies to overcome problems from environment using biological factors. Bioremediation is the most effective process for removal of heavy metal contamination from the agriculture environment. The term bioremediation has been used to describe the biological strategies to remove toxic waste from environment by using biological agents. Phytoremediation involves various strategies for removal of heavy metals from agriculture field such as phytoextraction, phytovolatalization, phytostabilization, phytodegradation and rhizofilteration. Another method of biological remediation is the use of microbes for removal of heavy metals (Kumar *et al*., 2015). The microbes change the pollutants ' physical and chemical properties, affecting the mobility and transformation of heavy metals in the soil. To remedy the contaminated environment, microbes are very helpful. Bioremediation involves the number of microbes including aerobes, anaerobes and fungi.

Conclusion

From the literature report it is clear that heavy metal pollution poses serious threat on agriculture environment and human health. When the concentration level of heavy metals are elevated in agriculture field, it reduced the soil quality, productivity and yields. Heavy metal pollution also destroys cells and their component in plant and animals/human due to the production of reactive oxygen species (ROS) and causes various deficiency diseases and disorders. Phytoremediation and microbial remediation processes should be applied to clean up metals from polluted sites. Awareness should be created among the common people about metal toxicity and carefully monitoring and discharge treated effluent of industries. Furthermore, the use of various fertilizers, pesticides, herbicides that contain heavy metals should be avoided so that the heavy metal accumulation within the agriculture field can be stopped.

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