2 A Comprehensive Evaluation of Heavy Metal Contamination in Foodstuff and Associated Human Health Risk: A Global Perspective

Saahil Hembrom, Bhaskar Singh, Sanjay Kumar Gupta, and Arvind Kumar Nema

Abstract

Heavy metal contamination has an adverse effect on the aquatic, terrestrial, and atmospheric environment. These may be natural or anthropogenic in origin and not easily degradable. Anthropogenic activities have unwantedly transferred these heavy metals in our food chain and food web. Directly or indirectly these heavy metals have entered in our food through irrigation by wastewater effluent released by industries; scarcity of available freshwater for irrigation, usage of fertilizers and insecticide, and other anthropogenic activities have caused acute and chronic diseases. The dose–response relationship suggests that the heavy metals have a narrow level of lethal concentrations which pose a threat to the target population. Anthropogenic sources of heavy metals generally dominate natural sources, and foreseeing the synergy of this with the degrading environmental conditions, the health of people is a matter of concern. When these heavy metals get accumulated in the human food, it results in abnormalities affecting human survival and mortality. Recent data suggest that the human body gets affected by heavy metal contamination at lower levels than previously anticipated and evidenced. Agrochemicals are resistant and adaptive in nature, and with the increasing dose and newly synthesized compounds to protect crops, undesired side effects and the costs of food production are on a hike. Practices like street food vending and addition of preservatives in packed food increase the chances of heavy metal contamination in food materials. A comprehensive evaluation of the food chain right from the primary producers to consumer level is necessary to ensure food security and quality.

S. Hembrom · B. Singh
Department of Environmental Sciences, Central University of Jharkhand, Ranchi, India

S. K. Gupta (✉) · A. K. Nema
Environmental Engineering, Department of Civil Engineering, Indian Institute of Technology Delhi, New Delhi, India

P. Singh et al. (eds.), *Contemporary Environmental Issues and Challenges in Era of Climate Change*, https://doi.org/10.1007/978-981-32-9595-7_2

Keywords
Anthropogenic activities · Wastewater · Agrochemicals

2.1 Introduction

The heavy metal pollution is one of the world's top environment-related problem, and has risen due with the increasing industrialization and urbanization. It has become one of a very serious threats due to it's deleterious effects on human being and environment (Yang and Sun 2009). With increased economic growth globally in recent years, production and uses of heavy metal has accelerated many folds, leading to pollution of the environment (Raju et al. 2013; Zojaji et al. 2014). Heavy metals have a higher density, atomic weights, or atomic numbers. Due to it's adverse effects exposure of heavy metals are always concidered as a potential risk to human beings and the environment. Toxic metals such as cadmium, mercury, lead, and arsenic are the main causes of human health problems. Contamination of heavy metals can't be physically identified or distinguished because of its colourless, odourless nature and easily get absobed. When environmental conditions changes or exceed the tolerance of the environment, heavy metals get converted in to ionic forms, which are active and bioavailable which may act as chemical time bombs and casues serious threat to the ecological system (Wood 1974). Exposure of even lower concentrations of some of these elements are very toxic to the human body and can cause acute or chronic diseases. In the past, only a few cases were reported about soil contamination by some of the specific heavy metals, but in the recent years, presence of various heavy metals have been reported in the each component of the ecosphere (Zhou 1995). Heavy metals may get released in the atmosphere through gases, dust, smoke from various industries, energy production, metallurgy, transportation, and constructional materials. Only mercury in the atmosphere is present in the form of aerosols and gets deposited in the soil by precipitation and natural sedimentation. Heterogeneous contamination of various heavy metals can intensify the lethal contamination concentration. Pollution by heavy metals in the environment has become a significant ecological concern because it takes a longer time period for degradation and has a longer biological half-life (Abii and Okorie 2011). Anthropogenic source of heavy metals includes various activities like pesticide and fertilizer application in the crop field, untreated effluent discharge from industrial activities, mining activities, and sewage irrigation etc. (Zhang et al. 2011). A report from Central Sweden by Lin (1998) stated that environmental pollution by lead is mainly due to urban industries. The lead contamination can spread or get transported by water and winds from the waste heap/dumps to another surrounding area. Lead contamination of ground water also occurs through percolation/leaching of industrial waste.

Another potential source of heavy metal pollution in the agricultural land is wastewater irrigation from sewage and industrial effluents. Due to lack of fresh water resrouces, domestic wastewater or industrial effluents are used for irrigation in urban and peri-urban agricultural practice (Singh et al. 2010). In India, approximately 73,000 ha of agricultural land is irrigated with wastewater (Kaur et al. 2014). Wastewater irrigation when continuously practised may lead to accumulation of toxicants (including heavy metals) in the soil as well as in vegetable crops (Marshall et al. 2007). Contamination of heavy metals in vegetables generally arises from irrigation of polluted water. However, contamination may also occure due to use of chemical fertilizers and pesticides, during the process of harvesting, transportation of vegetables, and the storage. The pollution of the environment is due to human activities owing to the discharge of heavy metals from tanning industries, lubricants used for maintenance of machinery, etc. Contamination of heavy metals in food via consumption can become a risk to human health. According to a report by WHO and FAO (2007), higher concentrations of heavy metals in India were found in milk and drinking water and have exceeded the safe limit. In peri-urban areas, heavy metal contamination is occurs mainly through dust and aerosols ladden with metals which enters in to the soil, and also gets deposited or absorbed by the leaves of the vegetables and plants (Abii 2012; Kachenko and Singh 2006). Vegetable crops grown in surrounding areas of industrial locations have been reported to possess high elevated concentration of heavy metals (Singh and Kumar 2006). The heavy metals get accumulated in the aquactic ecosystem as well which further get transferred in the fishes and other aquatic organisms. When the contaminated water is used for irrigation, the soil get contaminated and from the soil heavy metals get absorbed by the roots of the plants or crops and get accumulated in different part of the plants. Through the plants, these toxic metals finally entering into the food chain. The heavy metals contaminated fruits and vegetables when consumed through ingestion, causes various types of diseases and abnormalities in human beings depending upon the degree of contamination. Some of the heavy metals are essential in lower concentration to support vital functions but may inhibit enzymatic activities and poses toxic effects on higher concentrations (Koropatnick and Leibbrandt 1995). In past few decades, human health issues are of major concern with reference to the intake common food stuffs including fruits and vegetables contaminated with heavy metals (Milacic and Kralj 2003).

Based on the toxicity, some of the heavy metals such as arsenic, lead, mercury, and cadmium ranked first, second, third, and fourth in the list, respectively. Arsenic, lead, and mercury are ranked as the top three most hazardous substances in the priority list of the Agency for Toxic Substances and Disease Registry (ATSDR). Fig. 2.1 presents an sckechematic representation of sources of heavy metal contamination in the environment.

Cadmium, lead, arsenic, and mercury pose serious health risk when consumed through contaminated food. Cadmium and lead have significant health hazard since these elements are easily accessible to the food chain. Children are more vulnerable when exposed to these elements because it gets easily accumulated in tissues and causes retardation in children and adverse effect on the kidneys, cardiovascular system and auditory system (Rahimi 2013).

This chapter a detailed overeview of heavy metal contamination in foodstuff and associated human health risk. Contamination of foodstuff by heavy metal has

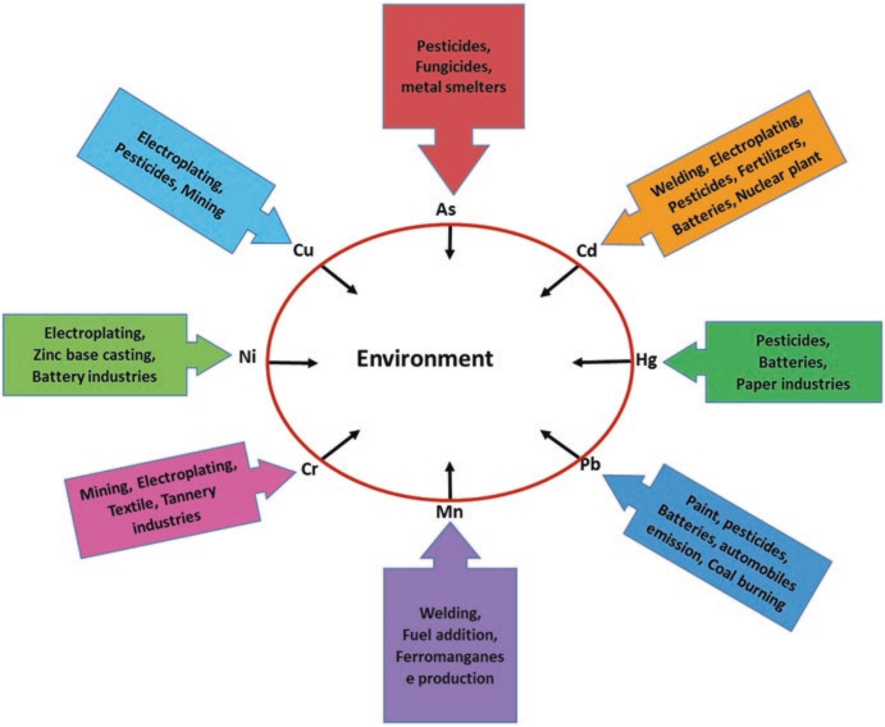

Fig. 2.1 Sources of heavy metals in the environment. (Modified from Paul 2017)

become a global problem. Appropriate prevention measures need to be seriously implemented to avoid metal contamination in food. People consume food on the basis of their social and financial capabilities. The situation in developing countries are more vulnerable, as low-income individuals are unable to afford the good quality food and the right amount of nutrition. The national and international regulatory bodies should attempt to reduce the urban pollution load to reduce contamination in fruits, vegetables, and cereals. The contamination of following heavy metals are most common in foodstuff.

2.1.1 Lead

Lead is a naturally occurring element and is the most commonly used element after iron. No significant biological function of lead in a human being is known. Exposure of lead can be from the air, water, dust, food, and consumer products (Lead poisoning and health 2016). Exposure of high concentration of lead can be poisonous and can affect the health of all ages of peoples. Lead can more severely affect vulnerable population especially infants, young children, pregnant women, etc. Lead contamination in food stuffs is mainly caused by the application of chemical fertilizers and pesticides or through contamination of soil by sewage and industrial effluents. Once in the food chain, lead can easily accumulated in the human body, which may result in acute poisoning (Tajkarimi et al. 2008). The three main body systems, i.e. nervous system, hematopoietic system, and renal system, are highly sensitive to this metal (Naseri et al. 2015; Zahir et al. 2005). Lead can affect many organs and functional systems of the body; further high exposure can be carcinogenic, damages the brain, and causes miscarriage in pregnant women. Regulatory limits of lead in air and water as per EPA are 0.15 micrograms per cubic metre (for air) and 15 ppb in drinking water.

2.1.2 Cadmium

Cadmium makes up to 0.1 ppm of the earth's crust (Wedepohl 1995). It is a toxic heavy metal present naturally in the environment. Primarly cadmium contaminal occurs from mining, smelting, and refining sulphidic ores of zinc as well as from dust generated by recycling iron and steel scrap (Ayres et al. 2003). Phosphate fertilizers contain varying amounts of cadmium up to 300 mg/kg, and therefore, application of high amount of chemical fertilizers in agricultural soils results Cd contamination in agricultural lands (Grant and Sheppard 2008; Jiao et al. 2004). The high level of cadmium contamination generally occurs in the industrial areas. A significant exposure of cadmium to human beings is also occure by cigarette smoking. Resident residing near hazardous waste dump sites or industries which emit Cd into the ambient air has a potential chance of exposure through respiration of such contaminated air. The Cadmium contamination into the groundwater, soil, and crops which has resulted in adverse health effects such as hypertension, mutagenesis, carcinogenesis, and kidney lesions (Binns et al. 2003). The main culprit of Itai-itai disease is cadmium exposure which is characterized by severe pain in spine and joints. The cadmium poisioning can affect calcium metabolism and results brittle bone and kidney failure (Abbasi 2015). Cadmium poisioning in mass level was first reported in Japan which was occurred due to consumption of contaminated rice grown in river water contaminated by cadmiun due to release of mining spealage. The concentration of cadmium should be under 5 ng/m^3 in the atmosphere, 2 mg/kg in the soil, 1 μg/L in freshwater, and 50 ng/L in seawater (Rieuwerts 2015).

2.1.3 Chromium

Chromium is a toxic heavy metal that occurs in the environment in oxidation states. Chromium(III) in traces, is an essential nutrient for human biological process. Both chromium(III) and chromium(VI) are stable elements, while chromium(VI) a very toxic form and also carcinogenic i.e. cancer-causing for human beings (Thompson et al. 2012; Costa and Klein 2006) and teratogenic i.e. malformations in a foetus (Xia et al. 2016). The release of chromium is mainly occurs through industries.

such as from tanning, mining, electroplating, and textile industries (Ajmal et al. 1996; Moncur et al. 2005). Coal and oil combustion also leads to release of Cr in the environment (ATSDR 2000). The exposure of chromium to human may be through oral, dermal, and/or through inhalation. The oral intake of these heavy metals is also occurs from contaminated wells (EPA 1998). Exposure of chromium may cause several types of diseases i.e. mouth ulcer, indigestion, acute tubular necrosis, vomiting, abdominal pain, kidney failure, and even death (Beaumont et al. 2008). The maximum concentration level of chromium in water supply should be 0.05gm/L according to Indian standards (Benazir et al. 2010).

2.1.4 Arsenic

Arsenic is a naturally occurring element and is present in water air and soil. Arsenic pollution and toxicity are one of a major global problem. Contamination of arsenic is occure by natural geological sources which results in groundwater contamination. Arsenic contamination also occur due to human activity like mining and industrial processes. It is present in both forms, i.e. organic and inorganic. The major use of As is in the alloys of lead, i.e. car batteries and ammunition. Arsenic is also widely used as a wood preservative. Leaching of As into the groundwater can be through rocks, soil, and pesticides. Volcanic eruptions and mining activities can also lead to the release of As in the environment. Groundwater contamination of As is a global problem. A higher level of As is usually found in the aquifers and less in surface water. Dietary intake of even a very small amount (less than 5 mg) could result in vomiting and diarrhoea (Kingston et al. 1993). Lethal dose of As ranges from 100 to 500 mg which results acute poisoning (Schoolmeester and White 1980). The permissible limit of As in drinking water is 0.01 mg/L as given by the Bureau of Indian Standards.

2.1.5 Mercury

Mercury is the only metal that is present in a liquid state at standard temperature and pressure and is a poor conductor of heat a fair conductor of electricity compared to other metals (Hammond 2005). It is also known as hydrargyrum (Random House Webster's Unabridged Dictionary 2014), a shiny metallic liquid present in trace amount in igneous and sedimentary rocks. Mercury exposure to human beings occur through ingestion, inhalation, and skin contact. Studies have suggested that mercury vapour inhalation can cause immune system disorders, kidney dysfunction, infertility, adverse effects on the foetus, heart failure, and Alzheimer's disease. Exposure to mercury can cause serious health problems and a threat to the early stage of development in children. Toxic effect of mercury is reported in the nervous, digestive, and immune systems and on the lungs, kidneys, skin, and eyes. People are often exposed to mercury in the form of organic mercury, that is, methylmercury, generally from consumption of fishes and shellfish from mercury contamination in seas and oceans (report by the WHO). Also, mercury exposure via food can be through the consumption of contaminated rice and other food stuff. Mercury poisoning can cause Minamata disease, which is a neurological syndrome. As per recommendations of EPA and Food and Drug Administration (FDA) mercury concentration should be less than 2 ppb in drinking water, less than 1 ppm in seafood as per guidlines of the Occupational Safety and Health Administration (OSHA). The organic mercury should be 0.1 milligrams of per cubic metre of workplace air, and the exposure should not be more than 0.05 milligrams per cubic metre of metallic mercury vapour for 8-h shifts and 40-h work week (OSHA).

2.2 Source of Heavy Metals

Metallic chemical elements that have higher density and higher atomic weight or mass and are capable of causing an adverse effect on human and environment in low concentrations due to its toxic and poisonous effect are generally termed as heavy metals (Lenntech 2014). These are naturally occurring elements found in the earth and rocks. Due to some of the natural but mainly due to anthropogenic activities, once these metals are released, get concentrated in the plants, animals, and human tissues via inhalation and ingestion and sometimes through misshandling or accidents. Chemical elements such as lead (Pb), cadmium (Cd), zinc (Zn), mercury (Hg), arsenic (As), silver (Ag), chromium (Cr), copper (Cu), iron (Fe), and the platinum (Pt) group are considered as heavy metals.

2.2.1 Natural Source of Heavy Metals

Metals have been present in the earth from the beginning of the earth's formation, i.e. billions of years ago (Dalzeil 1999) by the natural process of the biogeochemical cycle. The weathering process of underlying bedrocks is the result of naturally occurring heavy metals in the soil. Mendip region's soil (Great Britain) has been found to be heavily enriched with lead, zinc, and cadmium due to mineralized veins and high concentration of metal deposits in the bedrock (Fuge 1991). Bedrock weathering with slightly elevated heavy metal concentration can result in metal enrichment during soil formation process (Blaser et al. 2000). Both natural and anthropogenic sources are the main causes of increasing heavy metal contamination in the environment. Sources of natural cause can be from windblown soil particles, volcanic eruptions, forest fires, biogenic sources, and sea-salt sprays (Muhammad et al. 2011). Windblown dust naturally emitted is often from the industrial origin (Fig. 2.2).

Fig. 2.2 Natural sources of heavy metals in the environment

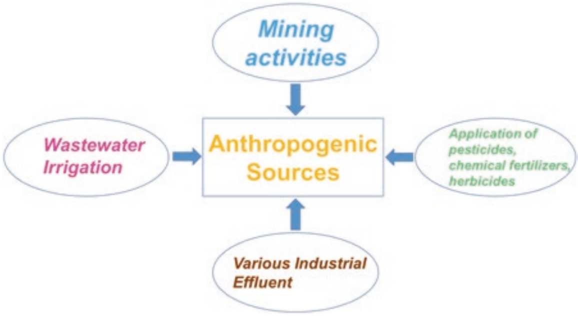

Fig. 2.3 Anthropogenic sources of heavy metals into the environment

2.2.2 Anthropogenic Sources

The anthropogenic sources of heavy metal contamination are mining activities; application of pesticides, chemical fertilizers, and herbicides; irrigation of crop fields with contaminated water released by small industries and tanning industries; and use of municipal waste as fertilizers (Alloway and Jackson 1999; Srivastava et al. 2018; Sarkar et al. 2018). Applications of mineral fertilizer that contains trace amount of heavy metals are some of the major sources of heavy metal contamination in the food that we consume (Gray et al. 1999). Other anthropogenic activities are the disposal of waste in farmland (Merian et al. 2004; Srivastava et al. 2015, 2016), traffic emission, use of lead as an antiknock in petrol, cigarette smoking, metallurgy and smelting, aerosol cans, sewage discharge, and building materials (Nriagu 1990; Srivastava et al. 2017) (Fig. 2.3).

2.3 Food Contamination by heavy metals

During the process of food production, packaging, and transport from 'farm to fork', there are several possible ways by which the food gets contaminated by various toxicants including heavy metals. Contamination has such potential to migrate into the food and become bioavailable after oral intake. The largest source of food contamination occurs through food contact materials. Plastics, printed papers, and boards are some of the basic food contact materials. These food contact materials are cheaper, durable, and non-porous which makes it primarily the most commercials' container for storage of food.

As the process of contamination from its primary source was carried in the environment, then contamination level and the concentration of heavy metals transferred into the food chain and food web through different trophic levels. Heavy metals present in the soil, air, and water get accumulated in the plants or animals, and ultimately reaching into the foodstuff. The contamination through human activities, as a result, can affect a large geographical area affecting the environment and human health. The bioaccumulation of heavy metals and their transfer occur from lower trophic level to the higher trophic level. The concentration is always higher in the higher trophic level.

A study was conducted in Ghana reported that irrigation with water contaminated with Cd and Pb resulted in the accumulation of these heavy metals and showed significant concentration in carrot, cabbage, and lettuce (Odai et al. 2008). The scientists from all over the globe are evaluating the daily intake of such substances from food and their accumulation rate in the human body and are making cautious effort to regulate and control these substances with the help of government and NGOs. Appropriate efforts and strategies are being made to combat and minimize the heavy metals to enter our food chain. Studies have been conducted in indigenous people's traditional diet which has been found to be contaminated by organochloride through marine fish and mammals in their diet especially in New Zealand (Stewart et al. 2011). Certain research has revealed that indigenous communities have elevated heavy metal contamination in the traditional diet (Hoekstra et al. 2005; Johansen et al. 2004; Odland et al. 2003; Van Oostdam et al. 1999, 2003). In the aquatic food chain, heavy metals easily get accumulated in the animals having comparably high lipid contents. An example of an aquatic animal, i.e. eels which are rich in lipid and are at the top of the food chain of New Zealand, were found to have comparably higher accumulation of contaminants (Stewart et al. 2011).

High concentration of heavy metals in the marine animals have drawn the interest in contamination in public food supply, especially in fish (Tariq et al. 1993; Kalay et al. 1999; Rose et al. 1999). Environmental scientists and toxicologists are putting efforts to measure such contamination in our food chain and have estimated the dietary intake and accumulation in our body. There are many regulatory agencies have specific recomendations for the acceptable limits of such contaminants. Heavy metals in food may be found naturally or by environmental contamination or during the process of making the food (Steve Hall 1995; Voegborlo et al. 1999). Aquatic ecosystems near the industries have a significantly greater amount of heavy metals. Even a small concentration of these heavy metals in the ocean has a significant effect on biological productivity. Heavy metal once released in the aquatic ecosystem, it can be distributed and accumulated in the different part of the aquatic biota including flora and fauna. Therefore, most of the species of flora and fauna act as an environmental indicator in the environment and hence monitored for the assessment of environmental risk and pollution load (Jorgenson and Pedersen, 1994; Widianarko et al. 2000). Fish are on the top of the consuming food in the aquatic system (Dallinger et al. 1987). Other than occupational exposure of heavy metals, consumption of fish is the largest source of mercury intake in our diet.

Heavy metals such as methylmercury and mercury have been reported in different aquatic organisms (Pandit et al. 1997). Accumulation of organometallic compounds in superior organisms is due to the high affinity to –SH groups of lipid tissues and proteins in organisms (Pongratz and Heumann 1999). The most common form of mercury found in the environment is methylmercury which is converted from ionic mercury to organomercury and has a potential of causing a hazard (Hintelman et al. 1993; Tripathi et al. 2003). Methylmercury can cause toxicity in the brain, especially in the central nervous system, which may occur at very low doses i.e. 3.0 μg/kg in humans (WHO 1976). Inorganic arsenic contamination in food has also been a potential hazard to human health because of its carcinogenic effect on human as well as deleterious effects on the urinary bladder, lung, and skin. Studies have revealed that due to anthropogenic activities, higher concentration of arsenic is found in aquactic ecosystems. Therefore, the arsenic exposure to human beings is mainly occur via ingestion of contaminated seafood and drinking water.

2.3.1 Application of Fertilizers and Pesticides in a Crop Field

Due to the rapid increase in the human population, the demand for food in the society has also accelerated, which has increased the demond of application of a huge amount of fertilizers to increase the crop yield. In the same manner, application of insecticide has increased many fold to protect the crops from the pest. Insecticides are not only used in agriculture, but also in the pharmaceuticals and other, industrindustries, and consumer products. Insecticides are claimed to be a major factor behind the increase in the twentieth-century agricultural productivity. Being toxic in nature, most of the insecticides have the potential to significantly alter ecosystems. Most of the pesticides get concentrated in the ecosystem spread along the food chain. A report by Islam et al. (2018) in Bangladesh stated that concentration of Cu, Cr, As, and Cd was higher than the irrigation water quality standard given by FAO. They also identified the problem and concluded that it was due to polluted water and the use of agrochemicals in the agricultural field.

2.3.2 Contamination by Anthropogenic Activities

Heavy metals like arsenic, lead, mercury, and cadmium are toxic and cause neurological problems in developing children (WHO 2017; Tchounwou et al. 2012). Anthropogenic activities like the burning of fossil fuels and mining activities are some of the major of these metals as these metals contaminate the agricultural soil by aerial deposition (Pollution 2007). Subsequently, the plants take up the metals from their root system from the soil resulting in contamination of vegetables and fruits. Urban farming and gardening practices also have contamination in food due to urban pollution.

2.3.3 Food Processing and Packaging

After harvesting, the crops need to be stored appropriately. The food is usually stored in the plastic containers because it is cheap, and easy to handle. But when the food gets in contact with the plastics, some of the chemicals present in the plastics, get leached out and contaminate the food (Radford 2019). Even in the contianers madeup of inert materials like ceramic, glass, the chemicals present in these materials can migrate to the food from their inner surface of the containers. Non-inert materials like adhesives, labels, coating, and inks can also contaminate the food. Canned food is often less nutritious than fresh or frozen food and sometimes get contaminated during storage and transpost (Muncke 2016). Sulphites are common preservatives used in various fruits which has adverse effects in the form of palpitations, allergies, headaches, and even cancer in the human beings. Nitrates and nitrites are used as curing agents in meat products. It gets converted into nitrous acid when consumed and is suspected of causing stomach cancer. Benzoates are used in foods as antimicrobial preservatives and have been suspected to cause allergies, asthma, and skin rashes. A serious issue arose when cooking the meat in grills as directly cooking meat and other food products with flames of gas, charcoal, and combusting wood, there are posibilities of getting it contaminated as charcoal and wood emits chemicals during burning known as polycyclic aromatic hydrocarbons (PAHs). PAHs are potential carcinogens and may cause severe damage to the skin, liver, and stomach in the long-term exposure.

2.3.4 Adulteration in Food

Adulteration in food is a common practice by the food producer so that they can increase their profit margin. Some of the common practice in food adulteration is adding water, chalk, urea, caustic soda, and skimmed milk in milk. It is also easy to adulterate oil and fats, which is undetectable. Ghee is often mixed with hydrogenated oils and animals fats. Adulteration in food grain includes the mixing of sand or crushed stone so that the finished food grain product increases the weight. In some vegetables, synthetic colours are used to give it a natural appearance to the consumers. Cheap, synthetic, and chemical colour flavours are used in some food products which are dangerous and may cause allergies to some of the consumers. Such adulteration practices should be strictly monitored and abandoned by the food quality regulatory organizations, and also the people should be made aware as what they are consuming (Radford 2019).

2.3.5 Contamination of Agricultural Soil and Crops by Irrigation of Wastewater

Rapid growth in the human population, industrialization and modern agricultural practices have accelerated the rate of contamination of heavy metals in the environment. Heavy metal contamination in irrigation water and soil from numerous activities such as irrgation of crops from domestic wastewater and industrial effluents are the major concerns. Further, release of untreated effluents in the water bodies, streams, lakes, and the river leading to heavy metal contamination in aquatic bodies and when such water is used for irrigation, agricultual soil and crops get contaminated. Even heavy metals leaching through the contaminated soil and industrial waste can contaminate the groundwater aquifers. Arsenic pollution in groundwater is the major issues in the globe.

The availability of freshwater resources are very scarce which is getting reduced every year and many part of the world are faciting water crisis even for the drinking purposes and some of the counties would soon face water scarcity in the near future. Throughout the world, farming depends on river water, lakes, and streams for irrigation. Groundwater is also an alternative water resource, but due to rapid uses, the water table is declining and would be deficient even for drinking purposes. With the increasing use of mineral fertilizers for high production of crops for maintaining the demand of food, unintentionally the groundwater aquifers are getting polluted especially for the nitrate contamination is increasing in drinking water (Schroder et al. 2004; Camargo and Alonso 2006). This is same in the case of almost all the developed and developing countries. In the past, soil contamination was not considered as an environmental problem compared to the air and water pollution. But in recent times, the soil contamination has become a major environmental problem.

The major problem with soil contamination is that, it takes a longer time to remediate (Wood 1974) and is difficult to reverse the effect of numerous types of contaminants through dilution or by self-purification and other techniques. whereas it is comparably easy to manage the water pollution by managing the point sources of pollution. Plants grown in contaminated soil car accumulate heavy metals in their tissues and act as bio-sinks for these heavy metals (Bhatia et al. 2001). Heavy metal contamination in water due to natural weathering of rocks is unpreventable however, contamination due to human activities can be managed up to some extent.

Wastewater use in irrigation is increase many folds in past few decades due to unavailability or shrinking of freshwater resources. The use of wastewater can conserve freshwater, reduce pollution in available water resource, and also provide micronutrients, organic matter, nitrogen, phosphorus, etc. (FAO, 1992; Murtaza et al. 2010; Hanjra et al. 2012). However, heavy metals and some of the organic contaminant not get removed during the conventional wastewater treatment, which subsequently ends up in the agricultural soil through irrigation water and ultimately to the human food chain (Fytianos, 2001). According to a study, consumption of heavy metals via food, milk, and drinking water in India was higher than that of the limits set by the WHO and FAO (2007). Heavy metal contamination in human food chain is shown in the Fig. 2.4.

2.4 Accumulation and Toxicity of Heavy Metals

The heavy metals has been proven to cause health-related issues and a major threat to the exposed population. Due to its ubiquitous nature and tendency to remain in the environment for a long time, thus get accumulated in different component of the environment and poses toxic effects (Gilbert and Weiss, 2006). Heavy metal exposure and toxicity can be divided into chronic and acute toxicity. Once metal contamination occure in the biological system, certain metals can combine with the sulfhydryl group, inhibiting various enzymes and processes in the biological process, due to it's high-affinity properties (Jan et al. 2015). Chronic exposure of heavy metals can induce neurotoxicity and hepatonephrotoxicity (Caito and Aschner 2014).

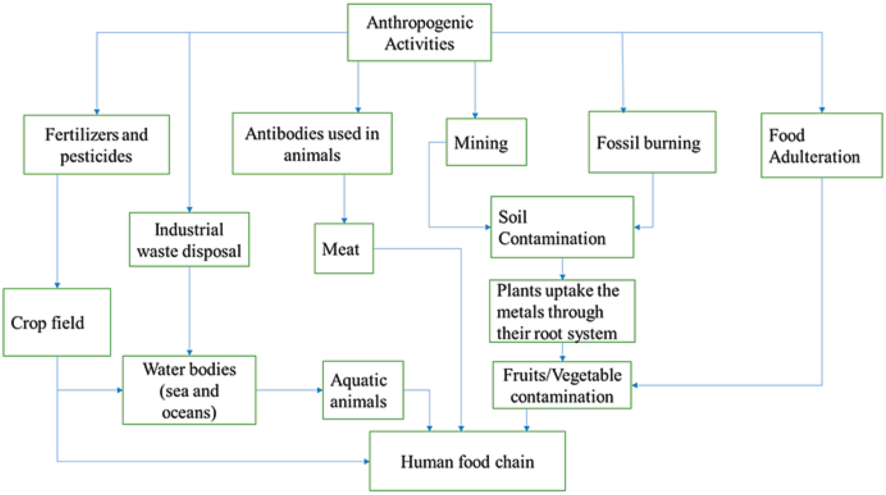

Fig. 2.4 Flow chart of heavy metal contamination in human food chain

2.4.1 In Agricultural Crops and Plants

The pathway by which the heavy metal ions enter through the food crops is from the root system of the crops, i.e. apoplast and symplast movements. These two movements are two different pathways by which water and metal ions pass through the root hair via the root cortex to the xylem. In the apoplast movement, more ion and water are transported through the apoplastic pathway (inner cellular space) in the cortex, whereas in symplast movement, water and ion are mainly delivered through the symplastic pathway beyond the cortex. Heavy metal movement occurs generally in the symplastic pathway, i.e. through crossing the plasma membrane (Peer et al. 2006). Further, the metal ions are facilitated inwards by the electrochemical gradient (Raskin et al. 1994). When the metals reach the xylem, the metal transport is mediated by the membrane transport protein (Thakur et al. 2016). Arid and semi-arid regions with short wet seasons and long dry seasons, rely on unconventional water resource and are being used to fulfil the increasing demand for food for the society. Vegetables/crops grown in wastewater irrigation-contaminated soil accumulate a significant level of heavy metal concentration than that grown in soils irrigated with freshwater (Balkhair and Ashraf 2016). A study by Khan et al. (2008) concluded that irrigation with untreated irrigation water increases Pb, Ni, and Cd concentration in the crops and poses an adverse effect on the health of humans. Leafy vegetables can accumulate comparably a higher concentration of heavy metals when grown in a site contaminated by heavy metals that are absorbed mostly in the leaves of the vegetable (Jassir et al. 2005). Vegetables like cauliflower, spinach, and cabbage can even grow well in a high level of heavy metal-contaminated soils and wastewater irrigation (Cobb et al. 2000), whereas some of the vegetable like radish is more sensitive to sewage water (Kapourchal et al. 2009).

Heavy metal uptake by food crops depends upon soil physicochemical characteristics and plant species (Zhuang et al. 2009). Bai et al. (2010) reported that cultivation history is an important factor related to the accumulation of heavy metals, particularly of Cu, Pb, and Zn. Heavy metal uptake in crops majorly depends on the temperature, moisture, pH, organic matter, nutrient availability, plant species and their uptake potential, or soil-to-plant transfer factors (Tangahu et al. 2011; Khan et al. 2008).

Elevated heavy metals in soil can result in a decline in soil productivity; lower the development process which are vital for plant growth like photosynthesis, mitosis, and water absorption; and lead to stunted growth of plants/crops (Bhattacharyya et al. 2008). Use of municipal waste, sewage sludge in the agricultural field is a general practice in developing nation worldwide to lower the cost of fertilizers. However, applications of waste and sludge may contaminate the soil and groundwater quality and may increase poisoning in the food chain.

2.4.2 In Aquatic Animals

Burning of coal, smelting, and industrial waste disposal into the seas and oceans are the main causes of pollution in ocean water (Global Mercury Assessment 2013). Due to this, the aquatic life in the seas and oceans are severly getting affected. Mercury has been the main contaminant in fish, inorganic and organic mercury disposed into lakes and rivers may be transformed into methylmercury, and the mercury levels found in fish, even from 'non-contaminated' areas, are higher than in most other foods. These get absorbed in algae and get biomagnified by the large fish and ultimately get into the human food (Mercury Levels in Commercial Fish and Shellfish 1990–2012).

A report from Guallar et al. 2002 [85] stated that high contamination of metals in fish have an adverse effect on many vital organs of human beings. As per a report from Lake Ontario, decline in woman fertility was observed due to the consumption of contaminated fish (Buck et al. 2000). Similarly, persistent organic compound is found in the aquatic environment, get accumulated in the fatty tissues of fish and passes through the food chain to higher trophic level (Håstein et al. 2006). Due to consumption of fish contaminated with the organochlorine compounds presence of such compounds has been reported in the human lipids and tissues and even in breast milk in women in the countries like India, Japan, and Argentina (Muñoz de Toro et al. 2006; Tsukino et al. 2006; Someya et al. 2010). Organic mercury has higher toxicity than inorganic mercury because of it's high solubility in lipids and low rate of elimination which causes bioaccumulation in the organisms (Díez 2009). In the aquatic system, heavy metals exposure to the organisms occurs through their food along with water (Phillips 1995). It was observed that fish accumulate comparably higher concentration of metals when the number of phytoplanktons are high in the region than the areas where the dencity of planktons are low. Heavy metal accumulation in the flora and fauna increases over the time. Summary of the concentration of heavy metals in agricultural soil irrigated by wastewater is presented in the Tables 2.1 and 2.2 provide a summary of heavy metals in various types of vegetables.

Table 2.1 Summary of the concentration of heavy metals in agricultural soil irrigated by wastewater

	The concentration of metals (mg/Kg) in soil irrigated with wastewater											
Type of water	Cd	Cr	Cu	Pb	Ni	Fe	Mn	Zn	As	Hg	Country	Year
Domestic wastewater												
Urban wastewater		118.90	39.44		39.75			50.07			Spain	Martínez–Cortijo and Ruiz–Canales (2018)
Wastewater	1.76	42.19	32.68	12.04			277.62	68.75			Iran	Cheshmazar et al. (2018)
Leather industry	0.45	976		50.32					1.94		Bangladesh	Mottalib et al. (2016)
Gold mining	2.867		106.10	723.50				452.90	15.81	12.195	China	Xiao et al. (2017)
Peri-urban industrial	0.605	57.65	5.405	37.6	88.90		359.55	151.3			India	Chabukdhara et al. (2016)
Smelting	7.52		128.7	1090.0				820.0	903.5		China	Zhou et al. (2016)
Domestic as well as industrial wastewater												
	1.42	63.48	107.65	213.93	34.75			427.80			Spain	Zimakowska– Gnoinska et al. (2000)
	0.78		95.00	23.00	57.00						America	Han et al. (2002)
			65.00	139.00	29.00			140.00			Slovakia	Wilcke (2005)
	13.5	48.5	48	55	29			88.5			USA	Jean–Philippe et al. (2012)
	0.82	2.19	1.20	0.95	4.34			28.24			India	Raju et al. (2013)
	0.34	10.36	9.62	5.17	11.28			11.56			Iran	Sayyed and Sayadi (2011)

Table 2.2 Summary of heavy metals in various types of vegetables

Type of vegetable	Concentration of metal (mg/kg)										Country	Author and year of publication
	Cd	Cr	Cu	Pb	Ni	Fe	Mn	Zn	As	Hg		
Leafy green												
Lettuce	<0.005	0.23	0.505	0.016				0.345	0.005	<0.008	China, Spain	Khan et al. (2008) and Ercilla–Montserrat et al. (2018)
Spinach		2.9	0.09	3.1	3.2			10			India	Chary et al. (2008)
Red amaranth	<0.1	<0.1		1.036	0.840	136.3	5.720	11.305	<0.1	<0.03	Bangladesh	Tasrina et al. (2015)
Beetroot	0.09	0.21		0.58	0.26						São Paulo, Brazil	Guerra et al. (2012)
Cruciferous												
Cabbage		0.23	0.505	0.016				0.345			China	Khan et al. (2008)
Cauliflower	0.014	0.02	0.6	0.03	0.68			5.45			China	Song et al. (2009)
Brussels sprouts												
Broccoli	0.08	0.48		0.93	0.26						São Paulo, Brazil	Guerra et al. (2012)
Marrow												
Pumpkin	0.01	1.45		0.25					0.02		Dhaka, Bangladesh	Islam et al. (2014)
Cucumber			0.38	0.031				1.30			China	Xiu-Zhen et al. (2009)
Italian zucchini	0.04	0.08		0.51	0.25						São Paulo, Brazil	Guerra et al. (2012)
Paulista zucchini	0.04	0.15		0.59	0.23						São Paulo, Brazil	Guerra et al. (2012)
Root												
Potato	0.015	0.03	1.03	0.067	0.054			3.77			China	Song et al. (2009)
Sweet potato	0.14	0.04		0.46	0.18						São Paulo, Brazil	Guerra et al. (2012)
Carrot	<0.1	<0.1		0.304	<0.1	8.824	1.257	1.206	<0.1	<0.03	Bangladesh	Tasrina et al. (2015)

Yam	0.06	0.20		0.72	0.20						São Paulo, Brazil	Guerra et al. (2012)
Edible plant stem												
Celery	0.05	0.14		0.47	0.19						São Paulo, Brazil	Guerra et al. (2012)
Asparagus bean	0.013		1.999	0.07				6.682	0.047		South China	Zhou et al. (2016)
Kidney beans	0.010		1.310	0.033				5.669	0.05		South China	Zhou et al. (2016)
Allium												
Onion	0.02	0.07		0.49	0.06						São Paulo, Brazil	Guerra et al. (2012)
Garlic	0.09	0.29		2.50	0.42						São Paulo, Brazil	Guerra et al. (2012)

2.5 Human Health Risk of Heavy Metals

Heavy metal toxicity is generally by cadmium, chromium, lead, mercury, and arsenic, and their exposure is commonly occure mainly through consumption of contaminated foodstuff, and through the contaminated environment. Toxicity of these heavy metals results from sudden, acute, or chronic exposure over a period of time. Symptoms of heavy metals toxicity depend upon metal absorbed, metals involved, and age of the person exposed to these metals. Cadmium particles or fumes can cause acute pulmonary effects and even the death of an individual (Seidal et al. 1993; Barbee and Prince 1999). Kidney damage is generally due to the heavy exposure of cadmium. Several reports have suggested that the kidney damage or bone effect in human can arise even from the exposure of a lower concentration of cadmium. High exposure of cadmium for the longer period can lead to skeletal damage, which was first recorded in Japan in the 1950s and it was named as ita-itai disease. This disease was occurred due to exposure through consumption of cadmium contaminated rice grown on a field irrigated with the contaminated water. The International Agency for Research on Cancer (IARC) has grouped cadmium as a human carcinogen (group I). Cadmium exposure can also cause prostate cancer.

Inorganic mercury acute poisoning can lead to lung damage, while chronic poisoning can cause neurological and psychological disorders, such as restlessness, tremor, changes in personality, anxiety, depression, and sleep disturbance. These symptoms are reversible only when the exposure has stopped, and the same can be observed for metallic mercury which causes kidney damage. Methylmercury poisoning can last from 1 month or longer even after acute poisoning, and it's main symptom is the damage of nervous system. Exposure of a higher dose of methylmercury can cause death of a person. Minamata disease was recorded due to dietary exposure of fish contaminated by methylmercury. The contamination of methylmercury in fish occurred due to the discharge of mercury in the water bodies. In the early 1970s, a similar incidence was occurred in Iran, which caused the death of around 10,000 people due to the consumption of baked bread which was prepared from mercury-contaminated grains.

Lead is also get accumulated in liver and kidney of aquatic animals; consuming this lead-rich diet can cause an unacceptably high level of lead in the human body. Lead contamination in food also occur through food containers like ceramic vessels with lead glaze, storage in lead-soldered cans and leaded crystal glass. Headache, irritation, and abdominal pain are some of the acute symptoms of lead exposure. Sleeplessness and restlessness are some mental disorders which are caused by lead encephalopathy, and children may also suffer from concentration loss, learning difficulties, and behavioural disturbances. Acute confusion, psychosis, and reduced consciousness are observed in adults who may suffer from lead encephalopathy. Lead is classified as a 'possible human carcinogen' by International Agency for Research on Cancer (IARC), in 1987. The upper limit for blood lead for adults is 10 μg/dl (10 μg/100 g) and for children, 5 μg/dl has been set by the Centers for Disease Control and Prevention (USA) (ACCLPP 2012; CFR USA 2005). The evidences from previous studies has revealed that lead poisoned people may suffer from lung cancer, stomach cancer, and gliomas (Steenland and Boffetta 2000). In the most developed nation, over 540,000 people have died due to the exposure of lead in the year 2016 (Lead poisoning and health 2016).

Acute toxicity of inorganic arsenic intake in large amount can cause gastrointestinal symptoms and disturbances in the cardiovascular system and central nervous systems and may lead to the death of an individual. Arsenic encephalopathy, bone marrow depression, polyneuropathy, haemolysis, hepatomegaly, and melanosis are also observed due to arsenic poisoning. Black foot disease in Taiwan is caused by drinking water contaminated by arsenic which damages the lower limbs resulting in progressive gangrene. A report from WHO on arsenic exposure via drinking water suggests that it may cause cancer in the lungs, kidney, bladder, and skin as well as precancerous lesions in the skin (WHO 2001).

Hence, these heavy metals have the potential to cause disease, cancer, or even death of the person if exposed of heavy metals through diet, inhalation, and/or dermal exposure. The exposure to heavy metals and its toxicity to human beings is one of the major issues for regulatory bodies, organization, and government bodies. The chemical toxic agency should provide ways by which such exposure can be minimized and also provide appropriate tools and techniques to reduce the level of heavy metals in the environment and prevent these metals from reaching it into the human, animals, and the environment in the future.

2.5.1 Carcinogenic Risk Due to Heavy Metals

A recent study that was carried in Palestine by Al-Khatib et al. (2019) predicted that the local residents especially children might have a higher chance of developing cancer due to the presence of Mg, Ba, Fe, Sr, K, Na, and Mg, and their values were greater than the standard limits, i.e. $>10^{-6}$. High level of groundwater contamination near the industrial waste site and municipal solid waste dump site due to poor management was reported in Chandigarh, India (Ravindra and Mor 2019). This study revealed that deeper aquifer was less contaminated than the shallow aquifers. The shallow aquifers are generally used for drinking and irrigation purposes which might directly or indirectly exposed human beings to those of the heavy metals.

2.5.2 Noncarcinogenic Risk of Heavy Metals

A recent study conducted in Iran and revealed that heavy metals like Zn, Fe, Al, Pb, Ni, Cd, Mn, As, and Cr were more accumulated in the medicinal plants than herbal plants and only Hg and Cu were found to be higher in herbal plants and its target hazard quotients (THQ) were less than 1 which is considered to be safe for consumption (Kohzadi et al. 2019). Fluoride contamination in Iranian drinking water was estimated to be low and does not had any carcinogenic risk for both adults and children, but fluoride contamination in food and air was high and had significant effect on human health (Keramati et al. 2019). Heavy metal contamination on crayfish, meat, fish, and cowskin was estimated in Nigeria, and it was found that the hazard index of raw, smoked, and cooked meat showed the greater noncarcinogenic adverse health effects (Taiwo et al. 2018). A study conducted in India also reported noncarcinogenic risk due to high arsenic contamination in Indian rice (Sharafi et al. 2019).

2.6 Pathway/Exposure of Heavy Metals

Heavy metal exposure to human beings is often from ingestion, dermal exposure, and inhalation (Asaduzzaman et al. 2017; Li et al. 2017). The exposure of heavy metals is usually occurred mainly through the contaminated drinking water and food. Mercury accumulation in human tissues has higher concentration through consumption of aquatic organisms, i.e. seafood, fishes, etc., in the form of methylmercury (Horvat et al. 2003). The main source of mercury intake in diet of the population is from fish as stated by Boudou et al. (2005).

2.6.1 Ingestion

The occurrence and level of contamination, chemical forms, and metal solubility are some of the factors affecting the absorption of trace metals through the gastrointestinal tract. Ingestion is the primary route of heavy metal intake through diet, and it contributes up to 90% of daily dietary intake compared with inhalation and dermal exposure (Loutfy et al. 2006). For example, arsenic exposure is through food and water, and the daily intake ranges from 20 to 300 μg/day (WHO 2010) depending upon the food type, food processing, and agricultural conditions (IARC 2012). The heavy metals are absorbed and accumulated in leafy vegetables (Arora et al. 2008). Exposure of chromium from food is through meat, molluscs, and crustaceans (U.S. EPA 1998). Kusiak et al. in 1993 have reported that even Cr (III) causes oral toxicity in humans.

2.6.2 Inhalation

Inhalation of heavy metals is considered another pathway of occupational exposure. In the metal plating and some of the other industries, chromium exposure occurs in both forms i.e. Cr(III) and Cr(VI). During inhalation, the Cr(III) gets absorbed in the tissues of the lung due to the reduction of Cr(VI) to Cr(III) (Flaherty, 1996). Chromium is responsible for wheezing, coughing, asthma, and other respiratory diseases (Langard, 1980). The Cr(IV) can even cause cancer in humans even via inhalation route and is classified as carcinogenic material (group 1) by international nodal agencies (IARC, 2012; Waseem and Arshad 2016, 198). Mercury present in the gaseous state, contributes to 80% of the atmospheric mercury (Wang et al. 2004).

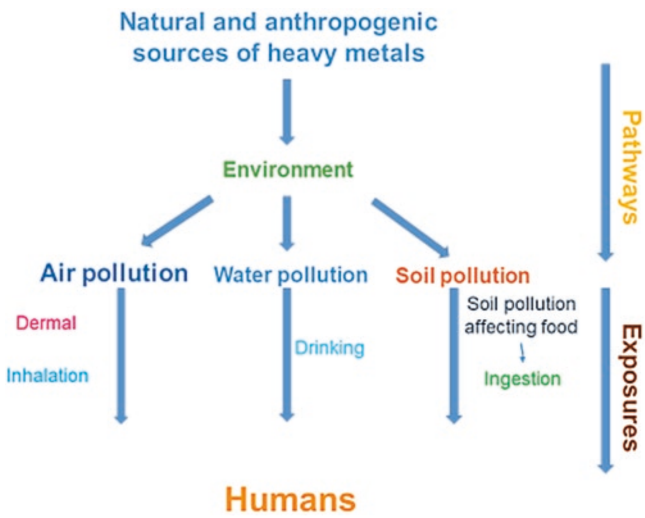

Fig. 2.5 Pathway/exposure of heavy metals in human beings and in the environment. (Modified from Thompson et al. 2012)

2.6.3 Dermal Exposure

The dermal exposure of heavy metals usually occurs when the large surface area of the skin get in to the contact of metal laden dust and fine particles. These small particles sometimes get deposited into the dermal layers of the skin and reached to the circulation system (Li and Zuo et al. 2013, Keshavarzi et al. 2015). The skin is the primary and effective barrier for the absorption of any substance, therefore, only few of the metals that have the ability to penetrate through the dermal layers of the skin, get absorbed. A report by Brandão and Gontijo (2012) stated that nickel metal exposure through the skin has become sensitive to human and is causing allergy in children, especially in developed nations. The exposure pathways of heavy metals is presented in the Fig. 2.5.

2.7 Preventive and Mitigation Measures

Mining, industrial process, and other human activities release several types of chemicals and waste containing heavy metals, in to the environment. Then the metals spread in and around the polluted site polluting the nearby areas. To prevent these heavy metals from polluting the area, the primary release of such type of metals or use of heavy metals in the form of pesticides or fertilizers in the environment should be carefully monitored and regulated. Appropriate waste management system should be adapted in mining areas and industries so that the disposal of such heavy metal waste can be prevented so that metals are not released into the environment. The major problem also lies in the disposal of untreated wastewater, sewage water, and industrial effluents into the river and water bodies, which further affects the aquatic ecosystem and also contaminating agricultural soil as well as the food crops once used for irrigation. So proper waste treatment plans should be adapted in industries and disposal of untreated effluents must be stopped. A proper waste disposal can prevent the heavy metals released in the environment.

Apart from preventive measures, sites that are already polluted should be reclaimed and should so that further harm to the environment can be prevented. Some are several mitigative measures that can be adapted to reclaim the polluted sites and bring back its original state. Some of them are as follows.

2.7.1 Excavation

It is the easiest, oldest physical remediation method for reclaiming contaminated soil. It is practised all around the world for the management of contaminated soil. The advantage of these methods is that the contaminated soil is completely removed and the contaminated site is rapidly cleaned (Wood 1997). The disadvantage of excavation is that while removing and transferring the soil from one place to another place, it should be monitored or else if the polluted soil spread by any means, it will contaminate another site. Soil with a large area of contamination requires a large area to be excavated. Therefore, this technique is very costly and time-consuming.

2.7.2 Stabilizing Metals in the Soil

Heavy metal-contaminated soil once excavated moves into another site for the stabilization process. This is another way by which their toxic effect can be reduced or their adverse effect can be minimized within a confined area (in situ). This process does not affect the environment or generate toxic waste; instead it lessens the toxic effect of the heavy metals with the help of added chemicals which can detoxify the pollutant. Adding phosphate fertilizer in the polluted soil can neutralize its toxic effect, especially for the sites contaminated with a high concentration of lead. Some other chemicals are also used to bind with the pollutants released form a mineral make a stable compound which is insoluble in water. These methods immobilizes the toxicants to the food chain, and once the metals biologically unavailable, they are harmless to the environment (Lambert et al. 1997).

2.7.3 Use of Plants

Some plants have special ability to reduce the toxic effect in areas and used in situ remediation of contaminated soil, air, and water and is often termed as phytoremediation (EPA 1998). Phytoremediation has certain advantages and is a widely accepted as a low-cost technique for remediation of the degraded, contaminated site (Schnoor 1997). Disadvantages of phytoremediation are that it takes a bit longer time for remediation. Sites that are contaminated can be revegetated with the help of some of the specific plant species, and this process is called phytostabilization. Plants help reduce wind erosion and soil erosion and also help in reducing the materials spreading from one contaminated site to another site. Another way by which plants can be used for cleaning up contamination is phytoextraction. Some plants have the ability to uptake certain heavy metals and concentrate them into their tissues. These plants can further be harvested and disposed of in safe places without harming the environment. Plants like Indian mustards, alfalfa, cabbage, juniper, tall fescue, and poplar trees have potential to accumulate heavy metals and do not possess any harm to the environment and any living organisms. Indian mustards can cure lead contamination in the soil. A rhizofiltration process is another technique used for remediating heavy metals in water bodies in which the roots of the plants directly remove the contamination with the help of some aquatic plant species or hydroponic methods (EPA 2000). Sunflower plants were used to remove radioactive metals in the water lakes of Chernobyl, which is an example of the rhizofiltration technique.

2.8 Conclusion

Food contamination with heavy metals has become a major problem all over the globe and has an adverse effect on human health and the environment. Heavy metals have been on the earth naturally. However, their release in the environment has been accelerated by human activities leading to pollution in the environment. These pollutants are nondegradable and have reached into our food chain and food web, resulting in abnormalities in the metabolism of humans leading to acute and chronic disease or even death. Local people residing nearby areas of pollution site should be made aware of the deleterious effects of the pollutants released and how that can be a threat to their life. The cultivation and production of food crops near area contaminated with a high concentration of heavy metals must be banned. Due to the scarcity of available freshwater, wastewater irrigation is used as an alternative source for irrigation. Unfortunately, continuous use of wastewater is also a prime cause of heavy metal pollution and contamination of food crops. Pollution in water bodies have also become an environmental concerns because water is the only source of survival for living organisms and the survival depend upon water before prehistoric time. In view of this, rainwater harvesting and watershed management must be adapted to harness the freshwater resource which could be utilized for farming.

References

Abbasi N (2015) Aspergillus spp. germ tubes induce stronger cytokine responses in human bronchial epithelial cells in comparison with spores. Curr Med Mycol 1:37–93

Abii T (2012) Levels of heavy metals (Cr, Pb, Cd) available for plants within abandoned mechanic workshops in Umuahia Metropolis. Res J Chem Sci 2(2):79–82

Abii TA, Okorie DO (2011) Assessment of the level of heavy metals [Cu, Pb, Cd and Cr] contamination in four popular vegetables sold in urban and rural markets of Abia State Nigeria: continental. J Water Air Soil Pollut 2(1):42–47

Advisory Committee On Childhood Lead Poisoning Prevention (ACCLPP). CDC. May 2012. Archived from the original on 4 May 2012. Retrieved 18 May 2012

Agency for Toxic Substances and Disease Registry (2000) "Toxicological Profile for Chromium."

Ajmal M, Rao WA, Peyton JN (1996) Effect of carbon and energy sources on bacterial chromate reduction. Biorem J 6:205–215

Al Jassir MS, Shaker A, Khaliq MA (2005) Deposition of heavy metals on green leafy vegerables sold on roadsides of Riyadh City, Saudi Arabia. Bull Environ Contam Toxicol 75(5):1020–1027

Al-Khatib IA, Arafeh GA, Al-Qutob M, Jodeh S, Hasan A, Jodeh D, van der Valk M (2019) Health risk associated with some trace and some heavy metals content of harvested rainwater in Yatta area, Palestine. Water 11(2):238

Alloway BJ, Jackson AP (1999) Behaviour of trace metals in sludge–amended soils. Sci Total Environ 100:151–176

Arora M, Kiran B, Rani S, Rani A, Kaur B, Mittal N (2008) Heavy metal accumulation in vegetables irrigated with water from different sources. Food Chem 111:811–815

Asaduzzaman K, Khandaker MU, Baharudin NAB, Amin YBM, Farook MS, Bradley DA, Mahmoud O (2017) Heavy metals in human teeth dentine: a bio indicator of metals exposure and environmental pollution. Chemosphere 176:221–230

Ayres RU, Ayres L, Råde I (2003) The life cycle of copper, its co–products and byproducts. Springer, pp 135–141. ISBN 978-1-4020-1552-6

Bai J, Cui B, Yang Z et al (2010) Heavy metal contamination of cultivated wetland soils along a typical plateau lake from southwest China. Environ Earth Sci 59:1781–1788

Balkhair KS, Ashraf MA (2016) Field accumulation risks of heavy metals in soil and vegetable crop irrigated with sewage water in western region of Saudi Arabia. Saudi J Biol Sci 23:S32–S44

Barbee JY Jr, Prince TS (1999) Acute respiratory distress syndrome in a welder exposed to metal fumes. South Med J 92:510–512

Beaumont JJ, Sedman RM, Reynolds SD, Sherman CD, Li LH, Howd RA, Sandy MS, Zeise L, Alexeeff GV (2008) Cancer mortality in a Chinese population exposed to hexavalent chromium in drinking water. Epidemiology 19(1):12–23

Benazir JF, Suganthi R, Rajvel D, Pooja MP, Mathithumilan B (2010) Bioremediation of chromium in tannery effluent by microbial consortia. Afr J Biotechnol 9(21):3140–3143

Bhatia A, Pathak H, Joshi H (2001) Use of sewage as a source of plant nutrient: potential and problems. Fertil News 46:61–64

Bhattacharyya P, Chakrabarti K, Chakraborty A, Tripathy S, Powell MA (2008) Fractionation and bioavailability of Pb in municipal solid waste compost and Pb uptake by rice straw and grain under a submerged condition in amended soil. Geosci J 12(1):41–45. https://doi.org/10.1007/s12303-008-0006-9

Binns J, Maconachie R, Tanko A (2003) Water, land, and health in urban and peri-urban food production: the case of Kano, Nigeria. Land Degrad Dev 14(5):431–444

Blaser P, Zimmermann S, Luster J, Shotyk W (2000) Critical examination of trace element enrichments and depletions in soils: As, Cr, Cu, Ni, Pb, and Zn in Swiss forest soils. Sci Total Environ 249:257–280

Boudou A, Maury-Brachet R, Coquery M, Durrieu G, Cossa D (2005) Synergic effect of gold mining and damming on mercury contamination in fish. Environ Sci Technol 39:2448–2454

Brandão MHT, Gontijo B (2012) Contact sensitivity to metals (chromium, cobalt and nickel) in childhood. J Braz Ann Dermatol 87:269–276

Buck GM, Vena JE, Schisterman EF, Dmochowski J, Mendola P, Sever LE, Fitzgerald E, Kostyniak P, Greizerstein H, Olson J (2000) Parental consumption of contaminated sport fish from Lake Ontario and predicted fecundability. Epidemiology 11:388–393

Caito S, Aschner M (2014) Neurotoxicity of metals. Handb Clin Neurol 131:169–189

Camargo JA, Alonso A (2006) Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: a global assessment. Environ Int 32:831–849

Chabukdhara M, Munjal A, Nema AK, Gupta SK, Kaushal RK (2016) Heavy metal contamination in vegetables grown around peri-urban and urbanindustrial clusters in Ghaziabad, India. Hum Ecol Risk Assess Int J 22(3):736–752

Chary NS, Kamala CT, Raj DSS (2008) Assessing risk of heavy metals from consuming food grown on sewage irrigated soils and food chain transfer. Ecotoxicol Environ Saf 69:513–524

Cobb GP, Sands K, Waters M, Wixson BG, Dorward-King E (2000) Accumulation of heavy metals by vegetables grown in mine wastes. Environ Toxicol Chem 19(3):600–607

Costa M, Klein CB (2006) Toxicity and carcinogenicity of chromium compounds in humans. Crit Rev Toxicol 36(2):155–163

Dallinger R, Prosi F, Segner H, Black H (1987) Contaminated food and uptake of heavy metals by rainbow trout (Salmo Gairdneri): a field study. Oecologia 73:91–98

Dalzeil IWD (1999) Vestiges of a beginning and the prospect of an end. In: Craig GY, Hull JH (eds) James Hutton: present and future, Geological Society Special Publication, London, pp 119–155

Díez S (2009) Human health effects of methylmercury exposure. In: Whitacre DM (ed) Reviews of environmental contamination and toxicology. Springer, New York, p 111

Ercilla-Montserrat M, Muñoz P, Montero JI, Gabarrell X, Rieradevall J (2018) A study on air quality and heavy metals content of urban food produced in a Mediterranean city (Barcelona). J Clean Prod 195:385–395

FAO (1992) Waste water treatment and use in agriculture. Irrigation and drainage paper, vol 47. FAO (Food and Agriculture Organization), pp 16–17

Fuge R, Glover SP, Pearce NJG, Perkins WT (1991) Some observations on heavy metal concentrations in soils of the Mendip region of north Somerset. Environ Geochem Health 13:193–196

Fytianos K, Katsianis G, Triantafyllou P, Zachariadis G (2001) Accumulation of heavy metals in vegetables grown in an industrial area in relation to soil. Bull Environ Contam Toxicol 67:423–430

Gilbert SG, Weiss B (2006) A rationale for lowering the blood lead action level from 10 to 2 μg/dL. Neurotoxicology 27(5):693–701

Grant CA, Sheppard SC (2008) Fertilizer impacts on cadmium availability in agricultural soils and crops. Hum Ecol Risk Assess 14(2):210–228

Gray CW, Mclaren RG, Roberts AHC, Condron LM (1999) The effect of long–time phosphatic fertilizer applications on the amounts and forms of cadmium in soils under pasture in New Zealand. Nutr Cycl Agroecosyst 54:267–277

Guallar E, Sanz-Gallardo MI, van't Veer P, Bode P, Aro A, Gomez-Aracena J et al (2002) Heavy metals and myocardial infarction study group: mercury, fish oils, and the risk of myocardial infarction. N Engl Med J 28:1747–1754

Guerra F, Trevizam AR, Muraoka T, Marcante NC, Canniatti-Brazaca SG (2012) Heavy metals in vegetables and potential risk for human health. Sci Agric 69(1):54–60

Hall S (1995) Fish: it's usually the last meat people give up, may be it should be the first. N Engl J Med 33(2):977

Han FX, Banin A, Su Y, Monts DL, Plodinec JM, Kingery WL, Triplett GE (2002) Industrial age anthropogenic inputs of heavy metals into the pedosphere. Naturwissenschaften 89(11):497–504

Hammond CR (2005) The elements archived 26 June 2008 at the wayback machine. In: Lide DR (ed) CRC handbook of chemistry and physics (86th edn). CRC Press, Boca Raton. ISBN 0-8493-0486-5

Hanjra MA, Blackwell J, Carr G, Zhang F, Jackson TM (2012) Wastewater irrigation and environmental health: implications for water governance and public policy. Int J Hyg Environ Health 215:255–269

Hastein T, Hjeltnes B, Lillehaug A, Utne Skare J, Berntssen M, Lundebye AK (2006) Food safety hazards that occur during the production stage: challenges for fish farming and the fishing industry. Rev Sci Tech 25(2):607–625

Hintelman H, Ebinghaus R, Wilken RD (1993) Accumulation of mercury(II) and methylmercury by microbial biofilms. Water Res 27:237–242

Hoekstra PF, O'Hara TM, Backus SM, Hanns C, Muir DCG (2005) Concentrations of persistent organochlorine contaminants in bowhead whale tissues and other biota from northern Alaska: implications for human exposure from a subsistence diet. Environ Res 98:329–340

Horvat M, Nolde N, Fajon V, Jereb V, Logar M, Lojen S, Jacimovic R, Falnoga I, Liya Q, Faganeli J, Drobne D (2003) Total mercury, methylmercury and selenium in mercury polluted areas in the province Guizhou, China. Sci Total Environ 304:231–256

International Agency for Research on Cancer (IARC), 2012. A review of human carcinogens. c. metals, arsenic, fibres and dust. In: International Agency for Research on Cancer: Monographs on the Evaluation of Carcinogenic Risks to Humans, Volume 100 (C)

Islam MA, Romić D, Akber MA, Romić M (2018) Trace metals accumulation in soil irrigated with polluted water and assessment of human health risk from vegetable consumption in Bangladesh. Environ Geochem Health 40(1):59–85

Islam MS, Hoque MF (2014) Concentrations of heavy metals in vegetables around the industrial area of Dhaka city, Bangladesh and health risk assessment. Int Food Res J 21:6

Jan A, Azam M, Siddiqui K, Ali A, Choi I, Haq Q (2015) Heavy metals and human health: mechanistic insight into toxicity and counter defense system of antioxidants. Int J Mol Sci 16(12):29592–29630

Jean-Philippe SR, Labbé N, Franklin JA, Johnson A (2012) Detection of mercury and other metals in mercury contaminated soils using mid-infrared spectroscopy. Proc Int Acad Ecol Environ Sci 2(3):139

Jiao Y, Grant CA, Bailey LD (2004) Effects of phosphorus and zinc fertilizer on cadmium uptake and distribution in flax and durum wheat. J Sci Food Agric 84(8):777–785

Johansen P, Muir D, Asmund G, Riget F (2004) Human exposure to contaminants in the traditional Greenland diet. Sci Total Environ 331:189–206

Jorgenson LA, Pedersen B (1994) Trace metals in fish used for time trend analysis and as environmental indicators. Mar Pollut Bull 28:235–243

Kachenko AG, Singh B (2006) Heavy metals contamination in vegetables grown in urban and metal smelter contaminated sites in Australia. Water Air Soil Pollut 169(1–4):101–123

Kalay M, Aly O, Canil M (1999) Heavy metal concentrations in fish tissues from the northeast mediterranean sea. Bull Environ Contam Toxicol 63:673–681

Kapourchal A, Pazira E, Homaee M (2009) Assessing radish (Raphanus sativus L.) potential for phytoremediation of lead–polluted soils resulting from air pollution. Plant Soil Environ 5:202–206

Kaur R, Wani SP, Singh AK, Lal K (2014) Wastewater production, treatment and use in India. http://www.ais.unwater.org/ais/pluginfile.php/356/mod_page/content/111/CountryReport_India.pdf

Keramati H, Miri A, Baghaei M, Rahimizadeh A, Ghorbani R, Fakhri Y et al (2019) Fluoride in Iranian drinking water resources: a systematic review, meta-analysis and non-carcinogenic risk assessment. Biol Trace Elem Res 188(2):261–273

Keshavarzi B, Tazarvi Z, Rajabzadeh M, Najmeddin A (2015) Chemical speciation, human health risk assessment and pollution level of selected heavy metals in urban street dust of Shiraz. Iran. Atmos Environ 119:1–10

Khan S, Cao Q, Zheng YM, Huang YZ, Zhu YG (2008) Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. Environ Pollut 152:686–692. https://doi.org/10.1016/j.envpol.2007.06.056

Kingston RL, Hall S, Sioris L (1993) Clinical observations and medical outcomes in 149 cases of arsenate ant killer ingestion. J Toxicol Clin Toxicol 31:581–591

Kohzadi S, Shahmoradi B, Ghaderi E, Loqmani H, Maleki A (2019) Concentration, source, and potential human health risk of heavy metals in the commonly consumed medicinal plants. Biol Trace Elem Res 187(1):41–50

Koropatnick J, Leibbrandt MEI (1995) Effects of metal on gene expression. In: Goyer RA, Cherian MG (eds) Handbook of experimental pharmacology, toxicology of metals, biochem. aspects, vol 115. Springer, pp 93–120

Kusiak RA, Ritchie AC, Springer J et al (1993) Mortality from stomach cancer in Ontario miners. Br J Med 50:117–126

Lambert M, Pierzynski G, Erickson L, Schnoor J (1997) Remediation of Lead, Zinc, and Cadmium–contaminated soils. In: Hester R, Harrison R (eds) Contaminated land and its reclamation. The Royal Society of Chemistry, Cambridge, pp 91–102

Langard S (1980) A survey of respiratory symptoms and lung function in ferrochromium and ferrosilicon workers. Int Arch Occup Environ Health 46:1–9

Lead poisoning and health. WHO. September 2016. Archived from the original on 18 October 2016. Retrieved 14 October 2016

Lenntech (2014) Water treatment and air purification 2004. Water treatment, Rotterdamseweg. www.excelwater.com/thp/filters/Water–urification.htm. Accessed 12 May 2014

Li H, Ji H, Shi C, Gao Y, Zhang Y, Xu X et al (2017) Distribution of heavy metals and metalloids in bulk and particle size fractions of soils from coal-mine brownfield and implications on human health. Chemosphere 172:505–515

Li H, Zuo XJ (2013) Speciation and size distribution of copper and zinc in urban road runoff. Bull Environ Contam Toxicol 90:471–476

Lin ZY (1998) The source and fate of Pb in central Sweden. Sci Total Environ 209(1):47–58

Loutfy N, Fuerhacker M, Tundo P, Raccanelli S, El Dien AG, Ahmed MT (2006) Dietary intake of dioxins and dioxin–like PCBs, due to the consumption of dairy products, fish/seafood and meat from Ismailia city, Egypt. Sci Total Environ 370:1–8

Marshall FM, Holden J, Ghose C, Chisala B, Kapungwe E, Volk J, Agrawal M, Agrawal R, Sharma RK, Singh RP (2007) Contaminated irrigation water and food safety for the urban and Peri–urban poor: appropriate measures for monitoring and control from field research in India and Zambia, Inception report DFID Enkar R8160, SPRU. University of Sussex, Rome

Merian E, Anke M, Inhat M, Stoeppler M (2004) Elements and their compounds in the environment. Wiley VCH, Weinheim, Germany. https://doi.org/10.1002/9783527619634

Milacic R, Kralj B (2003) Determination of Zn, Cu, Cd, Pb, Ni and Cr in some Slovenian foodstuffs. Eur Food Res Technol 217:211–214

Moncur MC, Ptacek CJ, Blowes DW, Jambor JL (2005) Release, transport and attenuation of metals from an old tailings impoundment. Appl Geochem 20:639–659

Mottalib MA, Sultana A, Somoal SH, Abser MN (2016) Assessment of heavy metals in tannery waste-contaminated poultry feed and their accumulation in different edible parts of chicken. IOSR J Environ Sci Toxicol Food Technol 10(11):72–78

Muhammad S, Shah MT, Khan S (2011) Health risk assessment of heavy metals and their source apportionment in drinking water of Kohistan region, northern Pakistan. Microchem J 98(2):334–343

Muncke J (2016) Chemical migration from food packaging to food

Muñoz-de-Toro M, Beldoménico HR, García SR, Stoker C, De Jesús JJ, Beldoménico PM et al (2006) Organochlorine levels in adipose tissue of women from a littoral region of Argentina. Environ Res 102(1):107–112

Murtaza G, Ghafoor A, Qadir M, Owens G, Aziz MA, Zia MH, Saifullah (2010) Disposal and use of sewage on agricultural lands in Pakistan: a review. Pedosphere 20:23–34

Naseri M, Vazirzadeh A, Kazemi R, Zaheri F (2015) Concentration of some heavy metals in rice types available in Shiraz market and human health risk assessment. Food Chem 175:243–248

Nriagu JO (1990) The rise and fall of leaded gasoline. Sci Total Environ 92:13–28

O'Flaherty EJ (1996) A physiologically – based model of chromium kinetics in the rat. Toxicol Appl Pharmacol 138:54–64

Odai SN, Mensah E, Sipitey D, Ryo S, Awuah E (2008) Heavy metals uptake by vegetables cultivated on urban waste dumpsites: case study of Kumasi, Ghana. Res J Environ Toxicol 2(2):92r99

Odland JO, Deutch B, Hansen JC, Burkow IC (2003) The importance of diet on exposure to and effects of persistent organic pollutants on human health in the Arctic. Acta Paediatr 92:1255–1266

Pandit GG, Jha SK, Tripathi RM, Krishnamoorthy TM (1997) Intake of methyl mercury by the population of Mumbai, India. Sci Total Environ 205:267–270

Paul D (2017) Research on heavy metal pollution of river ganga: a review. Ann Agrarian Sci 15(2):278–286

Peer WA, Baxter IR, Richards EL, Freeman JL, Murphy AS (2006) Phytoremediation and hyperaccumulator plants, molecular biology of metal homeostasis and detoxification. Top Curr Genet 14(84):299–340

Phillips DJH (1995) The chemistries and environmental fates of trace metals and organochlorines in aquatic ecosystems. Mar Pollut Bull 31(4–12):193–200

Pongratz R, Heumann KG (1999) Production of methylated mercury, lead and cadmium by marine bacteria as a significant natural source for atmospheric heavy metals in polar regions. Chemosphere 39:89–102

Radford S (2019) Sources of contamination in food

Rahimi E (2013) Lead and cadmium concentrations in goat, cow, sheep, and buffalo milk from different regions of Iran. Food Chem 136(2):389–391

Raju KV, Somashekar RK, Prakash KL (2013) Spatio–temporal variation of heavy metals in Cauvery River basin. Proc Int Acad Ecol Environ Sci 3(1):59–75

Raskin I, Kumar PN, Dushenkov S, Salt DE (1994) Bioconcentration of heavy metals by plants. Curr Opin Biotechnol 5(3):285–290

Ravindra K, Mor S (2019) Distribution and health risk assessment of arsenic and selected heavy metals in Groundwater of Chandigarh, India. Environ Pollut. https://doi.org/10.1016/j.envpol.2019.03.080

Rieuwerts J (2015) The elements of environmental pollution. Routledge, p 166. ISBN 978-0-415-85920-2

Rose J, Hutcheson MS, West CR, Pancorbo O (1999) Fish mercury distribution in Massachusetts, USA Lakes. Environ Toxicol Chem 18:1370–1379

Sarkar A, Das S, Srivastava V, Singh P, Singh RP (2018). Effect of wastewater irrigation on crop health in the indian agricultural scenario. In: Emerging trends of plant physiology for sustainable crop production. Apple Academic Press, pp 357–371

Sayadi MH, Sayyed MRG (2011) Comparative assessment of baseline concentration of the heavy metals in the soils of Tehran (Iran) with the comprisable reference data. Environ Earth Sci 63(6):1179–1188

Schnoor J (1997) Phytoremediation: groundwater remediation technologies analysis center technology evaluation report TE-98-01, 37

Schoolmeester WL, White DR (1980) Arsenic poisoning. South Med J 73:198–208

Schroder JJ, Scolefield D, Cabral F, Hofman G (2004) The effects of nutrient losses from agriculture on ground and surface water quality: the position of science in developing indicators for regulation. Environ Sci Pol 7:15–23

Seidal K, Jorgensen N, Elinder CG, Sjogren B, Vahter M (1993) Fatal cadmium–induced pneumonitis. Scand J Work Environ Health 19:429–431

Sharafi K, Nodehi RN, Yunesian M, Mahvi AH, Pirsaheb M, Nazmara S (2019) Human health risk assessment for some toxic metals in widely consumed rice brands (domestic and imported) in Tehran, Iran: uncertainty and sensitivity analysis. Food Chem 277:145–155

Singh A, Sharma RK, Agrawal M, Marshall FM (2010) Health risk assessment of heavy metals via dietary intake of foodstuffs from the wastewater irrigated site of a dry tropical area of India. Food Chem Toxicol 48(2):611–619

Singh S, Kumar M (2006) Heavy metal load of soil, water and vegetables in Peri–Urban Delhi. Environ Monit Assess 120(1–3):79–91

Someya M, Ohtake M, Kunisue T, Subramanian A, Takahashi S, Chakraborty P et al (2010) Persistent organic pollutants in breast milk of mothers residing around an open dumping site in Kolkata, India: specific dioxin-like PCB levels and fish as a potential source. Environ Int 36(1):27–35

Song B, Lei M, Chen TB, Zheng YM, Xie YF, Li XY, Gao D (2009) Assessing the health risk of heavy metals in vegetables to the general population in Beijing, China. J Environ Sci 21(12):1702–1709

Srivastava V, Ismail SA, Singh P, Singh RP (2015) Urban solid waste management in the developing world with emphasis on India: challenges and opportunities. Rev Environ Sci Biotechnol 14:317–337

Srivastava V, De Araujo ASF, Vaish B, Bartelt-Hunt S, Singh P, Singh RP (2016) Biological response of using municipal solid waste compost in agriculture as fertilizer supplement. Rev Environ Sci Biotechnol 15:677–696

Srivastava V, Sarkar A, Singh S, Singh P, de Araujo ASF, Singh RP (2017) Agroecological responses of heavy metal pollution with special emphasis on soil health and plant performances. Front Environ Sci 5:64

Srivastava V, Gupta SK, Singh P, Sharma B, Singh RP (2018) Biochemical, physiological, and yield responses of lady's finger (Abelmoschus esculentus L.) grown on varying ratios of municipal solid waste vermicompost. Int J Recycl Org Waste Agric 7(3):241–250

Steenland K, Boffetta P (2000) Lead and cancer in humans: where are we now? Am J Ind Med 38:295–299

Stewart M, Phillips NR, Olsen G, Hickey CW, Tipa G (2011) Organochlorines and heavy metals in wild caught food as a potential human health risk to the indigenous Māori population of South Canterbury, New Zealand. Sci Total Environ 409(11):2029–2039

Taiwo AM, Oyebode AO, Salami FO, Okewole I, Gbogboade AS, Agim C, Davidson N (2018) Carcinogenic and non–carcinogenic evaluations of heavy metals in protein foods from southwestern Nigeria. J Food Compos Anal 73:60–66

Tajkarimi M, Faghih MA, Poursoltani H, Nejad AS, Motallebi A, Mahdavi H (2008) Lead residue levels in raw milk from different regions of Iran. Food Control 19(5):495–498

Tangahu BV, Abdullah SRS, Idris HBM, Anuar N, Mukhlisin M (2011) A review on heavy metals (As, Pb, and Hg) uptake by plants through phytoremediation. Int J Chem Eng. https://doi.org/10.1155/2011/939161

Tariq J, Jaffar M, Ashraf M (1993) Heavy metal concentrations in fish, shrimp, seaweed, sediment and water from Arabian sea, Pakistan. Mar Pollut Bull 26:644–647

Tasrina RC, Rowshon A, Mustafizur AMR, Rafiqul I, Ali MP (2015) Heavy metals contamination in vegetables and its growing soil. J Environ Anal Chem 2(142):2380–2391

Tchounwou PB, Yedjou CG, Patlolla AK, Sutton DJ (2012) Heavy metals toxicity and the environment. EXS 101:133–164

Thakur S, Singh L, Ab Wahid Z, Siddiqui MF, Mekbib S, Atnaw SM, Md Dir MF (2016) Plant–driven removal of heavy metals from soil: uptake, translocation, tolerance mechanism, challenges, and future perspectives. Environ Monit Assess 188(4):188–206

The Code of Federal Regulations of the United States of America. U.S. Government Printing Office. 2005. p. 116. Archived from the original on 2017-11-05

Thompson CM, Fedorov Y, Brown DD, Suh M, Proctor DM, Kuriakose L, Haws LC, Harris MA (2012) Assessment of Cr (VI)–induced cytotoxicity and genotoxicity using high content analysis. PLoS One 7:e42720

Tripathi RM, Mishra S, Bhalke S, Mahadevan TN, Puranik VD (2003) Applications of SPME–GCMS for determination of methylmercury in environmental matrices. In: Proceedings of XII–National Symposium on Environment, pp 456–461

Tsukino H, Hanaoka T, Sasaki H, Motoyama H, Hirosima M, Tanaka T et al (2006) Fish intake and serum levels of organochlorines among Japanese women. Sci Total Environ 359:90–100

U.S. Environmental Protection Agency Washington, DC; TOXICOLOGICAL REVIEW OF TRIVALENT CHROMIUM; 1998; (CAS No. 16065-83-1)

US EPA (1998) A Citizen's Guide to Phytoremediation, Office of Solid Waste and Emergency Response (5102G) EPA 542-F-98-001 August 1998
USEPA (2000) Introduction to Phytoremediation, National Risk Management Research Laboratory, Office of Research and Development, EPA/600/R-99/107, February 2000
Van Oostdam J, Donaldson S, Feeley M, Tremblay N (2003) Canadian arctic contaminants assessment report II: human health. Ottawa, Northern Contaminants Program, p 127
Van Oostdam J, Gilman UA, Dewailly E, Usher P, Wheatley B, Kuhnlein H et al (1999) Human health implications of environmental contaminants in Arctic Canada: a review. Sci Total Environ 230:1–82
Voegborlo RB, Methnani AME, Abedin MZ (1999) Mercury, cadmium and lead content of canned tuna fish. Food Chem 67:341–345
Wang Q, Kim D, Dionysiou DD, Sorial GA, Timberlake D (2004) Sources and remediation for mercury contamination in aquatic systems – a literature review. Environ Pollut 131:323–336
Waseem A, Arshad J (2016) A review of Human Biomonitoring studies of trace elements in Pakistan. Chemosphere 163:153–176
Wedepohl KH (1995) The composition of the continental crust. Geochim Cosmochim Acta 59(7):1217–1232. Bibcode:1995GeCoA..59.1217W. https://doi.org/10.1016/0016-037(95)00038-2
WHO (1976) The International Programme on Chemical Safety (IPCSINCHEM Database) Environmental Health Criteria 1, Mercury. Available from: http://www.who.int/ipcs/publications/ehc/ehc_numerical/en/
WHO (2010) Exposure to arsenic: a major public health concern. World Health Organization, Public Health and Environment, Geneva, pp 1–5
WHO (2017) Lead poisoning and health [Online]
WHO (2001) Arsenic and arsenic compounds. Environmental health criteria, vol 224. World Health Organization, Geneva
Widianarko B, Van Gestel CAM, Verweij RA, Van Straalen NM (2000) Associations between trace metals in sediment, water and guppy, Poecilia reticulata (Peters), from urban streams of Semarang. Indones Ecotoxicol Environ Saf 46:101–107
Wilcke W, Krauss M, Kobza J (2005) Concentrations and forms of heavy metals in Slovak soils. J Plant Nutr Soil Sci 168(5):676–686
Wood JM (1974) Biological cycles for toxic elements in the environment. Science 183:1049–1052
Wood P (1997) Remediation methods for contaminated sites. In: Hester R, Harrison R (eds) Contaminated land and its reclamation. The Royal Society of Chemistry, Cambridge, pp 47–71
World Health Organization and Food and Agriculture Organization (2007) Joint FAO/WHO Food Standard Programme Codex Alimentarius Commission, 13th Session; Report of the Thirty–Eight Session of the Codex Committee on Food Hygiene, Houston
Xia W, Hu J, Zhang B, Li Y, Wise JP, Sr Bassig BA, Zhou A, Xiong C, Zhao J, Du X, Zhou Y, Pan X, Yang J, Wu C, Minmin J, Peng Y, Qian Z, Savitz DA, Zheng T, Xu S (2016) A case–control study of maternal exposure to chromium and infant low birth weight in China. Chemosphere 144:1484–1489
Xiao R, Wang S, Li R, Wang JJ, Zhang Z (2017) Soil heavy metal contamination and health risks associated with artisanal gold mining in Tongguan, Shaanxi, China. Ecotoxicol Environ Saf 141:17–24
Xiu-Zhen HAO, Dong-Mei ZHOU, Huang DQ, Long CANG, Zhang HL, Hui WANG (2009) Heavy metal transfer from soil to vegetable in southern Jiangsu Province, China. Pedosphere 19(3):305–311
Yang YB, Sun LB (2009) Status and control countermeasures of heavy metal pollution in urban soil. Environ Prot Sci 35(4):79–81
Zahir F, Rizwi SJ, Haq SK, Khan RH (2005) Low dose mercury toxicity and human health. Environ Toxicol Pharmacol 20(2):351–360
Zhang WJ, Jiang FB, Ou JF (2011) Global pesticide consumption and pollution: with China as a focus. Proc Int Acad Ecol Environ Sci 1(2):125–144

Zhou H, Yang WT, Zhou X, Liu L, Gu JF, Wang WL et al (2016) Accumulation of heavy metals in vegetable species planted in contaminated soils and the health risk assessment. Int J Environ Res Public Health 13(3):289

Zhou QX (1995) Ecology of compound pollution. China Environmental Science Press, Beijing

Zhuang P, Murray BM, Xia H, Li N, Li Z (2009) Health risk from heavy metals via consumption of food crops in the vicinity of Dabaoshan mine, South China. Sci Total Environ 407:1551–1561

Zimakowska-Gnoińska D, Bech J, Tobias FJ (2000) Assessment of the heavy metal pollution effects on the soil respiration in the Baix Llobregat (Catalonia, NE Spain). Environ Monit Assess 61(2):301–313

Zojaji F, Hassani AH, Sayadi MH (2014) Bioaccumulation of chromium by Zea mays in wastewater–irrigated soil: an experimental study. Proc Int Acad Ecol Environ Sci 4(2):62–67