Ingression of Heavy Metals in Urban Agroecosystems: Sources, Phytotoxicity and Consequences on Human Health

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1 Introduction

Globalisation and industrialisation have gradually altered and posed challenges to the agricultural growth and crop production system in peri-urban areas (Liu and Li 2017). Recent years have seen a lot of pressure placed on crop production systems due to shrinking peri-urban agroecosystems, climate change, unsustainable land use, human-driven ecological degradation and growing population to name a few (Kremen and Merenlender 2018; Fantini 2023). Due to these food security threat phenomena, global action plan and policy reforms are much needed to transform our food systems (Liebig et al. 2022; Woodhill et al. 2022). Structuring food systems efficient of provisioning urban clusters that guarantee food security as well as a healthy environment is crucial since the development of the agricultural-industrial paradigm has permitted the fast rise in urban population on a universal scale (Fantini 2023). As the world gradually urbanises, many regions are losing biodiversity and local food sources. Moreover, there is more emphasis on economic gains and crop production maximisation rather than environmental and human health values (Usman et al. 2021). Urban agroecosystems have been thought of as a strategy to encourage and maintain urban residents' access to food (Peroni et al. 2022). Urban farming is the practice of growing crops in or near a village, town, city or metropolis with at least some of their output intended for urban consumption (Mulier et al. 2022).

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Despite these advantages, urban agroecosystems may nonetheless confer a risk to human health because of the many anthropogenic activities that frequently result in high concentrations of risk components in urban soil (Malone 2022). Therefore, multiple potential drawbacks are associated with urban agriculture including human health risks and implications for the environment as well (Stewart et al. 2013). The skeleton and body of urban ecosystems depend upon energy use, import, transformation and export of materials (Bai 2016). Such energy and material transformations have beneficial implications on urban growth; however, in this process, certain xenobiotic compounds may pose potential negative impacts on ecosystem and human health (Stewart et al. 2013). The usage of wastewater, for instance, may contaminate the crops with organic and inorganic xenobiotics, alter the soil properties and pollute the groundwater owing to leaching (Lyu et al. 2022). Extensive application of pesticide and fertilisers may potentially endanger the environment and pose health hazards to urban residents.

Xenobiotics are the compounds, mainly the contaminants, that are not found in the natural environment and are generated or introduced as a consequence of human interventions (Stefanac et al. 2021). These xenobiotics usually impart negative influences on human population and their environment by meddling with metabolic and ecological processes (Ortiz et al. 2022). Xenobiotics can have lethal, mutagenic or teratogenic impacts on people even in minute quantities, when exposed over an extended time period (Dhuldhaj et al. 2023). In recent past, researchers become interested in the contamination of agroecosystems with xenobiotics since it has the propensity to contaminate the food chain, cause biomagnification in trophic levels and pose serious health risks to both humans and animals.

Xenobiotics may include inorganic contaminants, organic contaminants and biological contaminants (Atashgahi et al. 2018). Inorganic contaminants include heavy metals that are transferred to urban agroecosystems owing to anthropogenic activities required to fulfil energy and economy demands of human population in urban ecosystem (Singh et al. 2022). Organic wastes chiefly contain fertilisers, pesticides, pharmaceuticals, personal care products (PPCPs) and other emerging contaminants (ECs). These may be composed of polyaromatic hydrocarbons, chlorofluorocarbons and other highly toxic and hazardous contaminants (Gupta et al. 2022). In general, biological waste is discharged from labs, care establishments, nursing homes, mortuaries, autopsy centres and blood banks (Pepin et al. 2014). If not managed properly, this medical waste may further be a source of deadly microorganisms such as virus, bacteria or fungi and may pose severe health threats for human population (Ramteke and Sahu 2019).

It is vitally important to handle these wastes containing potentially harmful xenobiotics that could harm both human and ecological health (de Oliveira et al. 2020). However, in third-world countries, xenobiotics may end up concentrating in the urban components such as agroecosystems, water bodies and air owing to lack of high-end waste management facilities and eventually distressing the human health (Kumar and Chopra 2020; Karthigadevi et al. 2021). Agroecosystems are the ecosystems that have been altered by human intervention for the crop cultivation (Khumairoh et al. 2012). Due to the human interventions, agroecosystems have recurrent presence of heavy metals and agrochemicals, including pesticides, fertilisers and other anthropogenic contaminants (Alengebawy et al. 2021; Okereafor et al. 2020). Soil is an integral part of the agroecosystem and a living media for plants, microbes and animals. The soil has always been important to human and their health, providing a resource that can be used for food crop production (Steffan et al. 2018). It is also the foundation for various ecological processes; therefore, proper management is necessary to safeguard food safety and human health (Alengebawy et al. 2021).

With an atomic density greater than 5 g cm^{-3}, a class of metals and metalloids are referred to as "heavy metals" (Hawkes 1997). Heavy metal contamination affects food crops, water resources and agroecosystems and can endanger the health and welfare of both man and animal (Briffa et al. 2020). An excessive build-up of heavy metals may contaminate the soil, lower crop quality and compromise food safety (Liu et al. 2013). Several variables, including soil pH, organic matter, cation exchange capacity, crop growth phases, crop type, fertilisers, soil type, metal speciation, soil microorganisms present and other characteristics, affect the uptake, distribution and transport of heavy metals in the soil and crops (Liu et al. 2006). It is crucial to safeguard this resource and preserve its sustainability because heavy metal contamination in agroecosystems may cause soil dysfunction, interfere with crop growth and potentially harm human health through a polluted food chain (Singh et al. 2021).

Henceforth, this chapter provides a comprehensive and critical explanation of the distribution and sources of heavy metals in urban agroecosystems, as well as the factors that impact their ingression, accretion and migration within these systems and the consequences they have on crop plants and human health.

2 Sources of Heavy Metals in the Urban Agroecosystems

2.1 Wastewater Irrigation

Utilisation of wastewater for irrigation is a common practice in developing countries, particularly in arid and semi-arid regions (Minhas et al. 2022). Prolonged use of untreated municipal and industrial wastewater for irrigation leads to the heavy metal accretion in the soil, transferring it in the food crops, and causes numerous health disorders on contaminated crop consumption (Kumar and Chopra 2014; Pal et al. 2023). Long-term wastewater irrigation has potential to change the soil's physical and chemical properties and lead to heavy metal uptake by plants, mostly vegetables (Mahmood and Malik 2014). The high occurrence of Cd, Cr, Ni and Pb were reported in sewage water used to irrigate the urban agroecosystems of Faisalabad, Pakistan, by Jabeen et al. (2022). Wastewater irrigated vegetables had heavy metal concentrations higher than those allowed by the European Union and the World Health Organization (WHO). The hazard ratio for these heavy metals was larger than 1, indicating a severe health risk upon consumption of these vegetables by the region's urban residents. Wastewater irrigation practice over an extended period of time has been demonstrated to affect the crop growth by altering the physiology and biochemistry of crop plants and pose human health risks in India (Kumar et al. 2020). Thus, prolonged wastewater irrigation has been reported as a primary route to food chain contamination, leading to severe human health risks globally. Multiple sources of heavy metal contamination in agroecosystems have been shown in (Fig. 1).

2.2 *Fertilisers and Pesticides*

Application of inorganic fertilisers, herbicides, insecticides, composts and manure, among other agricultural techniques, is thought to increase the concentration of heavy metals including As, Cr, Cu, Zn and Cd in agricultural soils (Zhang et al. 2010). Because phosphorous is regarded as a vital mineral for agricultural plants' growth and development, phosphate-based fertilisers are the most popular among the many fertiliser types (Gupta et al. 2014). An Indian study reported that prolonged application of inorganic fertiliser acted as significant contributor to the Cd augmentation in top soil, further causing the Cd build-up in paddy (Rao et al. 2018). It was revealed that heavy metal concentrations were associated to fungicides and copper-based fertilisers (Schneider et al. 2019). Arsenic-based fungicides accounted

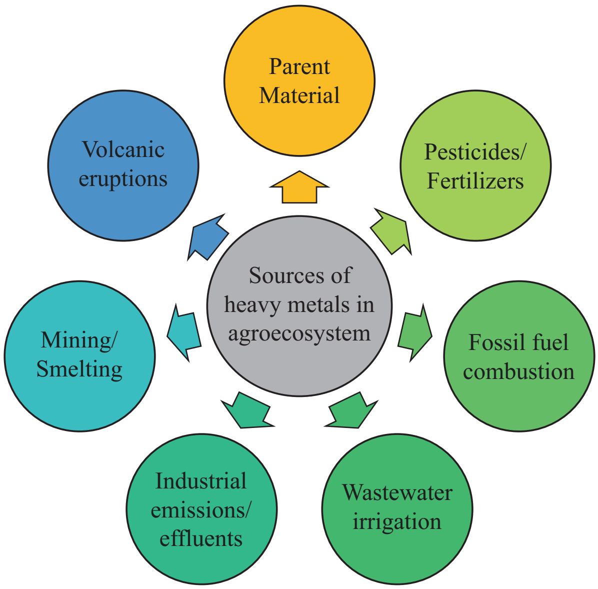

Fig. 1 Representation of natural and anthropogenic sources of heavy metal contamination in agroecosystems

for 0.28 to 3.84 mg ha^{-1} of the yearly arsenic influx into paddy fields (Wang et al. 2018). Since these agrochemicals have high shelf life and mostly are non-biodegradable in nature, their uncontrolled and prolonged application has resulted in the contamination of agroecosystems around the world.

2.3 Atmospheric Deposition

Heavy metals can be released into the atmosphere through both natural and human-driven processes in the form of particles, vapours or primary oxides. The principal contributors to the atmospheric deposition of heavy metals include the burning of fossil fuels, vehicular emissions, mining activities, metal smelting and other industrial processes. Particles containing heavy metals enter biological cycles and food chains by dry and moist deposition, depositing in topsoil and surface water layers (Guo et al. 2016). The atmospheric deposition of metal elements that fall as dust and are settled on the above-ground tissues of plants during mining activities may directly or indirectly absorb metal elements from the air. Prior research has shown that various heavy metals, viz. As, Cd, Cu, Hg and Pb, are released into the atmosphere from coal combustion, Zn, emanates from vehicular emissions and mining and Cr, from smelting (Huang et al. 2014).

2.4 Industrial Activities

Different industrial processes, which contribute to heavy metals contamination, discharge industrial effluent, solid waste and dry and wet deposition into the environmental components. Fly ash discharge, smoke, the dumping of untreated or inadequately treated effluent and the disposal of solid waste in that area all make the agroecosystems close to industrial areas susceptible to trace metal pollution. The soil contamination with Hg comes primarily from coal-fired power stations. According to a study, foods including lettuce, amaranth, water spinach, cowpea and cereals cultivated in soils with high levels of Hg are detrimental for human health if consumed over an extended period of time (Li et al. 2018). Industries, for instance, tannery, chrome plating, ammunition factories, steel and alloys, are the major sources of chromium into the environment (Nagarajappa et al. 2017), whereas the majority of the Pb is released from various smelting, mining and acid battery manufacturing (Cwieląg-Drabek et al. 2020). However, Zn is used for agrochemical manufacturing such as herbicides (Zinc sulphate), while Ni is associated with petrochemical emissions. Mombo et al. (2016) reported foliar transfer and Pb accumulation in lettuce (9.8 mg kg^{-1}) in kitchen gardens situated near a lead recycling factory.

2.5 Solid Waste Disposal

The massive production of municipal solid waste (MSW) worldwide as a result of expanding urbanisation and population growth is posing significant challenges for its management (Gui et al. 2019). Incineration, landfills and open dumps situated in urban areas are significant metal-release pathways into the soil. Incineration is the easiest way of disposing of the solid waste; however, large volume of fly ash, containing organic and inorganic pollutants (heavy metals), is generated during incineration (Singh et al. 2023). Hence, fly ash from the MSW incineration process has a potential to pose threats to human and environmental health and yet is frequently disposed of in landfills (Lo and Liao 2007). The frequently found heavy metals in fly ash include Pb, Hg, Ni, Cr, Cu, Cd and Zn (Tang et al. 2015). The leaching of heavy metals from landfills to the agroecosystems present in the vicinity may act as a potential route of heavy metal transfer to soil and the crops and subsequently into the food chain. Ma et al. (2018) found that the agroecosystems in an MSW incinerator's vicinity in North China were found severely contaminated by potentially toxic heavy metals (As, Hg, Pb, Cd) representing the incineration process as the chief cause of heavy metal contamination.

2.6 Mining

Across the globe, there is a lot of concern about heavy metal contamination in mining areas where farming is also practised (Wu et al. 2023). Heavy metals are released into the environment as a result of mining operations, viz. ore concentration, and transportation processes, which can endanger human health, ecological integrity, habitat and food security. Significant soil pollution in villages close to artisanal gold mining operations was documented by Xiao et al. (2017). Hg and Cd were discovered to have polluted surface soils significantly. In addition, it was discovered that the region's vegetables and cereal grains had increased levels of Pb and Hg. Consumption of heavy metal-contaminated food crops grown in close proximity to an acidic mining drainage area was reported to be linked to serious health concerns for humans (Xiao et al. 2017).

3 Factors Affecting Heavy Metal Transfer and Mobility in Urban Agroecosystems

3.1 Soil Parameters

Soil pH and redox potential (Eh) play key role in heavy metal mobility in soil-plant system. Heavy metal solubility decreases at high pH levels and increases at low pH levels (Sheoran et al. 2016). This is a result of soil components with varied surface charges and solute adsorption, such as silicate clays, organic compounds and Fe and Al oxides. The change in surface charge is what determines how pH affects adsorption (Bhargava et al. 2012). Low pH soils are more likely to have heavy metals migrate from the solid soil components into the soil solution. In alkaline soils, there is less of a risk of heavy metal leaching (Mn, Cu and Zn) and their bioavailability to agricultural plants, according to research conducted by Huang et al. (2014). The soil solution's propensity to receive or donate electrons is determined by the Eh of the soil (Sheoran et al. 2016). Dynamics of Eh conditions can directly or indirectly alter the dynamics of heavy metals, due to modifications in pH, dissolved organic carbon and the chemistry of Fe and Mn oxides (Husson 2013). Under anaerobic conditions, heavy metals associated with Fe/Mn oxides release because of the oxides' reduction-induced dissolution (Antoniadis et al. 2017). Change of Eh towards reducing conditions is usually accompanied with pH increase due to the consumption of protons required to reduce Mn and Fe (Rinklebe and Shaheen 2014).

A crucial component of the soil that has a significant role in maintaining the soil fertility is soil organic matter (SOM). SOM has the ability to retain heavy metals by complexion and adsorption; however an inner sphere and ion exchange reaction may also be occasionally involved (Evans 1989). Soil temperature mostly impacts the rate of organic matter transformation, which in turn affects how bioavailable heavy metals are in the soil. Temperature was found to have a significant impact on the bioavailability of metals in a study by Antoniadis and Alloway (2001); soil extracts and plant samples treated at 25 °C had higher amounts of Cd, Ni and Zn than those treated at 15 °C. The quick decomposition of organic matter at a greater temperature was the root of this. The soil texture reflects the particle size distribution of the soil and the content of fine particles such as oxides and clay. The heavy metal retention is higher in fine-textured soils than coarse-textured soils due to the presence of more pore spaces (Sheoran et al. 2010). Heavy metals in soil are dynamically mobilised and bioavailable due to cation exchange capacity (CEC). Compared to clay, which has stronger binding force, sand has a lower affinity for heavy metals and other cations, because clay has a large cation exchange capacity (Antoniadis et al. 2017). According to reports, clayey soils tend to have greater CEC values, which slow down the movement of cationic metals and reduce their availability in soils (Antoniadis and Golia 2015). While CEC only apprehends cations by description, anionic species are maintained at higher amounts in high-CEC soils than in low-CEC soils (Becquer et al. 2001). Additionally, it was observed that a rise in soil CEC could promote the precipitation and complexation of heavy metals in agricultural soils (Vega et al. 2010).

3.2 Interactions with Soil Microbiota

The release of organic acids, siderophores, enzymes, surfactants and other oxidation-reduction activities as well as biosorption makes microbial communities a powerful influencer in the soil that considerably alters the heavy metal mobility in the agroecosystems (Luo et al. 2011). Bacterial species such as *Stenotrophomonas* spp., *Bacillus subtilis* and *Escherichia coli* are fast growing and possess functional groups on their surface that can adsorb or precipitate heavy metals in the soil (Wang et al. 2014). *Bacillus* spp. and *Paenibacillus* spp. are known to adsorb and precipitate the heavy metals in the rhizospheric zone owing to their surface functional groups (Radhakrishnan et al. 2017). The polysaccharide-rich surface in *Paenibacillus* helps in the immobilisation of heavy metals such as Pb, Cu, Co and Zn (Prado et al. 2005). The majority of bacteria and fungi found in plants makes siderophores, which are stable complexes of iron with metals such as Al, Cd, Cu, Ga, In, Pb and Zn (Schalk et al. 2011). Some researchers have reported that organic acids released by plant-allied microbes aid in the uptake of heavy metals like Cu, Zn and Cd as well as Pb by plant roots (Sheng et al. 2008). Mycorrhizal fungi have a large surface area, their cell wall components and intracellular compounds that confer them a solid capacity to immobilise the metals in the interior of plant roots heavy metals from soil (Meharg 2003).

3.3 Plant Parameters

Numerous plant characteristics affect the uptake of heavy metals, including crop type, leaf area, leaf inclination angle, branching pattern, smoothness of exposed sections, canopy type, stomata size, exposed surface area and rate of transpiration, to mention a few (Shahid et al. 2017). Due to their rapid development, increased translocation and increased transpiration rates, leafy greens acquire more heavy metals than other vegetables (Gupta et al. 2021). A plant with many thin roots has a higher capacity to accumulate heavy metals than one with thick roots because of the increased surface area that allows for improved precipitation and ion exchange processes at the root surface (Page and Feller 2015). The rhizosphere's ability to move heavy metals is also impacted by root exudates.

4 Heavy Metal Toxicity on Crop Plants

Due to their universal occurrence and severe and long-lasting detrimental effects on crop plants, their growth and developmental processes, toxic heavy metal contamination of urban agroecosystems has become a solemn environmental-ecological health concern. At the molecular level, heavy metals can result in membrane disintegration, mutations of genetic material, breakage in DNA strands, molecular cross-linkage, oxidative stress, damage from reactive oxygen species (ROS) and ultimately stunt the development of crops (Hossain et al. 2010).

The production of ROS enhances a series of effects of heavy metal toxicity in crop plants resulting in oxidative stress, leading to membrane disintegration, biomolecule deterioration, ion leakage, lipid peroxidation and, most important, DNA

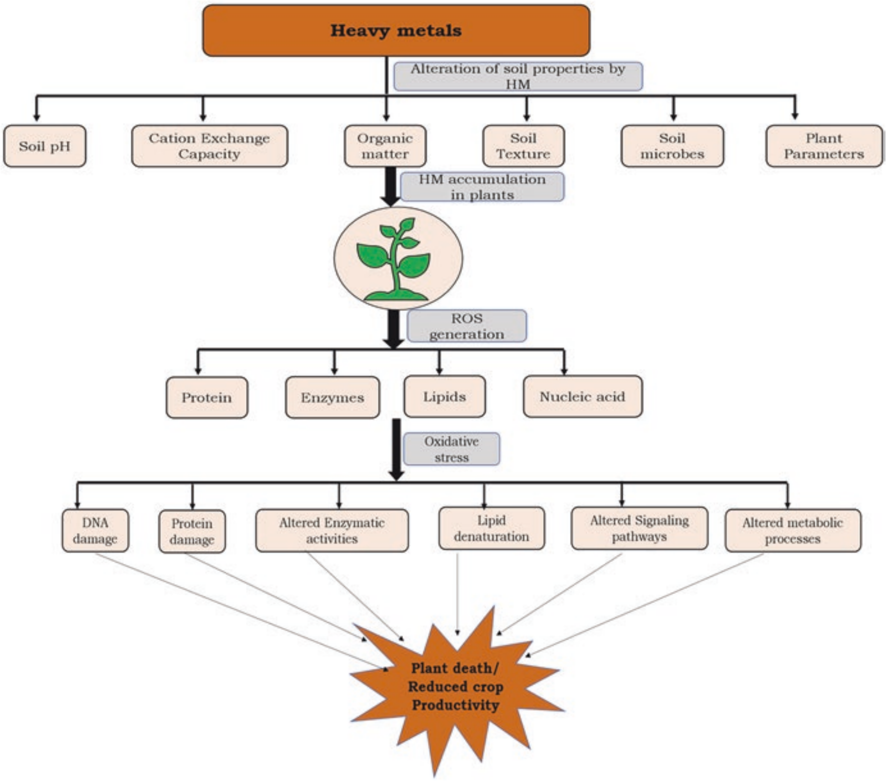

Fig. 2 Heavy metal-induced toxicity in crop plants

strand cleavage (Shahid et al. 2014) (Fig. 2). Heavy metals pose detrimental physiological impacts on several growth phases in crop plants, especially onset of germination and its frequency, seedling development and reproduction (Table 1). Ni in higher concentration is linked with seed germination inhibition and retardation in many crops owing to its toxic effects on biochemical activities affecting enzyme action. Additionally, it is reported that it interferes with the assimilation, uptake and mobilisation of food reserves (proteins, lipids and carbohydrates) in germinating seeds (Ashraf et al. 2011).

One of the key factors affecting photosynthesis that has a significant impact on CO_2 fixation, electron transport, photophosphorylation and enzyme action is Cr stress. On the other hand, when there is a high concentration of Pb in the soil, a number of plant species display abnormal morphology. High Ni concentrations in plant tissues indicate nutritional imbalance impairment and lead to dysfunctional cell membrane functioning. Delayed germination, leaf necrosis and wilting are signs of As phytotoxicity. These are followed by root discolouration and slowed shoot growth (Joardar et al. 2019). The mechanism of action leading to As toxicity includes, alteration in signaling pathways involved in membrane degradation, electrolyte leakage, and ROS generation (Smith et al. 2010).

Table 1 Heavy metal-induced phytotoxicity on morphological, physiological and reproductive traits of food crops

Heavy metals	Crops	Phytotoxic effects	References
Arsenic	*Vigna radiata*	Reduced shoot and root development; reduced biomass, total chlorophyll and carotenoid content; aberrant stomata caused by altered and delayed mitosis; cytoplasmic and microtubule assembly disintegration	Gupta and Bhatnagar (2015), Das and Sarkar (2018)
	Oryza sativa	Reduced growth and production, shorter roots and shoots, less dry biomass and elevated oxidative stress	Nath et al. (2014), Awasthi et al. (2017), Kalita et al. (2018)
	Glycine max	Reduced root absorption, metal uptake, stomatal conductance and osmotic potential in leaf, reduced chlorophyll content, cell death of root tips, structural damage to xylem and phloem tissues, lipid peroxidation, overall hampered growth, rise in ROS generation and DNA oxidation	Armendariz et al. (2017), Chandrakar et al. (2017), Vezza et al. (2018)
	Allium sativum	Reduction in root, shoot and plant biomass	Torres et al. (2017)
	Brassica juncea	Inhibition of root length, decrease in number of lateral roots, decreased root length ratio and root mass ratio, overproduction of ROS species	Pandey et al. (2016)
	Pisum sativum	Reduced seed germination	Yoon et al. (2015)
	Brassica juncea	Reduced growth and generation of ROS species	Kanwar and Poonam (2015)
	Vicia faba	Reduced photosynthetic rate due to stomatal limitations	Austruy et al. (2013)
	Helianthus annuus	Reduced plumule length, radicle length and seedling vigour index	Imran et al. (2013)
	Zea mays	Reduced fresh weight percentage and root length	Mallick et al. (2011)
Cadmium	*Zea mays*	Reduced plant growth, antioxidants and enzymatic activities, altered photosynthetic pigments	Akinyemi et al. (2017), Anjum et al. (2015)
	Cucumis sativus	Decreased nutrient uptake and photosynthetic performance	Sun et al. (2017)
	Solanum tuberosum	Reduced shoot and root length and dry weight of potato	Hassan et al. (2016)
	Brassica oleracea	Reduced leaf area and dry weight of leaf stem and root	Jinadasa et al. (2016)
	Capsicum annum	Reduced root length, shoot area and root tips	Huang et al. (2015)

(continued)

Table 1 (continued)

Heavy metals	Crops	Phytotoxic effects	References
	Glycine max	Decreased net photosynthetic rate, stomatal conductance and total chlorophyll content	Xue et al. (2014)
	Beta vulgaris	Reduced number of PSII super complexes, increase in monomeric form of the light-harvesting complex II (LHCII) antennae	Basa et al. (2014)
	Brassica napus	Cracked cell walls, undeveloped mitochondria, plasmolysis and the absence of endoplasmic reticulum in cells of root tips	Ali et al. (2013)
	Tomato	Decrease in Zn, Mn and K concentration in aerial parts of plant	Bertoli et al. (2012)
	Solanum tuberosum	DNA damage in root cells of seedlings	Gichner et al. (2008)
Chromium	*Eruca sativa*	Decrease in root growth	Kamran et al. (2015)
	Triticum aestivum	Reduction in plant biomass	Ali et al. (2015)
	Allium cepa	Genotoxicity	Kumari et al. (2016)
	Pisum sativum	Reduction in chloroplast volume and auto fluorescence	Rodriguez et al. (2012)
	Oryza sativa	Reduction in uptake of N, P, K, Cu, Zn, Fe	Sundaramoorthy et al. (2010)
Copper	*Glycine max*	Alteration in chloroplast structure	Sanchez-Pardo et al. (2014)
	Zea mays	Decrease in seedling biomass, reduction in plant height and leaf area	Barbosa et al. (2013), Dresler et al. (2014)
	Triticum aestivum	Reduction in seed germination, alteration in DNA and RNA structure and content, decrease in shoot, root and leaf weight	Gang et al. (2013) Kumar et al. (2012)
	Brassica juncea	Decrease in photosynthetic pigments and leaf chlorosis	Feigl et al. (2015)
	Cucumis sativus	DNA damage/alteration, reduction in leaf number and area	Zheng et al. (2010), Işeri et al. (2011)
	Vigna radiata	Reduction in growth, dry matter and yield	Manivasagaperumal et al. (2011)
Lead	*Medicago sativa*	Lipid peroxidation leading to oxidative stress	Hattab et al. (2016)
	Pisum sativum	Damage to oxygen-evolving centre (OEC), inhibition of photosystem I and II	Rodriguez et al. (2015)
	Zea mays	Chlorophyll reduction in leaves, reduction in root and shoot macro- and micro-nutrient concentrations	Singh et al. (2015)

(continued)

Table 1 (continued)

Heavy metals	Crops	Phytotoxic effects	References
	Sesbania grandiflora	Disruption of several metabolic processes, which leads to the decrease in biomass production	Malar et al. (2014)
	Oryza sativa	Morphological alteration in guard cells, stomatal dysfunction	Srivastava et al. (2014)
	Allium cepa	DNA damage in root cells	Jiang et al. (2014)
	Triticum aestivum	Biomass reduction	Ramesar et al. (2014)
	Luffa cylindrica	Decrease in fresh weights of cotyledons, hypocotyls and radicals	Jiang et al. (2010)
Mercury	*Helianthus tuberosus*	Delayed seedling emergence; decrease in plant height, internode length and leaf area; enhanced lipid peroxidation; reduced chlorophyll content and plant biomass	Lv et al. (2018)
	Jatropha curcas	Decreased growth	Negrete et al. (2016)
	Allium sativum	Inhibition of seedling growth, rotting of roots	Zhao et al. (2013)
	Arachis hypogaea	Decrease in seed germination, chlorophyll content, protein content	Abraham and Damodharan (2012)
	Oryza sativa	Inhibition in germination percentage, shoot and root length, lower fresh and dry weight	Gautam et al. (2010)
	Brassica oleracea	Inhibition of seed germination, reduced coleoptile growth and root elongation	Ling et al. (2010)
Nickel	*Hordeum vulgare L.*	Reduced grain and straw yield; reduced plant height, number of ears and grain weight; altered micronutrient levels	Kumar et al. (2018)
	Glycine max L.	Reduced dry and fresh weight of roots and shoots	Reis et al. (2017)
	Triticum aestivum L.	Reduced plant height, shoot and root growth	Parlak (2016)
	Coriandrum sativum	Reduced seed germination frequency and seedling growth	Poozesh and Tagharobian (2014)
	Arachis hypogaea	Reduced root and shoot length, number of nodules, leaf area, dry weight of root and shoot and biochemical constituent pigments, sugars, starch, amino acids. protein and proline contents of leaves	Kaveriammal and Subramani (2015)
	Brassica juncea	Reduced growth and yield	Gopal and Nautiyal (2012)

Heavy metals are translocated from roots of the plants to edible portions (Wijeyaratne and Kumari 2021). Therefore, the high concentration of heavy metals in the soil causes several adverse effects on the growth and productivity of crop plants (Table 1).

5 Consequences on Human Health

Owing to consumption of contaminated crops and food items, heavy metals are transferred into the food chain (Fig. 3). Even at very low exposure levels, heavy metals have the potential to interfere with physiological processes after entering the human body and bonding with biomolecules like proteins and lipids. For instance, inorganic arsenic (iAs) has the potential to cause cancer (IARC 2012), and chronic exposure has been linked to diabetes, cardiovascular disease and skin lesions. Overexposure to Pb could have harmful consequences on the immunological, circulatory and nervous systems (Liu et al. 2018).

Complex relationships exist between methyl mercury and developmental and cognitive disorders (Liu et al. 2017). It has been recognised that Cd is a powerful endocrine disruptor that can cause cancers of the prostate and lung, as well as anaemia, renal tubular failure, pulmonary oedema and osteoporosis (Kabir et al. 2015). Acute and chronic toxic effects of heavy metals on human health have been summarised in Table 2.

Human health risk in the soil-dust fall-plant system was evaluated by Wang et al. in 2018. It was discovered that the target hazard quotient (THQ) of the Cr in corn kernels and the Cr, Pb and Cd in rice grains and vegetables was more than 1, indicating that Cr via consumption of corn kernels and the Cr, Pb and Cd via consumption

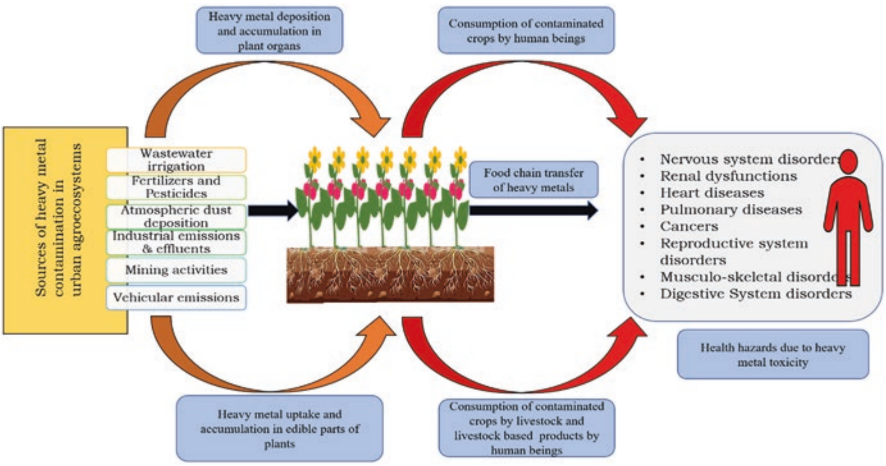

Fig. 3 Transfer of heavy metals in food chain and associated human health disorders

Table 2 Acute and chronic toxicity of heavy metals on human health

Heavy metal	Target organ/organ system	Clinical effects	References
Arsenic	Gastrointestinal, cardiovascular, pulmonary, renal, nervous, reproductive and integumentary system	Nausea, vomiting, headache, delirium, encephalopathy, seizures, respiratory failure, pulmonary oedema, encephalopathy, spontaneous abortion, low birth weight, blackfoot disease, ischaemic heart disease, cerebrovascular diseases, hypertension, dermatitis, diabetes mellitus, chronic bronchitis, liver damage, Bowen's disease	Chakraborti et al. (2016)
Cadmium	Skeletal system, reproductive system, renal organs	Spontaneous abortion, stillbirth; kidney damage; pregnancy-induced hypertension syndrome'; proteinuria; bladder cancer, pancreatic cancer and lung cancer; osteoporosis; male infertility; prostate cancer; itai-itai disease	Hagino and Yoshioka (1961), Jaishankar et al. (2014)
Chromium	Respiratory system, integumentary system, renal organs, reproductive system	Dermatitis and skin ulcers, bronchial carcinomas, bronchitis, dyslipidaemia, increased skin sensitivity and dermatitis, decrease in sperm count, cardiovascular collapse, facial erythema, renal dysfunction	Neghab et al. (2015), Buters and Biedermann (2017), Tsai et al. (2017)
Lead	Nervous system, reproductive system, digestive system, respiratory system	Dementia, anaemia, premature birth, low birth weight, arthritis, allergies, autism, birth deformities, brain damage, dyslexia, paralysis, weight loss, Parkinson's disease, loss of neurons, muscular tremors, reduced spermatogenesis, suppressed testosterone formation, abnormal sperm size	Eibensteiner et al. (2005), Pfadenhauer et al. (2014), Rodrigues et al. (2016)
Mercury	Nervous system, digestive system, immune system, pulmonary and renal organs	Eye and skin corrosion; impaired memory; impairment of the kidneys, lungs, digestive, immune and nervous systems; asthma; dermatitis; autoimmunity diseases, central nervous system damage; Alzheimer's disease	de Vos et al. (2007), WHO (2017), Aaseth et al. (2018), Kaur et al. (2018)

of rice grains and vegetables would pose a serious health risk to local residents in the Tongling mining area. Roy and McDonald (2015) used six species of houseplants to analyse soil contaminated with a range of heavy metals, such as Pb, Zn, Cd and Cu. They then assessed the health risk for inhabitants of Spelter, USA, based on the concentration of heavy metals in the plant's edible tissues. It was found that carrots accumulated Cd (40 mg kg^{-1}) at concentrations that were 5, 8 and 12 times, respectively, higher than the maximum allowable limits for males, females and children. They came to the conclusion that carrot and lettuce may increase the risk of Zn and Cd poisoning in adults, children and women.

As per an estimate, the global health risks, such as heavy metals, result in 420–960 million cases of food-borne disease and 420,000 fatalities each year (WHO 2021). To limit the presence of heavy metal residues in foods, governments and organisations have set severe norms and restrictions (OJEU 2006; SAMR 2017).

6 Conclusion and Recommendations

Research information reported in this chapter allowed us to understand, expand our knowledge and establish the source distribution of heavy metals in the urban agroecosystems, mechanisms and factors affecting their distribution and mobility in the agroecosystems and their phytotoxic effects on the crop plants along with the possible human health risks allied with consumption of heavy metal-contaminated crops over an extended period of time. Source distribution studies have revealed that prolonged application of fertilisers, pesticides, wastewater irrigation, vehicular emissions and industrial/urban activities in the vicinity of urban agroecosystems has resulted in the accretion of heavy metals in soils and food crops. The mobility and ingression of heavy metals in agroecosystems was shown to be influenced by factors, including pH, organic matter, temperature, texture, cation exchange capacity, type of microorganisms and other coexisting metals. Additionally, it was shown that the phytotoxic effects of heavy metals not only lower crop output but also contaminate the food chain, posing serious health risks when such contaminated products are consumed over an extended period of time.

Due to the transfer of heavy metals through the food chain, contamination of agroecosystems has resulted in a decline in the health and nutritional condition of soil and crops as well as posed threats to human health. The hazards to human health linked with heavy metal transfer to agroecosystems could be lessened through research and regulatory actions.

The following recommendations should be made in regard to the future control of the potential increase in heavy metal pollution of soil and food crops and their potential abatement:

- Avoiding cultivation of food/forage crops in urban and peri-urban areas with a high concentration of industries, traffic or mining activities that could seriously contaminate crops with heavy metals
- Monitoring of the urban/industrial effluents for the presence of heavy metals on a regular basis and provision of effluent treatment within the urban/industrial premises to prevent the release of untreated wastewater into the environment
- Providing kits for fast and easy detection and monitoring of soil/water/effluents at low cost
- Collaborations between governments; stakeholders, such as experts, professionals and politicians; and industry can catalyse innovation and create incentives for cleaner production and remediation technologies

- Creating global governance standards with the goal of enhancing agroecosystem management and protection for long-term soil-food productivity
- Focus on exploration of emerging underlying links between heavy metal pollution and associated adverse health outcomes

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