Chapter 3
Risk of Metal Contamination in Agriculture Crops by Reuse of Wastewater: An Ecological and Human Health Risk Perspective

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Abstract Agriculture sector is one of the major users of water resources. Due to limited availability of freshwater resources, domestic and industrial wastewater is being used in agriculture. Such water and wastewater contain varying number of micronutrients such as carbon and nitrogen as well as other toxic elements. Continuous irrigation with such type of water results overloading of these nutrients and some of the times pathogens, if not treated, in agricultural top soils. Heavy metals are nonbiodegradable and cumulative in nature. The accumulation and bioavailability of the metals depend on various environmental factors such as climatic conditions, temperature, rain pattern, and physicochemical properties of the soil, i.e., organic contents, pH, cationic exchange capacity, etc., which regulate accumulation of metals in soil and its bioavailability. Therefore, such toxic elements once enter in the food chain, get accumulated in various trophic levels, and exert undesirable effects to the flora and fauna. The major concern is its accumulation of toxic metal in agricultural crops from the wastewater-irrigated topsoil and associated health risk to the end-use consumers. Other than ingestion, there are various other routs of heavy metal exposure to the human beings. Therefore, for effective use and management of the wastewater in agriculture, periodic monitoring and risk assessment of heavy metal contamination are very important. This book chapter deals with the

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comprehensive evaluation of pros and cons of reuse of wastewater in agricultural with special reference to heavy metal contamination and associated human health risk.

Keywords Heavy metal contamination · Agricultural soil · Wastewater · Fruits · Human health risk

3.1 Introduction

The ever-increasing population has led to exponential increase in growth of urban areas and industries. In the process, there is an increase in consumption of resources and generation of wastes, which have reduced the environment's assimilation capacity and lead to accumulation of the wastes in the environment. Thus, the wastes, which comprise of various compositions of several noxious substances, are released into the environment. Considering the wastewater being released from several sectors of human society, it is supposed to contain organic matter, deposition of nutrients, pathogens, and innumerable heavy metals (Ping et al. 2011; Khan et al. 2013). The surge in the water scarcity is pushing the envelope of wastewaters for irrigation purpose (Khan et al. 2013) and, often, without prior treatment. It has been estimated that 20 million hectares of worldwide agricultural land are irrigated with wastewater (Wuana and Okieimen 2011). Another major problem particularly in developing countries is the improper discharge of industrial effluents into adjacent water bodies or into groundwater by reverse boring. Water from these sources is also used for irrigation which introduces the contaminants from the water into the agricultural soil. Due to this long-term and continuous use of the wastewaters in agricultural fields, the soil saturates with the heavy metals and leaches them into soil solution (Sharma et al. 2007). These soluble and bioavailable toxic heavy metals in the wastewater are absorbed by the crops, thereby, posing serious risks for contaminating the food chain and the environment. This eventually becomes another major concern, when the crops are food crops and are being consumed by humans in their daily diet, resulting in biomagnification. Besides, these heavy metals also tend to bind to the soil particles in the irrigated agricultural fields and pose threat when gets dislodged due to wind and suspends into the air to enter human body systems through inhalation exposure pathway. Another way this practice of reusing wastewater in agriculture results in heavy metal exposure to human beings is when the contaminated soil comes in contact to skin and adheres to it; however, absorption through this pathway is most likely to affect the farmers, since they are the ones coming in direct contact with the wastewater-irrigated soil. Apart from this, depending upon the soil properties and components, the heavy metals in soil solution may also leach down to the aquifers, if present, which contributes to the contamination of the groundwater. Further, governed by the type of aquifer and the underground topology, the groundwater is subjected to relocate to nearby areas. In that way, the ecosystem as well as humans is directly exposed to these heavy metals while utilizing the water for consumption. Since these numerous exposures and co-exposures of heavy metals produce a string of additive, antagonistic, or synergistic effects to human health (Wang and Bruce 2008; Tchounwou et al. 2012), including effect on circulatory, nervous, endocrine, pulmonary, renal, skeletal, enzymatic, and immune systems (Żukowska and Biziuk 2008; Zhang et al. 2012), it has become a matter of concern. Pertaining to this, several studies have been reported on the input of heavy metals in soil and edible plants as a result of irrigation using wastewater and the ecological and health risks associated with this. Considering the water availability of different countries, the practice of reusing wastewater in agricultural sector varies. Moreover, the concept of water footprint of a country (Hoekstra and Mekonnen 2012) also plays a role that determines the extent of use of wastewater in the country. Water footprint is the amount of water consumed for the production of commodities in a country. According to a report, China, India, and the United States contribute to the largest water footprint (1207, 1182, and 1053 Gm^3 /year, respectively) within their territory. It has also been reported that the water footprint in agricultural sector occupies the maximum share within all the three countries. Among these three countries, largest blue water footprint (24%) has been reported to be in India, where irrigation in wheat cultivation requires the largest share, followed by irrigation of rice and sugarcane, i.e., 33%, 24%, and 16%, respectively. However, the water availability per capita of the country is projected to be decreasing as reported by the Ministry of Water Resources, GOI (2009). Therefore, this chapter focuses on heavy metal concentrations in the agricultural soil and the comprehensive assessment of ecological risk as well as human health risk related to the reuse of wastewater in agriculture in different regions of India.

3.2 Heavy Metal Contamination of Soil due to Reuse of Wastewater

The pollution due to heavy metals has become a major concern, as the metals tend to become persistent in the environment and find their way into the other components of the environment through several biological and physiological processes. Once the heavy metals enter the food chain, they bioaccumulate in the living tissues, that is, the concentrations of heavy metals within a biological organism increase over a long time, and along with their magnification to higher trophic levels, than that in the environment (Du et al. 2013). Moreover, even a very low concentration of most heavy metals is toxic, and often a carcinogenic effect is produced in humans (Dockery and Pope 1996; Willers et al. 2005). While certain heavy metals are known to serve as essential elements to plants and humans at trace amount, a rise above the threshold concentration leads to adverse impacts on the living systems. The significant presence of the toxic heavy metals has also been held responsible for the inhibition of natural biodegradation of organic pollutants (Maslin and Maier

2000). The major concern for heavy metals is, thus, attributed to their high-level toxicity, long biological residence time, solubility, and potential of bioaccumulation (Arora et al. 2008).

In wastewater, the most significant sources of heavy metals are industries including effluents from power plants; metallurgical, chemical, and inorganic pesticide manufacturing plants; automobiles; pigment and dyes; textile; tannery; electroplating; galvanizing; cement; paint and asbestos industries; etc. (Ahluwalia and Goyal 2007), along with mine wastewater containing tailings (Moore and Ramamoorthy 1984; Dudka and Adriano 1997; Navarro et al. 2008). Besides, domestic sources may include corrosion of sewerage pipe and plumbing equipment, laundry detergents, cosmetic ingredients, and preservatives (Aonghusa and Gray 2002; Sharma et al. 2007; Sahu et al. 2014). Other major sources of wastewater containing significant amount of heavy metals are laboratories of educational, scientific, and medical institutions, which disposed chemicals, antibiotics, cancer therapeutics, anti-inflammatory drugs, contraceptives, and other hormones (Hernando et al. 2006; Nikolaou et al. 2007). While certain sources like metallurgical, chemical, and electroplating industries, etc. release innumerable heavy metals, effluents from industries producing dyes, textile, and tannery mainly comprise of chromium, zinc, iron, calcium, etc. (APHA 1995). Zinc, cadmium, and copper have been reported to be significant in laundry wastewater (Aonghusa and Gray 2002), whereas chromium, nickel, and mercury concentration dominates in cosmetic products such as lipsticks and fairness creams (Sahu et al. 2014). In most countries including India, the irrigation of vegetable crops with domestic or industrial wastewater has become a regular practice (Gupta et al. 2008a, b; Garg et al. 2014; Singh et al. 2010). The heavy metals present in such type of wastewater get accumulated in the agricultural soil, from which it is passed and accumulated in the agricultural crops (Krishna and Govil 2005; Godson et al. 2002; Barman et al. 2000; Fazeli et al. 1991).

Singh et al. 2009 reported the following ranges of heavy metals (mg/mL), i.e., Cd (0.03–0.04), Cr (0.05–0.147), Cu (0.043–0.053), Zn (0.093–0.117), Pb (0.043–0.063), Mn (0.077–0.11), and Ni (0.02–0.05), in the wastewater used for irrigation in Dinapur and Lohta sites of Varanasi district in India. The higher ranges of Ni, Cr, Pb, and Mn at the Lohta site were attributed to the untreated industrial effluents discharged from several industries where these metals were used for making of metal alloys, metal plating, and coloring (Singh et al. 2009). Dyeing and paint industries in Varanasi contribute to high concentrations of heavy metals especially Cd, Cr, and Pb to wastewater (Sharma et al. 2007), whereas Ni and Pb are added by battery- and metal-plating industries (Sharma et al. 2006, 2007). It has been suggested that substantial reduction of heavy metal concentration is possible by screening of sewage and other types of wastewater (Panicker 1995). However, certain metals in traces remain in screened wastewater which may get accumulated in the soil and agricultural crops over long-term use and can cause phytotoxicity (Ghafoor et al. 1999). Once the toxic metals get accumulated in plants, they induce physiological stress and subsequent changes in biochemical composition of the plants (Gupta et al. 2010). Various studies have reported decreased chlorophyll concentrations in vascular plants due to the physiological stress of toxic metals (Monni et al. 2001; Patsikka et al. 2002).

3.3 Heavy Metal Contamination of Food Crops Irrigated with Wastewater

The reuse of wastewater containing innumerable heavy metals for irrigation exposes them into the soil, then to the crops, and finally to the consumers. However, the dissolution, uptake, and bioaccumulation of heavy metals in edible crops, cereals, and vegetables are governed by various factors (Fig. 3.1). This may include climatic conditions; the nature and composition of soil, i.e., concentrations of organic matter and pH; and the presence and concentrations of various anions and the concentrations and solubility sequences of heavy metals in soil, assimilative capacity of the soil, atmospheric depositions, the plant species, and the degree of maturity of the plants during the harvesting period (Lake et al. 1984; Scott et al. 1996; Voutsa et al. 1996; Kafka and Kuras 1997). The extent of heavy metal binding to the soil particles is reliant on the pH and ion properties, as the binding forces of heavy metals are inversely related to the soil pH. Moreover, the metal ions with higher charges have higher tendency to adhere to soil particles than the ions with less charges (Dobrzanski and Zawadzki 1993). The sorption of heavy metals in the soil is also established to be influenced by the presence of humus in the soil which has a significant role in metal adsorption (Stevenson 1992). According to Schulten and Leinweber (2000), the heavy metal content reduces from clay to silt due to high surface area of clay, and soil containing organic matter and higher clay fractions can have higher concentration of heavy metals. Soil pH influences the solubility of the heavy metals, and it decreases with increase of soil pH (i.e., alkaline range). The increase in the organic contents of soil which facilitates more binding of metals to the soil therefore increases the metal solubility and adsorption in soil (Hough et al.

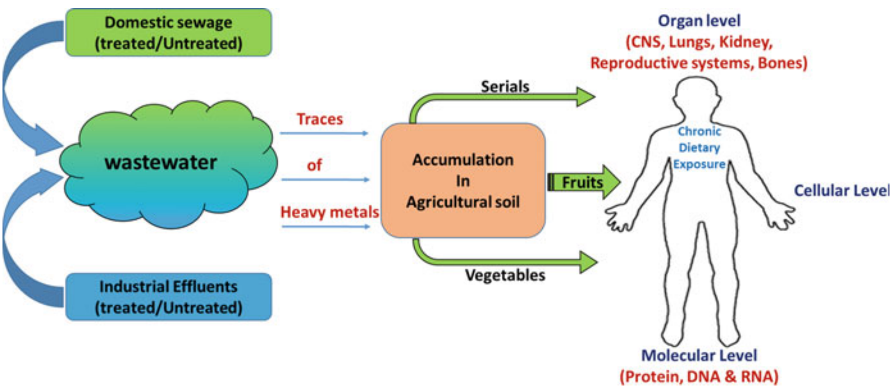

Fig. 3.1 Dietary exposure of heavy metals from agricultural products contaminated by wastewater

2003). The pH also affects the bioavailability of metals present in the wastewater-irrigated soils. It has been established that the hydrogen ions have a greater affinity for competing with metal ions; therefore, at lower pH metal ions are easily released from the soil and become available for the plant uptake (Singh et al. 2009). Rupa et al. 2003 reported the increased uptake of heavy metals in wheat plants at comparably higher levels of organic matters. Similarly, pH and organic contents enhance the solubility and availability of heavy metals and facilitate higher availability of metal ions to the plant from the soil (Ram et al. 2006).

Several studies suggest that heavy metal accumulation in plants varies in different species and different parts of plants. Mostly, leafy edible parts of vegetables are reported to contain high heavy metal concentrations than fruit crops or grain crops (Chopra and Pathak 2015). However, the leaves and roots of crops show a greater accumulation of heavy metals than the storage organs or fruits (Jinadasa et al. 1997; Lehoczky et al. 1998; Mapanda et al. 2005; Sharma and Agrawal 2006). Nevertheless, researchers (Davis et al. 1994; Traina and Laperche 1999; Violante et al. 2010) have suggested that bioavailability of heavy metals is majorly controlled by the metal species, affinity of the heavy metal for plant roots, the existing forms of metals in soil, and the properties of soil, instead of the total heavy metal concentrations. Even minute concentrations of heavy metals get adsorbed on soil particles and are retained for a long time as colloidal association (Sauve et al. 2000).

Through a study on *Beta vulgaris* receiving wastewater for irrigation, Sharma et al. (2007) have reported that concentrations of metals such as cadmium, zinc, mercury, and chromium were higher during summer, but in winter season, higher concentrations were measured in case of metals like copper, lead, and nickel. In another study by Sharma et al. (2008), the highest concentration of lead was observed in *Beta vulgaris*, whereas zinc and copper were highest in *Brassica oleracea*, and cadmium was highest in *Abelmoschus esculentus* and *Beta oleracea*. Rice grain has been reported to accrue very high concentrations of lead and cadmium (Zhuang et al. 2009). Fiber crops like flax and cotton, when cultivated in heavily contaminated soils, have also been detected to take up heavy metals (Angelova et al. 2004). It is evident that different species accumulate heavy metals. Various studies indicated that the duration of use of wastewater also correlated with heavy metal accumulation in vegetables (Sinha et al. 2005; Sharma et al. 2006, 2007).

3.4 Ecological Risk of Heavy Metal Contamination

In nature, soil acts as sink and filters for the heavy metals, by the process of binding and immobilization. Nevertheless, the continuous input of heavy metals in the soil by the means of wastewater irrigation alters the soil's capacity to retain the heavy metals, hence, leading to the consequent release of heavy metals (Sharma et al. 2007). This may also lead to imbalance in the essential trace metal composition of the soil, which is likely to further adverse ecological conditions in the soil microenvironment as well as to the plants growing on it. Increase in heavy metal concentration in soil results in increase in uptake of the metals by crops growing on the soil (Whatmuff 2002 and McBride 2003), which further creates and stimulates stress conditions in plants by impeding physiological and metabolic functioning of the plants. In plants, heavy metals can cause structural disorganization of organelles, disrupt cell membranes, and retard normal growth rate (Long et al. 2003; Zhang et al. 2002; Chien and Kao 2000; Kimbrough et al. 1999). Apart from these, the elevated concentration of heavy metals in soil also produces toxic effect on the soil microorganisms. Studies have reported that the heavy metals tend to alter the microbial processes in the soil ecosystem, which can be attributed to the physiological stress caused to the soil microbes by the activities of heavy metals. The metals in soil are also responsible for hindering enzymatic and metabolic activities of the soil microbiota (Giller et al. 1998; Wang et al. 2007). This further disrupts the microbial activities in the soil that are essentials for plants such as nitrogen fixation, other nutrient cycles, etc. Apart from directly posing enormous threat to the soil quality, and crops and vegetables cultivated in the contaminated soil, the heavy metals may get introduced to nearby surface water bodies through runoffs and threatens the aquatic ecosystem (Gupta et al. 2014). Fishes have been reported to accumulate significant quantities of toxic contaminants in their tissues on exposure to polluted aquatic bodies (Lewis et al. 2007; Yılmaz 2010; Chabukdhara and Nema 2012, 2013; Leung et al. 2014; Gupta et al. 2015). Therefore, it is well conformed from several studies that heavy metal contamination in soil initiates the interaction of the heavy metals with the other components of the ecosystem. When the contamination level and the load of heavy metal pollution exceed the threshold, limits pose risk to the environment.

3.4.1 Quantification and Assessment of Potential Ecological Risk of Heavy Metal Contaminations in Soils

Based on reported heavy metal concentration in the soil of the different regions of India, a cumulative assessment has been done to determine the level of pollution and associated ecological risk in particular due to reuse of wastewater for irrigation. The heavy metal concentration in the soil is equally important as that of their concentrations in the edible products because it is from the soil that the metals find their way into the plant tissues and then to the consumers.

3.4.1.1 Potential Ecological Risk

The potential ecological risk index (*RI*) proposed by Hakanson (1980) and Zhu et al. (2008) is one of the most common methods of the quantification of the potential ecological risk of the heavy metals, which can be calculated by contamination factor ($C^i{}_f$) and the "toxic-response" factor. The potential risk index can be obtained as:

$$E^i_r = T^i_r C^i_f \quad (3.1)$$

$$C^i_{f=Cn/Cnr} \quad (3.2)$$

$$C_{deg} = \sum C^i_f \quad (3.3)$$

$$RI = \sum E^i_r \quad (3.4)$$

where E^i_r is the potential ecological risk index of an individual metal, C^i_f is single-metal pollution factor, C_n is the concentration of the metal in samples, and C_{nr} is a background value for metal. The chemical compositions of the continental crust were used as the background values in this chapter which are 46,700 mg/kg for Fe, 95 mg/kg for Zn, 20 mg/kg for Pb, 68 mg/kg for Ni, 850 mg/kg for Mn, 45 mg/kg for Cu, 90 mg/kg for Cr, and 0.3 mg/kg for Cd (Turekian and Wedepohl 1961). Loska et al. (2004) classified the metal contamination levels as follows: low (Cif <1), moderate ($1 \leq$ Cif < 3), considerable ($3 \leq$ Cif < 6), and very high ($6 \leq$ Cif) contamination levels. The degree of contamination (C_{deg}) is the sum of contamination factors for all of the metals. Based on the value of C_{deg}, metal contamination levels are categorized as follows: low ($C_{deg} < 5$), moderate ($5 \leq C_{deg} < 10$), considerable ($10 \leq C_{deg} < 20$), and very high ($20 \leq C_{deg}$) degree of contamination (Duong and Lee, 2011). If the C_{deg} values exceeded 20, then necessary measures are required to reduce heavy metal contamination (Abdel-Latif and Saleh 2012). T^i_r denotes the "toxic-response" factor for heavy metals. The Tr values of Cu, Cr, Pb, Cd, Zn, Mn, and Ni are 5, 2, 5, 30, 1,1, and 5, respectively (Xu et al. 2008; Hakanson 1980). The scale of ecological risk can be categorized as follows: $E^i r < 40$, low risk; $40 \leq Er^i < 80$, moderate risk; $80 \leq Er^i < 160$, considerable risk; $160 \leq Er^i < 320$, high risk; and $Er^i \geq 320$, very high risk (Islam et al. 2015).

Based on the estimation, the degree of contamination and potential ecological risk index due to metal contamination in agricultural soils are presented in Table 3.1. As can be seen, most of the wastewater-irrigated sites showed very high degree of contamination due to heavy metals. The highest degree of contamination and ecological risk is found at Durgapur and Burdwan region of West Bengal (Gupta et al. 2008a, b) that were irrigated with wastewater, effluents, or effluent-contaminated water. Based on the study done in Delhi, where the major source of irrigation is groundwater, the soil showed least degree of contamination and risk (Kaur and Rani 2006). This indicates that the effluents or wastewater discharges are not safe for use in irrigation and these need proper treatment prior to disposal at different sites. Agricultural sites in Kanpur, Uttar Pradesh, and Delhi showed low risk (Sinha et al. 2006; Kaur and Rani 2006), Ghaziabad showed moderate risk (Chabukdhara et al. 2016), and Hyderabad showed considerable risk (Chary et al. 2008). All other sites showed high to very high risk.

Among metals, Pb and Cd showed the higher levels of contamination as compared to other metals in the wastewater-irrigated soil. As expected, the highest levels of ecological risks are also associated with Pb and Cd. While considering the degree of contamination to assess the contamination level in the affected soils of the

Table 3.1 Degree of contamination (C_{deg}) and ecological risk index (*RI*) due to heavy metals in Indian agricultural soils irrigated with wastewater

Agricultural soil site	C^i_f							C_{deg}	E^i_r							*RI*	References
	Cu	Cr	Pb	Cd	Zn	Mn	Ni		Cu	Cr	Pb	Cd	Zn	Mn	Ni		
Durgapur, West Bengal	0.00	0.61	44.80	20.00	0.00	0.10	0.00	**65.51**	0.00	1.22	224.00	600.00	0.00	0.10	0.00	**825.32**	Gupta et al. (2010)
Titagarh, West Bengal	2.00	1.65	6.52	102.40	2.29	0.00	1.52	**116.38**	10.00	3.30	32.61	3072.00	2.29	0.00	7.62	**3127.82**	Gupta et al. (2008a)
Ghaziabad, India	0.41	0.31	1.53	1.47	0.90	0.36	0.85	**5.83**	1.97	0.65	7.45	42.70	0.89	0.36	4.80	**58.82**	Chabukdhara et al. (2016)
Hyderabad, Andhra Pradesh	0.71	0.37	25.60	0.00	4.06	0.00	0.81	**31.55**	3.56	0.73	128.00	0.00	4.06	0.00	4.04	**140.40**	Chary et al. (2008)
Kanpur, Uttar Pradesh	1.58	1.87	0.00	0.00	3.23	0.37	0.62	**7.67**	7.89	3.75	0.00	0.00	3.23	0.37	3.08	**18.32**	Sinha et al. (2006)
Varanasi, Uttar Pradesh	0.71	1.05	0.89	8.61	0.79	0.19	0.21	**12.45**	3.55	2.09	4.45	258.33	0.79	0.19	1.07	**270.48**	Sharma et al. (2007)
Varanasi, Uttar Pradesh	0.47	0.21	1.07	10.40	0.61	0.00	0.35	**13.11**	2.35	0.43	5.35	312.00	0.61	0.00	1.74	**322.47**	Singh et al. (2010)
Varanasi, Uttar Pradesh	0.32	0.00	0.32	4.23	1.15	0.00	0.00	**6.03**	1.62	0.00	1.60	127.00	1.15	0.00	0.00	**131.37**	Singh et al. (2009)
Varanasi, Uttar Pradesh	0.32	0.20	0.90	14.22	0.26	0.49	0.20	**16.60**	1.59	0.41	4.51	426.60	0.26	0.49	1.02	**434.88**	Singh et al. (2009)
Burdwan, West Bengal	1.43	7.76	0.00	105.90	1.52	0.17	0.00	**116.78**	7.15	15.51	0.00	3177.00	1.52	0.17	0.00	**3201.35**	Gupta et al. (2008b)

(continued)

Table 3.1 (continued)

Agricultural soil site	C^i_f							C_{deg}	E^i_r							*RI*	References
Delhi	1.53	0.00	2.32	7.80	1.39	0.00	0.00	**13.04**	7.65	0.00	11.61	234.00	1.39	0.00	0.00	**254.64**	Singh and Kumar (2006)
Kanpur, Uttar Pradesh	1.97	0.21	0.76	6.97	0.30	0.00	1.19	**11.39**	9.85	0.43	3.78	209.00	0.30	0.00	5.93	**229.29**	Sanghi and Sasi (2001)
Varanasi, Uttar Pradesh	0.91	0.01	0.95	7.72	0.95	0.00	0.00	**10.54**	4.57	0.03	4.74	231.50	0.95	0.00	0.00	**241.79**	Rai and Tripathi (2008)
Varanasi, Uttar Pradesh	0.45	0.59	3.96	33.27	0.00	0.00	1.24	**39.51**	2.26	1.18	19.79	998.00	0.00	0.00	6.22	**1027.44**	Pandey et al. (2012)
Delhi	0.03	0.00	0.04	0.00	0.01	0.00	0.00	**0.09**	0.16	0.00	0.20	0.00	0.01	0.00	0.02	**0.40**	Kaur and Rani (2006)
Durgapur, India	0.00	0.61	44.80	20.00	0.00	0.10	0.00	**65.51**	0.00	1.22	224.00	600.00	0.00	0.10	0.00	**825.32**	Gupta et al. (2010)

country, there is a very high level of contamination estimated to have been persisting. In addition to the elevated contamination level, the pollution load index also depicts a deteriorating quality of the environment, where wastewater irrigation of agricultural soil is prevalent. However, the presence of cadmium poses a very high ecological risk in the environment where wastewater is being used for irrigation. In contrary to this, the ecological risk due to other metals considered for the evaluation has been determined to be low, except for lead, which has been detected to pose moderate ecological risk. Thereby, it is quite clear that the cumulative presence of cadmium in the soil as a result of wastewater irrigation in the studied areas of the country is beyond the safe limit and, therefore, requires intensive remediation measures.

3.5 Human Health Risk of Heavy Metals

In several studies, heavy metals have been accounted to interrupt the normal functioning of cellular organelles such as endoplasmic reticulum, lysosome, mitochondria, certain enzymes, nuclei, and cell membrane. This results in conformational changes in cellular structure and functions, leading to variation in cell cycle, apoptosis, and carcinogenic and teratogenic effects (Chang et al. 1996; Wang and Shi 2001; Beyersmann and Hartwig 2008). The production of reactive oxygen species (ROS) leads the subsequent oxidative stress in human bodies (Coman and Draghici 2011). Researchers have accounted that intake of heavy metal-contaminated food is capable of reducing the immunological defenses by depleting certain essential nutrients from the body. Several other health effects such as impaired fetus development, psychosociological behavior, gastrointestinal cancer, etc. are also associated with undernourishment. Various scientific literatures have established the disorders likely to occur in human bodies in relation to the dietary intake of food contaminated with heavy metals. While lead and cadmium have been held responsible for upper gastrointestinal cancer, breast cancer mortalities have been related to chromium intake (Iyengar and Nair 2000; Jarup 2003; Turkdogan et al. 2003; Pasha et al. 2010). Lead has also been recognized to cause encephalopathy in children, improper hemoglobin synthesis, renal infections, high blood pressure, and reproductive system disruption (Kanwal and Kumar 2011; Sanders et al. 2009; UNEP 2006; Fewtrell et al. 2003). The intake of excess cadmium through ingestion causes adverse health effects such as prostate and breast cancer; kidney, bone, and pregnancy disorders; as well as disturbances of male fertility (Kippler et al. 2012; Julin et al. 2012; Thomas et al. 2011; Godt et al. 2006). Cancer, fatigue, headache, skin rashes, dizziness, heart problems, and respiratory illness are also related with high concentration of nickel in food. However, the effects of heavy metals to human system are governed by age group, gender, prevalent health status of an individual, etc. Therefore, evaluation of health risk requires the consideration of these factors.

3.6 Exposure and Risk Assessment

An attempt has been made to summarize the health risk due to heavy metals via crop and vegetable consumption in India. The reported risk due to metals in crops and vegetables has been included as such in this chapter, and for others, the calculation of daily intake of metals (DIM) for adults was determined using the following equation:

$$\mathrm{DIM} = \left(\mathrm{C_{metal}\ X\ C_{factor}\ X\ D_{food\ intake}}/\mathrm{BW_{averageweight}}\right.$$

where C_{metal} stands for the heavy metal concentrations in plants/crops (mg/kg), C_{factor} stands for conversion factor (0.085) (Rattan et al. 2005), $D_{food\ intake}$ stands for daily intake of vegetables, and $BW_{averageweight}$ stands for average body weight. The average daily intakes of food crops and vegetables for adult were considered to be 0.345 kg/person/day (Ge 1992; Wang et al. 2005).

3.6.1 Health Risk Index (HRI)

In this review, we assessed the possible potential health risk of heavy metals for India which was based on reported heavy metal data in crops and vegetables. The health risk index was computed for Cd, Pb, Cr, Cu, Zn, and Ni as the ratio of average daily intake of metals to oral reference dose through dietary intake of crops/vegetables as food following the method of Cui et al. (2004).

$$\mathrm{HRI} = \mathrm{DIM}/\mathrm{RfD}$$

where DIM represents the daily exposure of metals and RfD represents reference oral dose. RfD value for Cu, Cr, Pb, Cd, Zn, and Ni is 0.04, 1.5, 0.004, 0.001, 0.003, and 0.02 (mg/kg bw/day), respectively (USEPA 2001, 1997; USEPA IRIS 2006).

3.6.2 Noncarcinogenic Risk of Heavy Metals for Adults Through Contaminated Cereals and Vegetables

Exposure of heavy metals to the human being generally occurs through ingestion of the food crops and vegetables cultivated in the agricultural lands irrigated with wastewater. As summarized in Table 3.2, HRI for Zn, Pb, and Cd exceeded the safe limit for many vegetables. This clearly revealed that dietary intake of such metal-contaminated vegetables is likely to induce serious health hazard to the consumers, i.e., human beings, if such vegetable is regularly consumed due to chronic exposure. Some of the heavy metals such as lead and cadmium are potential carcinogens as these metals are associated with aetiology of a number of diseases.

Table 3.2 Noncarcinogenic risk due to heavy metal exposures through vegetables grown in soil irrigated with wastewater (Based on the available data)

Agricultural soil site	Common name	Botanical name	Heavy metals						References
			Cu	Cr	Pb	Cd	Zn	Ni	
Hyderabad, Andhra Pradesh	Spinach	*Beta vulgaris*	1.18E-03	1.01E-03	4.07E-01		**1.75**	8.39E-02	Chary et al. (2008)
Titagarh, West Bengal	Spinach	*Beta vulgaris*	4.52E-01	3.37E-02	**6.53**	**7.65**	**2.70E + 01**	**1.82**	Gupta et al. (2008a)
Sri Ganganagar, Rajasthan	Spinach	*Beta vulgaris*	2.16E-01				**5.79**		Arora et al. (2008)
Varanasi, Uttar Pradesh	Spinach	*Beta vulgaris*	2.66E-01		1.31E-01	5.14E-01	**6.71**		Sharma et al. (2009)
Hyderabad, Andhra Pradesh	Spinach	*Beta vulgaris*		4.71E-03	**1.96**	**3.36**			Srikanth and Reddy (1991)
Delhi	Spinach	*Beta vulgaris*	3.11E-01		6.09E-01	**2.21**	**1.57E + 01**		Singh and Kumar (2006)
Durgapur, West Bengal	Spinach	*Beta vulgaris*	7.75E-01	3.60E-03	**6.36**	**2.62**	**2.57E + 01**	2.89E-01	Kisku et al. (2000)
Titagarh, West Bengal	Spinach	*Beta vulgaris*	4.21E-01	3.35E-02	**6.25**	**6.80**	**2.59E + 01**	**1.80**	Gupta et al. (2012)
Ludhiana, Punjab	Spinach	*Beta vulgaris*		2.36E-03	7.59E-01	2.36E-01		2.21E-01	Dheri and Brar (2007)
Varanasi, Uttar Pradesh	Spinach	*Beta vulgaris*	**1.04**		2.36E-01	**3.54**	5.40E-03		Sharma et al. (2008)
Varanasi, Uttar Pradesh	Spinach	*Beta vulgaris*	2.40E-02	2.40E-04	**2.91**	**4.62**	5.10E-03	**1.31**	Singh et al. (2010)
Varanasi, Uttar Pradesh	Okra	*Abelmoschus esculentus*	**2.68**		5.08E-01	**9.07**	1.86E-02		Sharma et al. (2008)
Hyderabad, Andhra Pradesh	Okra	*Abelmoschus esculentus*	7.87E-03	4.90E-04	4.72E-01		6.47E-01	6.30E-02	Chary et al. (2008)

(continued)

Table 3.2 (continued)

Agricultural soil site	Common name	Botanical name	Heavy metals						References
Varanasi, Uttar Pradesh	Okra	*Abelmoschus esculentus*	2.11E-01		1.15E-01	4.72E-01	**6.07**		Sharma et al. (2009)
Varanasi, Uttar Pradesh	Okra	*Abelmoschus esculentus*	6.00E-03	2.90E-04	**1.52**	**5.08**	5.70E-03	4.3E-01	Singh et al. (2010)
Varanasi, Uttar Pradesh	Cauliflower	*Brassica oleracea*	**7.49**		**1.33**	**2.28**	4.36E-02		Sharma et al. (2008)
Titagarh, West Bengal	Cauliflower	*Brassica oleracea*	2.00E-01	3.01E-02	**3.89**	**6.54**	**1.59E + 01**	**1.55**	Gupta et al. (2012)
Titagarh, West Bengal	Cauliflower	*Brassica oleracea*	2.05E-01	3.04E-02	**4.07**	**7.24**	**1.69E + 01**	**1.55**	Gupta et al. (2008a)
Sri Ganganagar, Rajasthan	Cauliflower	*Brassica oleracea*	6.86E-02				**7.03**		Arora et al. (2008)
Varanasi, Uttar Pradesh	Cauliflower	*Brassica oleracea*	2.18E-01	0.00E + 00	1.34E-01	6.61E-01	**9.01**		Sharma et al. (2009)
Varanasi, Uttar Pradesh	Cauliflower	*Brassica oleracea*	3.10E-03	2.00E-04	**7.49**	**3.88**	7.40E-03	**1.8**	Singh et al. (2010)
Varanasi, Uttar Pradesh	Amaranthus	*A. retroflexus*	1.60E-02	4.20E-04	**4.1**	**5.32**	3.40E-03	**1.61**	Singh et al. (2010)
Hyderabad, Andhra Pradesh	Amaranthus	*A. retroflexus*	1.84E-02	8.39E-04	3.80E-01		**1.40**	8.13E-02	Chary et al. (2008)
Hyderabad, Andhra Pradesh	Amaranthus	*A. retroflexus*		3.54E-03	**1.60**	5.77E-01			Srikanth and Reddy (1991)
Durgapur, West Bengal	Amaranthus	*Amaranthus viridis*	6.64E-01	3.15E-03	**7.58**	**1.57**	**2.55E + 01**	2.96E-01	Kisku et al. (2000)
Varanasi, Uttar Pradesh	Brinjal	*Solanum melongena*	8.00E-03	8.00E-05	**1.11**	**1.48**	1.10E-03	4.7E-01	Singh et al. (2010)

Hyderabad, Andhra Pradesh	Brinjal	*Solanum melongena*	9.18E-03	3.85E-04	3.93E-01		7.87E-01	8.13E-02	Chary et al. (2008)
Sri Ganganagar, Rajasthan	Brinjal	*Solanum melongena*	1.34E-01				**3.93**		Arora et al. (2008)
Durgapur, West Bengal	Brinjal	*Solanum melongena*	7.11E-01	3.81E-03	**8.60**	**2.47**	**2.43E + 01**	2.94E-01	Kisku et al. (2000)
Varanasi, Uttar Pradesh	Tomato	*Solanum lycopersicum*	5.00E-03	5.00E-05	4.3E-01	4.9E-01	6.00E-04	1.8E-01	Singh et al. (2010)
Varanasi, Uttar Pradesh	Bottle gourd	*Lagenaria siceraria*	6.00E-03	2.50E-04	8.2E-01	**1.07**	8.00E-04	3.7E-01	Singh et al. (2010)
Varanasi, Uttar Pradesh	Sponge gourd	*Luffa aegyptiaca*	9.00E-03	2.30E-04	9.5E-01	**2.1**	1.20E-03	5.4E-01	Singh et al. (2010)
Varanasi, Uttar Pradesh	Bitter gourd	*Momordica charantia*	3.00E-03	3.00E-04	**1.09**	**1.61**	1.00E-03	3.9E-01	Singh et al. (2010)
Varanasi, Uttar Pradesh	Pumpkin	*Cucurbita argyrosperma*	4.00E-03	7.00E-05	9.6E-01	**1.14**	1.00E-03	3.6E-01	Singh et al. (2010)
Varanasi, Uttar Pradesh	Pointed gourd	*Luffa acutangula*	4.00E-03	1.30E-04	3.1E-01	7.6E-01	5.00E-04	2.1E-01	Singh et al. (2010)
Varanasi, Uttar Pradesh	Radish	*Raphanus raphanistrum*	4.00E-03	4.00E-04	4.1E-01	4.9E-01	7.00E-04	2.1E-01	Singh et al. (2010)
Varanasi, Uttar Pradesh	Wheat	*Triticum aestivum*	5.16E-02	2.97E-04	**4.37**	**5.86**	4.81E-03	**2.4**	Singh et al. (2010)
Varanasi, Uttar Pradesh	Rice	*Oryza sativa*	4.39E-02	2.17E-04	**6.83**	**9.15**	8.40E-03	**1.32**	Singh et al. (2010)
Hyderabad, Andhra Pradesh	Cabbage	*Brassica oleracea*		2.17E-03	9.86E-01	**1.51**			Srikanth and Reddy (1991)
Durgapur, West Bengal	Cabbage	*Brassica oleracea*	5.72E-01	4.13E-03	**7.9**	**2.99**	**2.47E + 01**	2.12E-01	Kisku et al. (2000)
Titagarh, West Bengal	Radish	*Raphanus raphanistrum*	3.68E-01	2.73E-02	**7.56**	**9.33**	**2.43E + 01**	**1.64**	Gupta et al. (2008a)

(continued)

Table 3.2 (continued)

Agricultural soil site	Common name	Botanical name	Heavy metals						References
Sri Ganganagar, Rajasthan	Radish	*Raphanus raphanistrum*	7.82E-02				**3.93**		Arora et al. (2008)
Titagarh, West Bengal	Radish	*Raphanus raphanistrum*		2.87E-02	**2.89**	**3.41**			Gupta et al. (2008a)
Durgapur, West Bengal	Radish	*Raphanus raphanistrum*	7.78E-01	2.94E-03	**5.59**	**3.04**	**2.26E + 01**	1.86E-01	Kisku et al. (2000)
Titagarh, West Bengal	Radish	*Raphanus raphanistrum*	3.54E-01	2.67E-02	**6.79**	**8.48**	2.39E + 01	**1.58**	Gupta et al. (2012)
Titagarh, West Bengal	Lettuce	*Lactuca sativa*	3.27E-01	2.15E-02	**4.58**	**7.02**	**2.99E + 01**	**1.37**	Gupta et al. (2008a)
Titagarh, West Bengal	Celery	*Apium graveolens*	2.70E-01	1.22E-02	**3.18**	**6.31**	**1.63E + 01**	**1.12**	Gupta et al. (2008a)
Hyderabad, Andhra Pradesh	Coriander	*Coriandrum sativum*	1.57E-02	7.34E-04	3.54E-01	–	9.44E-01	7.08E-02	Chary et al. (2008)
Titagarh, West Bengal	Coriander	*Coriandrum sativum*	3.29E-01	1.69E-02	**4.08**	**7.37**	**2.38E + 01**	**1.35**	Gupta et al. (2008a)
Sri Ganganagar, Rajasthan	Coriander	*Coriandrum sativum*	1.59E-01	–	–	–	**5.40**	–	Arora et al. (2008)
Durgapur, West Bengal	Coriander	*Coriandrum sativum*	8.41E-01	2.69E-03	**9.46**	**3.88**	**2.59E + 01**	2.26E-01	Kisku et al. (2000)
Titagarh, West Bengal	Coriander	*Coriandrum sativum*	3.15E-01	1.54E-02	**4.04**	**6.92**	**2.35E + 01**	**1.34**	Gupta et al. (2012)
Ludhiana, Punjab	Coriander	*Coriandrum sativum*	–	1.14E-03	5.80E-01	1.52E-01	–	6.51E-02	Dheri and Brar (2007)
Hyderabad, Andhra Pradesh	Mint	*Mentha spicata*	1.44E-02	4.90E-04	2.89E-01	–	**1.14**	6.30E-02	Chary et al. (2008)

Titagarh, West Bengal	Mint	*Mentha spicata*	3.44E-01	2.37E-02	**2.83**	**5.44**	**2.43E + 01**	**1.41**	Gupta et al. (2008a)
Sri Ganganagar, Rajasthan	Mint	*Mentha spicata*	1.67E-01	–	–	–	**7.87**	–	Arora et al. (2008)
Titagarh, West Bengal	Mint	*Mentha spicata*	3.28E-01	2.29E-02	**2.74**	**4.93**	**2.35E + 01**	**1.46**	Gupta et al. (2012)
Ludhiana, Punjab	Mint	*Mentha spicata*	–	1.24E-03	5.50E-01	1.36E-01	–	6.06E-02	Dheri and Brar (2007)
Durgapur, West Bengal	Mustard	*Brassica nigra*	–	1.26E-03	**4.07**	**3.41**	–	–	Gupta et al. (2010)
Durgapur, West Bengal	Taro	*Colocasia esculenta*	–	9.55E-03	**3.15**	**3.30**	–	–	Gupta et al. (2010)
Burdwan, West Bengal	Tomato	*Solanum lycopersicum*	–	9.90E-03	–	**4.15**	**6.73**	–	Gupta et al. (2008b)
Varanasi, Uttar Pradesh	Tomato	*Solanum lycopersicum*	1.34E-02	–	3.15E-02	–	–	–	Rai and Tripathi (2008)
Delhi	Okra	*Hibiscus esculentus*	2.69E-01	–	3.36E-01	**1.94**	**1.95E + 01**		Singh and Kumar (2006)
Durgapur, West Bengal	Okra	*Hibiscus esculentus*	6.98E-01	3.22E-03	**7.11**	**2.89**	–	2.31E-01	Kisku et al. (2000)
Titagarh, West Bengal	Chinese onion	*Allium chinense*	2.30E-01	1.62E-02	**4.49**	**6.03**	**2.19E + 01**	**1.24**	Gupta et al. (2008a)
Titagarh, West Bengal	Parsley	*Petroselinum crispum*	3.88E-01	2.67E-02	**4.10**	**6.48**	**1.95E + 01**	**1.47**	Gupta et al. (2008a)
Titagarh, West Bengal	Parsley	*Petroselinum crispum*	3.73E-01	2.64E-02	**3.99**	**6.44**	**1.87E + 01**	**1.47**	Gupta et al. (2012)
Sri Ganganagar, Rajasthan	Turnip	*Brassica rapa*	2.11E-01	–	–	–	**5.12**	–	Arora et al. (2008)
Varanasi, Uttar Pradesh	Turnips	*Brassica rapa*	3.67E-02	–	8.79E-01	9.97E-01	–	–	Rai and Tripathi (2008)

(continued)

Table 3.2 (continued)

Agricultural soil site	Common name	Botanical name	Heavy metals						References
Sri Ganganagar, Rajasthan	Carrot	*Daucus carota*	2.20E-01	–	–	–	8.11	–	Arora et al. (2008)
Varanasi, Uttar Pradesh	Carrot	*Daucus carota*	1.61E-02	–	7.11E-01	–	–	–	Rai and Tripathi (2008)
Varanasi, Uttar Pradesh	Fenugreek	*Trigonella foenum-graecum*	2.39E-01	–	–	–	**4.74**	–	Arora et al. (2008)

The list may include diseases of the nervous system, kidney, blood, cardiovascular, and many others (Jarup 2003; WHO/FAO 2007). Among rooted vegetables, radish showed higher risk due to Pb, Cd, and Zn, while among leafy vegetables, coriander, mint, cauliflower, parsley, and onion showed higher risk for consumption. Cu and Cr showed no risk for consumption of vegetables. HRI values for Ni also exceeded the safe limit (HRI > 1) in some vegetables, but it was comparatively lower than those due to Zn, Pb, and Cd.

3.7 Conclusions

The scarcity of precious freshwater and groundwater initiated the search of alternative water resources for the agriculture crops. Recycling and reuse of wastewater seem the most suitable option among all others for the sustainable management of water resources. Reuse of domestic or treated industrial wastewater for irrigation is often viewed as the most economic and environmental-friendly option. However, such wastewater contains variety of chemicals including traces of heavy metals. Prolonged use of such wastewater for the production of crop and vegetables leads gradual accumulation of trace elements in the agricultural lands. Various environmental and geochemical factors often moderate the leachability and bioavailability of such metals from the soil which accumulate in the growing crops. Therefore the chronic exposure of such metals to the humans through dietary intake poses serious threat. An assessment of human health risk of heavy metals through dietary intake was comprehensively assessed on the basis of available literature in Indian scenarios. The results showed that the metal concentrations in agricultural soils in India are categorized as high to very high risk in most of the wastewater-irrigated sites. Furthermore, in Indian scenario, the potential health risk index exceeded the safe limit (HRI > 1) for some of the metals such as Cd, Pb, Ni, and Zn. The observed health risk clearly indicated the poor quality of wastewater due to the presence of some of the heavy metals, and irrigation of crops/vegetables with such wastewater could pose serious health risk to the consumers. Immediate action of regulatory authorities is recommended to regulate the use of such type of wastewater contaminated with traces of the selected heavy metals for safeguarding the health of the general public.

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