Chapter 11
Risk Assessment of Heavy Metal Contamination in Paddy Soil, Plants, and Grains (*Oryza sativa* L.)

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11.1 Introduction

Soils are considered to be an excellent media to monitor and assess heavy metal pollution because anthropogenic heavy metals are usually deposited in the top soils (Govil et al. 2001). Heavy metal-contaminated soil adversely affects the whole ecosystem when these toxic heavy metals migrate into groundwater or are taken up by flora and fauna, which may result in great threat to ecosystems due to translocation and bioaccumulation (Bhagure and Mirgane 2010). Heavy metals are potentially toxic to crop plants, animals, and human beings when the contaminated soils are used for crop production (Wong et al. 2002). Environmental contamination of the biosphere with heavy metals due to intensive agricultural and other anthropogenic activities poses serious problems for safe use of agricultural land (Fytianos et al. 2001). Agriculture with indiscriminate use of agrochemicals such as fertilizers and pesticides, along with mechanical cultivation, for higher crop productivity contaminates agriculture soils with potentially nonessential and essential heavy metals. Human health is directly affected through intake of crops grown in polluted soils. There is clear evidence that human renal dysfunction is related with contamination of rice with Cd in subsistence farms in Asia (Chaney et al. 2005). In Asia, rice is the most common crop in agricultural land, and it has been identified as one of the major sources of Cd and Pb for human beings (Shimbo et al. 2001). It has also been reported that crop plants have different abilities to absorb and accumulate heavy metals in their body parts and that there is a broad difference in metal uptake and translocation between plant species and even between cultivars of the same plant species (Kurz et al. 1999). Rice, a major food crop in many Asian regions, is now prone to heavy metal toxicity. Plants absorb heavy metals from the soil, and the surface 25 cm zone of soil is mostly affected by such pollutants resulting from

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anthropogenic activities. Heavy metals are adsorbed and accumulated in this soil layer probably due to relatively high organic matter. The plant parts of interest for direct transfer of heavy metals to human body are the edible parts such as the rice grain, which may consequently become a threat to human health. Nevertheless, heavy metals in the environment, consequently, are of immense concern, because of their persistence nature, bioaccumulation, and biomagnification characters causing ecotoxicity to plants, animals, and human beings (Alloway 2004). The micronutrients such as Zn, Mn, and Cu are required in small but critical concentrations for both plants and animals, and these have vital role in physical growth and development of crop plants such as paddy. The deficiency of Zn in soil casts a conspicuous adverse effect, with stunted growth of crop plants like paddy and groundnut (Karatas et al. 2007) reducing the overall productivity. Generally, the monitoring and assessment of total heavy metal concentrations in agricultural soils are required to evaluate the potential risk of paddy soils contaminated due to toxic heavy metals—Cd, As, and Pb (Singh et al. 2010). Heavy metals are known to accumulate in living organisms (Masironi et al. 1977). There is a tendency of plants to take up heavy metals that may subsequently transfer into the food chain. Use of polluted soil or water for crop cultivation mainly results in decrease of overall productivity and contaminates food grains and vegetables, which adversely affect human health too (Suzuki et al. 1980).

The deficiency of Zn in soil casts a conspicuous adverse effect, with stunted growth of crop plants like paddy and groundnut (Arao et al. 2010) reducing the overall productivity. Heavy metals are known to accumulate in living organisms (Masironi et al. 1977). There is a tendency of plants to take up heavy metals that may subsequently transfer into the food chain. Use of polluted soil or water for crop cultivation mainly results in decrease of overall productivity and contaminates food grains and vegetables, which adversely affect human health too (Suzuki et al. 1980). A number of reports on concentrations of toxic metal such as Cd and Pb in rice and paddy soils in Japan, China, and Indonesia are available (Suzuki and Iwao 1982). However, such studies are very few in India, with little information on toxic heavy metal contamination of paddy fields and risk assessment (Herawati et al. 2000), though rice is the most important staple food for Indian people.

The objective of the present study is the risk assessment of potential toxic and nonessential heavy metals—Cd, As, Pb, Zn, and Cr—in the surface soil of paddy fields at the predominantly paddy-cultivated area. Concentrations of the toxic heavy metals were assessed in soil, root, shoot, and grains of paddy crop to assess the bioaccumulation factor and transfer factor. Risk assessment was made assessing the potential risk factor for the local residents consuming rice, the staple food.

11.2 Heavy Metal Concentrations in Rice

The concentrations of As, Cd, Pb, and Zn in unpolished rice grown on the paddy soils field with the maximum permissible limit of 0.01–1.5 lg g^{-1} as (Kabata-Pendias 2011).

11.2.1 Arsenic (As)

Elevated levels of As and other heavy metals may be found in plants growing on contaminated soils. As is one of the hazardous element in the environment. As cause serious health effect which causes cancer in the skin, lungs, bladder, liver, and kidney. Numerous studies have focused on As concentrations in rice grains in several countries. As exposure via rice intake has aroused considerable attention throughout the world. The levels of As in rice have been shown to vary widely among different countries. The highest level of As, up to 2.05 mg kg^{-1} (range, 0.05–2.05 mg kg^{-1}), was reported in the southern part (Gopalganj, Rajbari, and Faridpur) of Bangladesh (Islam et al. 2004), whereas it was up to 1.84 mg kg^{-1} (range, 0.03–1.84 mg kg^{-1}) in western Bangladesh. As contamination in India, particularly in West Bengal, has a long history, and a number of studies from this region reveal high As concentration in rice. Roychoudhury et al. (2002, 2003) reported that As concentration in rice collected from the Murshidabad District of West Bengal varied from 0.09 to 0.66 mg kg^{-1} in 2002 and 0.04–0.61 mg kg^{-1} and 0.08–0.55 mg kg^{-1} in 2003. This finding was consistent with another of their studies in which the concentration ranged between 0.04 and 0.66 mg kg^{-1} (Roychowdhury 2008). Pal et al. reported that As concentrations in rice from Kolkata, West Bengal, ranged between 0.02 and 0.40 mg kg^{-1}. Although this level is relatively lower than those in the other Bengal rices reported above, it is comparable with the rice from the Bengal delta region of West Bengal (0.02–0.36 mg kg^{-1}, mean of 0.12 mg kg^{-1}) (Chatterjee et al. 2010) and market basket study of Indian rice (0.07–0.31 mg kg^{-1}) (Mehrag et al. 2009). Recently, Bhattacharya et al. (2009) and Anirban et al. (2011) reported high levels of arsenic in rice from a contaminated area of Bengal, ranging from 0.06 to 0.78 mg kg^{-1} and 0.1 to 0.81 mg kg^{-1} (0.19–0.78 mg kg^{-1} in boro and 0.06–0.6 mg kg^{-1} in aman), respectively, the maximum concentration (0.81 mg kg^{-1}) highest As concentration in Bengal rice reported so far (Fig. 11.1).

Arsenic exists in the soil in both inorganic and organic forms (species). The most common inorganic species are arsenate [As(V)] and arsenite [As(III)], while the most common organic species are monomethylarsonic acid (MMA) and dimethylarsenic acid (DMA) (Fitz and Wenzel 2002). Among all species, As(III) is considered to be more toxic than As(V), and both are more toxic than the organic species in the following order: As(III) > As(V) > MMA > DMA. Usually, the inorganic species predominate in rice paddies compared with the organic species (Abedin et al. 2002;

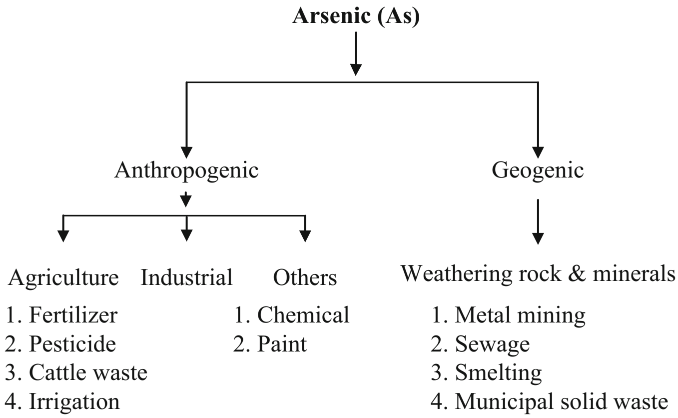

Fig. 11.1 Various sources of arsenic into paddy field (Source: Geosciences Journal)

Fitz and Wenzel 2002). However, inorganic species can be transformed into organic forms by methylation linked with microbial actions in paddy soil (Takamatsu et al. 1982). As speciation in soil is essential to assess the As toxicity in rice plants. Rice roots can take up all species, but the rate of organic species uptake is much lower than that of inorganic As (Odanaka et al. 1987; Abedin et al. 2002).

11.2.2 Lead (Pb)

Lead (Pb) is also thought to be one of the major chemically toxicologically dangerous trace metals. It is naturally present in small amounts in practically all environmental matrices. The Pb content in an edible portion of the plants grown in an uncontaminated area, as reported by various authors for the decade 1970–1980, ranges from 0.05 to 3 lg g^{-1}, while the mean Pb content calculated for cereal grains of various countries varies from 0.01 to 2.28 lg g^{-1} (Kabata-Pendias 2011). Pb concentrations higher than 1 lg g^{-1} are, however, considered to provide consumers with an excessive amount of Pb (Witek et al. 1992). Median concentrations for Pb higher than 0.190 lg g^{-1} were found in polished rice from South Korea (Jung et al. 2005). However, elevated concentrations of Pb, which may present a health risk to humans, could be found in food crops growing in contaminated soil; for example, unpolished rice from the paddy soil around the Pb-Zn Lechang mine (South China) showed mean Pb concentrations of about 4.67 lg g^{-1}. According to Jung et al. (2005), the concentrations of Pb in rice grain grown in soils contaminated by the Pb-Zn mining activities. Lead is being added and accumulating profoundly in the soil through anthropogenic activities. Moreover, Pb accumulation in rice grains also employs quality issues and adverse health complications (Shraim 2017). The sensitivity and tolerance index of rice against Pb stress mainly depends on uptake of Pb from the soil and internal sequestration of the plants (Rout et al. 2000). Roots are the first organ exposed to Pb and thus can be a major storage organ for Pb (mostly in tolerant cultivars) or can play an intermediary role for exporting the Pb ions from soil to the above ground plant parts. Mostly, lead effects on mineral accumulation in aerial plant parts are similar and follow a common trend, while in roots, it varies among plant species to species and amount of lead in the soil/rhizosphere (Gopal and Rizvi 2008). Lead adversely affects seed germination, root/shoot ratio, and their fresh and dry weight in rice (Mishra and Choudhari 1998). The effects were more adverse at higher concentrations of Pb^{2+} (Zeng et al. 2006).

11.2.3 Zinc (Zn)

Zinc is essential for both plants and animals. Zn affects several biochemical processes in the rice plant, thus severely affecting plant growth; zinc (Zn) deficiency is the most widespread micronutrient disorder in rice (*Oryza sativa*). Screening experiments in low-Zn nutrient solution and in a Zn-deficient field did not produce similar tolerance rankings in a set of segregating lines, which suggested that rhizosphere effects were of greater importance for lowland rice than internal Zn efficiency. Zn deficiency can be corrected by adding Zn compounds to the soil or plant, but the high cost associated with applying Zn fertilizers in sufficient quantities to overcome Zn deficiency places considerable burden on resource-poor farmers, and it has therefore been suggested that breeding efforts should be intensified to improve the tolerance to Zn deficiency in rice cultivars. Zn deficiency causes multiple symptoms that usually appear 2–3 weeks after transplanting (WAT) rice seedlings; leaves develop brown blotches and streaks that may fuse to cover older leaves entirely, plants remain stunted and in severe cases may die, while those that recover will show substantial delay in maturity and reduction in yield. Zn deficiency has been associated with a wide range of soil conditions: high pH (>7.0), low available Zn content, prolonged submergence and low redox potential, high organic matter and bicarbonate content, high magnesium (Mg) to calcium (Ca) ratio, and high available P (Neue and Lantin 1994). Several factors could be responsible for the poor understanding of tolerance to Zn deficiency in rice. As stress factors associated with Zn deficiency vary between soil types (high pH on calcareous soils; low redox potential on perennially flooded soils). Zinc fertilizers can be applied to zinc-deficient soils, once deficiency is identified. The most common fertilizer sources of zinc are zinc chelates (contain approximately 14% zinc), zinc sulfate (25–36% zinc), and zinc oxide (70–80% zinc), where zinc sulfate is the most commonly used source of zinc.

11.2.4 Copper (Cu)

Copper (Cu) is an essential nutrient element for plant growth and is a toxic heavy metal in excess concentrations. As such, its concentration and availability in soils are of great agricultural and environmental concern. The amount of Cu available to plants varies widely by soils. Available Cu can vary from 1 to 200 ppm (parts per million) in both mineral and organic soils as a function of soil pH and soil texture. Cu is related to soil pH. As soil pH increases, the availability of this nutrient decreases. Copper is not mobile in soils. It is attracted to soil organic matter and clay minerals. Copper becomes attached to the soil organic matter and is not moved through the soil by water. Leaching is prevented, but the Cu is still available to plants. If the soil test for Cu is in the high range, annual applications of Cu are not needed. Large amounts of Cu in soils can be toxic to plants; it is important to accurately control applications. To avoid toxicity problems, annual applications of Cu should certainly be less than 40 lb per acre. Toxicity problems are difficult to correct.

In various plants grown in uncontaminated soils, Cu levels do not generally exceed 20 lg g^{-1}. In cereal grains from different countries, Cu concentrations were in the range 0.6–10.3 lg g^{-1}. In plants grown in contaminated sites impacted by the metal-processing industry, Cu concentrations could be as high as 560 lg g^{-1} (Kabata-Pendias 2011). Jung et al. (2005) reported that the Cu concentrations in polished rice from South Korea were in the range of 1.29–2.53 lg g^{-1}, with a median value of 1.85 lg g^{-1}. Elevated Cu concentration levels of up to 15.5 lg g^{-1} were measured by Cao et al. (2003) in brown rice grown in paddy soils irrigated with Cu-rich wastewater. Lee et al. (2001) found that the Cu concentration in rice grain from heavy metal impacted paddy.

11.3 Heavy Metal Concentration in Different Plant Parts

The mean concentrations of heavy metals in the paddy plant parts (Table 11.1) showed that most of the metals accumulated more in the roots than in other plant parts, shoots, and grains and ranged from 14.4 to 21.9 μg g^{-1} for Mn, 4.7–16.9 μg g^{-1} for Zn, 3.6–5.3 μg g^{-1} for Pb, 0.6–1.7 μg g^{-1} for Cr, 0.2–0.5 μg g^{-1} for Cu, and 0.1–0.2 μg g^{-1} for Cd among the five sites. It indicated that the Cd concentrations were minimum in the paddy soil, in contrast to the Cd concentrations of paddy soil. The mean concentrations of heavy metals in the paddy plant parts showed that most of the metals accumulated more in the roots than in other parts. In general metal uptake was higher for the micronutrients; Mn and Zn in the roots were followed by Pb, Cr, Cu, and Cd. In the present study, concentration of Pb was found to be higher in roots than in shoots and grains. *Calluna vulgaris* (L.) Hull (common heather) and *Agrostis vinealis*, harvested from an abandoned Pb mine in the UK, contained 320 and 2930 mg kg^{-1} dry wt., respectively, in shoot tissue, while Pb values for root were 9610 and 9740 mg kg^{-1}, indicating high plant availability of the Pb in the soil as well

Table 11.1 Mean concentrations of heavy metals along with standard deviation in soil and different plant parts

Heavy metals	Soil range (g g^{-1})	Root range (g g^{-1})	Shoot range (g g^{-1})	Grain range (g g^{-1})
Pb	5.30 ± 0.4–19.8 ± 1.3	3.6 ± 0.2–5.3 ± 0.04	0.3 ± 0.01–1.2 ± 0.01	0.01 ± 0.001–10 ± 0.02
Cd	0.02 ± 0.005–0.6 ± 0.04	0.11 ± 0.008–0.2 ± 0.01	0.2 ± 0.01–0.3 ± 0.01	0.02 ± 0.001–0.05 ± 0.002
Cu	0.03 ± 0.004–5.41 ± 0.5	0.2 ± 0.02–0.5 ± 0.04	0.04 ± 0.008–0.3 ± 0.03	0.01 ± 0.008–0.3 ± 0.01
Cr	1.3 ± 0.01–7.8 ± 0.3	0.6 ± 0.02–1.7 ± 0.04	0.4 ± 0.01–0.9 ± 0.04	0.1 ± 0.02–0.6 ± 0.01
Mn	12.5 ± 0.2–53.9 ± 1.5	14.4 ± 0.9–21.9 ± 0.03	25 ± 2.8–2.9 ± 1.9	5.6 ± 0.04–7.5 ± 0.03
Zn	3.8 ± 1.7–33.8 ± 1.3	4.7 ± 0.1–16.9 ± 0.9	2.3 ± 0.01–6 ± 0.2	3.2 ± 0.05–7.2 ± 0.008

Source: Biomed Research International Journal

as its limited mobility inside the plant. Cu was also found to be more in roots than that in shoots and grains, which is in corroboration with findings of earlier workers. Yang et al. reported that accumulation of Cu was more in roots, while a small fraction (10%) of absorbed Cu was translocated to stem. The Cu and Zn accumulated at their highest concentration in roots of the rice plants followed by shoots and grains. Most metals, Fe, Mn, Zn, and Cu, that were found profusely in the paddy plants were the micronutrients that are required for various enzyme activities and play important roles in photosynthesis and growth of the plant (Tripathi and Tripathi 1998).

It was seen that Mn and Cd were accumulated more in shoot than in root and found in the ranges of 25–32.9 μg g^{-1} for Mn, 2.3–6 μg g^{-1} for Zn, 0.4–0.9 μg g^{-1} for Cr, 0.3–1.2 μg g^{-1} for Pb, 0.2–0.3 μg g^{-1} for Cd, and 0.05–0.3 μg g^{-1} for Cu. In the shoots, concentrations of Mn and Cd were higher than their concentrations in roots and grains. Jarvis, Jones, and Hopper reported that Cd was easily taken up by plants and transported to different parts, although it is nonessential and is of no beneficial effects on plants and animals. Moreover, Cd is toxic to animals and plants, and plants when exposed to this metal show reduction in photosynthesis and uptake of water and nutrient. Higher concentration of Mn in leaves of both the plants indicated its high mobility, as leaf chlorophyll content requires Mn for photosynthesis. In contrast, Gupta and Sinha reported higher accumulation of Mn in roots followed by leaves in Chenopodium. The mean concentrations of heavy metals in the grains were found in the ranges of 5.6–7.5 μg g^{-1} for Mn, 3.2–7.2 μg $g^{-1}$for Zn, 0.1–0.6 μg g^{-1} for Cr, 0.1–0.3 μg g^{-1} for Cu, 0.02–0.05 μg g^{-1} for Cd, and 0.01–1 μg g^{-1} for Pb among the five sites (Table 11.1). In grains, among all metals, Mn and Zn were in more elevated concentrations than Cr, Cu, Cd, and Pb, but their concentrations were between 0.01 μg g^{-1} and 1 μg g^{-1}. The highest Pb content was found in S-4 (1 μg g^{-1}) and S-5 (0.9 μg g^{-1}), which exceeds the values given by Pilc et al. the corresponding limit defined by the Commission Regulation Directive

EC. However, the concentrations of Cr, Cu, and Cd ranged between 0.1 μg g^{-1} and 0.6 μg g^{-1}, 0.1 μg g^{-1} and 0.2 μg g^{-1}, and 0.02 μg g^{-1} and 0.05 μg g^{-1}, respectively. The mean concentrations of all the elements in the rice grain were below their maximum allowable levels except for Pb. The results indicate that the concentration of Pb in rice grain may have been affected by various anthropogenic activities such as use of tractor for farming and use of chemical fertilizers and pesticides.

11.4 Sources of Heavy Metals in Agricultural Soils

Heavy metal accumulation in crops is a function of complex interactions between the soil, the plant, and environmental factors. It has been well documented that the content of heavy metals in crop plants is closely related to the levels in the soil (Cheng et al. 2006). The elevated concentrations of As, Cd, Cu, Pb, and Zn in paddy soil and rice undoubtedly indicated heavy metal contamination related to mining activities and acid mine drainage-impacted riverine water, which is used by local farmers for irrigation purposes.

It is important to identify the sources and status of soil contamination by toxic metals so as to take proper treatments to reduce soil contamination and to keep sustainable agricultural development. The initial sources of heavy metals in soils are the parent materials from which the soils were derived, but the influence of parent materials on the total concentrations and forms of metals in soils is modified to varying degrees by pedogenetic processes (Herawati et al. 2000). In areas affected lightly by human activities, heavy metals in the soils are derived mainly from pedogenetic parent materials, and metal accumulation status was affected by several factors such as soil moisture and management patterns. A research conducted in Gansu province, China, by Lin concluded that the main factor for heavy metal accumulation was lithological factor in three arid agricultural areas. It is reported that soil aqua regia soluble fraction of Co, Ni, Pb, and Zn were highly correlated with soil Al and Fe. These elements were associated with indigenous clay minerals in the soil high in Al and Fe.

High concentration of metals in the soil does not necessarily imply their availability to plants. In the solid phase, the metals are distributed among the various soil components thereby producing various physicochemical forms that determine metal mobility. Thus, in order to better assess the bioavailability of metals and their chemical association with the soil components, metal fractionation behavior was studied.

11.5 Discussion

The most common elements from atmospheric deposition were Hg, Pb, As, Cd, and Zn, and nonferrous metal smelting and coal combustion were two of the most important ways contributing to metal pollutants in the air. Streets et al. (2005) have pointed out that, among the Hg emissions in China, approximately 38% of Hg comes from coal combustion, 45% from nonferrous metal smelting, and 17% from miscellaneous activities, of which battery and fluorescent lamp production and cement production are of most importance. Zn was the metal deposited in agricultural soils in the largest amount from the atmosphere in China, and Pb and Cu followed. Heavy metal input to arable soils through fertilizers causes increasing concern for their potential risk to environmental health. Lu et al. (1992) reported that the phosphate fertilizers were generally the major source of trace metals among all inorganic fertilizers, and much attention had also been paid to the concentration of cadmium in phosphate fertilizers. However the concentration of Cd in both phosphate rocks and phosphate fertilizers from China was in general much lower than those from the USA and European countries. It should be concerned that although the contents of toxic metals in most of the fertilizers in China were lower than the maximum limits, the trace element inputs to agricultural land were still worth concern, since the annual consumption of fertilizers accounted to 22.2, 7.4, and 4.7×10^6 tons for N, P, and K fertilizers (in pure nutrient), respectively (Luo et al. 2009). Traditionally, agriculture has been the main base of the economies in this region. In some of the countries mentioned above, phosphatic fertilizers have been used for long periods. For instance, the great majority of agricultural soils in Malaysia are heavily fertilized by this kind of fertilizers, which was reported by Zarcinas et al. (2004). Soils in southern Asian countries have P requirements, so that histories of P fertilizer addition, associated with impurities (Cd, Cu, As, and Zn), seem to be greater on these countries (Zarcinas et al. 2004). Agricultural use of pesticides was another source of heavy metals in arable soils from nonpoint source contamination. Although pesticides containing Cd, Hg, and Pb had been prohibited in 2002, there were still other trace element-containing pesticides in existence, especially copper and zinc. It was estimated that a total input of 5000 tons of Cu and 1200 tons of S were applied as agrochemical products to agricultural land in China annually (Luo et al. 2009; Wu 2005). Coca, groundnut, mustard, and rice had elevated concentrations of heavy metals (especially Cu and Zn) assessed when compared to the other plants (cabbage, oil palm, aubergine, lady's fingers). This may be contributed by the widespread use of Cu and Zn pesticides on these crops. A survey also showed that heavy metal concentration in surface horizon and in edible parts of vegetables increased over time. Pandey et al. (2000) reported that the metal concentration in soil increased from 8.00 to 12.0 mg kg^{-1} for Cd and for Zn from 278 to 394 mg kg^{-1}. They also suggested that if the trend of atmospheric deposition is continued, it would lead to a destabilizing effect on sustainable agricultural practice and increase the dietary intake of toxic metals. Sinha et al. concluded that the vegetables and crops growing in such area constitute risk due to accumulation of metals in India. The researchers also studied the effect of municipal wastewater irrigation on the accumulation of heavy metals in soil and vegetables in the agricultural soils in India. The mean concentrations of Pb, Zn, Cd, Cr, Cu, and Ni in wastewater-irrigated soil around Titagarh region were 130, 217, 30.7, 148, 90.0, and 104 mg kg^{-1}, respectively. Also, the concentrations of Pb, Zn, Cd, Cr, and Ni in all vegetables (pudina, cauliflower, celery, spinach, coriander, parsley, Chinese onion, and radish) were over the safe limits. The industrial effluents often contain many heavy metals. In industrial areas, many agricultural fields are inundated by mixed industrial effluent or irrigated with treated industrial wastewater. The plant-available metal content in soil showed the highest level of Fe, from 529 to 2615 mg kg^{-1}, and lowest level of Ni, from 3.12 to 10.5 mg kg^{-1}. It is also suggested that the accumulation of Cr in leafy vegetables was found more than fruit-bearing vegetables and crops. Sewage irrigation can alleviate the water shortage to some extent, but it can also bring some toxic materials, especially heavy metals, to agricultural soils, and cause serious environmental problems. This is particularly a problem in densely populated developing countries where pressure on irrigation water resources is extremely great. In Chhattisgarh, central India, soil was irrigated with As-polluted groundwater. People in this region were suffering from arsenic borne diseases. The arsenic concentration ranged from 15 to 825 μg L^{-1} in the polluted water, exceeding the permissible limit, 10 μg L^{-1}. The contaminated soil had the median level of 9.5 mg kg^{-1} (Patel et al. 2005). Many industrial plants in this region operate without any, or minimal, wastewater treatment and routinely discharge their wastes into drains, which either contaminate rivers and streams or add to the contaminant load of biosolids (sewage sludge). Copper is strongly attached to organic material and may be added as a contaminant with organic soil amendments. There is also now a considerable body of evidence documenting long-term exposure to high concentrations of heavy metals (e.g., Cu) as a result of past applications of sewage sludge. Cu and Zn input to agricultural soils by farm-animal manure (Christie and Beattie 1989), and past applications of Cu-containing fungicides (Zelles et al. 1994).

Among the metals concerned, Cd was a top priority in agricultural soils in China, with an average input rate of 0.004 mg kg^{-1} $year^{-1}$ in the plough layer (0–20 cm) (Luo et al. 2009). Conventional approaches employed for control and remediation of metals from contaminated sites include (1) land filling, the excavation transport and deposition of contaminated soils in a permitted hazardous waste land; (2) fixation, the chemical processing of soil to immobilize the metals, usually followed by treatment of the soil surface to eliminate penetration by water; and (3) leaching, using acid solutions as proprietary leaching agent to leach metals from soil followed by the return of clean soil residue to site (Krishnamurthy 2000). Conventional methods used for metal detoxification produce large quantities of toxic products and are cost effective. The advent of bioremediation technology has provided an alternative to conventional methods for remediating the metal-polluted soils (Khan et al. 2009). Systematic remediation technologies for contaminated soil have been developed, which included bioremediation, physical/chemical remediation, and integrated remediation.

Phytoremediation is another emerging low-cost in situ technology employed to remove pollutants from the contaminated soils. Much work in metal phytoremediation based on laboratory, glasshouse, and field experiments has been carried out in China during the last decade. The efficiency of phytoremediation can be enhanced by the judicious and careful application of appropriate heavy metal-tolerant, plant growth-promoting rhizobacteria including symbiotic nitrogen-fixing organisms (Khan et al. 2009). Vegetables, especially mint, from SIDWS (soil amended with and irrigated with wastewater) contained high levels of Zn, Cd, and Pb than vegetables grown in the same site, suggesting that the cultivation of leafy vegetables should be avoided (Jamali et al. 2007). The results suggested that phytoremediation of Cd contaminated soil through soil-plant-rhizospheric processes. The *Bacillus sphaericus* could be tolerant to 800 mg L^{-1} Cr (VI) and reduced >80% during growth (Pal and Paul 2004). A study revealed the relationship between adsorption of Cd by soil and the property of soil and the influence on the uptake by plant roots. The results indicated that the adsorption capacity of the soils for Cd increased with the increase in the pH or alkalinity of the soil.

However, the adsorption rate decreased with the increased in pH. The results also indicated that Cd adsorption capacity of tropical vertisols was higher than those of temperate vertisols (Ramachandran and D'Souza 1999). Adhikari and Singh (2008) studied the effect of city compost, lime, gypsum, and phosphate on cadmium mobility by columns. Among the treatments, lime application reduced the movement of Cd from surface soil to lower depth of soil to a large extent. The results show that the high soil pH may reduce the mobility of Cd and the organic matter control Cd in soil. It is imperative to develop wide-use, safe, and cost-effective in situ bioremediation and physical/chemical stabilization technologies for moderately or slightly contaminated farmland, to develop safe, land reusable, site-specific physical/chemical and engineering remediation technologies for heavily polluted industrial site. Besides, it also needs to develop guidelines, standards, and policies for management remediation of contaminated soil (Luo et al. 2009). The Asian countries should take more efforts in promoting international exchanges and regional cooperation in soil environmental protection and in enhancing capacities of the management and technologies innovation. Pb and Cd possessed high mobility due to their very high extractability in acid-soluble fraction. The correlation coefficient matrix evidenced that enhanced metal levels in soil may lead to their accumulation in aerial parts of plants but not in edible parts of plants, that is, grains. A quite hazardous situation was observed where the rice grains in addition to aerial parts of plants also accumulated Pb, which may lead to various health hazards.

11.6 Conclusion

Rice is one of the favorite food for more than three billion people around the world. Although the total heavy metal concentrations in the rice from field can play an important role in their uptake into local diet, the potential for human intoxication by heavy metals is not simply related to the concentration in the food. The total dietary intake of heavy metals, however, is not only determined by their level in food but also by the amount of consumed contaminated food in the whole diet and the intake of heavy metals from other sources such as drinking water, atmosphere, occupational exposure, and everything in the environment. Therefore, up to now it has been impossible to predict the human health hazard related to element toxicity based only on heavy metal concentrations in the rice field during study.

To predict a dietary intake of these heavy metals by the human population and to assess the possible health risk, more detailed studies on heavy metal contamination in agricultural soils, irrigation and drinking water, rice, and other edible crops as well as a dietary study of the local population are needed. It has been well documented that the content of heavy metals in crop plants is closely related to the levels in the soil. The concentrations of Pb, Cd, Cu, Cr, and Zn except for Mn in the paddy soils were comparable to those of worldwide normal soils, which were higher than the value of uncontaminated soil. The uptake of Mn and Zn was higher in the roots of paddy plants, which were followed by Pb, Cr, Cu, and Cd accumulated more in the shoots than in roots and grains. Organic agriculture with little use of agrochemicals could be the alternative solution for reducing the contamination of toxic heavy metals particularly the toxic Cd, Cr, and Pb in the paddy fields producing rice, the staple food in India and other Southeast Asian countries.

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