

Soil Contamination with Heavy Metals and Its Impact on Food Security in China

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Abstract

With the rapid economic expansion, environmental degradation has become increasingly severe during the past three decades. Soil pollutions associated with toxic organic compounds and heavy metals have been identified in China. The accumulation of heavy metals in soils and its impact on food safety is of increasing concern. It has been reported that more than 20 million ha of land have been contaminated with heavy metals that can result in the potential health risks to human beings and soil ecosystems. This can potentially jeopardize the food security in China. Accumulation of heavy metals in suburb and rural soils is closely related to many anthropogenic activities, such as application of fertilizers and pesticides, irrigation of wastewater, discharge of mining, improper disposal of metal containing wastes, land application of animal manures, sewage sludge and coal combustion residues. Arable crops and vegetables in suburb and rural can take up heavy metals from contaminated soils, which is one of the main pathways of introducing heavy metals to human food chain. Events related to soil and vegetable contamination, food safety and human health risks, e.g., rice and vegetables with elevated concentrations of cadmium, are often reported in the media in recent years. The Chinese government has recently developed a number of new policies for prevention of soils from further soil contamination, and remediation of contaminated soils. This presentation will provide a comprehensive review on heavy metal pollution in soils and its impacts on food security in China, and also summarize some new technologies for remediation of soils contaminated with heavy metals.

Keywords

Soil, Heavy Metals, Food Security, China

1. Introduction

Since food is the paramount necessity of the people, food security is the prerequisite for human survival and the fundamental guarantee for human healthy. A variety of food contamination issues have led to food scares and public attention to food safety in recent years (Sriprachote et al., 2012; Akhtar, 2013; He et al., 2013). In China, food security issues, such as percent of pass food and poisoning food-borne disease, happen occasionally in China (Zhang et al., 2005; Li et al., 2013). So food security and safety are becoming hot topics and have been written into document at the Fifth Plenary Session of the 15th Congress of CPC in China.

The potential impact of heavy metals, pesticide residues and numerous adulterants on food security is one of the most important public health issues worldwide (Miraglia et al., 2009; Wei & Yang, 2010; Akhtar, 2013; Sun et al., 2013). Because of their toxicity, non-biodegradability and persistence, heavy metals are especially dangerous (Yan et al., 2013). Heavy metals constitute an ill-defined group of inorganic chemical hazards, and those most commonly found at contaminated sites are lead (Pb), chromium (Cr), arsenic (As), zinc (Zn), cadmium (Cd), copper (Cu), mercury (Hg), and nickel (Ni) (Lu et al., 2011). Heavy metal pollution not only affects the production and quality of crops, but also can cause problems in the aerosphere and water bodies, and may be finally accumulated in the human body, causing serious health problems (Kapaj et al., 2006; Zheng et al., 2007; Lai et al., 2010; Wei & Yang, 2010; John & Andrew, 2011; Lin et al., 2013; Fu & Wei, 2013). Unlike organic contaminants that are oxidized to carbon oxide by microbial action, most heavy metals do not undergo microbial or chemical degradation (Kirpichtchikova et al., 2006), thus heavy metals in soils persist for a long time (Adriano, 2003) and their presence can severely inhibit the biodegradation of organic contaminants (Maslin & Maier, 2000). As the primary reservoir of heavy metals in the atmosphere, hydrosphere and biota, soil serves vital function for food production and safety (Micó et al., 2006; Cao et al., 2010; Akhtar, 2013). Therefore, soil heavy metal pollution has also become of great concern to the public (Liu et al., 2006; Rogan et al., 2009; Römkens et al., 2009; He et al., 2013).

China has made outstanding economic progress since 1990, however, food security level of China is still inferior (Chen, 2007; Fu & Wei, 2013; Li et al., 2013). Remarkably, with the rapid economic growth and consequential food security accidents in recent years, soil heavy metal pollution and its negative influence on food security and human health has also aroused people's wide concern in China (Zhang et al., 2005; Howard & Sammy, 2012; Li et al., 2013; Wu & Chen, 2013). Therefore, the aim of the present review is to: 1) clarify the pollution of soil heavy metals in an agricultural urban soils; 2) find out the possible sources of heavy metals contamination in soils; 3) provide a comprehension of the impact of soils heavy metal pollution on food and human body and 4) propose measures to control and limit the accumulation of heavy metals in soils and

food crops.

Heavy metals in soil pose potential threats to the environment and can damage human health (Park et al., 2004; Al-Saleh et al., 2004; Komárek et al., 2008; Lu et al., 2011) through following approaches: 1) direct ingestion or contact with contaminated soil, 2) the food chain, 3) drinking of contaminated ground water, 4) reduction in food quality via phytotoxicity and 5) reduction in land usability for agricultural production causing food insecurity (McLaughlin et al., 2000; Ling et al., 2007).

2. Heavy Metal Pollution of Soils

Soil serves many vital functions in our society, particularly for food production. It is thus of extreme importance to protect this resource and ensure its sustainability. With the rapid development of industry and the economy, more and more pollutants are being released into soils (Kachenko & Singh 2006; Montagne et al., 2007; Li et al., 2008; Yang et al., 2009). Excessive accumulation of heavy metals (e.g., Pb, Cr, As, Zn, Cd, Cu, Hg and Ni) in soils may not only result in soil contamination, but also lead to elevated heavy metal uptake by crops, and thus affect food quality and safety (Park et al., 2004; Al-Saleh et al., 2004; Komárek et al., 2008; Lu et al., 2011). Thus, heavy metal pollution in soils has become an important issue both in developed and developing countries (Nicholson et al., 2003).

2.1. Heavy Metals in Agricultural Soils

Because heavy metals have the characteristics of toxicity, non-biodegradability and persistence, they are especially dangerous relative to different kinds of contaminants (Yan et al., 2013). Because of the potential human health risks, heavy metal accumulation in soils-plants system has led to a growing public concern (Wei & Yang, 2010; Fu & Wei, 2013). Meanwhile, the heavy metal contamination of soils has also received increased attention in China in recent years (Chen, 2007; Huang et al., 2007; Wei & Yang, 2010; Li et al., 2013).

Heavy metal contamination of soils has been reported in several provinces of China in recent several decades (Table 1; Huang et al., 2007; Liu et al., 2005; Wang et al. 2003; Zhao et al., 2007). Although the geological background levels of heavy metals are low in China, the mean concentrations of Cu (40.42), Pb (39.32), Zn (119.95), Ni (32.05), Cd (0.50) and Hg (0.31) mg/kg (dry mass) in agricultural soils of all the 15 cities are higher than their background values (Table 1). This indicates that the agricultural soils are under contaminated by the heavy metals. Wei and Yang (2010) also calculated the Igeo values for Cd and Hg in agricultural soils of China are higher than 1. Results suggest that the agricultural soils are significantly contaminated by Cd and Hg in many cities of China. Especially, the Igeo values for Cd and Hg are highest in the agricultural soils of Xuzhou and Guangzhou, respectively, indicating the agricultural soils may be considerably contaminated by Cd and Hg in the two cities. There

Table 1. Concentrations of heavy metals in agricultural soils of China (mg/kg).

Site	Cu	Zn	Ni	Pb	Cr	Hg	As	Cd
Beijing	28.1	81.1		18.5	75.7			0.18
Shanghai	31.4	106.2		26.4	85.6	0.13	7.8	0.20
Nanjing	33.2	87.8		45.6				0.66
Guangzhou	24.0	162.6		58.0	64.7	0.73	10.9	0.28
Wuhan	36.0	113.0	26.0	19.0		0.43		0.69
Changsha	35.1	153.4	31.1	55.1	32.9		17.3	0.54
Xiangtan	41.5	158.0	31.0	66.6	29.4		17.3	0.75
Zhuzhou	35.6	183.3	30.6	104.3	31.5		18.0	1.04
Hengyang	31.0	110.1	29.7	44.4	26.7		16.1	0.39
Cixi	34.0	88.9		28.1				0.15
Dongguan				69.2	40.6	0.26	15.2	0.92
Nanchang	43.1	101.4	25.1	45.7	57.6	0.64	18.1	0.21
Lanzhou	41.6	69.6		37.4			17.3	
Zhengzhou				17.1	67.7	0.08	6.7	0.12
Yangzhou	33.9	98.1	38.5	35.7	77.2	0.20	10.5	0.30
Wuxi	40.4	112.9		46.7	58.6	0.16	14.3	0.14
Taihang	21.2	70.0	25.0	18.8	57.8	0.08	6.2	0.15
Chengdu	42.5	227.0		77.3	59.5	0.31	11.3	0.36
Hainan	30.3	52.2	15.5	48.0	22.7		8.1	0.28
Jinghe				22.4	44.2		14.9	0.14
Kunshan	34.3	105.9	31.1	30.5	87.7	0.20	8.2	0.20
Xuzhou	35.3	149.7		56.2				2.57
Tianjin	73.0		44.0	36.0		0.80	10.7	0.61
Baiyin	99.3	147.0	44.2	84.1				0.98
China Background	22.6	74.2	26.9	26.0	61.0	0.07	11.2	0.10

Note: China Background = background values in soil of China.

are over 12,000 ha Cd polluted soils in 11 irrigation regions of China (Liao, 1993). Large amounts of soil Cd have accumulated in China soils that the Cd content in heavily polluted soil reaches levels of 5 - 7 mg/kg and the content in rice is 1 - 2 mg/kg in the Zhangshi irrigation area. The average concentrations of soil Cd, Cu and Zn in Wenling (Zhejiang province of China) were higher than their local background values, and the mean values of soil Cu and Cd increased during the past 5 years soil (Li et al., 2014). Since long farmed history, the contents of Cu and Pb also have been high and a common pollution in vegetable fields of China (Zhang & Gong 1996). Therefore, the soil pollution of heavy metals is widespread in agricultural soils in China.

Owing to rapid economic development, heavy metal contamination of agri-

cultural soils has become increasingly serious in China (Li et al., 1997; Liu et al., 2005; Huang et al., 2007; Li et al., 2016). The main pollution sources of heavy metals are different in different areas (Huang et al., 2007; Liu et al., 2005; Wang et al., 2003; Zhao et al., 2007). The sources of Cu, Pb, Zn and Ni in the agricultural soils of Xuzhou and Guangzhou may be mainly derived from industrial sources. The sources of the metals in agricultural soils are mainly influenced by sewage irrigation in Beijing and Zhengzhou. However, the sources of the metals in agricultural soils in the other cities may be mainly influenced by parent materials, urban effluent and vehicle exhausts. On the other hand, the increasing reliance on agrochemicals for higher yields is also an important source of heavy metals in agricultural soils (Li et al. 1997). Today's agriculture in China has become increasingly reliant upon agrochemical usage (Li et al., 1997a & 1997b). According to the Food and Agriculture Organization, the use of inorganic fertilizer in China increased by about 100 times from 3.9 kg/ha in 1949 to 379 kg/ha in 1995, which was more than 2.5 times of the world's average. Moreover, China is the world's second largest producer of pesticide, and there was more than 260,000 t of pesticide production in 1994. About 90% of the pesticides is used on crops (Li et al., 1997a). Some fertilizers and pesticides are known to contain various levels of heavy metals, including Cd and Cu. Thus, agricultural soils and crops are suffering from increasing damage from heavy metals in China.

2.2. Heavy Metal Pollution in Urban Soils

As the urban population continues to grow, more and more attention has been given to the influence of heavy metal pollution of urban soils on urban eco-environment and human health. Many studies have indicated that urban soils are contaminated by heavy metals in China (Figure 1; Lu et al., 2003; Li et al., 2013). Heavy metals in urban soils can be accumulated in human body via directly inhalation, ingestion and dermal contact absorption (Madrid et al., 2002; Ferreira-Baptista & De Miguel 2005; De Miguel et al., 2007; Poggio et al., 2008; Marjorie et al., 2008; Lim et al., 2008). In addition, intake of heavy metals via the soil-crop system has been considered as the predominant pathway of human exposure to environmental heavy metals in suburb area (Liu et al., 2007). In China, due to the modern industries, traffic and mining activities and rapid urbanization in urban areas, the heavy metal contamination of urban soils has become increasingly serious during the last two decades (Wei & Yang, 2010).

In China, heavy metal pollution in urban soils becomes serious with the rapidly industrialization and urbanization, thus quite a few studies associated with heavy metal contamination in urban soils have been carried out in recent decades (Figure 2; Wei & Yang, 2010). Although the geological background levels of heavy metals are low in China, soil, water, air and plants are polluted by heavy metals in many cities. Heavy metal pollution of soils do harm to human health through the directly intake or the food chain (Lu et al., 2011). Heavy metal pollution in urban soil is present in various cities, such as Beijing

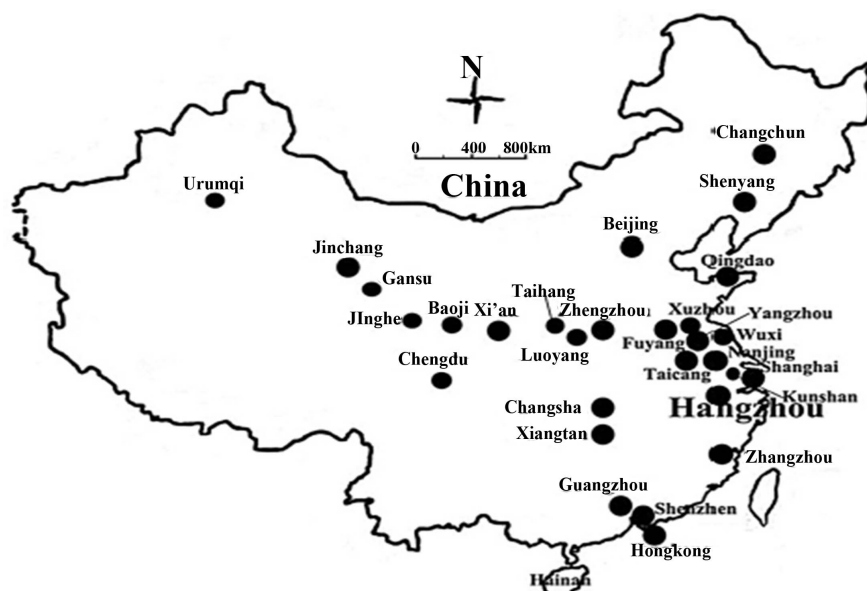


Figure 1. Distribution of urban soils with heavy metal contaminations in China.

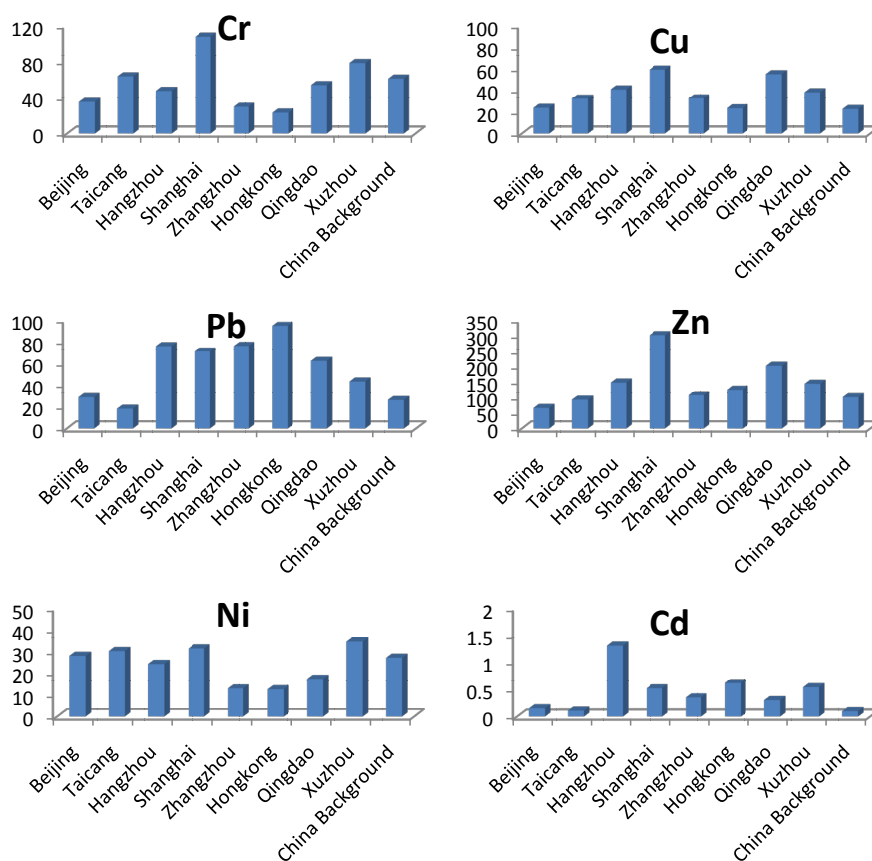


Figure 2. Concentrations of heavy metals in urban soils from the cities in China (mg/kg).

and Shanghai. Significant enrichment of lead (Pb), zinc (Zn), copper (Cu), chromium (Cr) and cadmium (Cd) in urban soil of Shanghai has been reported.

Most of the concentrations of heavy metals in urban soils are higher than their background values (**Figure 2**). The Pb concentrations of urban soils in Beijing, Qingdao, Hangzhou, Shanghai, Zhangzhou, Hongkong and Xuzhou are much higher than their background values. It is significantly apparent that the Cd and Cu concentrations of urban soils in the cities are all exceed their background values. The highest concentrations of Cr, Cu, Pb, Zn and Cd are also found in the cities of Shanghai, Shanghai, Hongkong, Shanghai and Hangzhou, respectively. Moreover, several studies of soil metal contamination in Chinese cities also concluded that heavy metal contamination is widespread in urban soils (Wei & Yang, 2010).

The cause of heavy metal accumulation in soils can be either natural or anthropogenic (Krzysztof et al., 2004), including industries (Jan et al., 2010; Chabukdhara & Nema, 2013) and urbanization (Chen, 2007). Generally speaking, the sources of Cd, Cu, Pb, Zn, Cr and Ni in urban soils are mainly derived from traffic emission and industrial emission. The main pollution sources of the metals are different among the cities. The pollution sources of the heavy metals in the urban soils of Shenyang, Baoji, Guangzhou and Changchun may be mainly derived from industrial emission and traffic emission, while the heavy metals in Beijing, Shanghai, Wenzhou, Qingdao and other cities may be mainly derived from traffic emission. Therefore, human activities, such as industrial and energy production, vehicle exhaust, waste disposal, and coal and fuel combustion are all potential sources for heavy metals to urban soils.

3. The Impact of Heavy Metals on Food Security

With the development of industrialization and consequential food security accidents, soil heavy metal pollution has become of great concern to the public (He et al., 2013; Liu et al., 2006; Rogan et al., 2009; Römkens et al., 2009). Cultivation of crops for human or livestock consumption on contaminated soil can potentially lead to the uptake and accumulation of heavy metals, and chronic intakes of heavy metals have damaging effects on human beings and other animals (Zheng et al., 2007; Lai et al., 2010; John & Andrew, 2011). Thus, heavy metal pollution of soil has an important influence on the health of human beings (McBride, 2007; Demek-Poprawa & Sawicka-Kapusta, 2004; Akhtar, 2013; He et al., 2013; Sriprachote et al., 2012). It has been reported that serious systemic health problems can develop as a result of excessive dietary accumulation of heavy metals such as Cd, and Pb in the human body (Oliver, 1997). Although Zn and Cu are essential elements, their excessive concentration in food and feed plants are of great concern because of their toxicity to humans and animals (Kabata-Pendias & Mukherjee, 2007). Lead and Cd are considered potential carcinogens and are associated with etiology of a number of diseases, especially cardiovascular, kidney, nervous system, blood as well as bone diseases (Jarup, 2003). Soil and vegetables polluted with Pb and Cd can lead to decrease of human life expectancy within the affected areas. Pruvot et al. (2006) and Bosso and

Enzweiler (2008) showed that children living around a former smelter had high blood Pb levels in France and Brazil. Although Zn and Cu are essential elements, their excessive concentration in food and feed plants are of great concern because of their toxicity to humans and animals (Kabata-Pendias & Mukherjee, 2007). When exceed their safe threshold values, Cu and Zn can cause non-carcinogenic hazardous such as neurologic involvement, headache and liver disease. As one of the highest toxic heavy metals, Cd is harmful to plant growth and human health. Dietary Cd intake through the food chain was associated with an increased risk of postmenopausal breast cancer, and its accumulation pose a serious health issue to humans, such as the “itai-itai” disease (Sun et al., 2013). Soil pollution has negative impacts on humans and the environment, especially for the ubiquitous and non-biodegradable heavy metals, the negative effects persist for several decades and even longer. Therefore, it is important to get information about heavy metal concentrations in food products and their dietary intake, and heavy metal pollution of soil and its impact on food security are receiving more attention (Akhtar, 2013; He et al., 2013; Römkens et al., 2009).

Rice production is the dominant agricultural activity in China, with rice forming the staple diet of more than 65% of the Chinese population (Zhang et al., 2005). China ranks as the second largest rice producer in the world. The mean consumption of rice grain in China is 206 kg per year per person (Zhang et al., 2005). Both the qualities of soil and rice produced are extremely closely related to local public health. Rice cultivated on soils polluted with Cd, Pb, Cr, Hg, As, Cu, Ni and Zn has been reported to accumulate the metals in root, leaf, stem and grain causing food-chain and ecotoxicological problems (Wu & Chen, 2013). For example, in the Zhangshi irrigation area of China, large amounts of Cd have accumulated in irrigated soils, and the cadmium content in rice grain, is also relatively high. Heavy metal accumulation in the soil-rice systems would poses potential environmental risks (Li et al., 2014).

Additionally, with the food structural adjustment of China in recent years, the consumption of vegetables for Chinese residents is also increasing greatly (Liu et al., 2005). Vegetables take up heavy metals by absorbing them from contaminated soils, as well as from deposits on parts of the vegetables exposed to the air from polluted environments. So as much as 50% of food intake may be assumed to be grown on contaminated soil in China, and long term consumption of food would pose a potentially high health risk caused by heavy metal exposure to consumers (He et al., 2013; Zhang et al., 2005). There are a series of standards on the tolerance limit of trace elements in foods (Table 2). According to this standard, the edibility of foods can be determined and the safety of foods can be guaranteed. Although some elements were lower than food standards, the heavy metal pollution cannot be ignored. The pollution in vegetables directly affects the health of humans via consumption. Fed with a diet containing 1 mg/kg of Cd for 12 days, the maximum of Cd in Nile tilapia was 0.129 mg/kg, but declined to 86% following a no-Cd diet. Cd accumulated in the organism is not easy to excrete and affect the health of animals in the whole lifecycle. Although the levels

of As in water and food were lower than the national food standard, the levels of As exposure of residuals were equal to or even over that of the severe cases of chronic arsenic poisoning reported in China, which occurred in the area with As concentrations in drinking water which were 0.18 - 0.85 mg/kg.

4. Remediation of Soil Contaminated with Heavy Metals

The overall objective of any soil remediation approach is to create a final solution that is protective of human health and the environment. Effective methods for reducing soil heavy metal pollution involve severe control of pollution sources or strict implementation of environmental regulation in terms of waste discharge. Since the 1980s, much effort has been made to control pollution sources and to set up environmental quality standards in China. Some countermeasures for remediation of soil contaminated with heavy metals have been investigated including soil moisture management, amendment application, addition of organic manure, selection of crop varieties with a low uptake of heavy metals, and agro-ecological engineering techniques.

For heavy metal-contaminated soils, the physical and chemical form of the heavy metal contaminant in soil strongly influences the selection of the appropriate remediation treatment approach. USEPA (2010) has broadly classified remediation technologies for contaminated soils into 1) source control and 2) containment remedies. According to **Table 3**, there is another classification of remediation technologies for heavy metal-contaminated soils: isolation, immobilization, toxicity reduction, physical separation, and extraction.

Immobilization technology often uses organic and inorganic amendment to accelerate the attenuation of metal mobility and toxicity in soils (Wuana & Okieimen, 2011). Because of the complexity of soil matrix and the limitations of current analytical techniques, the exact immobilization mechanisms have not been clarified, which could include precipitation, chemical adsorption and ion exchange, surface precipitation, formation of stable complexes with organic ligands, and redox reaction (Wang et al., 2009). Soil washing is essentially a volume reduction/waste minimization treatment process. It is done on the excavated soil or in situ. Acid and chelator soil washing are the two most prevalent removal methods. Phytoremediation, also called green remediation, botanoremediation, or vegetative remediation, can be defined as an in situ remediation strategy that uses vegetation and associated microbiota, soil amendments, and

Table 2. Tolerance limit of heavy metals in foods in China [mg/kg].

Foods types	Cu	Zn	Pb	Cr	As	Cd
Crops	10	50	0.4	1.0	0.7	0.05
Vegetable	10	20	0.2	0.5	0.5	0.05
Fruit	10	5	0.2	0.5	0.5	0.03

Table 3. Technologies for remediation of heavy metal-contaminated soils.

Category	Remediation technologies
Isolation	Capping
	Subsurface barriers
Immobilization	Solidification/stabilization
	Vitrification
	Chemical treatment
Toxicity and/or mobility reduction	Chemical treatment
	permeable treatment walls
	biological treatment bioaccumulation, phytoremediation, bioleaching, biochemical processes
Physical separation	
Extraction	Soil washing
	in situ soil flushing
	Pyrometallurgical extraction
	Electrokinetic treatment

agronomic techniques to remove, contain, or render environmental contaminants harmless (Helmisaari et al., 2007). Phytoremediation is energy efficient, aesthetically pleasing method of remediating sites with low-to-moderate levels of contamination, and it can be used in conjunction with other more traditional remedial methods as a finishing step to the remedial process (Figure 3). The advantages of phytoremediation are as follow: it is less disruptive, less risk of spreading the contamination, but more economically viable and more likely to be accepted by the public.

5. Conclusion

With the activity of humans, heavy metal pollution of soils becomes serious and even affects human health through the food chain during the last two decades in China. Although the geological background levels of heavy metals are low in China, both urban soils and agricultural soils are polluted by heavy metals. Nearly all the heavy metals concentrations of urban and agricultural soils are higher than their background values in China. Moreover, the concentrations of Cd and As in agricultural soils are higher than their background values. In agricultural area, intake of heavy metals via the soil-crop system has been considered as the predominant pathway of human exposure to environmental heavy metals; in urban area, heavy metals in urban soils and urban road dusts can be accumulated in human body via directly inhalation, ingestion and dermal contact absorption. The sources of heavy metals in urban soils and urban road dusts are mainly derived from traffic sources and industrial sources, but the sources of heavy metal in agricultural soils are mainly influenced by parent materials, mining, fertilization and pesticide application and so on.

Phytoremediation of Metal-Contaminated Soils

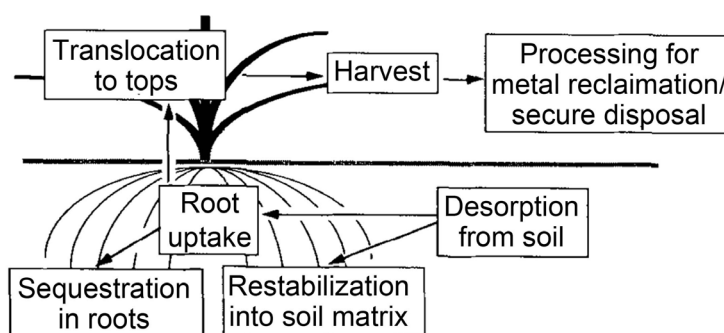


Figure 3. Scheme for the application of phytoremediation technology to metal-contaminated soils.

Heavy metals will accumulate in plants, and especially in foods to bring the toxicity and diseases to human beings, and this kind of pollution is covert, long-term and non-reversible. Thus, humans should be careful with heavy metal polluted water and food. To remediate and improve environmental quality is a long-term strategy for the polluted area to keep humans healthy and away from geological disease. Therefore, remediation of soil contaminated by heavy metals is necessary, which is a hot topic throughout the world. We have summarized some countermeasures for remediation of soil contaminated with heavy metals. Immobilization, soil washing and phytoremediation are frequently listed among the best available technologies for cleaning up heavy metal contaminated soils (Wuana & Okieimen, 2011). As an optimum, a clean biosphere could be displayed in front of us in the near future.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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