Article

A review on heavy metal contamination in the soil worldwide: Situation, impact and remediation techniques

Chao Su[1], **LiQin Jiang**[1], **WenJun Zhang**[1,2]
[1]School of Life Sciences, Sun Yat-sen University, Guangzhou 510275, China; [2]International Academy of Ecology and Environmental Sciences, Hong Kong
E-mail: zhwj@mail.sysu.edu.cn, wjzhang@iaees.org

Received 26 March 2014; *Accepted 21 April 2014*; *Published online 1 June 2014*

Abstract
Heavy metals in the soil refers to some significant heavy metals of biological toxicity, including mercury (Hg), cadmium (Cd), lead (Pb), chromium (Cr), and arsenic (As), etc. With the development of the global economy, both type and content of heavy metals in the soil caused by human activities have gradually increased in recent years, which have resulted in serious environment deterioration. In present study we compared and analyzed soil contamination of heavy metals in various cities/countries, and reviewed background, impact and remediation methods of soil heavy metal contamination worldwide.

Keywords soil; heavy metals; contamination; remediation; world.

Environmental Skeptics and Critics
ISSN 2224-4263
URL: http://www.iaees.org/publications/journals/environsc/online-version.asp
RSS: http://www.iaees.org/publications/journals/environsc/rss.xml
E-mail: environsc@iaees.org
Editor-in-Chief: WenJun Zhang
Publisher: International Academy of Ecology and Environmental Sciences

1 Introduction

Heavy metal contamination refers to the excessive deposition of toxic heavy metals in the soil caused by human activities. Heavy metals in the soil include some significant metals of biological toxicity, such as mercury (Hg), cadmium (Cd), lead (Pb), chromium (Cr) and arsenic (As), etc. They also include other heavy metals of certain biological toxicity, such as zinc (Zn), copper (Cu), nickel (Ni), stannum (Sn), vanadium (V), and so on.

In recent years, with the development of the global economy, both type and content of heavy metals in the soil caused by human activities have gradually increased, resulting in the deterioration of the environment (Han et al., 2002; Sayyed and Sayadi, 2011; Jean-Philippe et al., 2012; Raju et al., 2013; Prajapati and Meravi, 2014; Sayadi and Rezaei, 2014; Zojaji et al., 2014). Heavy metals are highly hazardous to the environment and organisms. It can be enriched through the food chain. Once the soil suffers from heavy metal contamination, it is difficult to be remediated.

In the past, soil contamination was not considered as important as air and water pollution, because soil contamination was often with wide range and was more difficult to be controlled and governed than air and water pollution. However, in recent years the soil contamination in developed countries becomes to be serious. It is thus paid more and more attention and became a hot topic of environmental protection worldwide.

To understand the current situation and the impact of heavy metal contamination of soils in the world, in present study we will compare and analyze the contamination data of various cities/countries, and explore background, impact and remediation methods of heavy metal contamination of soils.

2 Characteristics, Sources and Harmfulness of Heavy Metal Contamination in the Soil

2.1 Characteristics of heavy metal contamination of soils

2.1.1 Wide distribution

With the development of economy and society, heavy metal contamination has become increasingly common in the world. It is almost a serious threat to every country. In the world's top ten environmental events, two events have related to heavy metal contamination (Yang and Sun, 2009).

2.1.2 Strong latency

Heavy metal contamination is colorless and odorless, so it is difficult to be noticed. It does not explicitly damage the environment in a short period. Nevertheless, when it exceeds the environmental tolerance, or when environmental conditions have changed, heavy metals in the soil may be activated and cause serious ecological damage. So heavy metal contamination is usually chemical Time Bombs (CTBs) (Wood, 1974).

2.1.3 Irreversibility and remediation hardness

If the air and water are polluted, the pollution problem can be reversed certainly by dilution and self-purification after switching off the sources of pollution. However, it is difficult to use dilution or self-purification techniques to eliminate heavy metal contamination and to get soils improved. Some soils contaminated by heavy metals are likely to take one or two hundred years to be remediated (Wood, 1974). Therefore, heavy metal contamination needs relatively high cost of remediation and the remediation cycle is relative long.

2.1.4 Complex heavy metal contamination

In the past, soil contamination was mainly caused by a single heavy metal. However, in recent years more cases are found to be caused by a variety of heavy metals (Zhou, 1995). The complex contamination caused by a variety of heavy metals will always amplify the contamination by heavy metals separately. Qin et al. (2008) showed that in terms of the influence on soil respiration, Cu+ Pb > Pb > Cu.

2.2 Sources of heavy metals

Excess heavy metals in the soil originate from many sources, which include atmospheric deposition, sewage irrigation, improper stacking of the industrial solid waste, mining activities, the use of pesticides and fertilizers (Zhang et al., 2011), etc. Table 1 shows various sources of heavy metals contaminating soils in the world (Qin et al., 2008).

2.2.1 Atmosphere to soils pathway

Heavy metals in the atmosphere are mainly from gas and dust produced by energy, transport, metallurgy and production of construction materials. Excepting mercury, heavy metals basically go into the atmosphere in the form of aerosol and deposit to the soil through natural sedimentation and precipitation, etc. For example, the lead pollution (Lin, 1998) in a downtown, Central Sweden, was reported mainly from the urban industrial copper plant, sulfuric acid plant, paint factory, and the large amount of waste from mining and chemical industries. Due to transporting by wind, these fine lead particles spread from industrial waste heap to surrounding areas. The superimposed chromium contamination by a heavy industrial factory producing chromium (Zhang, 1997) in Nanjing, was reported more than 4.4 times of the local background value. The chromium contamination was centered on the chimney of workshop, ranging up to 1.5 km^2, and extending 1.38 km away. A sulfuric acid production plant in Russia (Meshalkina, 1996) was reported to contaminate the environment because of the discharge of S, V, and As from the factory chimneys.

Table 1 Different sources of heavy metals contaminating soils annually in the world (1000 t • a^{-1}).

Sources	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Agriculture and food waste	0~0.6	0~0.3	4.5~90	3~38	0~1.5	6~45	1.5~27	12~150
Farmyard manure	1.2~4.4	0.2~1.2	10~60	14~80	0~0.2	3~36	3.2~20	150~320
Logging and timber Industry wastes	0~3.3	0~2.2	2.2~18	3.3~52	0~2.2	2.2~23	6.6~8.2	13~65
Municipal wastes	0.09~0.7	0.88~7.5	6.6~33	13~40	0~0.26	2.2~10	18~62	22~97
Municipal sludge	0.01~0.24	0.02~0.34	1.4~11	4.9~21	0.01~0.8	5.0~22	2.8~9.7	18~57
Organic wastes	0~0.25	0~0.01	0.1~0.48	0.04~0.61	-	0.17~3.2	0.02~1.6	0.13~2.1
Metal processing solid wastes	0.01~0.21	0~0.08	0.65~2.4	0.95~7.6	0~0.08	0.84~2.5	4.1~11	2.7~19
Coal ash	6.7~37	1.5~13	149~446	93~335	0.37~4.8	56~279	45~242	112~484
Fertilizer	0~0.02	0.03~0.25	0.03~0.38	0.05~0.58	-	0.20~3.5	0.42~2.3	0.25~1.1
Marl	0.04~0.5	0~0.11	0.04~0.19	0.15~2.0	0~0.02	0.22~3.5	0.45~2.6	0.15~3.5
Commodity impurities	36~41	0.78~1.6	305~610	395~790	0.55~0.82	6.5~32	195~390	310~620
Atmospheric deposition	8.4~18	2.2~8.4	5.1~38	14~36	0.63~4.3	11~37	202~263	49~135
Total	52~112	5.6~38	484~1309	541~1367	1.6~15	106~544	479~1113	689~2054

Source from Nriagu and Pacyna, 1988.

Transport, especially the automotive transport, causes serious heavy metal contamination (Pb, Zn, Cd, Cr, Cu, etc.) of the atmosphere and soils (Falahiardakani, 1984). Heavy metals come from burning leaded gasoline and the dust produced by automobile tire wear. According to the report, the exhaust from the car contained Pb up to 20 ~ 50 μg / L, which formed a zonal distribution and there was a clear difference as the change of the distance of from railway, traffic highway, city center, and the car traffic volume. In the Nanjing section of Nanjing-Hangzhou highway, the soil on both sides of the road had formed contamination zone of Pb, Cr, and Co. And the contamination zone was distributed along the direction of the highway. The contamination was weakened along the direction of the both sides of the highway. The amount of heavy metals which went into the soil through natural deposition and raining sedimentation are related to the level of development of heavy industry, the city's population density, land utilization and traffic level. Soil contamination became to be heavier as closing to the city (Chen, 2002).

2.2.2 Sewage to soils pathway

Wastewater can be divided into several categories, sanitary sewage, chemical wastewater, industrial mining wastewater and urban mining mixed sewage, etc. Heavy metals are brought to the soil by irrigative sewage and are fixed in the soil in different ways. It causes heavy metals (Hg, Cd, Pb, Cr, etc.) to continually accumulate in the soil year by year.

Sewage irrigation is a feasible way to solve the problem of crop irrigation in the arid area. However, heavy metal contamination caused by sewage irrigation must be paid enough attention. Quality of irrigative sewage must be strictly controlled within the national quality standard for irrigation water.

2.2.3 Solid wastes to soils pathway

There are a variety of solid wastes which have complex composition. Of which mining and industrial solid waste contamination is the most serious. When these wastes are in the process of being piled or governed, heavy metals move easily due to the facilitation of sunlight, raining and washing. And they spread to the surrounding water and soils at the shape of funnel and radiation.

With the development of industry and the acceleration of urban environmental construction, sewage treatment is continuing to be strengthened. China now has more than 80 sewage treatment plants, with the estimated 400 million tons of sludge production. Due to the high content of organic matter, nitrogen and phosphorus in the sludge, soils become the main places for soil sludge treatment. In general, Cr, Pb, Cu, Zn and As in the sludge will exceed the control standards easily (Ding, 2000).

Solid wastes can expand contamination scope easily with the help of wind and water.

2.2.4 Agricultural supplies to soils pathway

Fertilizers, pesticides and mulch are important agricultural inputs for agricultural production (Zhang and Zhang, 2007; Zhang et al., 2011). Nevertheless, the long-term excessive application has resulted in the heavy metal contamination of soils. The vast majority of pesticides are organic compounds, and a few are organic - inorganic compound or pure mineral, and some pesticides contain Hg, As, Cu, Zn and other heavy metals (Arao et al., 2010).

Heavy metals are the most reported pollutants in fertilizers. Heavy metal content is relatively low in nitrogen and potash fertilizers, while phosphoric fertilizers usually contain considerable toxic heavy metals. Heavy metals in the compound fertilizers are mainly from master materials and manufacturing processes. The content of heavy metals in fertilizers is generally as follows: phosphoric fertilizer> compound fertilizer> potash fertilizer> nitrogen fertilizer (Boyd, 2010). Cd is an important heavy metal contaminant in the soil. Cd is brought to soils with the application of phosphoric fertilizers. Many studies showed that, with the application of a large amount of phosphate fertilizers and compound fertilizers, the available content of Cd in soils increases constantly, and Cd taken by plants increases accordingly. In recent years, the mulch has been promoted and used in large areas, which results in white pollution of soils, because the heat stabilizers, which contain Cd and Pb, are always added in the production process of mulch. This increases heavy metal contamination of soils (Satarug et al., 2003).

2.3 Impact of heavy metal contamination of soils

2.3.1 Impact on soil microorganisms and enzymatic activity

Microbial activity and enzymatic activity of the soil can sensitively reflect the quality of the soil (Lee et al., 1996). Aceves et al. (1999) held that microbial biomass of the soil was an important indicator of determining the extent of soil contamination. Microbial activity is inhibited significantly in the heavy metal contaminated soil. Kandeler et al. (1997) indicated that the microbial biomass in the soil contaminated by Cu, Zn, Pb and other heavy metals were inhibited severely. The soil’s microbial biomass near the mine was significantly lower than that far away from the mine. And the effects of different concentrations of heavy metals and different heavy metals on soil microbial biomass were different. Chander et al. (1995) studied the effect of different concentrations of heavy metals on soil microbial biomass, and found that only if the concentration of heavy metals in the soil was three times above the environmental standard, established by the European Union, it could inhibit microbial biomass. Fliebbach et al. (1994) found that low concentrations of heavy metals could stimulate microbial growth and increase microbial biomass; while high concentrations could decrease soil microbial biomass significantly. In addition, the enzymes in the soil play an important role in the process of organic matter decomposition and nutrient cycling. Studies have showed that the activities of enzymes in the soil are related to the heavy metal contamination. Chander et al. (1995) found that the activities of almost all enzymes in the soil were significantly reduced by 10 to 50 times with the increase of the concentration of heavy metals.

2.3.2 Impact on the plants

Low concentration of soil heavy metals, regardless of necessary or unnecessary to plants, will not affect the growth of plants in a certain range. But if the concentration is too high, the content of heavy metals enriched by the plant exceeds its tolerance threshold, and thus the plant will be poisoned and it even leads to death of the plant. In Florida, it was found that if the copper content in soil was more than 50 mg/ kg, it would affect citrus seedlings; if soil copper content reached 200mg/ kg, wheat would wither (Zhang et al., 1989). Research found that the growth of cabbage and bean seedling under Cd concentration of 30 μ mol/ L was inhibited: the root length decreased, and the plant height and leaf area dropped (Qin et al., 1994). Cd may interfere crop photosynthesis and protein synthesis, and may cause membrane damage, etc (Acar and Alshawabkeh, 1993; Kale, 1993).

2.3.3 Impact on humans

Existing research showed that heavy metals in urban soils may go into the human body through skin absorption and inhalation of dust, etc., and thus directly damage, especially children's health. They also affect the urban environmental quality and damage human health indirectly through polluting the food, water and atmosphere. In a study on the content of Pb in children blood, Yabe et al. (2010) found that the contaminated soil dust in the city was an important factor to affect human health. According to the survey, there is about 30% of Chinese children's blood whose content of Pb exceeds the home standard (100 g/ L); this rate in cities is more than 60%. According to a study (Robert and Jones, 2009), the content of Pb in urban children's blood and the content of Pb in the soil of the city exhibited a significant exponential relationship (blood Pb=18.5+7.2*soil Pb± 0.4).

Cd may damage the metabolism of calcium, which will cause calcium deficiency and result in cartilage disease and bone fractures, etc. Agency for Toxic Substances Management Committee has listed Cd as the sixth most toxic substance that damages human health.

Pb mainly enters human body through the digestive tract and respiratory tract, and then goes into the blood circulation in the form of soluble salts, protein complexes or ions, etc. 95% of the insoluble phosphate lead accumulates in bones. Pb is strongly pro-organizational. It affects and damages many of the body organs and systems, such as kidney, liver, reproductive system, nervous system, urinary system, immune system and the basic physiological processes of cells and gene expression.

Cu, Zn and Ni are essential trace metals in the human body, but if the body takes excessive Cu, Zn and Ni from the outside environment, they will damage human health. Ni and Cu are tumor promoting factors, whose carcinogenesis effect has attracted global concerns. Workers who are in close contact with the nickel powder are more likely to suffer from respiratory cancer, and the content of Ni in the environment is positively correlated with nasopharyngeal carcinoma (Chen, 2011).

According to a latest report (Phoenix Satellite TV, 2014), As has resulted in serious damage to farmers in Heshan Village, Shimen County, Changde City, Hunan Province, China (Fig. 1 & 2). There was ever a As processing factory in this village between 1951 and 1978. Most farmers had worked in the factory during that period. Since 1951, waters, soils, crops and the environment have been terribly contaminated by As. The As content in the soil has reached 92.7 mg/kg^{-1}, and in the river water it is now 10 times of the permissible limit. Many plants have been dying. Crops can only be produced for livestock use. About 1800 workers in the factory (they are also farmers in the village) have suffered from chronic As poisoning (Fig. 2). About 400 workers have died from various As-induced cancers between 1951 and 2012: skin cancer, liver cancer, lung cancer, colorectal cancer, uterine cancer, etc., of which there are 300 lung cancer cases. A typical case is that 7 people in the same family died from cancers. Due to the serious contamination over more than 100 hectares of lands in the village, 821 householders of the village are now appealing for migrating to the other regions, although the environmental remediation project has started in recent years.

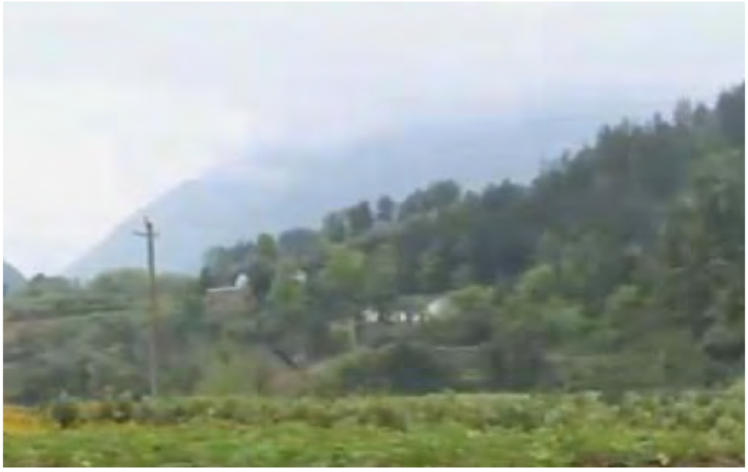

Fig. 1 A profile of Heshan Village, Shimen County, Changde City, Hunan Province, China (Phoenix Satellite TV, 2014).

(a) (b) (c)

Fig. 2 Skin symptoms of As poisoning of three farmers (Phoenix Satellite TV, 2014). a: ZhaoYuan Gong, left-down back; b: QiBing Zhao, back; c: QianKuan Zhang, right hand. Small white spots caused by As will enlarge to become pimples, and then fester. Systematic festering usually means that cancer cells have spread to whole body.

3 Current Situation of Soil Heavy Metal Contamination in the World

In recent years, several studies have shown that the characteristics of the heavy metal contamination in urban soils and agricultural soils are different (Babula et al., 2008). Heavy metals in urban soils may go into the body directly through ingestion, skin contact, etc. Heavy metals in agricultural soils are absorbed and accumulated by crops. Ingesting heavy metals through the soil - crop system is a major way of damaging human health (Aeliona et al., 2008).

Numerous studies indicated that the major sources of heavy metal contamination in urban soils include emissions from transport (exhaust, tire wear debris particles, particles formed by weathering street, etc.), industrial wastes (from power plants, coal combustion, metallurgical industry, automobile repair plants, chemical plants, etc.), household garbage, building and weathered particles of sidewalk and precipitation in the atmosphere, etc. However, the major sources of heavy metal contamination in agricultural soils include the impact from the city, smelting minerals, waste treatment (such as landfill, etc.), sewage sludge, automobile exhaust, fertilizers and pesticides, etc (Montagne et al., 2007).

In recent years, heavy metal contamination in China's urban and agricultural soils is rapidly getting worse with the development of industrial activities. According to Bulletin on National Survey of Soil Contamination, jointly issued by Ministry of Environmental Protection of China and the Ministry of Land Resources of China in recent days, nearly 4 million of hectares of arable lands have been contaminated moderately or severely, which accounts for about 2.9% of China's arable lands. The proportion of soils that exceeds environmental standard reaches 16.1%, of which the proportion for the slight, mild, moderate and severe contamination are 11.2%, 2.3%, 1.5% and 1.1%, respectively. Most of soil contamination is inorganic (82.8%), seconded by organic, and the third is complex contamination. Contamination of arable land soil exceeds the 19.4%, of which the proportion for the slight, mild, moderate and severe contamination is 13.7%, 2.8%, 1.8% and 1.1%, respectively, and the most contaminants include Cd, Ni, Cu, As, Hg, Pb, DDT and PAHs.

Worldwide the samples of urban soils and agricultural soils are mainly collected from the depths of the 10 cm to 20 cm of soils. In urban soils, samples are collected from parks, green spaces and urban street. These samples are mixed, dried and screened out through a mesh of less than 2 mm, and then is processed and cleared up through a mixed acid (such as HF, $HClO_4$, HNO_3, H_2O_2, H_2SO_4, etc.). Finally, the content of the heavy metals (Cd, Cr, Cu, Ni, Pb, Zn, As, Hg, etc.) is measured using such methods as ICP, ICP-MS, ICP-AES, ICP-OES, CV-AAS, AAS, XFS or XRF, etc.

Table 2 The content of heavy metals in urban soils (mg/kg^{-1}).

City/Country	Cr	Cu	Pb	Zn	Ni	Cd	Reference
Beijing	35.60	23.70	28.60	65.60	27.80	0.15	Zheng et al., 2008
Guangzhou	-	62.57	108.55	169.24	25.67	0.50	Lu et al., 2007
Shanghai	107.90	59.25	70.69	301.40	31.14	0.52	Shi et al., 2008
Changsha	121.00	51.40	89.40	276.00	-	6.90	Xi et al., 2008
Hong Kong	23.10	23.30	94.60	125.00	12.40	0.62	Li et al., 2004
Qingdao	54.00	55.00	62.00	201.00	17.30	0.30	Yao et al., 2008
Baoji	102.40	112.14	25380.55	1964.12	72.10	-	Li and Huang, 2007
Luoyang	71.42	85.40	65.92	215.75	-	1.71	Lu et al., 2007
Wenzhou	-	34.59	65.22	169.40	-	-	Chen et al., 2007
Nanjing	84.70	66.10	107.30	162.60	-	-	Lu et al., 2003
Cincinnati	37.00	26.00	41.00	60.00	19.00	-	Turer et al., 2001
Syria	57.00	34.00	17.00	103.00	39.00	-	Moller et al., 2005
France	42.08	20.06	43.14	43.14	14.47	0.53	Hernandez et al., 2003
Spain	-	57.01	1505.45	596.09	-	3.76	Rodrguez et al., 2009
Iran	63.79	60.15	46.59	94.09	37.53	1.53	Sayadi and Rezaei, 2014
Turku, Finland	59.00	23.00	17.00	90.00	24.10	0.17	Salonen and Korkka-Niemi, 2007
Range	23.10~121.00	20.06~112.14	17~25380.55	60.00~1964.12	12.40~72.10	0.15~6.90	
Average	66.08	49.60	1733.94	289.78	29.14	1.52	
Background	61.00	22.60	26.00	100.00	26.90	0.10	CEPA, 1990
Environ.capacity	200.00	100.00	300.00	250.00	50.00	0.30	CEPA, 1995

3.1 Contamination situation

The content of heavy metals in urban and agricultural soils worldwide is listed in Table 2 and 3 respectively. In order to facilitate research and comparative analysis, environmental background values in the tables use the standard values issued by Chinese Ministry of Environmental Protection in 1990 (CEPA, 1990). The maximum permissible concentrations of potential toxic metals, namely PTE-MPC, adopt the environment capacity (CEPA, 1995).

Table 2 indicates the heavy metal content of soils in urban soils worldwide. We can find that the average contents of Cr, Cu, Pb, Zn, Ni and Cd in urban soils are 66.08, 49.60, 1733.94, 289.78, 29.14, and 1.52 mg/kg, respectively.

Table 3 The content of heavy metals in the agricultural soils (mg/kg^{-1}).

City/Country	Cr	Cu	Pb	Zn	Ni	Cd	Hg	As	Reference
Beijing	75.74	28.05	18.48	81.10	-	0.18	-	-	Liu et al., 2005
Guangzhou	64.65	24.00	58.00	162.60	-	0.28	0.73	10.90	Li et al., 2009
Yangzhou	77.20	33.90	35.70	98.10	38.50	0.30	0.20	10.20	Huang et al., 2007
Wuxi	58.60	40.40	46.70	112.90	-	0.14	0.16	14.30	Zhao et al., 2007
Chengdu	59.50	42.52	77.27	227.00	-	0.36	0.31	11.27	Liu et al., 2006
Kunshan	87.73	34.27	30.48	105.93	31.08	0.20	0.20	8.15	Chen and Pu, 2007
Xuzhou	-	35.28	56.20	149.68	-	2.57	-	-	Liu et al., 2006
Changde	-	-	-	-	-	-	-	92.7	PSTV, 2014
Spain	63.48	107.65	213.93	427.80	34.75	1.42	-	-	Zimakowska-Gnoinska et al., 2000
America	-	95.00	23.00	-	57.00	0.78	-	-	Han et al.., 2002
Korea	-	2.98	5.25	4.78	-	0.12	0.05	0.78	Kim and Kim, 1999
Slovakia	-	65.00	139.00	140.00	29.00	-	-	-	Wilcke, 2005
USA	48.5	48	55	88.5	29	13.5	-	-	Jean-Philippe etal., 2012
India	2.19	1.20	0.95	28.24	4.34	0.82	-	-	Raju et al., 2013
India	1.23	2.62	2.82	4.65	0.14	0.05			Prajapati and Meravi, 2014
Iran	10.36	9.62	5.17	11.56	11.28	0.34	-	-	Sayyed and Sayadi, 2011
Iran	11.15	-	-	-	-	-	-	-	Zojaji et al., 2014
Range	1.23~87.73	1.20~107.65	0.95~213.93	4.65~427.8	0.14~57.00	0.05~13.50	0.05~0.73	0.78~92.7	
Average	46.69	38.03	51.19	117.35	26.12	1.50	0.28	21.19	
Background	61	22.6	26	74.2	26.9	0.097	0.065	11.2	CEPA, 1995
Environ. capacity	200	100	300	250	50	0.3	0.3	30	Zheng et al., 2008

Table 3 shows the content of heavy metals in agricultural soils of various 11 regions. We can find that the average content of heavy metals Cr, Cu, Pb, Zn, Ni, Cd, Hg, and As in agricultural soils are 46.69, 38.03, 51.19, 117.35, 26.12, 1.50, 0.28, 21.19 mg/kg, respectively.

It is obvious that the average content of heavy metals Cr, Cu, Pb, Zn, Ni, and Cd in urban soils is higher than that in agricultural soils.

3.2 Further analysis

The level of heavy metal contamination in the soil is analyzed and determined by geoaccumulation index (I_{geo}), which was established by Muller (1969). This method began to be widely used in the late 1960s (Muller, 1969). I_{geo} is obtained by comparing the contamination levels before contamination and present contamination. The computation of I_{geo} is: $I_{geo}= \log_2(C_n/ 1.5B_n)$, where C_n is the measured mass fraction of the metal (mg/kg^{-1}). B_n is the background mass fraction of the metal (mg/kg^{-1}). Here we use the CEPA environmental background values (Wang et al., 2007) to calculate I_{geo}. Muller's evaluation method (Muller, 1969) can be used to evaluate the level of heavy metal contamination in soils, as shown in Table 4.

Table 4 Classification of geoaccumulation index.

Geoaccumulation index	Classification	Level of contamination
$5 < I_{geo} \le 10$	6	Extremely serious
$4 < I_{geo} \le 5$	5	Strong to extremely serious
$3 < I_{geo} \le 4$	4	Strong
$2 < I_{geo} \le 3$	3	Moderate to strong
$1 < I_{geo} \le 2$	2	Moderate
$0 < I_{geo} \le 1$	1	Light to moderate
$I_{geo} \le 0$	0	Non contamination

3.2.1 Analysis of heavy metal contamination in urban soils

We can find from Table 5, that heavy metal contamination in Luoyang, Baoji and Spain is more serious; Pb contamination in Baoji and Spain is very serious. In addition, Cd contamination in Changsha is extremely serious. However in exception of Cd, soils worldwide show no contamination, and even the Cd contamination is moderate to strong. In addition, the contents of Pb and Cd indicate a light contamination.

Table 5 Heavy metal contamination in urban soils (I_{geo}).

City/Country	Cr	Cu	Pb	Zn	Ni	Cd
Beijing	-1.36	-0.52	-0.45	-1.19	-0.54	0.04
Guangzhou		0.88	1.48	0.17	-0.65	1.78
Shanghai	0.24	0.81	0.86	1.01	-0.37	1.84
Changsha	0.40	0.60	1.20	0.88		5.57
Hong Kong	-1.99	-0.54	1.28	-0.26	-1.70	2.09
Qingdao	-0.76	0.70	0.67	0.42	-1.22	1.04
Baoji	0.16	1.73	9.35	3.71	0.84	
Luoyang	-0.36	1.33	0.76	0.52		3.55
Wenzhou		0.03	0.74	0.18		

Nanjing	-0.11	0.96	1.46	0.12		
Cincinnati	-1.31	-0.38	0.07	-1.32	-1.09	
Syria	-0.68	0.00	-1.20	-0.54	-0.05	
France	-1.12	-0.76	0.15	-1.80	-1.48	1.86
Spain		0.75	5.27	1.99		4.69
Turku, Finland	-0.63	-0.56	-1.20	-0.74	-0.74	0.22

3.2.2 Analysis of heavy metal contamination in agricultural soils

Table 6 shows that South Korea's agricultural soils are almost not polluted by heavy metals, and the Cd contamination in Spain, the United States and Xuzhou is more serious. Heavy metal contamination in the agricultural soils of Wuxi and Chengdu is relatively serious than other cities. Hg contamination in Guangzhou and Chengdu are relatively serious. Worldwide speaking, the contents of Cu and Hg in most of agricultural soils reach light contamination, which is different from the Pb and Cd in cities' soil.

Table 6 Heavy metal contamination in agricultural soils (I_{geo}).

City/Country	Cr	Cu	Pb	Zn	Ni	Cd	Hg	As
Beijing	-0.27	-0.27	-1.08	-0.46		0.31		
Guangzhou	-0.50	-0.50	0.57	0.55		0.94	2.90	-0.62
Yangzhou	-0.25	0.00	-0.13	-0.18	-0.07	1.04	1.04	-0.72
Wuxi	-0.64	0.25	0.26	0.02		-0.06	0.71	-0.23
Chengdu	-0.62	0.33	0.99	1.03		1.31	1.67	-0.58
Kunshan	-0.06	0.02	-0.36	-0.07	-0.38	0.46	1.04	-1.04
Xuzhou		0.06	0.53	0.43		4.14		
Spain	-0.53	1.67	2.46	1.94	-0.22	3.29		
America		1.49	-0.76		0.50	2.42		
Korea		-3.51	-2.89	-4.54		-0.30	-1.12	-4.43
Slovakia		0.94	1.83	0.33	-0.48			

4 Remediation of Heavy Metal Contaminated Soils

4.1 Engineering remediation

Engineering remediation refers to using physical or chemical methods to control heavy metal contamination of soils.

4.1.1 Replacement of contaminated soil, soil removal and soil isolation

Replacement of contaminated soil means adding large amount of clean soil to cover on the surface of the contaminated soil or to blend with the latter. Soil removal refers to remove the contaminated soil and renew it with the clean soil, which is necessary for the seriously contaminated soil with little area. Soil isolation means that to isolate the contaminated soil from the uncontaminated soil, but to completely remedy it still needs other auxiliary engineering measures (Zheng et al., 2002). All of these methods will cost large amount of manpower and material resources, so they can only be applied to small area of soils.

4.1.2 Electrokinetic remediation

Soil electrokinetic remediation is a new economically effective technology. The principle is that the

DC-voltage is applied to form the electric field gradient on both sides of the electrolytic tank which contains the contaminated soil; contaminants in the soil is taken to the processing chamber, which is located at the two polar sides of electrolytic cell, through the way of electro-migration, electric seepage or electrophoresis, and thus reduce the contamination. The method performs well in the soil with low permeability (Hanson et al., 1992).

4.1.3 Soil leaching

The principle of soil leaching is to wash the heavy metal contaminated soil with specific reagents and thus remove the heavy metal complex and soluble irons adsorbed on the solid phase particles. By using this method, heavy metals are separated from the soil, and heavy metals are then recycled from extracting solution.

4.1.4 Adsorption

Adsorption method is based on the fact that almost all heavy metal ions can be fixed and adsorbed by clay mineral (bentonite, zeolite, etc.), asteel slag, furnace slag, etc (Wang and Zhou, 2004).

4.1.5 Other methods

Other engineering methods include washing and compounding, heat treatment, physical solidification, chemical improvers, chemical curing lamp remediation, etc.

4.2 Bioremediation

4.2.1 Phytoremediation

Grow specific plants in the soil contaminated by heavy metals. These plants have the certain hyper-accumulation ability for the contaminants in the soil (accumulated mainly in the root or above the root). When the plants are ripe or reach certain enrichment level of heavy metals, remove heavy metals in the contaminated soil layer thoroughly by harvesting, burning and curing plants. Using plants and their coexisting microbial system to remove heavy metals is a new technology. The key of the method is to find the suitable plants with strong ability for heavy metal accumulation and tolerance. Now more than 400 species of such plants have been found in the world, and most of them belong to Cruciferae, including the genus Brassica, Alyssums, and Thlaspi (Xing et al., 2003).

4.2.2 Microbial remediation

Microbial remediation refers to using some microorganisms to perform the absorption, precipitation, oxidation and reduction of heavy metals in the soil. Siegel et al. (1986) found that fungi could secrete amino acids, organic acids and other metabolites to dissolve heavy metals and the mineral containing heavy metals. Fred et al. (2001) reported that the fungi, *Gomus intraradices*, may improve the tolerance and absorption of sunflower to Cr.

Cultivating microorganisms that have degradation capacity on heavy metals by using biotechnology (genetics, genetic engineering, etc.) are one of the current focuses in this area.

4.2.3 Animal remediation

Some animals living in the soil (maggots, earthworms, etc.) can take heavy metals in the soil. Wang et al. (2007) proved that when the concentration of Cu was low in the soil, the activities and secretion of earthworms could promote the absorption of Cu by ryegrass.

Acknowledgment

The authors Chao Su and WenJun Zhang contributed the same to the present article, and both of them are first authors. We are thankful to the support of the project, Studies on Measuring Methods of Permissible Limits of Toxic Heavy Metals in Apple Orchards of China (2012.1-2014.12), from Yangling Institute of Modern Agricultural Standardization, China.

References

Acar YB, Alshawabkeh AN. 1993. Principles of electrokinetic remediation. Environmental Science and Technology, 27(13): 2638-2647

Aceves MB, Grace C, Ansorena J, et al. 1999. Soil microbial biomass and organic C in a gradient of zinc concentration in soils around a mine spoil tip. Soil Biology and Biochemisty, 31(6): 867-876

Aeliona CM, Davisa HT, McDermottb S. 2008. Metal concentrations in rural topsoil in South Carolina: potential for human health impact. Science of the Total Environment, 402: 149-156

Arao T, Ishikawa S, Murakam IM, et al. 2010. Heavy metal contamination of agricultural soil and counter measures in Japan. Paddy and Water Environment, 8(3): 247-257

Baath E, Frostegard A, Diaz-Ravina M, et al. 1998. Effect of metal-rich sludge amendments on the soil microbial community. Applied and Environmental Microbiology, 64: 238-245

Babula P, Adam V, et al. 2008. Uncommon heavy metals, metalloids and their plant toxicity: A review. Environmental Chemical Letter, 6: 189-213

Boyd RS. 2010. Heavy metal pollutants and chemical ecology: Exploring new frontiers. Journal of Chemical Ecology, 36: 46-58

CEPA (Chinese Environmental Protection Administration). 1990. Elemental Background Values of Soils in China. Environmental Science Press of China, Beijing, China

CEPA (Chinese Environmental Protection Administration). 1995. Environmental Quality Standard for Soils (GB15618-1995). Environmental Science Press of China, Beijing, China

Chander K, Brookes PC, Harding SA. 1995. Microbial biomass dynamics following addition of metal-enriched sewage sludge to a sandy loam. Soil Biology and Biochemistry, 27(11): 1409-1421

Chen F, Pu L. 2007. Relationship between heavy metals and basic properties of agricultural soils in Kunshan County. Soils, 39: 291-296

Chen HM. 2002. Behaviors and Environmental Quality of Chemical Substances in the Soil. Science Press, Beijing, China

Chen HM, Zhou J, et al. 2007. Concentration and chemical peciation of Cu, Zn, Pb in Wenzhou urban soils. Journal of Soil and Water Conservation, 21: 75-78

Chen YF. 2011. Review of the research on heavy metal contamination of China's city soil and its treatment method. China Population, Resources and Environment, 2011, 21(3): 536-539

Ding Y. 2000. The management of polluted soils by heavy metal. Environment and Development, 15(2): 25-28

Falahiardakani A. 1984. Contamination of environment with heavy metals emitted from automotives. Ecotoxicology and Environmental Safety, 8: 152-161

Fliepbach A, Martens R, Reber H. 1994. Soil microbial biomass and activity in soils treated with heavy metal contaminated sewage sludge. Soil Biology and Biochemistry, 26: 1201-1205

Fred T, Davies J, Jeffrey DP, et al. 2001. My-corrhizal fungi enhance accumulation and tolerance of chromium in sunflower (*Helianthus annuus*). Journal of Plant Physiology, 158: 777-786

Han FX, Banin A, et al. 2002. Industrial age anthropogenic inputs of heavy metals into the pedosphere. Naturwissenschaften, 89(11): 497-504

Hanson A, David T, Sabatin A. 1992. Transport and Remediation of Subsurface Contaminants. 108-120, American Chemical Society, Washington DC, USA

Hernandez, L, Probst A, Probst JL, et al. 2003. Heavy metal distribution in some French forest soils: Evidence for atmospheric contamination. Science of The Total Environment, 312(1-3): 195-219

Huang SS, Liao QL, Hua M,et al. 2007. Survey of heavy metal contamination and assessment of agricultural soils in Yangzhong district, Jiangsu Province, China. Chemosphere, 67: 2148-2155

Jean-Philippe SR. Labbé N, Franklin JA, et al. 2012. Detection of mercury and other metals in mercury contaminated soils using mid-infrared spectroscopy. Proceedings of the International Academy of Ecology and Environmental Sciences, 2(3): 139-149

Kale H. 1993. Response of roots of trees to heavy metals. Environmental and Experimental Botany, 33: 99-119

Kandeler E, Lurienegger G, Schwarz S. 1997. Influence of heavy metals on the functional diversity of soil microbial communities. Biology and Fertility of Soils, 23: 299-306

Kim KH, Kim SH. 1999. Heavy metal contamination of agricultural soils in central regions of Korea. Water Air and Soil Contamination,111: 109-122

Lee DH, Zo YG, Kim SJ 1996. Nonradioactive methods to study genetic Profies of natural bacterial communities by PCR-single-strand-conformation polymorphism. Applied and Environmental Microbiology, 62(9): 3112-3120

Li JH, Lu Y, Yin W, et al. 2009. Distribution of heavy metals in agricultural soils near a petrochemical complex in Guangzhou, China. Environmental Monitoring and Assessment, 153: 365-375

Li X, Lee S, Wong S, et al. 2004. The study of metal contamination in urban soils of Hongkong using a GIS-based approach. Environmental Pollution, 129: 113-124

Li X, Huang C. 2007. Environment impact of heavy metals on urban soils in the vicinity of industrial area of Baoji city, P.R. China. Environmental Geology, 52: 1631-1637

Lin ZY. 1998. The source and fate of Pb in central Sweden. Science of the Total Environment, 209(1): 47-58

Liu CP, Shang YN, Yin G. 2006. Primary study on heavy metals pollution in farm soil of Chengdu city. Guangdong Trace Elements Science, 13: 41-45

Liu H, Han B, Hao D. 2006. Evaluation to heavy metals pollution in agricultural soils in northern suburb of Xuzhou City. Chinese Journal of Eco-Agriculture,14: 159-161

Liu WH, Zhao JZ, Ouyang ZY, et al. 2005. Impacts of sewage irrigation on heavy metal distribution and contamination in Beijing, China. Environment International, 31: 805-812

Lu S, Bai S,Xue Q. 2007. Magnetic properties as indicators of heavy metals pollution in urban topsoils: a case study from the city of Luoyang, China. Geophysical Journal International, 171: 568-580

Lu Y, Gong Z, Zhang G, et al. 2003. Concentrations and chemical speciations of Cu, Zn, Pb and Cr of urban soils in Nanjing, China. Geoderma, 115: 101-111

Lu Y, Zhu F, Chen J, et al. 2007. Chemical fractionation of heavy metals in urban soils of Guangzhou, China. Environmental Monitoring and Assessment, 134: 429-439

Meshalkina TL. 1996. Spatial variability of soil contamination around a sulphwreous acid producing factory in Russia. Water, Air and Soil Pollution, 92(3/4): 289-313

Moller A, Müller HW, Abdullah A, et al. 2005. Urban soil contamination in Damascus, Syria: concentrations and patterns of heavy metals in the soils of the Damascus Ghouta. Geoderma, 124(1-2): 63-71

Montagne D, Cornu S, Bourennane H. 2007. Effect agricultural practices on trace-element distribution in soil. Communications in Soil Science and Plant Analysis, 38: 473-491

Muller G. 1969. Index of geoaccumulation in sediments of the Rhine River. Geojournal, 2(3): 108-118

Nriagu JO, Pacyna JM. 1988. Quantitative assessment of world-wide contamination of air, water and soils by trace metals. Nature, 333: 134-139

Phoenix Satellite TV. 2014. Poisoned District: A survey to Arsenic Pollution in Shimen. She Hui Nen Jian Du (10:00 pm- 10:30 pm). http://v.ifeng.com/documentary/society/2014004/031f8d54-996c-4846-9418-e21d8a2495ec.shtml#_v_www6. Accessed Apr 24, 2014

Prajapati SK, Meravi N. 2014. Heavy metal speciation of soil and Calotropis procera from thermal power plant area. Proceedings of the International Academy of Ecology and Environmental Sciences, 4(2): 68-71

Qin TC, Wu YS, Wang HX. 1994. Effect of cadmium, lead and their interactions on the physiological and biochemical characteristics of *Brassica chinensis*. Acta Ecologica Sinica, 14(1): 46-49

Qin YS, Zhao J, Liu ZQ, et al. 2008. Study on the influences of combined pollution of heavy metals Cu and Pb on soil respiration. Journal of Anhui Agricultural Sciences, 36(3): 1117-1128

Raju KV, Somashekar RK, Prakash KL. 2013. Spatio-temporal variation of heavy metals in Cauvery River basin. Proceedings of the International Academy of Ecology and Environmental Sciences, 3(1): 59-75

Robert L, Jones PD. 2009. Blood lead levels and blood lead the change tendency of the test in the United States from 1998 to 2004. Pediatrics, 4(8): 502-514

Rodrguez L, Ruiz E, Alonso-Azcárate J, et al. 2009. Heavy metal distribution and chemical speciation in tailings and soils around a Pb–Zn mine in Spain. Journal of Environmental Management, 90(2): 1106-1116

SalonenVP, Korkka-Niemi K. 2007. Influence of parent sediments on the concentration of heavy metals in urban and suburban soils in Turku, Finland. Applied Geochemistry, 22(5): 906-918

Satarug S, Baker JR, Urbenjapol S. 2003. A global perspective on cadmium pollution and toxicity in non-occupationally exposed population. Toxicology Letters, 137: 65-83

Sayadi MH, Rezaei MR. 2014. Impact of land use on the distribution of toxic metals in surface soils in Birjand city, Iran. Proceedings of the International Academy of Ecology and Environmental Sciences, 4(1): 18-29

Sayyed MRG, Sayadi MH. 2011. Variations in the heavy metal accumulations within the surface soils from the Chitgar industrial area of Tehran. Proceedings of the International Academy of Ecology and Environmental Sciences, 1(1): 36-46

Shi G, et al. 2008. Potentially toxic metal contamination of urban soils and roadside dust in Shanghai, China. Environmental Pollution, 156: 251-260

Shi WU, et al. Progress in the remediation of hazardous heavy metal-polluted soils by natural zeolite.Journal of Hazardous Materials, 2009, 170:1-6

Siegel SM, Keller P, et al. 1986. Metal Speciation. Kluwer Academic Publishers, Chicago , USA

Turer D, et al. 2001. Heavy metal contamination in soils of urban highways: comparison between runoff and soil concentrations at Cincinnati, Ohio. Water air and Soil contamination, 132: 293-314

Wang DD, Li HX, Hu FG, et al. 2007. Role of earthworm-straw interactions on phytoremediation of Cu contaminated soil by ryegrass. Acta Ecologica Sinica, 27(4): 1292-1299

Wang X, Zhou QX. 2004. The ecological process, effect and remediation of heavy metals contaminated soil. Ecologic Science, 23(3): 278-281

Wilcke W, Krauss M, et al. 2005. Concentrations and forms of heavy metals in Slovak soils. Journal of Plant Nutrition and Soil Science, 168(5): 676-686

Wood JM. 1974. Biological cycles for toxic elements in the environment. Science, 183: 1049-1052

Xi C, Dai T, Huang D. 2008. Investigation and assessment on pollution caused by soil heavy metals in Changsha city, Hunan Province. Earth and Environment, 36: 136-141

Xin QG, Pan WB, Zhang TP. 2003. On phytoremediation of heavy metal contaminated soils. Ecologic Science, 22(3): 275-279

Yabe J, Ishizuka M, et al. 2010. Current Levels of Heavy metal contamination in Africa. Journal of Veterinary Medical Science, 72(10): 1257-1263

Yang YB, Sun LB. 2009. Status and control countermea sure s of heavy metal pollution in urban soil. Environmental Pprotection Science, 35(4): 79-81

Yao D, Sun M, et al. 2008. Environmental geochemistry of heavy metals in urban soils of Qingdao city, China. Geology in China, 35: 539-550

Zhang H. 1997. Chromium contamination in the soil from an alloy steel factory in Nanjing. China

Environmental Science, 17(2): 80-82

Zhang WJ, Jiang FB, Ou JF. 2011. Global pesticide consumption and pollution: with China as a focus. Proceedings of the International Academy of Ecology and Environmental Sciences, 1(2): 125-144

Zhang WJ, Zhang XY. 2007. A forecast analysis on fertilizers consumption worldwide. Environmental Monitoring and Assessment, 133: 427-434

Zhang ZJ, Lu QF, Fang F. 1989. Effect of mecury on the growth and physiological function of wheat seedlings. Chinese Journal of Environmental Science, 10(4): l0-13

Zheng XS, LU AH, Gao X, et al. 2002. Contamination of heavy metals in soil present situation and method.. Soils and Environmental Sciences, 11(l): 79-54

Zheng Y, Chen T, He J. 2008. Multivariate geostatistical analysis of heavy metals in top soils from Beijing,China. Journal of Soils Sediments, 8: 51-58

Zhao Y, Shi X, et al. 2007. Spatial distribution of heavy metals in agricultural soils of an industry-based peri-urban area in Wuxi, China. Pedosphere, 17: 44-51

Zhou QX. 1995. Ecology of Compound Pollution. China Environmental Science Press, Beijing, China

Zimakowska-Gnoinska D, Bech J, Tobias FJ. 2000. Assessment of the heavy metal contamination effects on the soil respiration in the Baix Llobregat (Catalonia, NE Spain). Environmental Monitoring and Assessment, 61: 301–313

Zojaji F, Hassani AH, Sayadi MH. 2014. Bioaccumulation of chromium by *Zea mays* in wastewater-irrigated soil: An experimental study. Proceedings of the International Academy of Ecology and Environmental Sciences, 4(2): 62-67