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REVIEW ARTICLE

Status and future perspective for soil contamination of arable land in China

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Abstract

China is currently facing great challenges in protecting its arable soil from contamination by heavy metals, especially Cd in paddy soil. China enacted the first soil environmental quality standards (SEQS) for ten pollutants in 1995, and the Ministry of Ecology and Environment released the results of the first nationwide soil survey in 2014. The soil survey showed that as much as 16% of China's soil and 19% of the agricultural soils were contaminated mainly with heavy metals and metalloids beyond the environmental quality limits. The exceeded rate of the contaminant limits in food crops was widespread in China, and the most severe regions were East and Southwest China. Heavy metals and metalloids accounted for 82.4% of the contaminants in soils while organic pollutants accounted for 17% of the contaminants in the soil. Among the heavy metals and metalloids exceeding the Ministry of Environmental Protection (MEP) limit, cadmium (Cd) was highest at 7.0%, followed by nickel (4.8%), arsenic (2.7%), cobalt (2.1%), mercury (1.6%) and lead (1.5%). However, all the average concentrations of the pollutants were lower than the recommended values for the contaminants except for Cd for three levels of pH (< 6.5, 6.5 - 7.5, and > 7.5). According to the Action Plan on Prevention and Control of Soil Pollution released by the State Council in 2016, 90% of contaminated farmland will be made safe by 2020 with an increase to 95% by 2030. Therefore, it is necessary to improve the soil quality to meet the environmental quality standard for soils and heavy metal standards for food safety.

Keywords: arable land, China, heavy metal, SEQS, soil contamination

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Introduction

Up until very recently, the problems and the reality of the true extent of soil pollution in China was not known to Chinese people since the government had consistently refused to make comprehensive soil pollution data public (Delong, 2017). The Ministry of Environmental Protection (MEP) and the Ministry of Land and Resources (MLR) of the

People's Republic of China (2014) issued a joint report on the current status of a nationwide soil survey across 6.3 million square kilometers of land, two-thirds of the country's total in China. The survey showed that as much as 16% of China's soil, 19% for the agricultural soils, are contaminated based on China's soil environmental quality limits, mainly with heavy metals and metalloids (MEP, 2014; NPC, 2014; Zhao et al., 2015). Despite the lack of details, the released data caused widespread concern (He, 2014).

Much of the contaminated areas which are located in the eastern and central China, the developed regions, such as the Yangtze River Delta, Pearl River Delta may cause a domino effect in the China's society involving the food safety, water safety and even depreciation of commercial property (Pan, 2016).

Soil Ten Plan, the Action Plan for Prevention and Control of Soil Pollution to improve soil quality and to ensure safe agricultural products and a healthy living environment for people in China, was finally issued by the China State Council in May of 2016 (CSC, 2016; CWR, 2016). The main objectives of Soil Ten Plan including with pollution prevention, monitoring, restoration are to curb the nation's increasing soil pollution by 2020, thoroughly control environmental risks of soil by 2030, and improve the environmental quality of soil completely by 2050 (CSC, 2016).

With these strategic plans, China ensures that approximately 90% of contaminated farmland and sites can be used safely by 2020 as well as increase this proportion to 95% by 2030. To achieve these goals, arable land and agricultural products shall be concurrently monitored and evaluated based on detailed survey of soil contamination by 2020 (NPC, 2014). Therefore, the Chinese government is planning to spend tens of billions of yuan on demonstration projects of heavy metal contaminated soil restoration and over-exploited groundwater comprehensive treatment to tackle the soil pollution driven by the urgent environmental deterioration.

Pan (2016) reported that this Soil Ten Plan might open up ample opportunities for land remediation specialists of foreign countries such as US, UK, Japan or some leading European countries because of the lack of China's core technological capabilities of soil remediation, especially for the countries possessing the proprietary technologies and know-how for in-situ immobilization, bioremediation, safe disposal and resource recovery. According to statistics by Perfect in 2017, about 43.8% of Chinese soil remediation project scale was small. The relatively large scale projects accounted for only 18.8%. According to the analysis report released by the Institute of industry research, the contract amount of the national soil remediation contract reached approximately 2.13 million yuan in 2015, an increase of 67% compared with 1.27 million yuan in 2014. The number of enterprises engaged in soil remediation business has increased to more than 900, and nearly doubled in 2014 (Perfect, 2017).

However, the development trend of soil remediation in the bud stage is very active. With the strong market demand and governmental support, there are enough incentives for the foreign remediation companies to take this chance in China. To prevent further heavy metal pollution in soil and enact effective measures to remediate metal contamination, it is essential to understand the contaminated areas and their sources on a national scale. In this study, we reviewed the opportunities for benefit from China's soil pollution woes with respect to a number of factors such as soil contamination status and market size, soil remediation technological standards, and market mechanisms for soil remediation in China, that will be able to contribute to the recommendations and solutions to accelerate the challenges in participation into the soil remediation in China.

Land uses and development of Chinese soil environmental quality standards (SEQS)

The land area of China in 2016 was 9.6 million km^2 and approximately 14.1% of total land area of China was classified as arable land area (Lee et al., 2018). About 34% of China was covered by pastures, and 14% by forests. Mountains covered 58% of China (NBSC, 2017). The others were deserts (28%) and plains and basins (35%), respectively (The World Bank, 2017). China's land use data are divided into three levels. The first level is divided into agricultural land, garden and forest land, construction land, water body, grass land, and unused (bare) land. The agricultural land, used for agricultural production, is classified into arable land (ploughed land), gardens (for planting perennial woody and herbaceous plants intended for intensive fruit and leaf management), woodlands (natural, secondary, or man-made forests), and grasslands (for growing herbs or shrubs aimed to develop livestock production) (NPC, 1986; Qin et al., 2012).

For distribution of land uses in China as seen in Fig. 1, the green area indicates more farmlands while the yellow and the orange indicate less farmlands. The majority of China's arable land lies in the central eastern coast and around the Yangtze and Yellow river valleys whereas the southern part of the Yangtze consists of hilly and mountainous terrain. The west and the north of the country are dominated by sunken basins, rolling plateaus, and towering massifs (The Statistics Portal, 2015; Lee et al., 2018). The majority of China's cultivated land including newly created land from other uses such as forestry, grasslands, and wetlands lies in eastern China. Nearly 13% of the country is cultivated as the arable land. China was divided into six areas according to the soil classification system of China as follows: north, northeast, northwest, south central, southwest, and east. The typical agricultural soil type was Semi- Luvisols in the north, Pedocal and Luvisols in the northeast, Entisols and Inceptisols in the northwest, Ferralsols in the south central area, Ferralsols and Anthrosol in the southwest, and Ferralsols and Luvisols in the east (Shi et al., 2006).

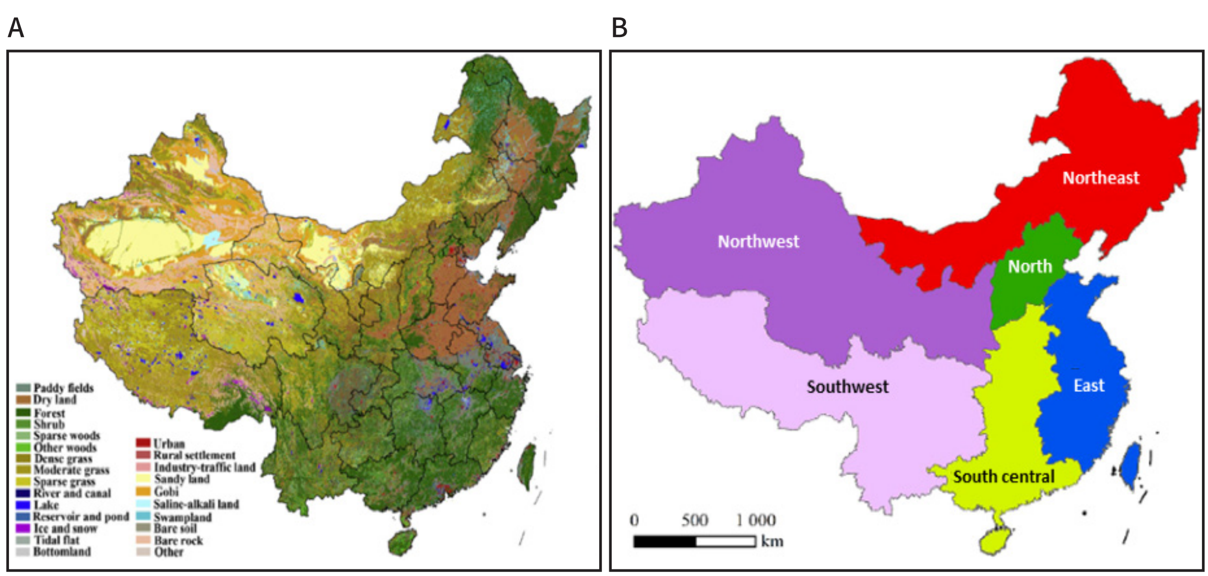

Fig. 1. Distribution of land uses (a) and geographic division (b) in China (Modified from Zhang et al., 2014; Wan et al., 2018).

Soil pollution by heavy metals (HMs) and organic pollutants such as dichloro-diphenyl-trichloroethane (DDT) and polycyclic aromatic hydrocarbons (PAHs) has been widespread in China due to rapid economic development over the past several decades (Chen et al., 2018). In 1995, China enacted SEQSs (GB 15618-1995) for ten pollutants (eight heavy metals), which was developed through large numbers of experiments and soil surveys. It aimed to provide the allowed concentration limit of soil pollutants based on protection targets and soil properties classified into three grades (A, B, and C), as well as the corresponding monitoring methods (Zhang et al., 2015). The first SEQS covering three grades included the allowed concentration limit of soil pollutants and monitoring methods according to soil use functions, protection objectives and soil quality to implement the environmental protection law of the people's Republic of China in 1995. Grade A soils are natural conservation land, tea gardens or soils in which the concentration of heavy metals is close to the reference background values without any risks for public health or the environment. Grade B values in GB 15618-1995 were set up according to the least soil environmental threshold capacity for various types of soil across the country. Grade B soils consist of farmland, vegetable, tea, fruit, and grazing lands, that the level of soil contamination that can be regarded as the upper acceptable limit does not create immediate risks to humans, environment or particular land use. Grade C soils in which the maximum allowable concentrations of HMs implies a danger are suitable for forestry or areas with greater absorption capacity. The standard was applied to soil of farmland, vegetable field, tea garden, orchard, rangeland, woodland and nature reserves (Teng et al., 2014; Chen et al., 2018).

In 2006 and 2007, the State Environmental Protection Administration of China issued the revision of Environmental Quality Evaluation Standards for Farmland of Edible Agricultural Products (HJ/T 332-2006), Environmental Quality Evaluation Standards for farmland of greenhouse vegetable production (HJ 333-2006). This SEQSs were classified into 3 classes (I, II, and III).

Class I values represent the natural background depending on the soil parent materials and pedogenetic processes, that can be used for the protection of regional natural ecosystems from contamination although the natural background concentrations of heavy metals and metalloids substantially vary across the country because the soil parent materials and pedogenetic processes that are geochemically diverse vary among different soil types. Class II that can be applied to agricultural, orchard and pasture land is to protect agricultural production and human health via the food chain. The values of Class II are dependent on soil pH and the types of land use while there are debates on whether the Class II values are overprotective or under-protective because the studies regarding to soil to plant transfer models suggest that the Class II for the limit of Cd may be set too low for soils with near neutral to alkaline pH (Zhu et al., 2015), compared with the limit (1 - 3 mg kg^{-1}) adopted by the EU for land applications of sewage sludge or up to 39 mg kg^{-1} in the US-EPA's rules on land applications of biosolids (McGrath et al., 1994; US EPA, 2005; EU, 2007; Zhang et al., 2011; Ding et al., 2013). Class III is for the protection of crops or forests from phytotoxicity and may also be used where the natural background is elevated (Table 1).

Table 1. Environmental quality standard for soils in China (GB 15618-1995; MEP, 1995), heavy metal standards for food safety (GB2715-2005; MEP, 2005) (mg kg^{-1}).

Metal/metalloid	Class I	Class II			Class III	Food safety standards (in rice)
		pH < 6.5	pH 6.5 - 7.5	pH > 7.5	pH > 6.5	
Cd	0.2	0.3	0.3	0.6	1.0	0.20
As						
Paddy	15	30	25	20	30	0.15
upland	15	40	30	25	40	0.10
Hg	0.15	0.3	0.5	1.0	1.5	0.02
Cu						
farmland	35	50	100	100	400	-
orchard	-	150	200	200	400	-
Pb	35	250	300	350	500	0.20
Cr						
Paddy	90	250	300	350	400	1.00
upland	90	150	200	250	300	-
Zn	100	200	250	300	500	-
Ni	40	40	50	60	200	-

Status of soil contamination in China

China had no official statistics on soil pollution until April of 2014 when the results of a national soil pollution survey was released by MEP and MLR of China. The report of a nationwide soil survey in 2014 was based on surveys of soils between 2005 and 2013, covering more than 70% of China's land area. For this investigation, surface soil samples between 0 - 20 cm were collected from 8×8 km grids for 367 areas involving 163 prefecture-level cities. Those areas were categorized into arable land (159 areas), gardens (77 areas), woodlands (30 areas), grasslands (20 areas), and agricultural land. The soil samples were analyzed for 13 inorganic contaminants (As, Cd, Co, Cr, Co, F, Hg, Mn, Ni, Pb Se, Va, and Zn) and 3 types of organic contaminants including HCH, DDT, PAHs (Zhao et al., 2015; Zhu et al., 2015). In 2012, the Ministry of Agriculture also began to investigate heavy metal pollution not only to determine the historical and current pollution status and to ascertain pollution characteristics and distribution of As, Cd, Cr, Hg, and Pb in agricultural land, but also to provide background information for revision of SEQSs adopting a total amount to restrict HM contents in soils. (BSEMA, 2012). At present, this investigation is still being carried out at the national scale (Chen et al., 2018; Lu et al., 2018).

The status of soil pollution varied among land-use types and geographic areas. Regarding geographic distribution, soil pollution in South China was much severe than that in North China and the most severe regions were East China and Southwest beyond the environmental quality standard as seen in Fig. 2. (Zhang et al., 2015; Zhu et al., 2015; Wan et al., 2018).

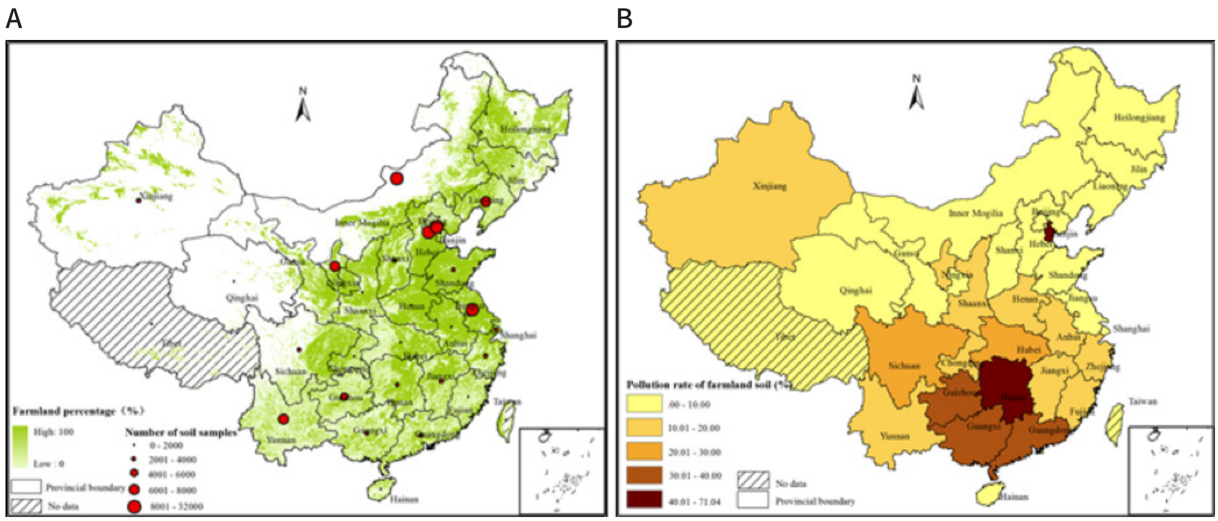

Fig. 2. Soil sampling points (a) and pollution rate of farmland soil by heavy metals (b) on a provincial scale (Modified from Zhang et al., 2015).

A nationwide investigation showed that as much as 16% of China's soil contained higher-than-the environmental quality standard set by the MEP. Soil pollution in different geographic areas may significantly vary depending on land uses in addition to the natural background and anthropogenic input. In terms of land-use types, garden soil showed the heaviest pollution, followed by arable land and woodland (Fig. 3). 19.4% (2.63×10^7 ha) out of China's total arable land (1.35×10^8 ha) was badly contaminated by heavy metals. MEP and MLR (2014) in China divided soil pollution into five classes according to degree as follows: non-polluted (soils with a pollutant level that does not exceed the quality standard); lightly (soils with levels that are not more than 2 times the maximum); mildly (soils with levels that are between 2 and 3 times the maximum); moderately (soils with levels between 3 and 5 times the maximum) and severely (soils with levels that are more than 5 times the maximum). The breakdown of soil classes for total 16.1% contaminated soils were registered as non-polluted (11.2%), light (2.3%) moderately (1.5%), and severely (1.1%) (Takahashi, 2016).

The first results of a nationwide soil pollution survey revealed the pollution of one-fifth of agricultural land with inorganic chemicals, such as cadmium, nickel, and arsenic (Fig. 3). However, Wan et al. (2018) indicated that the results released by the survey on the soil contamination in China in 2014 did not provide detailed information on current pollutant concentrations (ER, 2015).

The main contaminants in soil include inorganic and organic pollutants. Inorganic pollutants are mainly toxic elements which are difficult to remove because they cannot be degraded or are persistent in soil. Contamination by heavy metals and metalloids accounted for the majority (82.4%) of the soils, with organic contaminants accounting for the rest (17%). Zou et al. (2015) reported that inorganic pollutants such as Cd, As, and Hg were originated from anthropogenic sources, whereas Cr, Cu, Ni, and Zn were mainly contributed by the natural background value. Based on the principal component and clustering analyses for the results of soil survey between 2005 and 2013, Wan et al. (2018) also assumed that As, Hg, HCH, and DDTs were mainly contributed by anthropogenic sources while Cr, Cu, Ni and Zn were primarily caused by natural background. But they

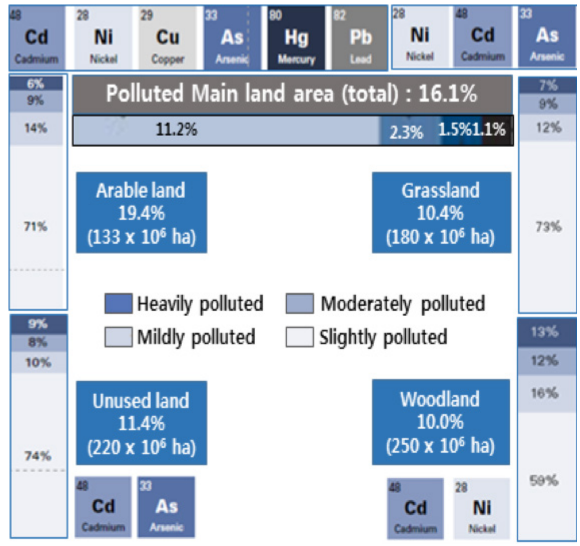

Fig. 3. Pollution levels for China's arable land, grassland, woodland and unused land (Modified from Zhu et al., 2015).

assumed that Cd and Pb were contributed by both human activities and natural background.

Among the heavy metals and metalloids, cadmium (Cd) ranked the first in the % age of soil samples (7.0%) exceeding the MEP limit, followed by nickel (4.8%), arsenic (2.7%), cobalt (2.1%), mercury (1.6%), lead (1.5%). As for organic contaminants, DDT and PAHs were 1.9% and 1.4%, respectively (Fig. 4). For these results, Zhang et al. (2015) and Shifaw (2018) suggested that irrigation, and use of chemical fertilizers and insecticides had accelerated the metals concentration of agricultural soils in China, due to agricultural intensification with modern inputs and in response to the decline of farmland and the growing demand for food in China. Also, Shifaw (2018) figured out that chemical fertilizers and insecticides significantly contributed to the high pollution rate for Cd (7.24%) and nickel (Ni) (3.04%), as well as 2% pollution of soil samples by copper (Cu) and Hg.

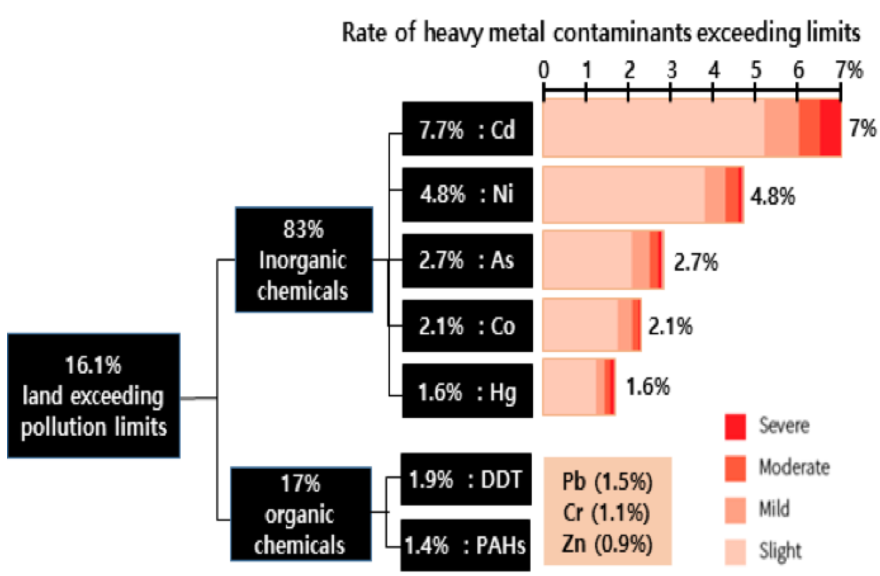

Fig. 4. Pollution rate in soils by heavy metals and organic contaminants in China (Adapted from MEP, 2014).

To understand the relationships among pollutants by principal component analysis and clustering analysis, Wan et al. (2018) examined distribution of pollutants and concentrations and over-standard rates of pollutants under different land-use types based on the published data on soil environmental quality from 2000 to 2016 in China. The average concentration of Cd was in the order of woodland > grassland ≃ arable land > agricultural land > garden while that of Ni was in the order of woodland > garden > arable land > agricultural land > grassland. The average concentrations of As, Cu, Hg, Ni, and Pb were the highest in garden whereas Zn concentration in arable land and Cd and Cr concentrations in woodland were the highest. Thus, pollutant concentrations were influenced by land-use types (Table 2). Cu, Pb, Zn, and As showed high correlation coefficients amongst each other, and Cd had a close correlation to Cu and Zn, indicating that these heavy metals might share some common sources.

Table 2. Concentrations of pollutants in soil under different land-use types (Modified from Wan et al., 2018).

Category	Cd	As	Zn	Cr	Hg	Cu	Ni	Pb	HCH	DDT
	(mg kg^{-1})									
Agricultural land (n = 367)										
Average	0.69	13.9	149.0	61.7	0.27	32.0	31.6	44.2	0.004	0.004
Min	0.01	0.05	1.13	0.53	ND	1.17	0.93	0.77	ND	ND
Max	40.6	328.0	3598	370.0	12.7	175.0	129.9	976.9	0.16	0.51
Arable land (n = 159)										
Average	0.75	13.8	178.3	65.7	0.20	33.3	32.2	45.3	0.03	0.07
Min	0.04	1.70	43.6	0.92	ND	2.50	12.7	11.2	ND.	ND
Max	40.6	93.4	3598	370.0	1.79	111.0	111.5	976.9	0.11	0.51
Garden (n = 77)										
Average	0.58	19.1	117.6	58.6	0.68	35.3	35.7	56.2	0.01	0.03
Min	0.03	0.05	26.1	5.50	0.03	1.80	8.10	10.4	ND	ND
Max	9.95	328.0	480.2	150.8	12.7	175.0	101.3	360.0	0.05	0.00
Woodland (n = 30)										
Average	0.94	18.6	76.5	76.6	0.26	28.6	37.6	35.8	0.01	0.00
Min	0.07	L37	22.6	9.24	0.02	2.30	5.99	9.05	0.00	0..00
Max	6.06	92.5	214.7	315.0	1.50	168.6	129.9	132.3	0.02	0.00
Grassland (n = 20)										
Average	0.75	9.47	89.2	32.3	0.10	28.9	16.9	20.2	0.003	0.001
Min	0.01	3.21	27.10	5.33	0.02	13.8	5.19	3.16	ND	ND
Max	3.28	19.4	218.3	59.3	0.40	73.7	25.2	28.5	0.022	0.007
RD value[w]										
pH < 6.5	0.30	(30.0[x]) 30.0	200.0	(250.0[y]) 200.0	0.30	(150.0[z]) 100.0	40.0	250.0	0.50	0.50
pH 6.5 - 7.5	0.30	(25.0[x]) 25.0	250.0	(300.0[y]) 250.0	0.50	(200.0[z]) 100.0	50.0	300.0	0.50	0.50
pH > 7.5	0.60	(20.0[x])	300.0	(350.0[y])	L0	(200.0[z])	60.0	350.0	0.50	0.50

HCH, hexachlorocyclohexane; DDT, dichloro-diphenyl-trichloroethane; ND, below the detection limit.
[w]recommended value indicates the value regulated by China’s Environmental Quality Standard for Soils (GB15618-1995, Grade II), which applies to agricultural soil, including farmland, garden, woodland, and grassland.
[x]recommended value for As concentration specifically in paddy soil, regulated by China’s Environmental Quality Standard for Soils (GB15618-1995, Grade II).
[y]recommended value for Cr concentration specifically in paddy soil, regulated by China’s Environmental Quality Standard for Soils (GB15618-1995, Grade II).
[z]recommended value for Cu concentration specifically in orchard soil, regulated by China’s Environmental Quality Standard for Soils (GB15618-1995, Grade II).

Fig. 5 and 6 show the average and maximum concentrations of pollutants in soil under different land-use types obtained from the results of a nationwide soil pollution survey in 2014. Except for Cd, all the average concentrations of the pollutants were lower than the recommended value of the contaminant throughout three levels pH (< 6.5, 6.5 - 7.5, and > 7.5) according to SEQS set by MEP. The average concentrations of Zn were the highest for all the land-use types although their average concentrations were below the recommended values of three pH levels (Fig. 5). However, the maximum concentrations of Cd were much higher than those of the recommended values of three pH levels for all the land-use types while the maximum concentrations of HCH and DDT were much lower or slightly higher than that of the recommended values of three pH levels for all the land-use types.

For the over-standard rates of pollutants depending on the types of land uses, inorganic pollutants were higher than those of organic pollutants. Cd were the most distinctive pollutant as of 29.6% and 42.8 % among the inorganic pollutants for agricultural land and garden. Others in agricultural land were Hg (8.47%), Ni (7.14%), Zn (4.52%), As (3.88%), Cu (2.72%), Pb (1.4%), and Cr (0.86%), whereas the organic pollutants were DDT (1.54%) and HCH (0%) (Table 2). Thus, the over-standard rates of Cd in arable land and garden which belonged to agricultural land were much higher than those of grassland and woodland, that could be attributed by excessive agrichemical application. The over-standard rates of As, Cu, and Pb were highest in woodlands, whereas the over-standard rates of inorganic and organic pollutants were lowest in grassland. Wan et al. (2018) assumed that the comparatively least pollution of inorganic and organic pollutants in the grassland were attributed by less human disturbance and location in areas with limited populations (Table 3).

Table 3. Over-standard rates of pollutants in soil under different land-use types (in %).

Pollutant	Type of land				
	Agricultural (n = 367)	Arable (n = 159)	Garden (n = 77)	Wood (n = 30)	Grass (n = 20)
Cd	29.6	30.5	42.9	21.1	11.1
As	3.88	4.72	9.09	10.0	0
Zn	4.52	4.08	9.62	37.0	0.00
Cr	0.86	0.97	1.92	0	0
Hg	8.47	3.19	32.4	18.2	11.1
Cu	2.72	1.96	1.72	37.0	0
Ni	7.14	2.00	19.4	12.5	0
Pb	1.40	0.72	3.33	3.57	0
HCH	0	0	0	0	0
DDT	1.54	9.09	0	0	0

HCH, hexachlorocyclohexane; DDT, dichloro-diphenyl-trichloroethane.

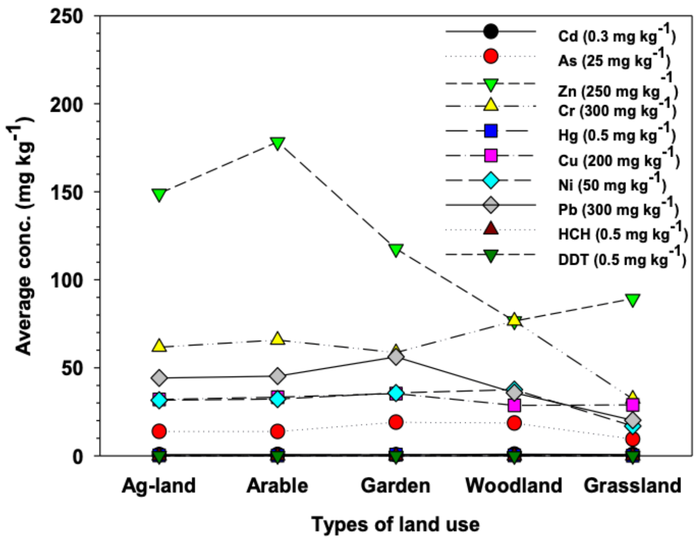

Fig. 5. Average concentrations of pollutants in soil under different land-use types. ( ) indicates the recommended value of the contaminant for pH (6.5 - 7.5) according to soil environmental quality standards (SEQS) set by Ministry of Environmental Protection (MEP).

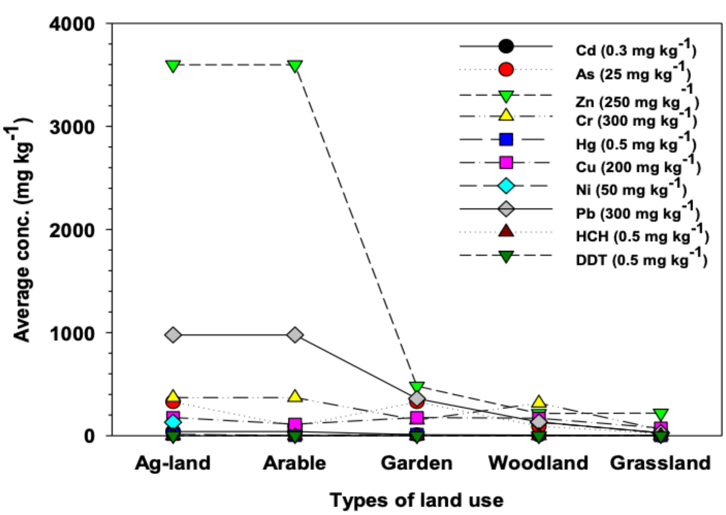

Fig. 6. Maximum concentrations of pollutants in soil under different land-use types. ( ) indicates the recommended value of the contaminant for pH (6.5 - 7.5) according to soil environmental quality standards (SEQS) set by Ministry of Environmental Protection (MEP).

Future perspective for soil contamination of arable land in China

According to the MEP, the total area of arable land polluted with heavy metals has reached 20 million ha, accounting for approximately 16.1% of the total arable land in China. More than 6 million ha of farmland was polluted with industrial and urban wastes in the early 1990s, and acid rain affected soil from 1.5 to 2.5 million ha from 1985 to 1994 (Xie and Li, 2010). About 10.2% of the contaminated arable soil exceeding the class II values was not safe for crop planting (Teng et al., 2010; Zhu et al., 2015; Shifaw, 2018).

From a food contamination perspective in the arable land, excessive levels of heavy metals such as Pb, Cd, Hg, and As are the most common pollutants, regardless of the origin in the soil, resulting in soil quality degradation, crop yield reduction, and poor quality of agricultural products, posing significant hazards to human, animal, and ecosystem (SCMP, 2016). Many studies found that heavy metal contamination in southern China are higher than the recommended levels of contaminants in food crops (Zhang et al., 2015; Zhu et al., 2015; Sodango et al., 2018; Wan et al., 2018). Fig. 7 shows that it was apparent that the Cd pollution was more serious in the south than in the north. Therefore, China has adopted and applied several control measures and policies to protect arable soils against soil contamination mainly caused by heavy metal pollutants in surface soils in which sewage irrigation is one of the main sources of heavy metal pollution (UNESCO, 2012; MEP 2014; Zhao et al., 2015).

China's per capita arable land area is less than half of the world average. The MEP estimated that China's grain self-sufficiency declined from 93% in 2008 to 86% in 2014, although the number of annual new births was largely stable during the same period. According to soil survey released in 2014 by MEP, heavy metal contamination affected 12×10^6 tons of grain in China every year, which was enough to feed 24×10^6 people (Lu et al., 2015, Liu et al., 2016). More issues about rice have arisen due to severe contamination of paddy soils by heavy metals. Heavy metals accumulated in soil might elevate heavy metal uptake by crops, thus affecting food quality and safety. 10.3% of rice products exceeded the limitation of environmental quality standard for soils in 2002 in China (Liu et al., 2013; Luan et al., 2013).

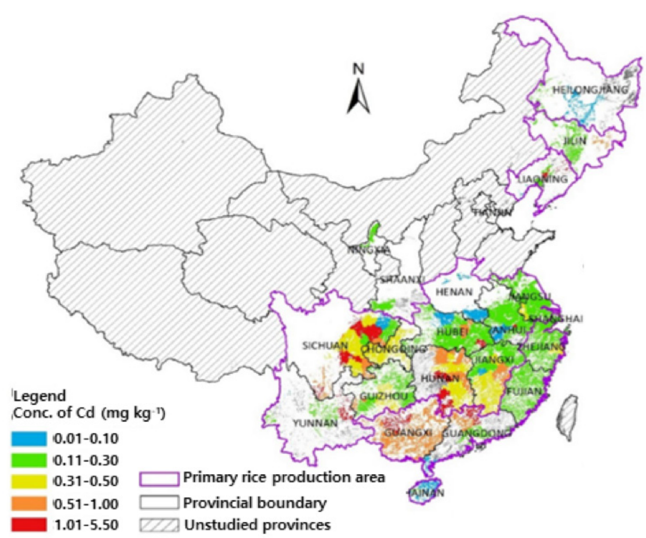

Fig. 7. Spatial distribution of Cd concentration in Chinese paddy soils at the administrative region scale (Modified from Liu et al., 2016).

For the pollution rate of farmland soil by heavy metals on a provincial scale (Fig. 8a), Tianjin had the highest pollution rate by 70% followed by Hunan Province (55.93%), Guangxi Zhuang Auto region (36.25%), Guizhou Province (38.75%), and Guangdong Province (30.80%). Considering the proportion of affected grain production in each province in China (Fig. 8b), 13.86% of the grain production was affected by heavy metal pollution. This ratio was higher than the pollution rate of arable soil (10.18%). (Zhang et al., 2015).

It is imperative to remediate the contaminated paddy fields. Recently, China's State Council (2016) released a

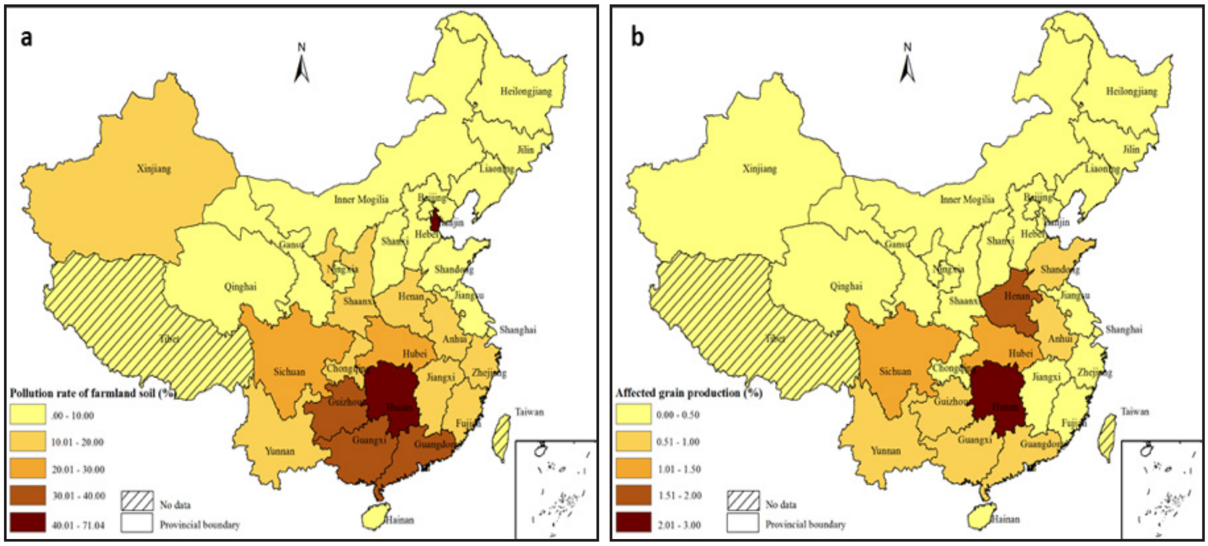

Fig. 8. Pollution rate of farmland soil by heavy metals (a) and the relative % age of grain production affected by soil contamination (b) on a provincial scale in China (Modified from Zhang et al., 2015).

nationwide Action Plan for Soil Pollution Prevention and Control as the third government's environmental action plan in recent years, aiming to make 90% of polluted arable land safe for human use by 2020, and increases that target to 95% by 2030. However, the government and farmers cannot afford to pay the high remediation cost of cropland because the crop production from the contaminated land are not enough to cover the remediation cost of soil beyond the lack of adequate and specific remediation technologies. These soil contamination remediation activities has led to businesses gradually operating independently, which also creates a virtuous cycle that encourages the entry of more remediation businesses and which raises hopes for the future.

Conclusion

The majority of China's arable land consisted of nearly 13% of the country lies in the central eastern coast and around the Yangtze and Yellow river valleys whereas the southern part of the Yangtze consists of hilly and mountainous terrain. National soil contamination survey issued by the MLR and MEP Report in the 2014 showed that soil pollution in southern part of China was much severe than that in North China and the most severe regions were East China and Southwest beyond the environmental quality standard, and 19.4% (2.63×10^7 ha) of China's total arable land (1.35×10^8 ha) was badly contaminated by heavy metals of which Cd, contributed by both human activities and natural background, was the most serious contaminant exceeding the MEP limit. For the over-standard rates of pollutants of the types of land uses, inorganic pollutants were higher than those of organic pollutants. Except for Cd, all the average concentrations of heavy metals were lower than the recommended value of SEQS set by MEP for three levels of pH (< 6.5, 6.5 - 7.5, and > 7.5). The total area of arable land polluted with heavy metals has reached to 16.1% (approx. 20 million ha) of the total arable land in China. Heavy metal contamination in southern China are higher than the recommended levels of contaminants in food crops. Especially, Cd pollution was more serious in the south than in the north, resulting in decline of China's grain self-sufficiency and quality and safe of food. Therefore, it is necessary to improve soil quality to meet environmental quality standard for soils and heavy metal standards for food safety. To achieve this goal, Chinese government should emphasize contaminated site restoration in addition to preventing soil pollution throughout proper cost-effective and efficient remediation technologies for arable land specific.

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