Assessment of cadmium (Cd) concentration in arable soil in China

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Abstract Cadmium (Cd) concentration in arable soil has drawn broad public attention due to its direct effect on Cd concentration in food. However, there have been few studies of surveying Cd accumulation on the national scale in China. This paper collected 486 studies of Cd concentrations in Chinese arable soil. The results showed that the average Cd concentration was 0.27 mg/kg, higher than its background value, indicating that Cd had been introduced into arable soil by human activity. The Cd concentrations in areas of mining and smelting, urban areas, and areas irrigated by wastewater were obviously higher than that in remote areas. Spatially, Cd concentrations were lower in the north than those in the south, and many hotspots existed throughout China due to mining and smelting activities. Most Cd in the arable soil were accumulated from external sources in all investigated provinces except Ningxia Hui Autonomous Region.

Keywords Cd concentration · Arable soil · China

Introduction

Cadmium (Cd) is regarded as one of the most toxic trace elements in the environment, since it can cause serious health problems in the animals and humans (Recatalá et al. 2010). Thus, the Cd accumulations in grains and vegetables have aroused a lot of attention (Fang et al. 2014; Kosolsaksakul et al. 2014). The Cd pollution in the edible parts of grains and vegetables is particularly heavy in China due to the rapid industrialization and the wide application of agrochemicals in agricultural activities. Two investigations conducted separately in 2002 and 2008 showed that about 10 % of rice samples on the market nationwide contained excessive levels of Cd in China (Zhen et al. 2008) (https://www.chinadialogue.net/article/show/single/en/4197–China-stainted-rice-%20trail).

Soil is one of the main sources of Cd concentration in grains or vegetables (Cambra et al. 1999; Islam et al. 2007). Previous studies on the soil’s Cd contents in China largely focused on local areas (Li et al. 2009b; Liu et al. 2006; Su and Yang 2008; Zhang et al. 2013, 2009). These studies have shown that Cd variations in arable soil are greatly influenced by parent material and soil properties, as well as human activities, such as industrial production, traffic, application of fertilizers, and wastewater irrigation. A comprehensive understanding of Cd concentration in arable soil and its controlling factors is helpful to raise public awareness of soil contamination, facilitate research on pollution control, and design strategies to minimize pollution or exposure.

Several national-scale studies of soil Cd concentrations in China have been reported. China’s Ministry of Environmental Protection and Ministry of Land recently revealed that the 7 % of the soil samples collected during 2005–2013 were polluted with Cd (http://www.ndrc.gov.cn/fzggzz/mcjj/zhd/201404/t20140418_607888.html). Wei and Yang (2010) found the Cd concentration in agricultural soil in urban
environments based on 12 published studies. Song et al. (2013) reviewed 127 studies and reported the Cd concentration in arable soil was 0.25 mg/kg. However, little is known about Cd concentration in arable soil and its spatial distribution on the national scale. Niu et al. (2013) obtained the spatial distribution of Cd concentration throughout China and calculated a Cd average based on 131 farmland soil samples. However, the limited number of samples is not enough to identify the Cd sources and evaluate the level of Cd concentrations on the national scale.

In this study, we conducted a statistical analysis combining with GIS that quantitatively synthesized the results from available researches on the Cd concentration in arable soil in China. The objectives of this study were (1) to map the spatial variation of soil Cd concentration in arable soil, (2) to identify the possible sources of Cd accumulations in soil, and (3) to evaluate Cd pollution in arable soil in China.

Materials and methods

Data collection

Systematic review is a type of literature review that aims to identify, appraise, and synthesize all relevant studies to answer a particular research question. The relevant studies were selected through the ISI Web of Knowledge website and the Chinese CNKI website using key words on Cd concentrations in arable soil. The detailed information on the selection process could be found in the manuscript by Zhang et al. (accepted to the CLEAN- soil, air, water). From the resultant database, 486 peer-reviewed articles were selected. Basic information, such as sample locations, the arithmetic mean of Cd concentrations, land uses, the number of soil samples, and the time of investigation, were collected from each study. The total number of the original and processed data records is 1112 (S1).

One of the objectives is to map the spatial distribution of Cd concentration in arable soil of China. The inverse distance weighted (IDW) interpolation is used to obtain Cd spatial distribution, which is a deterministic method for multivariate interpolation with a weighted average of the values available at the known points. Thus, we try to obtain Cd concentrations at many locations. In this study, two scales of Cd concentrations are separately recorded. One is at the point scale, such as the arithmetic Cd concentration around a mining or smelting activity, industry plant, or some specific points. The other is at county scale (the map with the minimum administrative unit we can obtain), and Cd concentration can be taken as a surface data. If several data records are collected in one point, the sample-number-weighted mean is calculated as the Cd concentration. If several data records are located in a county, and the land use for the Cd concentration at point is not consistent with that in the county, the data at point will be kept separately to keep the local variations; otherwise, the sample-number-weighted mean will be used as the Cd concentration in this county.

From these data records, 640 were selected to get the general information on Cd concentrations in Chinese arable soil, including the data at the scales of point, county, and the prefecture or province. The numbers of the records on Cd concentrations at the point and county scales were 259 and 361 respectively, which are mapped in Fig. 1.

Among 640 data records, the land category information, including the areas around a) mining and smelting plants, b) irrigation area, c) urban and sub-urban area, and d) remote area (the area without obvious point pollution sources), was collected from the original studies. The overlap area with more than two land uses will be classified to the land category which had the highest Cd concentration. For example, if the study area is located in the urban area around mine and smelter, it will be taken as the mining and smelting area. The number of Cd concentration records for these areas was 130, 61, 98, and 351 respectively.

Statistic methods

Conventional statistical analysis (mean, minimum, maximum, standard deviation) is conducted as a first step to understand Cd concentrations in arable soil. Since the arithmetic mean of Cd concentration is calculated based on the equal weight of each data record, it might not reflect the real situation of the Cd concentrations due to the consider variations of sample numbers in each data record. Thus, the sample number is taken as the weight to calculate the average of Cd concentration in arable soil, which means that the study with more soil samples will pose greater contribution on Cd concentrations at regional or national scale. The sample-number-weighted mean(C) of Cd concentration is calculated as

\[
C = \frac{C_i \times N_i}{\sum_{i=1}^{n} N_i}
\]  

(1)

\(N_i\) is the sampling number in the data record \(i\), \(C_i\) is Cd concentration in the data record \(i\), and \(n\) is the number of the data records. \(N_i\) and \(C_i\) are obtained from the original studies (S1).

Spatial distribution

To estimate and map soil Cd concentrations in China, the IDW interpolation method is used. It bases on a basic principle of geography: things that are close are more related than things that are further apart. It involves using known \(z\) values and weights determined as a function of distances between the...
unknown and known points. A general form of finding an interpolated value $\mu$ at a given point $x$ based on samples $u_i = u(x_i)$ for $i = 1, 2, \ldots, N$ using IDW is an interpolating function:

$$u(x) = \begin{cases} \sum_{i=1}^{N} w_i(x) u_i, & \text{if } d(x, x_i) \neq 0 \text{ and } d(x, x_i) \neq 0 \text{ for all } i \quad (2) \\ u_i, & \text{if } d(x, x_i) = 0 \text{ for some } i \end{cases}$$

where $w_i(x) = \frac{1}{d(x, x_i)^p}$, $d$ is a given distance from the known point $x_i$ to the unknown point $x$, $N$ is the total number of known points used in the interpolation, and $p$ is a positive real number.

Results and discussions

Cd concentrations in arable soil throughout China

The total investigated area was about 739,000 km², accounting for about 54.59% of the total arable land (1,353,850 km², http://news.xinhuanet.com/english/china/2013-12/30/c_133007338.htm), indicating that more than half of the arable soil have been investigated. The number of the total sample points in the 640 data records was 132,071, about one sample every 5.60 km² of land.

Total Cd concentrations ranged from 0.01 to 152.95 mg/kg, with the standard deviation (SD) of 9.44 mg/kg. The wide range of Cd concentrations and the high SD value denoted that the Cd concentrations were spread out over a large range of values across regions covered in previous studies. The sample-number-weighted mean of Cd concentration was 0.27 mg/kg, which was higher than the background value of soil Cd concentration of 0.097 mg/kg (China Environmental Monitoring Center 1990), but a bit lower than the grade II reference value of 0.30 mg/kg (pH<7.5) or 0.60 mg/kg (pH>7.5) (China soil environment quality standard, GB15618-1995). Compared with other studies, the average of Cd concentration in this study was close to the result of 0.25 mg/kg in the work by Song et al. (2013), but higher than 0.21 mg/kg by Niu et al. (2013) and lower than 0.43 mg/kg by Wei and Yang (2010).
Compared to other countries or regions (Table 1), the average of soil Cd concentrations in Chinese arable soil was close to that in agricultural soil in the USA (Holmgren et al. 1993), but lower than New Zealand (McDowell et al. 2013) and Zambia (Ikenaka et al. 2010), and higher than Malaysia (Zarcinas et al. 2004a), Thailand (Zarcinas et al. 2004b), 26 countries in Europe (Lado et al. 2008), and Australia (de Vries et al. 2011). We should notice that the maximum Cd concentration in China was much higher than the other countries. The number of samples with Cd concentrations higher than 23.60 mg/kg (the maximum Cd concentration in 26 European countries) was 56 in 15 data records, accounting for 0.04% of the total investigated sample number.

The frequency of the data records on Cd concentrations is shown in Fig. 2. It demonstrated that 90.16% of the data records had higher Cd concentrations than the background concentration of Cd, indicating that external sources of Cd had been introduced into arable soil due to human activities. Among them, the Cd concentrations in 26.25% data records exceeded the reference value of 0.60 mg/kg, indicating that more than one quarter of the data exceeded the maximum permissible concentrations of potential toxic elements in the soil environment quality standard, making these areas inappropriate for planting crops or vegetables. This value was close to the study based on 138 regions, where the estimated pollution probability of Cd was about 26.71% (Song et al. 2013). In this study, about 18.91% of the data records exceeded the III references (1.00 mg/kg, China soil environment quality standard, GB15618-1995).

### External sources of Cd in arable soil

The Cd concentrations in arable soil are determined by geological parent material compositions and human activity (Salomons 1995; Wei et al. 2009; Wu et al. 2013). To understand the potential external sources, the Cd concentrations in arable soil in the mining and smelting area, urban and suburban areas, wastewater irrigation areas, and remote areas were investigated (Table 2).

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**Table 1** Comparison of Cd concentration in arable soil in China with previously published surface soil Cd concentration data in other countries or regions

<table>
<thead>
<tr>
<th>Country</th>
<th>Land uses</th>
<th>Number of samples</th>
<th>Mean (mg/kg)</th>
<th>Minimum (mg/kg)</th>
<th>Maximum (mg/kg)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>Arable soil</td>
<td>130,871</td>
<td>0.27</td>
<td>0.01</td>
<td>152.95</td>
<td>This study</td>
</tr>
<tr>
<td>United states of America</td>
<td>Agricultural soil</td>
<td>3,045</td>
<td>0.27</td>
<td>0.01</td>
<td>152.95</td>
<td>(Holmgren et al. 1993)</td>
</tr>
<tr>
<td>Zambia</td>
<td></td>
<td>47</td>
<td>0.53</td>
<td>0.02</td>
<td>18.65</td>
<td>(Ikenaka et al. 2010)</td>
</tr>
<tr>
<td>Malaysian</td>
<td>Crop soil</td>
<td>241</td>
<td>0.12</td>
<td>0.01</td>
<td>2.02</td>
<td>(Zarcinas et al. 2004a)</td>
</tr>
<tr>
<td>Thailand</td>
<td>Crop soil</td>
<td>318</td>
<td>0.03</td>
<td>0.01</td>
<td>1.30</td>
<td>(Zarcinas et al. 2004b)</td>
</tr>
<tr>
<td>26 European countries</td>
<td>Agricultural soil</td>
<td>1,588</td>
<td>0.01</td>
<td>23.60</td>
<td>(Lado et al. 2008)</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>Crop soil</td>
<td>36</td>
<td>0.13</td>
<td>0.015</td>
<td>0.46</td>
<td>(de Vries et al. 2011)</td>
</tr>
<tr>
<td>New Zealand</td>
<td>Agricultural soil</td>
<td>939</td>
<td>0.32</td>
<td>0.01</td>
<td>2.70</td>
<td>(McDowell et al. 2013)</td>
</tr>
</tbody>
</table>

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**Fig. 2** Frequency distribution of Cd concentrations in arable soil in China
Cd concentrations in arable soil in mining and smelting areas

The soil in mining and smelting areas had obviously higher Cd concentrations than that in other land uses. The average of Cd concentrations in these areas was four times more than that in the irrigation areas, 17.70 times the value in the urban and suburban areas, and 52.36 times the value in the remote areas. The high Cd concentration in arable soil in mining area was mainly due to the mineral excavation, ore transportation, smelting and refining in these areas, and disposal of the tailing and wastewater around mines, leading Cd to flow and accumulate into soil (Salomons 1995; Shao et al. 2013).

The range of Cd concentrations in the arable soil around mining and smelting activities was from 0.03 to 152.95 mg/kg, with a high SD value of 18.45 mg/kg. The highest value was over 250 times more than the grade II reference of 0.60 mg/kg. The frequency distribution of the data records in mining and smelting areas showed that about 71.54 % of the data records had a higher Cd concentration than the upper limit of the grade II reference of 0.60 mg/kg. The frequency distribution of the data records in mining and smelting areas was mainly due to the mineral excavation, ore transportation, smelting and refining in these areas, and disposal of the tailing and wastewater around mines, leading Cd to flow and accumulate into soil (Salomons 1995; Shao et al. 2013).

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The sample-number-weighted mean of 8.22 mg/kg for Cd concentration was much lower than the value of 11.00 mg/kg based on reviewing 73 soil Cd concentrations around mining areas (Li et al. 2014), mainly due to the fact that only Cd concentrations in arable soil were collected in this study. Compared to the soil Cd concentrations of mining areas in other countries, this study gained a higher result than that of 6.59 mg/kg in Spain based on 16 examined mines and the value of 1.99 mg/kg in South Korea (Li et al. 2014; Ordonez et al. 2011).

Cd concentrations in arable soil in irrigation areas

With severe competition for water resources, increasing attention has been directed to the reuse of reclaimed urban or industrial wastewater (Pereira et al. 2011). At the end of 2012, the total irrigation area in China was about 630,360 km² (National Bureau of Statistics of China 2011). Reclaimed water provides convenient disposal of waste products and has the beneficial aspects of adding valuable plant nutrients and organic matter to soil (Horswell et al. 2003; Liu et al. 2005). However, these effluents are rich in toxic metals and are chief contributors to metal loadings in wastewater irrigated and amended soil (Adeel and Naseem 2014). In our

Table 2 Cd concentrations in arable soil around mining and smelting activities, irrigation area by wastewater, urban and suburban area, and remote areas

<table>
<thead>
<tr>
<th></th>
<th>Mining and smelting activities</th>
<th>Wastewater irrigation</th>
<th>Urban/suburban</th>
<th>Remote area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of studies</td>
<td>130</td>
<td>61</td>
<td>98</td>
<td>351</td>
</tr>
<tr>
<td>Sample-weighted mean</td>
<td>8.27</td>
<td>1.91</td>
<td>0.46</td>
<td>0.16</td>
</tr>
<tr>
<td>Arithmetic mean</td>
<td>8.62</td>
<td>2.55</td>
<td>0.47</td>
<td>0.27</td>
</tr>
<tr>
<td>Min</td>
<td>0.03</td>
<td>0.01</td>
<td>0.05</td>
<td>0.00</td>
</tr>
<tr>
<td>Max</td>
<td>152.95</td>
<td>54.05</td>
<td>3.15</td>
<td>2.04</td>
</tr>
<tr>
<td>SD</td>
<td>18.45</td>
<td>7.93</td>
<td>0.56</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Fig. 3 Frequency of Cd concentrations in arable soil in the areas of mining and smelting activities, wastewater irrigation, urban, and remote areas in China.
study, the mean value in the irrigated area ranked second highest in the four land uses. The mean was 1.92 mg/kg, about 12.18 times the value in the remote area, and also much higher than the background value of 0.097 mg/kg in China, indicating that Cd was introduced by irrigation water.

The Cd concentrations in irrigated soil ranged from 0.01 to 54.05 mg/kg, and the standard deviation was also high (7.93 mg/kg). This demonstrated that the Cd concentrations varied greatly in the irrigation areas and that the Cd concentrations were determined by the quality of the irrigation water. If the irrigation water was clear, the Cd concentrations would be low in the soil; If the irrigation water contained high Cd contents, such as some reclaimed water from industries, Cd concentrations would be high in the soil (Xie et al. 2011; Zhu et al. 2010).

About 47.54% of the data records had a mean value exceeding 0.6 mg/kg in irrigation areas. This percentage was lower than the ratio in the soil in mining areas. The two highest values of Cd concentrations used the wastewater from the Ni-Cd, Fe-Ni battery manufacturers in Xinxiang (Zhu et al. 2009, 2010), and the other four data records with Cd concentrations higher than 4.0 mg/kg were irrigated by the wastewater from smelting plants (Jin 2012; Li et al. 2009a; Liu 2011; Song 2012). The values lower than 0.30 mg/kg accounted for 37.70%, and about 14.75% ranged from 0.30 to 0.60 mg/kg. This also denoted that about half of the irrigated area had water safe enough to be used to irrigate crops.

**Cd concentrations in arable soil in urban areas**

The sample-number-weighted mean of Cd concentration of 0.46 mg/kg in arable soil in urban and suburban areas was higher than that in the remote areas, indicating that the urban activities had induced Cd accumulation in arable soil. Suburban farmland located in the spatial transition zone between urban and rural, experienced a more rapid growth of industrialization than in rural areas in China. Thus, in the arable soil in suburban areas, Cd may have been deposited and accumulated as a result of rapid urban and industrial development (Micó et al. 2006; Yang et al. 2009). The average of Cd concentration in urban arable soil was close to the value of 0.43 mg/kg in agricultural soil around 12 cities (Wei and Yang 2010) and the value of 0.40 mg/kg in the soil of 31 metropolises in China (Cheng et al. 2014) but much lower than the 0.68 mg/kg based on 43 investigated cities (Wang et al. 2012) and 0.88 mg/kg on reviewing 21 cities (Luo et al. 2012).

The Cd concentration in arable soil ranged from 0.05 to 3.15 mg/kg, with a standard deviation of 0.56 mg/kg. The data records with Cd concentrations exceeding 0.60 mg/kg accounted for about 18.37%, denoting that nearly one fifth of arable soil in the investigated urban areas had been contaminated by Cd.

Since urban areas have high population densities and intensive anthropogenic activities, there are a great number of Cd sources in cities. First, irrigation with reclaimed water from cities and industry plants is becoming a common practice in the suburban of major cities, due to its easy availability, disposal problems, and the scarcity of fresh water (Biggs and Jiang 2009; Chen et al. 2013; Yang et al. 2013). Second, transportation is one of the major sources of urban soil pollution by Cd through atmospheric deposition and road runoff (Islam et al. 2007). Some studies in Beijing (Xi et al. 2010), Hongkong (Li et al. 2004), Shanghai (Shi et al. 2008), and Qinghai-Tibet (Yan et al. 2013) have indicated that the Cd concentrations in roadside soil were obviously higher than corresponding background values, and the Cd concentrations decreased with the roadside distance increasing (Bénédicte et al. 2004; Grace et al. 2006; Xi et al. 2010; Yan et al. 2013). Third, the heavy application of fertilizers and pesticides in the urban and suburban farmland also introduced a large amount of Cd into arable soil (Chang et al. 2004; Chen et al. 2006).

**Cd concentrations in arable soil in remote areas**

In the remote areas, the Cd concentration ranged from 0.01 to 2.04 mg/kg, with the SD value of 0.24 mg/kg. The sample-number-weighted mean of Cd concentration of 0.16 mg/kg was much lower than the grade II reference, and only 8.55% of the data had the Cd values higher than 0.60 mg/kg.

However, it should be noted that the average Cd concentration was higher than the background value of 0.097 mg/kg in China, indicating that Cd has been introduced in soil by the agricultural practices of applying liquid and soil manure or inorganic fertilizers (Zahra et al. 2010). Some chemical fertilizers contain high level of Cd, and fertilizer applications also can influence Cd speciation and complexation which affects the Cd movement to plant roots as well as Cd uptake (Wångstrand et al. 2007). The application of farmyard manure to soil is a common practice in China, as a means of recycling plant nutrients in crop production as well as a method of disposing of unwanted waste (Wu et al. 2013). The manure often contains a lot of heavy metals which are added in order for animal feeds to prevent disease and increase weight gain and feed conversion (Nanthi et al. 2004). The application of manure also increases the Cd accumulation in soil (Wu et al. 2012), and manure has become an important Cd source when applying to agricultural land, accounting for approximately 11% of Cd inputs to agricultural land (Fiona et al. 2003; Veeken and Hamelers 2002).

Spatial distribution of soil Cd concentrations in arable land in China

Using the soil Cd concentrations at points and counties, the spatial variation of Cd concentration in arable soil in China...
was estimated. First, the surface data of counties were converted into points at the spatial resolution of 20 km × 20 km, and were combined into the data points. Finally, the Cd values at 6739 points were achieved. IDW interpolation was used to obtain the filled contours map (Fig. 4). Great variability was shown in Cd distribution in China. In general, northern China had lower Cd concentrations than the south, which was consistent with the results of Niu et al. (2013).

Of the spatial distribution of Cd in arable soil, there were some hotspots in Liaoning, Guangxi, Guangdong, Hunan, Yunnan, Gansu, and Henan Provinces. The largest area with hotspots was located in Guangxi Zhuang Autonomous Region, and it connects to the hotspots of Hunan, Guangdong, and Yunnan Province. These investigations were conducted in six Mn mining areas (Lai et al. 2009), one Ti-Pb smelter (Xiang et al. 2010), one Ti mine (Wang et al. 2010), three Pb/Zn mines in Changning (Wei et al. 2009), one Fe mine (Zhuang et al. 2013), and one region irrigated by waste water (Wang et al. 2008; Xiang et al. 2011). These areas were well known for producing Pb, Mn, and Zn ores, and the tailings contained Cd ranging from 32.6–224 mg/kg (Liao et al. 2008).

Other hotspots were located in Liaoning Province, mainly because of the biggest Zn mine of Asia and a high degree of irrigation by wastewater from chemical plants in Huludao (Zheng et al. 2009); in Gansu Province, mainly due to a large amount of copper, silver, and gold mining and smelting activities in Baiyin (Zhao and Wang 2010). The relatively lower hotspot in Henan Province is mainly due to irrigation by wastewater from plants producing Ni-Cd, Fe-Ni, and Zn-Ag alkaline batteries (Zhu et al. 2010, 2009). The hotspots in Jiangxi and Hubei were mainly due to Fe ores in Daye of Hubei and W ores in Dayu of Jiangxi Province (Feng et al. 2011; Sun et al. 2012).

Cd accumulation in arable soil on provincial scale

The spatial distribution of Cd concentrations and the spatial distribution of Cd accumulations on provincial scales are demonstrated in Fig. 5. It shows that the provinces in northern China had lower Cd concentrations than those in southern China. The provincial Cd concentrations ranged from 0.06 to 4.17 mg/kg. The lowest Cd concentration (0.06 mg/kg) was in the Ningxia Hui Autonomous Region, the only province to have a negative value of Cd accumulation. About 15 provinces located in the north and the east had Cd concentrations lower than 0.30 mg/kg, accounting for about half of the investigated provinces. For these provinces, the Cd accumulation values were also low.

The highest Cd concentration (4.17 mg/kg) was in Yunnan Province. The Guangxi Zhuang Autonomous Region and Hunan Province also had high Cd concentrations, with values of 3.63 mg/kg and 1.51 mg/kg, mainly due to the large amount of non-ferrous metal reserves in the three provinces. The reserves of Zn, Cd, Ti, Sr, Pb, Sn, In, Pt, Cu, Mg, and Sb in Yunnan Province rank in the top five in China (http://www.mining120.com/show/1210/20121010_91720.html); Mg, As, V, W, Sb, Ag, and Al in Guangxi were in the top six (http://www.mining120.com/html/1009/20100909_20478.asp); and Sb, Bi, and W in Hunan Province ranked among the top ten
in China (http://www.360doc.com/content/09/0824/09/79442_5200208.shtml).

The Cd concentrations in Guizhou Province, Shaanxi Province, and the Xinjiang Uyghur Autonomous Region were in the range of 0.60 to 1.00 mg/kg. The high Cd concentrations in Guizhou Province was likely due to the large amounts of mine and smelting activities, while the reason for Xinjiang might be because of the large number of areas irrigated by wastewater, the combining effect of wastewater irrigation and mining and smelting activities might be the reason for the high Cd concentration in Shaanxi Province.

Considering the spatial distribution of Cd accumulation in Chinese arable soil, all of the investigated provinces but Ningxia exceeded the background value of Cd concentrations. This indicated that the soil Cd had been accumulating since 1990 (The background values were investigated from 1986–1990) in most of the provinces of China. Moreover, we should note that the spatial distributions of Cd concentration and accumulation were not consistent. Some provinces had high Cd concentration with low accumulation, such as Guizhou Province, which might be due to the high Cd background of 0.659 mg/kg there. Other provinces had low Cd concentrations with high Cd accumulations, for example, Henan and Anhui provinces. This is mainly due to the low Cd backgrounds in these provinces.

Limitations and uncertainties

According to the results of the second national land survey released in December 2013, the total arable land in China is about 1,353,850 km². Therefore, the investigated arable soil of 739,000 km² in this study may not represent China’s overall situation of Cd concentration in arable soil. Moreover, discrepancies in the sampling methods in the collected data may impact the consistency of the evaluation on Cd concentrations and the pollution assessments. Particularly, the biggest factor influencing the assessment results might be the fact of that sample numbers were used as the weights to calculate the total average of the Cd concentrations. Also, the sample distributions in different locations and different land uses were not systematically designed may affect the evaluation results.

Conclusions

The average Cd concentration in Chinese arable soil was about 0.27 mg/kg, higher than the background Cd concentration in soil in China. This indicated that the Cd had been introduced by human activities into soil. The Cd concentrations in soil were mostly introduced by mining and smelting activities, wastewater irrigation, and urban development. The Cd concentrations in arable soil around mining and smelting activities, irrigation areas and urban area were obvious higher than those in remote area. The spatial pollution of Cd showed many hotspots throughout China due to mining and smelting activities, and northern China had lower Cd concentrations than the south. On provincial scale, the spatial distribution of Cd concentrations showed consistent trends. The Cd concentrations in arable soil in all of the investigated provinces but
Ningxia Hui Autonomous Region exceeded the background value of Cd concentrations, indicating the external sources introduced Cd into arable soil.

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