

Distribution of Heavy Metal Pollution in Surface Soil Samples in China: A Graphical Review

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Abstract Soil pollution in China is one of most wide and severe in the world. Although environmental researchers are well aware of the acuteness of soil pollution in China, a precise and comprehensive mapping system of soil pollution has never been released. By compiling, integrating and processing nearly a decade of soil pollution data, we have created cornerstone maps that illustrate the distribution and concentration of cadmium, lead, zinc, arsenic, copper and chromium in surficial soil across the nation. These summarized maps and the integrated data provide precise geographic coordinates and heavy metal concentrations; they are also the first ones to provide such thorough and comprehensive details about heavy metal soil pollution in China. In this study, we focus on some of the most polluted areas to illustrate the severity of this pressing environmental problem and demonstrate that most developed and populous areas have been subjected to heavy metal pollution.

Keywords Heavy metal · Distribution · Soil · Cadmium · China

Today, soil pollution in China is one of the most wide and serious in the world, and will direct China's environmental management in next several decades (Bi et al. 2013; Chen and Ye 2014; Li et al. 2014b; Teng et al. 2014). The China

Soil Pollution Survey published in 2014 indicated that 16.1 % of arable land is polluted and inorganic pollutants, particularly cadmium (Cd) is found in high quantities in 7 % (MEP 2014) of surveyed sites. Moreover, arsenic (As), copper (Cu), lead (Pb), chromium (Cr) and zinc (Zn) are also found in the soil, although in fewer areas and quantities than cadmium. It is well known that the soil in many large and populous cities (including Guangzhou, Shanghai, Hong Kong, Changsha, Hangzhou, Nanjing, Xuzhou, Qingdao, Xiangtan and Zhuzhou) has been subjected to heavy metal pollution (Li et al. 2014a; Teng et al. 2014). At present, heavy metal contamination poses increasingly serious health risks to local residents in many regions of China (Li et al. 2014b) and although the severity and harm of soil pollution has reached critical levels across the Chinese mainland, the distribution of numerous pollution patches remains unknown.

It has taken 8 years and one billion Chinese Yuan (about 161 million US dollars) to carry out China's National Soil Pollution Survey (Ma 2006). To complete the survey, researchers adopted a sampling method of 8 × 8 km uniform grid, and acquired tens of thousands of soil pollutant data across the nation. While this is a laudable and necessary effort, there are some methodological weaknesses with this technique. For example, one soil sample per 64 km² unit may provide sufficient information in unpolluted areas, thereby it is hard to avoid sampling risks of concealing the pollution and the complexity of heavy metal distribution in more polluted areas (MEP 2014). Besides, the survey working groups has not attempted to present soil pollution distribution maps to date.

To remedy these weaknesses, we draw on journal articles and dissertations conducted by thousands of researchers working on soil pollution in China over the last 10 years. Our work consisted in assembling and mapping

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the data thus making essential information available. Because most authors pay more attention to heavily polluted regions, the data acquired through this method will provide some more detailed and objective pictures of the polluted areas. In this study, via compilation and visualisation of data, some heavy metal soil pollution maps were constructed and a series of conclusions about the distribution of heavy metal pollution across the country were obtained.

Materials and Methods

We collected 12,970 papers focusing on China's soil pollution, published within the country and abroad. We narrowed our analysis to 2450 papers that focus on six heavy metals (As, Cu, Pb, Cr, Zn and Cd) in surface soil. Some studies were excluded for lack of sampling methods or geographic coordinates, and eventually, 850 references were included (Fig. S7). According to the present form of sample data in papers, three means of data separation was adopted. In some papers, direct extraction, metal concentrations and geographical coordinates of sampling sites could be acquired directly, was used. Meeting those documents only provided pollution index and corresponding formulas, we brought back calculation to obtain concentrations. Besides, there also were some papers merely displayed the pollutant distribution, a digital inversion of maps was used via Origin 8.0 (OriginLab, Northampton, Massachusetts, USA). In addition, WGS-84 (World Geodetic System-1984 Coordinate System), which was adopted for most Chinese researchers, was used as the uniform geographic coordinate system in the process of data extraction. Eventually, the number of obtained sample sites of As, Cu, Pb, Cr, Zn and Cd are 1340, 1997, 2489, 1774, 1789 and 2253, respectively. And their precise geographic coordinates and heavy metal concentrations (Table S1) were extracted.

In conventional environmental and geographical investigations, methods such as grid sampling and spatial interpolation provide the spatial distribution of soil elements. However, due to their aggregating characteristics, heavy metal pollution sometimes fluctuates in soil on a scale of hundreds of meters (Lin et al. 2010; Xie et al. 2011). Most heavy metal pollution presents a patchy distribution over a large territory. Therefore, in an area as vast as China, bringing out a high-precision contour map requires enormous sampling units. Based on the Grade II environmental quality standards for soils in China (MEP 2008), those of the US Environmental Protection Agency (USEPA 1996, 2002) and some values adopted by pollution experts (Bhuiyan et al. 2010; Maas et al. 2010; Malandrino et al. 2011), we use the following concentration limits for our chosen six metals: cadmium (1 mg/kg), lead (80 mg/kg), zinc (300 mg/kg), arsenic (45 mg/kg), copper (200 mg/kg) and chromium (350 mg/kg), respectively.

zinc (300 mg/kg), arsenic (45 mg/kg), copper (200 mg/kg) and chromium (350 mg/kg), respectively. Correspondingly, samples with concentrations of metal beyond the above limits were identified as Over Limit Sites (OLS), including man-made pollution sites and naturally metal enriched sites. In addition, the surface soil samples data were collected in a depth range from 0 to 20 cm and soil particle size ranges (in mm) were mainly focus on 0.5–4 (excluding 4 mm). The pollution concentration value per site means a mathematic average of three or more sampling values, and all OLSs in the maps are based on the averages (MEP 2004). Arc-Gis10.0 (Esri, Redlands, California USA), was utilized to construct OLSs' distribution maps.

Results and Discussions

Six heavy metal concentrations and distribution of sampling sites were listed in Table S1 (including Cd, Pb, Zn, As, Cu and Cr). The table presents precise geographic coordinates and concentration data. These data were used to construct distribution maps. It is our hope that these maps and exact data can be used by a variety of environmental researchers. In addition, different from conventional methods of grid sampling, these data have a bias towards high pollution studies. It means some direct inferences to the total area need more of dense investigation; but the precise geographic coordinates and concentration data are helpful to contact accurately the pollutants with local status.

According to Fig. 1, although most sites did not exceed any individual criteria, to exhibit the pollution level of

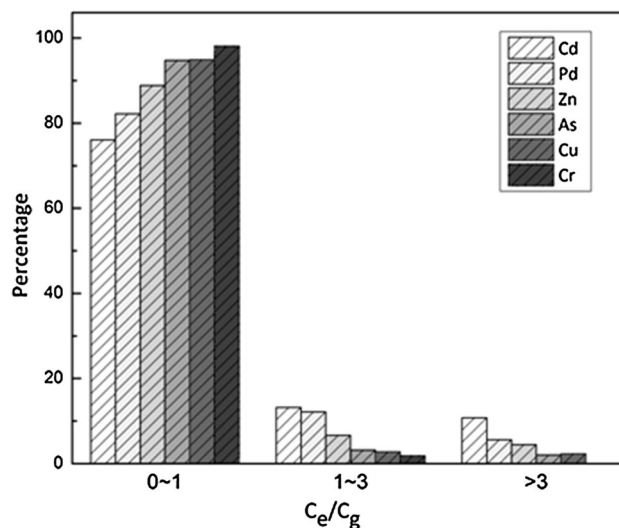


Fig. 1 Metal contents statistics of all sampling sites referring to the regulatory limits (C_g): cadmium (1 mg/kg), lead (80 mg/kg), zinc (300 mg/kg), arsenic (45 mg/kg), copper (200 mg/kg) and chromium (350 mg/kg). The C_e is the measured metal contents

these six heavy metals in a macro-scale, the maps will present an even more biased view because they show only sites at which the criterion for each metal was exceeded. The obtained maps allow us to draw a series of conclusions about the distribution of heavy metal pollution across the country. For example, polluted sampling sites are not distributed equally between Northwest and Southeast China (Fig. S1 to S6) and the OLSs are mainly found in Southern China. Importantly, many districts with high concentrations of OLSs also overlap with highly populated areas. Most of these areas have developed in recent years, such as the Bohai economic zone, the Yangtze River economic zone and the Pearl River Delta economic zone. These highly-polluted areas also cover major grain-producing land including the Northeast Plain, the North China Plain and the middle-lower Yangtze Plains, where arable land constitutes more than 5×10^5 km². Cadmium pollution is more serious than any of the other five metals (Fig. 1), which supports the conclusions reached by the last national soil survey of China (MEP 2014). Lead contamination is also severe, although to a lesser extent than cadmium. Zinc, arsenic, copper and chromium pollutions are comparatively lower, yet certain districts present high occurrence of OLSs.

When divided into provinces, Guangdong, Jiangsu, Shandong, Zhejiang, and Henan have the most OLSs. These five provinces have highest frequency of OLSs in terms of economy. Finally, being relevant to watershed and water quality management, the OLSs tend to concentrate along the three largest rivers: the Yangtze, the Yellow and the Pearl River. In the following section, we review the particularities of respective heavy metal pollution, particularly cadmium and lead, but also zinc, arsenic, copper and chromium.

Cadmium Pollution Distribution

Cadmium is the most serious soil heavy metal pollutant in China; out of 2253 sampling sites (Fig. 2b), 539 are cadmium OLSs (Fig. 2a). These OLSs are present in many provinces, but are most notable in Guizhou, Hunan, Guangxi, Guangdong and Fujian, and most are located south of the Yangtze River. The most intensive distribution occurs at Weijing, a city of 26,853 km², located in Northwest Guizhou (Fig. 2e). The area is abundant in non-ferrous metal (coal, lead, zinc) and hosts the largest germanium mine in the world. Hunan is another province hosting a high concentration of cadmium OLSs, particularly in Yueyang, Yiyang, Changsha, Xiangtan and Zhuzhou City (Fig. 2f). In Fujian province, a number of lead and zinc smelting plants are scattered around Sanming City, resulting in dense concentration of cadmium pollution (Fig. 2g). Dense cadmium OLSs are grouped together at

Hechi and Liuzhou City in Guangxi province for the same reasons (Fig. 2g). Moreover, there are also some cadmium OLSs in Shandong, Henan, Jiangsu, Liaoning provinces as well as in Tianjin in North China. These are all important economic areas with particularly large populations. Also in North China, the cities of Jinan and Qingdao in Shandong province, and Xinxiang and Shangqiu in Henan province all contain many cadmium OLSs (Fig. 2d). The Liaodong Peninsula in Northeast China (Fig. 2c) also has important cadmium OLSs due to its long history in the heavy metal industry. Lastly, considering that the regulatory limit of cadmium in the soil is 1 mg/kg, the concentration in the soil in Lanping County in Yunnan exceeds the limit by 578 times having a cadmium concentration of 578 mg/kg (Fig. 2b, see red star, N26.43346°, E99.41192°). Lanping County is close to the Jinding super-large scale lead–zinc deposit.

Lead Pollution Distribution

Lead concentration is another serious threat to human health and ecological balance (Mielke et al. 1999; Zhang et al. 2012). Out of 2489 sampling sites compiled for lead assessment (Fig. 3b), there are 443 lead OLSs (Fig. 3a). Many cities in Southern China are confronted with acute condition of lead pollution. To note, two important demographic and economic agglomerations suffer from particularly excessive amounts of lead in the soil, namely Shanghai (Fig. 3e) and Guangzhou (Fig. 3g). Hezhang in Guizhou province (Fig. 3f) and Sanming in Fujian province (Fig. 3g), where lead and zinc mining is important, also present dense lead OLSs. Based on the obtained data, the highest concentration of lead in soil found in China (30,430 mg/kg) occurs in Sanming, in the Youxi zone (Fig. 3g, see red star, N26.30773°, E118.29596°), close to a lead and zinc smelting plant in Qili village. In Southern China, many other cities including Tongling in Anhui (Fig. 3e), Taizhou in Zhejiang (Fig. 3e), Fuzhou in Fujian (Fig. 3g) and Hechi, Liuzhou, Yulin in Guangxi (Fig. 3h) also present heavy lead pollution in soil.

Zinc, Arsenic, Copper and Chromium Pollution Distribution

While there are much fewer cases of lead OLSs in Northern than in Southern China, and the density is far lower, there are still some cases of relatively high concentrations. For example, Liaodong peninsula in Northeast China presents a relatively dense concentration of lead OLSs (Fig. 3d). And so does the line from Chengxian, Gansu province to Xi'an, Shaanxi province (Fig. 3c). This is not surprising considering that the Chengxian is located in the famous Xihe-Chengxian lead–zinc mineral band where a super-large

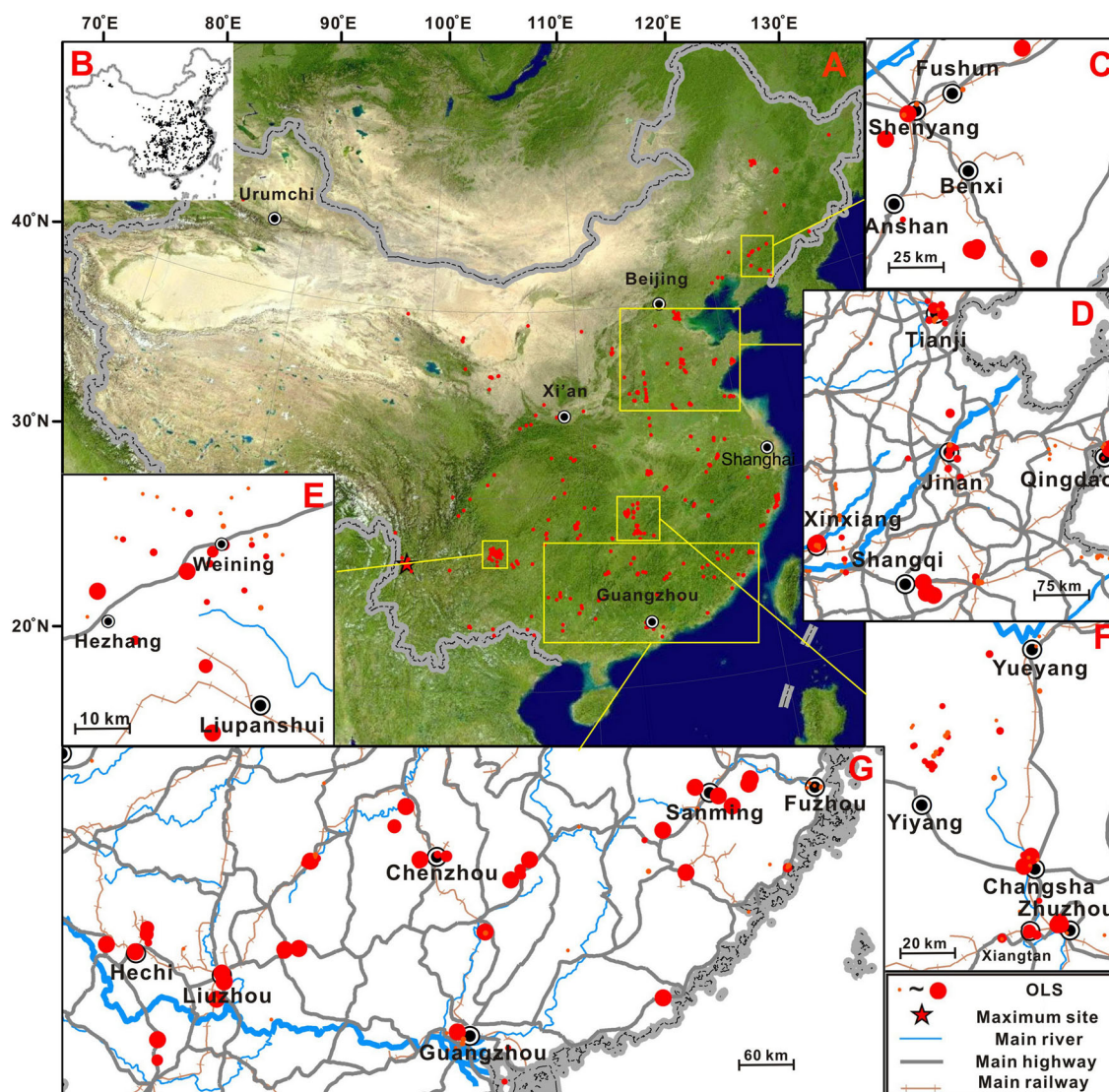


Fig. 2 China's distribution of cadmium OLSs (a); Cadmium sampling sites distribution (b). Main regions containing high concentrations of cadmium OLSs: Liaodong peninsula (c); Northeast China (d); Bijie, Guizhou province (e); Hunan province (f); South of the Yangtze

River (g). In (c) (d) (e) (f) and (g), OLSs (red dots) were grouped into 4 classes: 1–3, 3–5, 5–10, and >10 according to the multiples of the limit value (Cd: 1 mg/kg) (Color figure online)

mine zone has been mined since the Ming Dynasty (Tang 1996).

While these heavy metals pollute the soil across the country, they are not as commonly found as cadmium and lead. As shown in Fig. 4, compared with that of cadmium and lead, the number of zinc, arsenic, copper and chromium OLSs are small. The occurrence rank is as follows: zinc, arsenic, copper and chromium.

Out of the 1789 zinc sampling sites, most of the 199 zinc OLSs are found in Southern China (Fig. 4a). Many zinc OLSs are found along the Yangtze River valley, from Guizhou province to Shanghai, particularly clustering at Hezhang and Weining County in Guizhou province (Fig. 4e) and Jishou in Hunan province (Fig. 4f). In Southern China, zinc OLSs are

most common in Fujian, particularly in Sanming and Nanping City (Fig. 4k), which neighbor lead and zinc mines and smelters. This is also the case near Xinxiang, in Henan province (Fig. 4j). The highest zinc OLS (N26.43346°, E99.41192°) was found at Lanping County in Yunnan province, where the zinc concentration of 49,210 mg/kg is 164 times higher than the standard zinc limit.

Arsenic in soil is primarily linked to arsenic-contaminated groundwater (Rodríguez-Lado et al. 2013). Out of 1339 sample sites, our research found about 70 arsenic OLSs. Those large arsenic OLSs are distributed mostly in the North China Plain, particularly in Tianjin, and Jinan in Shandong province. Some of the other arsenic OLSs are scattered in Southern China. The largest arsenic OLS

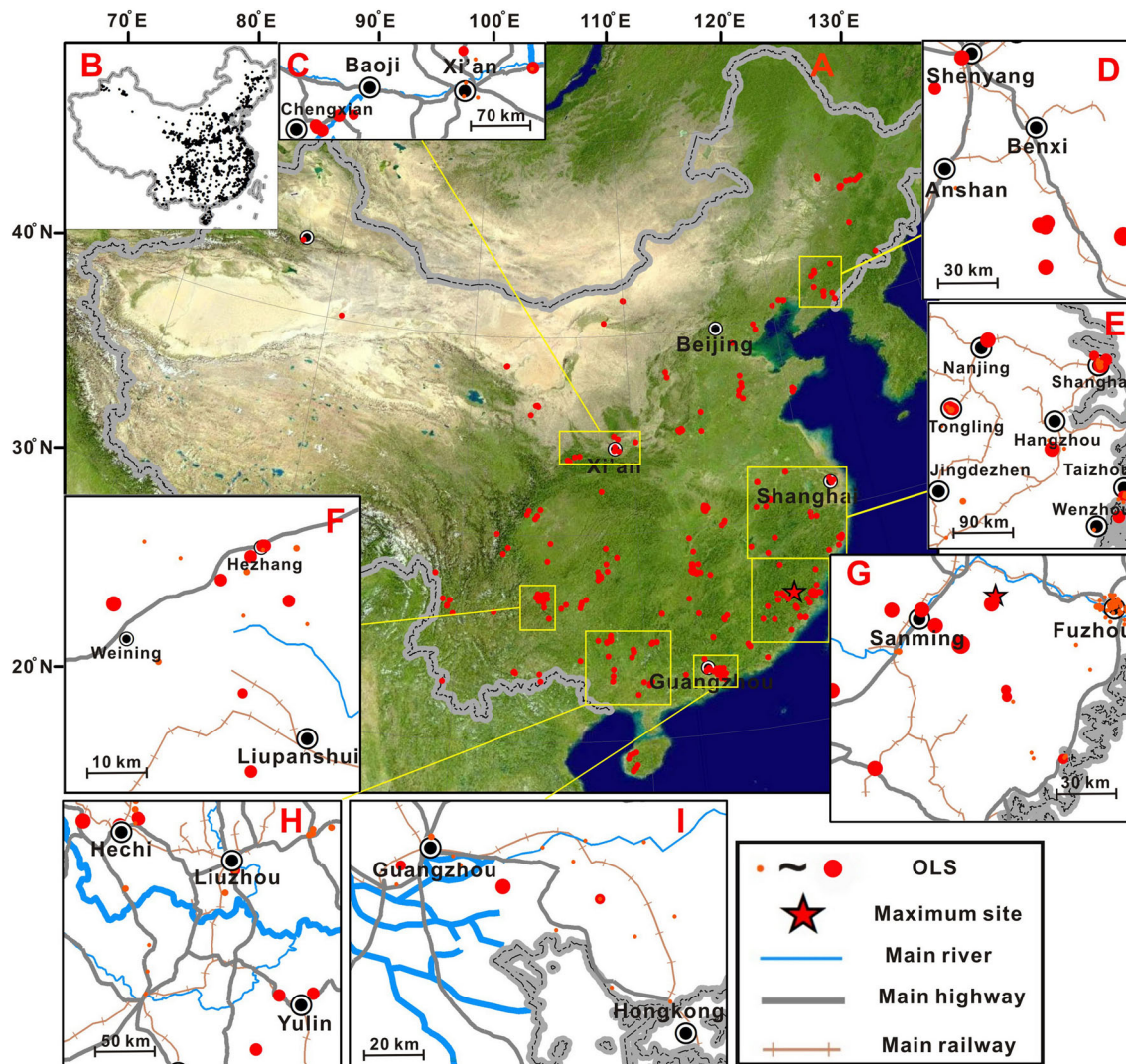


Fig. 3 China’s distribution of lead OLSs (a); Lead sampling sites distribution (b). Main regions containing high concentrations of lead OLSs: *Line* between Chenxian and Xi’an in Northwest China (c); Liaodong peninsula (d); Yangtze River Delta (e); Bijie, Guizhou province (f); North of Fujian province (g); Central Guangxi province

(h); Pearl River Delta (i). In (c) (d) (e) (f) (g) (h) and (i), OLSs (red dots) were grouped into 4 classes: 1–3, 3–5, 5–10, and >10 according to the multiples of the limit value (Lead: 80 mg/kg) (Color figure online)

(2300 mg/kg; N30.90369°, E117.79676°) is found in Tongling along the Yangtze River (Fig. 4h) and this concentration is 51 times higher than the standard limit (45 mg/kg). Within the area of the Pearl River basin, arsenic OLSs surround Hechi City in Guangxi province (Fig. 4m).

There are 101 copper OLSs within 1997 copper sampling sites. Most copper OLSs tend to occur on the southeast coast (Fig. 4c), and concentrate in Guangzhou City (Fig. 4l). But the extreme copper OLS (N38.91407°, E115.64507°) appears at Baoding City in Hebei province located in North China where the highest concentration (33,010 mg/kg), is 165 times the standard limit (200 mg/kg).

Chromium OLSs are less common (Fig. 4d), and the number of chromium OLSs amounts to 33 out of 1774 sample sites. Moreover the chromium concentration in all

OLSs is very low: at the highest chromium OLS (N26.02885°, E119.41859°), near Fuzhou in Fujian province (Fig. 4n), the chromium concentration is 875.59 mg/kg, which is about 2.5 times the standard limit (350 mg/kg).

After analyzing these distribution maps and the precise geographic data, we can find that more polluted sites overlap almost perfectly with intensive mining industries or mineral processing and the regions with dense population and industries are burdened with the most severe soil pollution. It means that China’s agricultural land and the health of people living in the vicinity of these areas (or consuming produce grown in this soil) are under threat of heavy metal pollution. According to the China soil pollution survey communique (MEP 2014), soil heavy-metal pollution affects more than 36 million hectares of arable

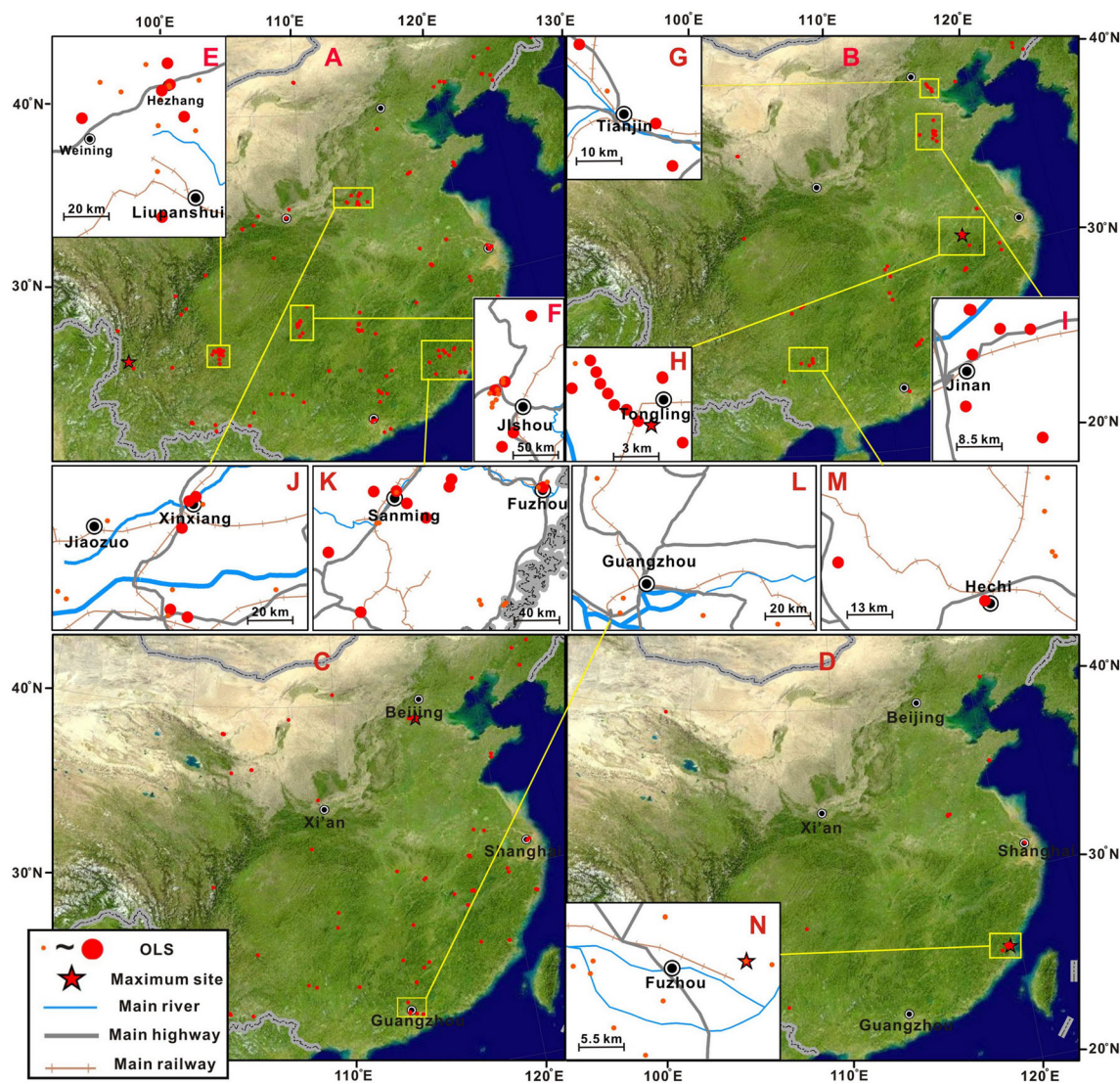


Fig. 4 Zinc (a), arsenic (b), copper (c) and chromium (d) OLSs distribution across the country. Area of high concentration of zinc OLSs: Bijie, Guizhou province (e); Jishou, Hunan province (f); North of Henan province (j); North of Fujian province (k). Area of high concentration of arsenic OLSs: Northeast China (g, i); Tongling, Anhui province (h); Northwest of Guangxi province (m). Area of

high concentration of copper and chromium OLSs: Pearl River Delta (l); Fuzhou, Fujian province (n). In (e) (f) (g) (h) (i) (j) (k) (l) (m) and (n), OLSs (red dots) were grouped into four classes: 1–3, 3–5, 5–10, and >10 according to the multiples of the limit values (Zinc: 300 mg/kg, Arsenic: 45 mg/kg, Copper: 200 mg/kg and Chromium: 350 mg/kg) (Color figure online)

crops, causing an average loss of ten million tonnes of grain each year. Besides, in above maps, we have found that multi-metal contamination in soil is severe in some regions. It should much more deserve its attention to those who focus on these areas.

Conclusion

Due to discontinuous spatial distribution of heavy metal contamination, we did not analysis in the conventional way of grid sampling and spatial interpolation. Here we provided a series of distribution maps containing all the

exposed pollution sites known to date. These maps effectively illustrate the distribution of heavy metal contamination across China. This data was obtained by compiling individual studies, which have been completed by researchers who focus on existing or potentially polluted regions. Our chosen methodology allows us to access and make available to other researchers a large quantity of data at a time when gathering soil pollution information is expensive, labor-intensive and potentially politically sensitive. Correlated with other GIS databases involving population, land-use type, water resources, our database will present also some impressing and interesting suggestions.

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