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A meta-analysis of heavy metals pollution in farmland and urban soils in China over the past 20 years

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ABSTRACT

A total of 713 research papers about field monitor experiments of heavy metals in farmland and urban soils in China, published from 2000 to 2019, were obtained. A meta-analysis was conducted to evaluate the level of China's heavy metal pollution in soils, mainly focusing on eight heavy metals. It was found that the average concentrations of cadmium (Cd), lead (Pb), zinc (Zn), copper (Cu), mercury (Hg), chromium (Cr), nickel (Ni), and arsenic (As) in China were 0.19, 30.74, 85.86, 25.81, 0.074, 67.37, 27.77 and 8.89 mg/kg, respectively. Compared with the background value (0.097 mg/kg), the Cd content showed a twofold (0.19 mg/kg) rise in farmland soils and a threefold (0.29 mg/kg) rise in urban soils. The decreasing order of the mean I_{geo} was Cd (1.77) > Pb (0.62) > Zn (0.60) > Cu (0.58) > Hg (0.57) > Cr (0.54) > Ni (0.47) > As (0.28). Nearly 33.54% and 44.65% of sites in farmland and urban soils were polluted with Cd. The average concentrations of eight heavy metals were not sensitive change in recent two decades in farmland and urban soils. The average P_n values for urban (2.52) and farmland (2.15) soils showed that heavy metal pollution in urban soils was more serious than that in farmland, and the middle Yangtze River regions, where industrial activity dominates, were the most polluted. The meta-analysis comprehensively evaluated the current pollution situation of soil heavy metal, and provided important basis for soil management and environment prevention in China.

Introduction

The heavy metal contamination of soils has become a significant problem negatively impacting on human health and environmental security (Wang et al., 2019), which is visible in some of the farmland and urban soil all over the world. For example, heavy metal, in particular Cd, contamination in soils in the United States, European, Australia, Russia, and India were severe (Weissmannová and Pavlovský, 2017; Sun et al., 2020; Rate, 2018). Cu, Pb and Zn in urban soils in Mexico and Italy have reached the level of pollution (Tang et al., 2019). Similarly, China's urban and agricultural soils are also polluted severely by heavy metals (Hu et al., 2013; Qiao et al., 2020). The results of the national survey of soil contamination showed that there were over 20 million hectares of contaminated land in China (Hu et al., 2014). He et al. (2017) found that numerous cases

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of soil pollution have occurred in China. Zheng et al. (2020) investigated the heavy metal contamination of southern Jiangxi Province, and found that heavy metal contents in all soil samples exceeded the background values. Li et al. (2018) revealed 86% of paddy fields in eastern Hunan were polluted by Cd. Zhou and Wang (2019) revealed industrial activities caused the increase of heavy metal concentration in the Jing-Jin-Ji Region. Jing et al. (2018) analyzed the temporal change of soil heavy metal contents and found that the contents accumulated with an increase of fertilizer. Zhang et al. (2018a) found that Hg and Cd have great potential ecological risk to the southern alluvial plain of the lower Yellow River.

At present, it is of great significance to understand the current situation of soil pollution control. Scholars have used a number of single or integrated indices to evaluate pollution level. The single indices of pollution such as geo-accumulation index (I_{geo}), monomial pollution index (P_i), threshold pollution index (PIT), enrichment factor (EF), and contamination factor (CF), have proven to be helpful in soil pollution evaluation (Weissmannová and Pavlovský, 2017). The I_{geo} and P_i are usually applied to evaluate the degree of pollution because they are considered more accurate (Cheng and Hu, 2012; Li et al., 2020a; Jiang et al., 2014). Integrated indices of pollution such as Nemerow pollution index (P_n), sum of pollution index (PI_{sum}), average pollution index (PI_{avg}), integrated pollution index (IPI), pollution load index (PLI), which are calculated based on single pollution indices. The Nemerow synthetical pollution index is widely used, which highlights the impact of high-concentration pollution element and avoids the phenomenon of weakening the weight of contaminated metals due to the average effect (Guo et al., 2011), while the pollution indices used varies in assessing soil pollution around the world.

In China, previous researches about soil heavy metal pollution were focusing on the levels, sources, spatial distribution, temporal changes, and pollution assessment in different regions (Hu and Cheng, 2013; Li et al., 2020b; Liu et al., 2020; Qiao et al., 2019; Yang et al., 2011; Yu et al., 2019; Wu et al., 2010; Zhang et al., 2018b; Zeng et al., 2019). However, there are three deficiencies: (1) the heavy metal pollution evaluation based on small regions or small points may limit its comprehensive assessment; (2) the lack of large-scale and long-term surveys of contaminants in agricultural and urban soils make it difficult to identify the potential pollution level of Chinese soils; and (3) some analysis about pollution status does not comprehensively compare the status of heavy metal pollution in farmland and urban soil. A meta-analysis based on the existing literature provides a good way to comprehensively understand the current situation of soil heavy metal pollution in China, the potential pollution level and the impact of human activities on soil heavy metal pollution.

Meta-analysis is a method to synthesize the information extracted from the original researches and to obtain the overall trend of the subject (Bengtsson and Weibull, 2005) through the process of synthesizing the results of independent experiments (Zhou et al., 2016) to obtain quantitative and comprehensive conclusions. This technique has been widely used and proven to be effective to address numerous ecological and environmental questions (Shao et al., 2016; Chen et al., 2012; Parmesan and Yohe, 2003; Guo and Gifford, 2002).

In this study, a meta-analysis based on the published and peer-reviewed research papers of field monitor experiments about heavy metals content in farmland and urban soils of China from 2000 to 2019, was been conducted to evaluate the status of soils heavy metals pollution in China. The main objectives of this study were to (1) analyze the pollution status of eight soil heavy metals (Cr, Ni, Cd, Pb, Zn, Cu, Hg, and As) in China, (2) investigate the level of heavy metals pollution, (3) obtain the temporal trends of heavy metal contents and identify the reasons for the variation, and (4) assess the spatial distribution of the pollution index (P_i and P_n) in different regions.

1. Materials and methods

1.1. Literature synthesis and data collection

Conducted a literature search in the ISI Web of Knowledge website with the following search string: “TS= (lead OR chromium OR arsenic OR cadmium OR mercury OR zinc OR copper OR nickel OR Cr OR Pb OR Cd OR Cu OR Ni OR Zn OR As OR Hg) AND (agriculture soil OR farmland OR urban soil) AND (China).” In addition, the search was restricted to articles published between 2000 and 2019. A total of 10,491 and 6405 English and Chinese documents, respectively, were collected. Finally, 713 documents (410 and 303 about farmland and urban soils, respectively) were hits. In order to control the quality of every studies, articles must meet the following restrictions: (1) must be the field experiment based on normal farmland (exclusive the mining and smelting areas) and urban soil, (2) monitored heavy metals in the surface soil, (3) had clearly coordinates of sampling points and study area, (4) the number of soil samples collected were more than 30, (5) prepared and analyzed soil samples using acceptable methods, and (6) included data quality control in analysis.

1.2. Data test and homogeneity analysis

Before meta-analysis, the data should be tested. The existence of extreme values will affect the overall analysis results to some extent. Therefore, outlier diagnosis is needed. In this study, we chose Studentized deleted residual to outlier diagnostic index (Viechtbauer and Cheung, 2010). The Q statistic was used to judge heterogeneity (Hoaglin, 2016), and the Q statistic follows chi-square test, which the degree of freedom is k-1, and the p is obtained by referring to the table of *Chi-square* values. When $p > 0.05$ shows that multiple similar studies have homogeneity, and we can choose fixed effect model to calculate the combined effect value; when $p < 0.05$ shows that the result of multiple studies has heterogeneity. The Q statistic was calculated by Eq. (1):

$$Q = \sum_{i=1}^{N} w^*_i r_i^2 - \frac{\left(\sum_{i=1}^{N} w^*_i r_i\right)^2}{\sum_{i=1}^{N} w^*_i} \tag{1}$$

where, r_i (mg/kg) the effect value of a single study; w^*_i (mg/kg) is the reciprocal of variance of a single study (Eq. (2)).

$$w^*_i = \frac{1}{\mathrm{var}(r_i)} \tag{2}$$

where, var(r_i) is the sample variance.

1.3. Calculation the weighted average

The process of calculating the average value of the studied variables in meta-analysis is known as the combined effect quantity. In essence, the combined effect amount is a weighted average value. In this study, because the measurement method and unit of the intervention measure were exactly the same, the weighted average difference of continuous variable was selected to calculate the national average values of the eight heavy metals (Cu, Zn, Cd, Pb, Hg, Cr, Ni, and As). According to the field experiment characteristics, the larger the monitoring areas, the more sampling points, the smaller the variation, and the more representative the soil heavy metal content data. Therefore, it is generally believed that the study with the larger the research area, the more the samples and the smaller the variance will be more reliable to infer the integral level, so the greater the weight should be given. In view of this, the weight (w_i, mg/kg) was calculated according to Eq. (3):

$$w_i = A_i \times \frac{N_i}{SD_i} \tag{3}$$

where, A_i (km^2) is the study area, N_i is the number of soil sample points, and SD_i is the standard deviation.

The weighted average C (mg/kg) was calculated by Eq. (4):

$$C = C_i \times \frac{w_i}{\sum_{i=1}^{N} w_i}, \tag{4}$$

where, C_i (mg/kg) is the average concentration of heavy metals in each study.

1.4. Assessment of soil pollution

The geo-accumulation index (I_{geo}) was calculated by Eq. (5) (Muller, 1969), and has been widely used to assess the pollution level of heavy metals in soil (Li et al., 2014; Liu et al., 2020; Odewande and Abimbola, 2007; Modabberi et al., 2018):

$$I_{geo} = \log_2\left(\frac{C_n}{1.5B_n}\right) \tag{5}$$

where, C_n (mg/kg) is the measured content of heavy metal n in the soil, and B_n (mg/kg) is the background value of the metal n. A factor of 1.5 represents the influence coefficient of possible variation of environment and human anthropogenic. The classification criteria are shown in Table 1.

The monomial pollution index (P_i) is defined according to the following Eq. (6) (Guo et al., 2011):

$$P_i = \frac{C_i}{S_i} \tag{6}$$

where, C_i (mg/kg) is the measured concentration of metal i in soil, and S_i (mg/kg) is the evaluation standard of soil pollution in difference regions of China. In this study, the national soil environmental quality standards (GB15618–2018) was used as evaluation standards. The $P_i \leq 1$ means no contamination, $1 < P_i \leq 2$ means slight contamination, $2 < P_i \leq 5$ means moderate contamination, and $P_i > 5$ means severe contamination (Chen et al., 2005), the higher P_i value and the more serious the pollution degree.

Table 1 – Soil quality classification according to I_{geo}.

Class	Value	Soil quality
0	$I_{geo} \leq 0$	Unpolluted
1	$0 < I_{geo} < 1$	Unpolluted to moderately polluted
2	$1 < I_{geo} < 2$	Moderately polluted
3	$2 < I_{geo} < 3$	Moderately to heavily contaminated
4	$3 < I_{geo} < 4$	Strongly polluted
5	$4 < I_{geo} < 5$	Strongly to extremely polluted
6	$5 < I_{geo}$	Extremely polluted

Table 2 – Classification criteria of pollution degree.

Grade	Pollution index	Pollution level
1	$P_n \leq 0.7$	Safety domain
2	$0.7 < P_n \leq 1.0$	Precaution domain
3	$1.0 < P_n \leq 2.0$	Slightly polluted domain
4	$2.0 < P_n \leq 3.0$	Moderately polluted domain
5	$P_n > 3.0$	Seriously polluted domain

There are more than one heavy metals in polluted soil. The comprehensive pollution degree can be measured by the Nemerow synthetical pollution index (P_n), the formula used is as follows (Guo et al., 2011):

$$P_n = \sqrt{\left(P_{i\max}^2 + \bar{P}_i^2\right)/2} \tag{7}$$

where, $P_{i\max}$ and $\bar{P}_i$ are the maximum and the average value of P_i, respectively. The P_n is classified into five grades values (Cheng and Hu, 2012) and showed in Table 2.

1.5. Data analysis

Statistical analysis was performed and the figures generated using OriginPro9.1. Meta-analysis was using Stata13.0. The distribution of P_i and P_n in different regions was performed using ArcMap 10.2.

2. Results

2.1. Publication bias and homogeneity analysis

Appendix A **Figs. S1** and **S2** showed that the heavy metal contents in farmland and urban soils presents skewed distribution, indicating that the extreme value exists in the database. And publishing bias were existing within the literature analysis because researchers and publishers pay more attention to hot spots or contaminated areas. We used Studentized deleted residual to outlier diagnosis. Then the data excluding outliers was used for homogeneity analysis. Appendix A **Table S1** were the result of homogeneity the analysis, and the $p > 0.05$ in different sub-regions which shows that multiple similar studies have homogeneity and the fixed effect model can be used to combine the effect values.

Table 3 – Literature survey of heavy metal in China.

Element	Cd	Pb	Cu	Zn	Hg	Cr	Ni	As
Number of farmland soil samples	355	372	330	305	247	324	223	276
Percentage of exceedances[a]	33.54	1.11	11.56	6.55	9.78	0.00	9.13	6.92
Number of outliers[b]	29	3	6	13	10	11	5	13
Number of urban soil samples	219	275	267	258	121	238	161	159
Percentage of exceedances[a]	44.65	1.82	27.17	18.60	18.18	2.99	17.61	7.05
Number of outliers	3	38	5	5	3	9	8	6
Weighted average of farmland soil (mg/kg)	0.18	30.25	25.73	83.87	0.07	66.81	27.67	8.45
Weighted average of urban soil (mg/kg)	0.29	35.24	26.58	104.28	0.08	72.59	28.69	12.98
Weighted average of China (mg/kg)	0.19	30.74	25.81	85.86	0.07	67.37	27.77	8.89
I_{geo}	1.77	0.62	0.58	0.60	0.57	0.54	0.47	0.28
Standard value[c]	0.30	80.00	50.00	200.00	0.50	250.00	60.00	30.00
Background value[d]	0.097	26.00	22.60	74.20	0.065	61.00	26.90	11.20

[a] Percentage exceeds the quality standards (GB 15618–2018).
[b] Outliers were removed by heterogeneity of meta-analysis.
[c] Standard values adopted the secondary standard of heavy metal content (paddy fields with pH ≤ 5.5) (GB 15618–2018).
[d] The background values were selected the CNEMC (China National Environmental Monitoring Center), 1990.

Table 4 – Pearson correlation coefficients between the different heavy metals.

	Cr	Ni	Cu	Zn	As	Cd	Pb	Hg
Cr	1.00	**0.51****	**0.37****	**0.24****	0.09	0.18**	0.10	−0.01
Ni		1.00	**0.33****	**0.22****	0.14*	0.17**	0.04	−0.03
Cu			1.00	**0.52****	**0.22****	0.37**	0.33**	0.18**
Zn				1.00	**0.20****	**0.42****	0.50**	0.25**
As					1.00	0.15*	**0.18****	0.11
Cd						1.00	**0.35****	**0.25****
Pb							1.00	**0.36****
Hg								1.00

** $P < 0.01$ significance level.* $P < 0.05$ significance level.The bold values are the significant positive correlation coefficients.

2.2. *Current concentrations of soils heavy metal in China*

The literatures survey was given in Table 3. The majority of studies were on Pb (648) and Cd (574), but fewer on Ni (384) and Hg (368). In addition, the average concentrations of Cd, Pb, Zn, Cu, Hg, Cr, Ni, and As in China were 0.19, 30.74, 85.86, 25.81, 0.074, 67.37, 27.77, and 8.89 mg/kg, respectively. Compared with the background value (0.097 mg/kg), the concentration of Cd showed a twofold (0.19 mg/kg) rise in farmland soils and a threefold (0.29 mg/kg) rise in urban soils. In addition, compared with the secondary farmland environment quality standard (GB 15618–2018) in China, Cd pollution was serious, representing nearly 33.54% and 44.65% of the polluted sites in farmland and urban soils. This indicated that Cd was the most critical toxic metal threatening soil environmental and the pollution with Pb, Zn, Cu, Hg, Cr, Ni, and As was relatively slight impact.

2.3. *Integrated evaluation of soil pollution with heavy metals*

As the summary statistics shown in Table 4, the decreasing order of the mean I_{geo} was Cd (1.77) > Pb (0.62) > Zn (0.60) > Cu (0.58) > Hg (0.57) > Cr (0.54) > Ni (0.47) > As (0.28). The Cu, Hg, Zn, Cr, Pb, Ni, and As values were in class 1, indicating an unpolluted contamination level. However, Cd was in Class 2, indicating a moderate pollution level. Fig. 1**a, b** shows the percentage of sample distribution in each of the classes defined by the I_{geo}. In farmland soils, 87% of Cr, 86.43% of Ni, 69.35% of Cu, 68.51% of Zn, 81.58% of As, and 70.28% of Pb samples belonged to class 0. The major pollutants were Cd and Hg, and 76.99% and 59.31% of I_{geo} values of these pollutants were higher than class 0, respectively. For Cd, 30.73% and 7.39% of samples were at the medium-strength pollution level. For Hg, 18.61% and 4.38% of samples were at the medium-strength pollution level. However, in urban soils, 75.21% of Cr, 82.81% of Ni, 53.21% of Cu, 51.74% of Zn, 80.89% of As, 46.38% of Pb samples belonged to class 0. For Cd and Hg, 76.15% and 77.68% of the I_{geo} values of these pollutants were higher than class 0, and sample pollution rates reached 46.77% and 46.42%, respectively, in the medium-strength pollution level. In general, soil heavy metals in China were polluted by Hg and Cd, whereas the other heavy metal contents in the top layer of soils were not increased to any visible extent and were also far below the secondary environmental quality standard (GB 15618–2018). This revealed that soils heavy metal pollution in Chinese was not serious. However, it was clearly to see the continuously accumulated of Cd and Hg. Therefore, necessary measures need to be taken to prevent further deterioration of pollution.

2.4. *Temporal variation of heavy metal in farmland and urban soils*

The temporal variation of the heavy metals average content revealed different patterns in the farmland and urban soils from 2000 to 2019 (Fig. 2). The Cr, Hg, Cd, and Ni concentrations showed increasing trends during 2000–2009 and then decreased after 2009. The trends of Pb, Cu, and Zn showed slight fluctuations during the studied periods. The concentration trend of As increased rapidly from 2000 to 2019, especially in the farmland soil. In summary, the average concentrations

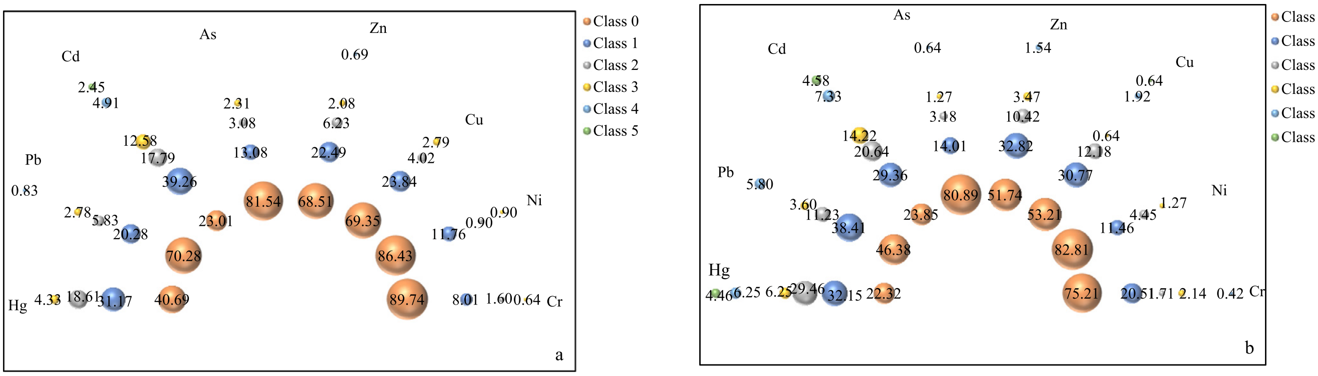

Fig. 1 – Class distribution and percentage of I_{geo} in the farmland soils (a) and urban soils (b).

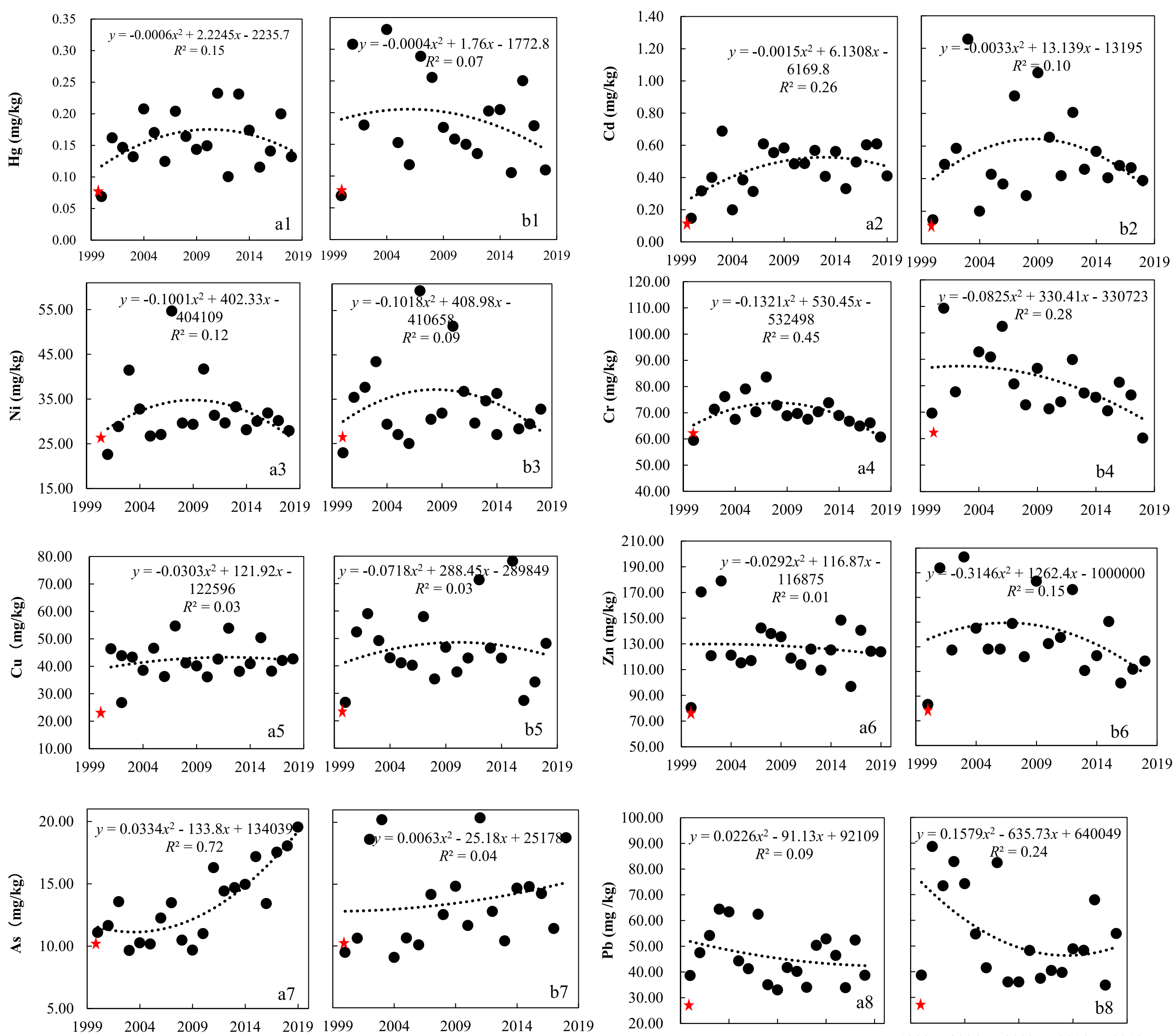

Fig. 2 – Temporal variation (year 1999 - 2019) of heavy metals in farmland (a) and urban (b) soils (red stars represent the background value for each element).

Table 5 – P_i and P_n values in the farmland topsoil from the different regions.

Region	P_i Cd	Pb	Cr	Ni	Cu	Zn	As	Hg	P_n
East coast	1.74	1.10	0.96	0.99	1.20	1.02	0.92	1.22	1.55
North coast	2.48	1.07	0.81	0.99	1.03	1.05	0.87	1.95	2.34
Northeast	1.51	0.91	0.85	0.99	1.36	1.07	1.03	1.79	1.59
Northwest	1.31	1.34	0.56	0.71	0.76	1.12	1.13	1.67	1.50
South coast	3.09	1.15	1.98	2.02	2.24	1.51	0.92	2.50	2.84
Southwest	2.00	1.80	0.96	0.80	1.09	1.54	0.84	1.55	2.22
Middle Yellow River	2.51	1.29	1.20	1.01	1.09	1.11	0.86	2.98	2.53
Middle Yangtze River	2.86	1.34	1.04	0.82	1.39	1.31	0.96	2.50	2.74
Average	1.74	1.10	0.96	0.99	1.20	1.02	0.92	2.04	2.15

Table 6 – P_i and P_n values in the urban topsoil from the different regions.

Region	P_i Cd	Pb	Cr	Ni	Cu	Zn	As	Hg	P_n
East coast	3.68	2.05	1.28	1.10	2.10	2.44	1.44	1.42	2.95
North coast	1.86	1.06	0.98	1.10	1.18	1.51	0.95	1.75	1.88
Northeast	2.97	2.72	1.08	1.95	2.11	0.93	1.87	4.71	2.94
Northwest	2.76	1.10	1.27	0.72	1.14	1.15	1.08	0.96	2.25
South coast	2.97	1.19	2.11	1.72	1.48	1.25	1.03	1.38	2.13
Southwest	2.52	1.75	1.04	1.81	1.52	1.39	0.96	2.09	2.41
Middle Yellow River	2.75	1.41	1.83	0.93	1.19	1.10	1.08	3.68	2.71
Middle Yangtze River	3.25	2.26	1.18	1.12	1.49	1.25	1.10	1.99	3.07
Average	3.68	2.05	1.28	1.10	2.10	2.44	1.44	2.17	2.52

of the eight heavy metals showed slightly variation over the past two decades.

Table 4 provided the correlation coefficient with Pearson correlation analysis. The content of Cu, Ni, Cr, Cd, Zn, and As, had a positively and significantly ($p < 0.01$) correlation with each other, and the correlation coefficient is shown in bold in Table 4.

2.5. *Spatial distribution of heavy metals pollution in different regions of china*

In this study, heavy metals data of P_i and P_n in different regions were assessed. The average P_i values of farmland soil (Table 5) decreased in the following order: Cd (2.11) > Hg (2.08) > Cu (1.31) > Pb (1.26) > Zn (1.23) > Ni (1.04) > Cr (1.01) > As (0.97). The average P_i values of urban soils (Table 6) decreased in the following order: Cd (2.80) > Hg (2.17) > Pb (1.65) > Cu (1.48) > Zn (1.36) > Cr (1.32) > Ni (1.28) > As (1.15), which showed that Cd and Hg were in the moderate contamination category and the other heavy metals were in the slight contamination category. The P_n values for urban and farmland soils in different regions shows that except the northern coast, the pollution in other areas were greater in urban areas than in farmland. And the average P_n for urban (Table 6) and farmland soils were 2.52 and 2.15, respectively, both within the moderately polluted category, showed that heavy metal pollution in urban soils were more serious than that in agricultural.

The spatial distribution in eight economic regions in China (southwest, middle Yangtze River, middle Yellow River, northeast, south coast, east coast, northwest, and north coast) is considered. For farmland soils, the pollution situation of the different regions decreased in the order south coast (2.84) > middle Yangtze River (2.74) > middle Yellow River (2.53) > north coast (2.32) > southwest (2.22) > northeast (1.59) > east coast (1.55) > northwest (1.50) (Table 5). The pollution level of different regions was more apparent. The Cd, Ni, Cu, and Cr contents were highest in the south coast region; Zn and Pb were highest in the southwest; and As was highest in the northwest region. However, in the urban soils, the pollution status in the eight regions decreased in the order middle Yangtze River (3.07) > east coast (2.95) > northeast (2.94) > middle Yellow River (2.71) > southwest (2.41) > northwest (2.25) > south coast (2.13) > north coast (1.88) (Table 6). The analysis showed that the level of soil heavy metal pollution is higher in the economically developed areas (such as the middle reaches of the Yangtze River, the east coast and the south coast), which are dominated by industrial activities.

The average P_i and P_n of different heavy metals in farmland topsoil (Table 5) showed that the main pollutants in different regions were Cd and Hg, the pollution level ranging from uncontaminated to the extremely contaminated. In the farmland soils, the Cd and Hg pollution patterns in south coast (Guangdong, Hainan, and Fujian) and middle Yellow River (Inner Mongolia, Shanxi, Henan, and Shaanxi) reached the moderate contamination level. However, in the urban soils, the Cd and Hg pollution patterns in the east coast (Shanghai, Jiangsu and Zhejiang) and the northeast (Heilongjiang, Liaoning, Jilin) reached the moderate contamination level.

Table 7 – Concentration of heavy metals in soils worldwide.

Element	Cd	Pb	Cu	Ni	Cr	Zn	As	Hg	Review/field monitoring	Reference
China	0.19	30.74	25.81	27.77	67.37	85.86	8.89	0.07	Review of 713 articles	This article
World	1.10	25.00	4.00	18.00	42.00	62.00	4.70	0.10	–	Alina, 2000
Europe	0.15	15.00	12.00	14.00	22.00	48.00	6.00	0.037	852 soil samples	Salminen, 2005
England and Wales	0.33	49.00	30.10	21.00	68.00	76.00	15.00		569 soil samples	Rawlins et al., 2012
America	0.16		17.30	18.30	24.00				1903 soil samples	Burt et al., 2003
Netherlands	0.14	15.60	10.20	4.94	15.70	40.30	5.60		100 soil samples	Brus and Nieuwenhui, 2009
Iran	1.53	46.59	60.15	35.53	63.79	94.09			–	Sayadi et al., 2015
India		41.80	79.05	52.46	147.05	178.50	9.99		32 Indian cities	Adimalla et al., 2019
Africa	5.00	150.00	100.00	100.00	250.00	500.00			–	Yabe et al., 2010

"–": not mentioned.

The average P_i and P_n of different heavy metals in urban topsoil (**Table 6**) reflected that the pollution levels in the middle Yangtze River, the east coast, and the south coast regions with faster industrial development were higher than those in the northwest and northeast regions with slower industrial development. the middle Yangtze River region (Hubei, and Anhui, Jiangxi, Hunan) had relatively high P_n values than the other regions and the urban soils reached the seriously polluted domain levels of grade 5.

3. Discussion

3.1. *Comparison of heavy metal concentrations in China with elsewhere in the world*

Table 7 presents a comparison of soil heavy metals concentrations between China and other countries (or regions) in the world, such as Europe, England and Wales, USA, Denmark, the Netherlands, Iran, India, and Africa. The variations of concentrations among countries or regions reflected the differences of soil parent materials and the human inputs (Adimalla et al., 2019). The heavy metal concentrations in China were higher than those in Europe and USA but lower than those in India and Africa. This may be due to different levels of industrialization in different countries. It was interesting to find although contents of Hg and Cd were relatively serious in China, were lower than those in global average contents (Alina, 2000), whereas the contents of Cr, Zn, As, Ni, Cu, and Pb in China with slight pollution were higher than the global average contents. However, China should still pay attention to the continued accumulation of Cd and Hg.

3.2. *Integrated situation of soil pollution with heavy metals*

As the summary statistics shows in Table 7, the weighted mean values of the study were only a small differences compared with the studies of Huang (2019), Chen (2015), and Pan (2017), which showed the reasonability of using the weighted average value to calculate the soil heavy metals. Cd is the most seriously polluted heavy metal in China's soil, with 33.54% and 44.65% of the pollution in farmland and urban soil. This finding was consistent with the results reported by Chen et al. (2015), Zhao et al. (2015), and Hu et al. (2014). This may because China's coal-burning Cd emissions have grown rapidly in the past 30 years (Cheng et al., 2014). In addition, the anthropogenic emissions have resulted in the soil Hg accumulate continuously, and it can pollute other areas by long-distance transportation (Eckley et al., 2015; Jiang et al., 2006). Thus, the information of pollution tendency and spatial distribution reveal that environmental management should emphasize treating the soil polluted by Cd and Hg.

The heavy metal pollution in urban soils was generally higher than that in farmland soils, which resulted from the difference of heavy metal pollution sources between farmland and urban soils (Yang et al., 2018). Farmland soils inflow pathways mainly come from irrigation, fertilization, and atmospheric deposition (Lu et al., 2012; Guo et al., 2006), while the urban soils mainly originate from industrial emissions (e.g., electronics, metallurgical industry, chemical manufacturing industries, waste disposal, and power plants) (Rizo et al., 2013.), energy production, and vehicle exhausts (Li et al., 2013).

3.3. *The causes of spatial and temporal variation of farmland and urban soil heavy metal in China*

The temporal variation of Hg, Cd, Cr, and Ni showed an increasing trend during 2000–2009 and then decreasing after 2009, which may indicate the success of major measures to reduce pollution levels by economic transition and environmental management (Hu et al., 2014). In addition, the As content in China was very low, but the increasing speed was rapid, especially in the farmland soils, and many studies have shown that excessive phosphate fertilization was the main source of As in the soils (Chen et al., 2005). The significant interrelationships of heavy metals indicated that Pb, Zn, Cd, Cu, and As may have common sources and pathways (Ha et al., 2014; Huang et al., 2007). Therefore, it is necessary to strengthen the cleaning and standardization of industrial and agricultural production to avoid the further enrichment and accumulation of heavy metals.

The spatial distribution maps of P_n in China reflected that the pollution levels in the middle Yangtze River, the east coast and the south coast regions with faster industrial development were higher than those in the northwest and northeast regions with slower industrial development. The variation of soil heavy metal pollution in different regions are the result of natural process and industrial activity (Cheng et al., 2019). Previous studies revealed that industrial activities contributed more than 60% of the heavy metal concentrations in soils (Shi et al., 2018). The Yangtze River region (Hubei, and

Anhui, Jiangxi, Hunan) had relatively high P_n values than the other regions, because the economic growth rate in the region has accelerated since 2000. As a result, gradually increased the total amount of industrial water, waste gas, and solid emissions, aggravating environmental pollution (Xie et al., 2019; Yang et al., 2018). Therefore, industrial activities have great influence on the increase of heavy metals in soil.

4. Conclusions

This study, we used a meta-analysis, which based on the published and peer-reviewed research papers of field monitor experiments about heavy metals content in farmland and urban soils of China from 2000 to 2019, to evaluate the status of soils heavy metals pollution in China. The concentrations, the I_{geo}, the temporal variations of eight heavy metals, the P_i and P_n in different regions were analyzed. The results revealed that China's soils were partly polluted by eight heavy metals. Cd is the most seriously polluted heavy metal in China's soil, with 33.54% and 44.65% of the pollution in farmland and urban soil. The average concentrations of heavy metals showed no significant change over the past 20 years. The average pollution level of heavy metals in urban soils were higher than that in agricultural. The analysis showed that the levels of soil heavy metal pollution were higher in the economically developed areas (such as the middle reaches of the Yangtze River, the east coast and the south coast). This would be of great significance for the development of heavy metal pollution control strategies towards reduced environmental contamination and improved human health.

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Appendix A. Supplementary data

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jes.2020.08.013.

REFERENCES

Adimalla, N., Qian, H., Wang, H., 2019. Assessment of heavy metal (HM) contamination in agricultural soil lands in northern Telangana, India: an approach of spatial distribution and multivariate statistical analysis. Environ. Monit. Assess 191 (4), 190–208.

Alina, K.P. (Ed.), 2000. Trace Elements in Soils and Plants, 3rd Ed.. Crc Press, New York.

Bengtsson, J., Weibull, A.C., 2005. The effects of organic agriculture on biodiversity and abundance: a meta-analysis. J. Appl. Ecol. 42 (2), 261–269.

Brus, D.J., Lamé, F.P.J., Nieuwenhuis, R.H., 2009. National baseline survey of soil quality in the Netherlands. Environ. Pollut. 157 (7), 2043–2052.

Burt, R., Wilson, M.A., Mays, M.D., Lee, C.W., 2003. Major and trace elements of selected pedons in the USA. J. Environ. Qual. 32 (6), 2109–2121.

Chen, H.Y., Teng, Y.G., Lu, S.J., Wang, Y.Y., Wang, J.S., 2015. Contamination features and health risk of soil heavy metals in China. Sci. Total. Environ. 512-513, 143–153.

Chen, T.B., Zheng, Y.M., Lei, M., Huang, Z.C., Wu, H.T., Chen, H., et al., 2005. . Assessment of heavy metal pollution in surface soils of urban parks in Beijing, China. Chemosphere 60 (4), 542–551.

Chen, S., Chao, L., Sun, L.N., Sun, T.H., 2012. The study of heavy metal pollution characteristics in soil of typical urban-industrial wasteland. Appl. Mech. Mater. 260–261, 1189–1194.

Cheng, H.F., Hu, Y.N., 2012. Mercury in municipal solid waste in China and its control: a review. Environ. Sci. Technol. 46 (2), 593–605.

Cheng, K., Tian, H.Z., Zhao, D., Lu, L., Wang, Y., Chen, J., et al., 2014. . Atmospheric emission inventory of cadmium from anthropogenic sources. Int. J. Environ. Sci. Technol. 11 (3), 605–616.

Cheng, Y.Y., Nathanail, C.P., Ja'afaru, S.W., 2019. Generic assessment criteria for human health risk management of agricultural land scenario in Jiangsu Province. China. Sci. Total. Environ. 697, 1–10.

Eckley, C.S., Blanchard, P., McLennan, D., Mintz, R., Sekela, M., 2015. Soil–Air mercury flux near a large industrial emission source before and after closure (Flin Flon, Manitoba, Canada). Environ. Sci. Technol. 49 (16), 9750–9757.

Guo, L.B., Gifford, R.M., 2002. Soil carbon stocks and land use change: a meta-analysis. Global. Change. Biol. 8 (4), 345–360.

Guo, X., Li, Y., Wang, G., 2006. Heavy metal concentrations and correlations in rain-fed farm soils of Sifangwu village, central Gansu Province, China. Land. Degrad. Dev. 18 (1), 77–88.

Guo, X.X., Liu, C.Q., Zhu, Z.Z., Wang, Z.L., Li, J., 2011. Evaluation method of heavy metal pollution in soil. Chinese. J. Ecol. 30 (05), 889–896.

Ha, H.H., Olson, J.R., Bian, L., Rogerson, P.A., 2014. Analysis of heavy metal sources in soil using kriging interpolation on principal components. Environ. Sci. Technol. 48 (9), 4999–5007.

He, K.L., Sun, Z.H., Hu, Y.N., Zeng, X.Y., Yu, Z.Q., Cheng, H.F., 2017. Comparison of soil heavy metal pollution caused by e-waste recycling activities and traditional industrial operations. Environ. Sci. Pollut. Res. 24 (10), 9387–9398.

Hu, Y.N., Liu, X.P., Bai, J.M., Shih, K., Zeng, E.Y., Cheng, H.F., 2013. Assessing heavy metal pollution in the surface soils of a region that had undergone three decades of intense industrialization and urbanization. Environ. Sci. Pollut. Res. 20 (9), 6150–6159.

Hu, Y.N., Cheng, H.F., 2013. Application of stochastic models in identification and apportionment of heavy metal pollution sources in the surface soils of a large-scale region. Environ. Sci. Technol. 47 (8), 3752–3760.

Hu, H., Jin, Q., Kavan, P., 2014. A study of heavy metal pollution in China: current status, pollution-control policies and counter measures. Sustain 6 (9), 5820–5838.

Huang, Y., Wang, L.Y., Wang, W.J., Li, T.Q., He, Z.L., Yang, X.E., 2019. Current status of agricultural soil pollution by heavy metals in China: a meta-analysis. Sci. Total. Environ. 651, 3034–3042.

Huang, S.S., Liao, Q.L., Hua, M., Wu, X.M., Bi, K.S., Yan, C.Y., et al., 2007. . Survey of heavy metal pollution and assessment of agricultural soil in Yangzhong District, Jiangsu Province, China. Chemosphere 67 (11), 2148–2155.

Hoaglin, D.C., 2016. Misunderstandings about Q and "Cochran's Q Test" in meta-analysis. Stat. Med. 35 (4), 485–495.

Jiang, X., Lu, W.X., Yang, Q.C., Yang, Z.P., 2014. Potential ecological risk assessment and prediction of soil heavy-metal pollution

around coal gangue dump. Nat. Hazard. Earth. Syst. Sci. 14 (6), 1599–1610.
Jiang, G.B., Shi, J.B., Feng, X.B., 2006. Mercury pollution in China. Environ. Sci. Technol. 40 (12), 3672–3678.
Jing, F., Chen, X.M., Yang, Z.J., Guo, B.L., 2018. Heavy metals status, transport mechanisms, sources, and factors affecting their mobility in Chinese agricultural soils. Environ. Earth. Sci. 77 (3), 104–112.
Li, C., Sanchez, G.M., Wu, Z.F., Cheng, J., Zhang, S.Y., Wang, Q., et al., 2020b. Spatio temporal patterns and drivers of soil contamination with heavy metals during an intensive urbanization period (1989–2018) in southern China. Environ. Pollut. 260, 1–10.
Li, C.Z., Wang, X.F., Huang, H., Wang, L., Wei, F., Zhang, C.L., et al., 2020a. Effect of multiple heavy metals pollution to bacterial diversity and community structure in farmland soils. Hum. Ecol. Risk Assess. 1–18.
Li, X.Z., Zhao, Z.Q., Yuan, Y., Wang, X., Li, X.Y., 2018. Heavy metal accumulation and its spatial distribution in agricultural soils: evidence from Hunan Province, China. Rsc. Adv. 8 (19), 10665–10672.
Li, Z.Y., Ma, Z.W., van der Kuijp, T.J., Yuan, Z.W., Huang, L., 2014. A review of soil heavy metal pollution from mines in China: pollution and health risk assessment. Sci. Total. Environ. 468-469, 843–853.
Li, H.M., Qian, X., Wang, Q.G., 2013. Heavy metals in atmospheric particulate matter: a comprehensive understanding is needed for monitoring and risk mitigation. Environ. Sci. Technol. 47 (23), 13210–13211.
Liu, L.L., Liu, Q.Y., Ma, J., Wu, H.W., Qu, Y.J., Gong, Y.W., et al., 2020. Heavy metal(loid)s in the topsoil of urban parks in Beijing, China: concentrations, potential sources, and risk assessment. Environ. Pollut. 260, 1–10.
Lu, A.X., Wang, J.H., Qin, X.Y., Han, P., Zhang, S.Z., 2012. Multivariate and geostatistical analyses of the spatial distribution and origin of heavy metals in the agricultural soils in Shunyi, Beijing, China. Sci. Total. Environ. 425, 66–74.
Modabberi, S., Tashakor, M., Sharifi, S.N., Hursthouse, A.S., 2018. Potentially toxic elements in urban soils: source apportionment and contamination assessment. Environ. Monit. Assess. 190 (12), 715–733.
Muller, G., 1969. Index of geo-accumulation in sediments of the Rhine River. J. Geol. 2 (3), 108–118.
Odewande, A.A., Abimbola, A.F., 2007. Contamination indices and heavy metal concentrations in urban soil of Ibadan metropolis, southwestern Nigeria. Environ. Geochem. Health. 30 (3), 243–254.
Parmesan, C., Yohe, G., 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421 (6918), 37–42.
Pan, L.B., Wang, Y., Ma, J., Hu, Y., Fang, G.L., Wang, L., 2017. A review of heavy metal pollution levels and health risk assessment of urban soils in Chinese cities. Environ. Sci. Pollut. Res. 25 (2), 1055–1069.
Qiao, P.W., Yang, S.C., Lei, M., Chen, T.B., Dong, N., 2019. Quantitative analysis of the factors influencing spatial distribution of soil heavy metals based on geographical detector. Sci. Total. Environ. 664 (10), 392–413.
Qiao, D.H., Wang, G.S., Li, X.S., Wang, S., Zhao, Y.Y., 2020. Pollution, sources and environmental risk assessment of heavy metals in the surface AMD water, sediments and surface soils around unexploited Rona Cu deposit, Tibet, China. Chemosphere 248, 1–13.
Rawlins, B.G., McGrath, S.P., Scheib, A.J., Breward, N., Cave, M., Lister, T.R., et al., 2012. The Advanced Soil Geochemical Atlas of England and Wales. British Geological Survey, Keyworth, U.K..
Rate, A.W., 2018. Multielement geochemistry identifies the spatial pattern of soil and sediment contamination in an urban parkland, Western Australia. Sci. Total Environ. 627, 1106–1120.
Rizo, O.D., Morell, D.F., López, J.O., Muñoz, J.L.B., Rodríguez, K.D., Pino, N.L., et al., 2013. Spatial distribution and contamination assessment of heavy metals in urban topsoils from Las Tunas City. Cuba. B. Environ. Contam. Tox. 91 (1), 29–35.
Salminen, R., 2005. Geochemical Atlas of Europe, Part 2. Geological Survey of Finland, Espoo.
Sayadi, M.H., Shabani, M., Ahmadpour, N., 2015. Pollution index and ecological risk of heavy metals in the surface soils of Amir-Abad Area in Birjand City, Iran. Health. Scope 4 (1), 21137.
Shao, D.W., Zhan, Y., Zhou, W.J., Zhu, L.Z., 2016. Current status and temporal trend of heavy metals in farmland soil of the Yangtze River Delta Region: field survey and meta-analysis. Environ. Pollut. 219, 329–336.
Shi, T.R., Ma, J., Wu, X., Ju, T.N., Lin, X.L., Zhang, Y.Y., 2018. Inventories of heavy metal inputs and outputs to and from agricultural soils: a review. Ecotox. Environ. Safe. 164, 118–124.
Sun, M.X., Wang, T., Xu, X.B., Zhang, L.X., Li, J., Shi, Y.J., 2020. Ecological risk assessment of soil cadmium in China's coastal economic development zone: a meta-analysis. Ecosyst. Health. Sust. 6, 2332–8878.
Tang, J.Y., Zhang, J.C., Ren, L.H., Zhou, Y.Y., Gao, J., Luo, J., et al., 2019. Diagnosis of soil contamination using microbiological indices: a review on heavy metal pollution. J. Environ. Manage. 242 (15), 21–130.
Viechtbauer, W., Cheung, M.W., 2010. Outlier and influence diagnostics for meta-analysis. Res. Synth. Methods. 1 (2), 112–125.
Wang, S., Cai, L.M., Wen, H.H., Luo, J., Wang, Q.S., Liu, X., 2019. Spatial distribution and source apportionment of heavy metals in soil from a typical county-level city of Guangdong Province, China. Sci. Total. Environ. 655, 92–101.
Weissmannová, H.D., Pavlovský, J., 2017. Indices of soil contamination by heavy metals – methodology of calculation for pollution assessment (minireview). Environ. Monit. Assess. 189 (12), 616.
Wu, S., Xia, X.H., Lin, C.Y., Chen, X., Zhou, C.H., 2010. Levels of arsenic and heavy metals in the rural soils of Beijing and their changes over the last two decades (1985–2008). J. Hazard. Mater. 179 (1–3), 860–868.
Xie, S.W., Yang, F., Feng, H.X., Wei, C.Y., Wu, F.C., 2019. Assessment of potential heavy metal contamination in the peri-urban agricultural soils of 31 provincial capital cities in China. Environ. Manage. 64 (3), 366–380.
Yabe, J., Ishizuka, M., Umemura, T., 2010. Current levels of heavy metal pollution in Africa. J. Vet. Med. Sci. 72 (10), 1257–1263.
Yang, Z.P., Lu, W.X., Long, Y.Q., Bao, X.H., Yang, Q.C., 2011. Assessment of heavy metals contamination in urban topsoil from Changchun City, China. J. Geochem. Explor. 108 (1), 27–38.
Yang, Q.Q., Li, Z.Y., Lu, X.N., Duan, Q.N., Huang, L., Bi, J., 2018. A review of soil heavy metal pollution from industrial and agricultural regions in China: pollution and risk assessment. Sci. Total. Environ. 642 (15), 690–700.
Yu, H.Y., Li, T.J., Liu, Y., Ma, L.M., 2019. Spatial distribution of polycyclic aromatic hydrocarbon contamination in urban soil of China. Chemosphere 230, 498–509.
Zeng, S.Y., Ma, J., Yang, Y.J., Zhang, S.L., Liu, G.J., Chen, F., 2019. Spatial assessment of farmland soil pollution and its potential human health risks in China. Sci. Total. Environ. 687, 642–653.
Zhao, F.J., Ma, Y.B., Zhu, Y.G., Tang, Z., McGrath, S.P., 2015. Soil contamination in China: current status and mitigation strategies. Environ. Sci. Technol. 49 (2), 750–759.
Zhang, P.Y., Qin, C.Z., Hong, X., Kang, G.H., Qin, M.Z., Yang, D., 2018a. Risk assessment and source analysis of soil heavy metal pollution from lower reaches of Yellow River irrigation in China. Sci. Total. Environ. 633, 1136–1147.

Zhang, X., Zha, T., Guo, X., Meng, G., Zhou, J., 2018b. Spatial distribution of metal pollution of soils of Chinese provincial capital cities. Sci. Total. Environ. 643, 1502–1513.
Zhou, T., Li, L., Zhang, X., Zheng, J., Joseph, S., Pan, G.X., 2016. Changes in organic carbon and nitrogen in soil with metal pollution by Cd, Cu, Pb and Zn: a meta-analysis. Eur. J. Soil. Sci. 67 (2), 237–246.
Zhou, X.Y., Wang, X.R., 2019. Impact of industrial activities on heavy metal contamination in soils in three major urban agglomerations of China. J. Clean. Prod. 230 (1), 1–10.
Zheng, X.J., Chen, M., Wang, J.F., Liu, Y.C., 2020. Ecological risk assessment of heavy metals in the vicinity of Tungsten mining areas, southern Jiangxi Province. Soil. Sediment. Contam. 29 (6), 665–679.