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Heavy metal contamination of urban topsoils in a typical region of Loess Plateau, China

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Abstract
Purpose Heavy metals pollution of city soil has become a serious environmental issue. Attention has been given to the issue of soil contamination in big cities, but little research has been done in the Loess Plateau, which is the largest loess deposition area in the world. The aim of this study was to assess the contamination of topsoil.
Materials and methods Forty soil samples were collected from different districts and sieved through nylon sieves. The coarse particles (2 mm) were used to determine pH and electrical conductivity using a suspension of 1:5 soil to deionized water. The fine particles (150 μm) were used to determine soil organic matter and selected heavy metals. Metals were measured in digested solutions by a flame atomic absorption spectrophotometer.
Results and discussion The mean concentrations of heavy metals in urban soils in the study area are significantly lower than the mean concentrations across China. The integrated pollution index was determined to be 1.13, indicating moderate pollution. Weathering of parent material, the use of pesticide and fertilizer, discharge of waste from traffic, wastes from commodities and industry, and coal combustion are considered to be the main sources of heavy metal pollution in the study area.
Conclusions The results indicate that, at least in the study area, land use greatly influences the soil quality and heavy metal contents in urban topsoils. Soil backfill may change heavy metal contents to some extent. Deep digging and backfill can be effectively used for the remediation of heavy metal contaminated soil and sediments.

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1 Introduction

According to the UNFPA (2007) Report on Unleashing the Potential of Urban Growth, almost five billion people will be living in urban areas by 2030. There are positive and negative impacts associated with this unprecedented change, including enhanced development, greater sustainability, more extensive poverty, and accelerated environmental degradation. The state of the environment in urban areas is an important factor influencing both quality of life and public health (Khalil et al. 2013). Urban soils have peculiar characteristics with unpredictable layering, poor structure, wide spatial diversity of soil quality, and higher concentrations of heavy metals (Tiller 1992; Khalil et al. 2013).

Heavy metals in soils are either derived from natural or anthropogenic sources; the latter include municipal, mining, smelting, waste disposal, urban effluent, vehicle exhausts, tannery industries, and commercial and agricultural operations (Möller et al. 2005; Kachenko and Singh 2006; Montagne et al. 2007; Kasassi et al. 2008; Li et al. 2009; Khalil et al. 2013). These activities have become important processes in the geochemical cycling of these heavy metals in urban areas where various stationary and mobile sources release large quantities of heavy metals into the atmosphere and soil, in quantities that exceed the natural emission rates (Bilos et al. 2001; Chen et al. 2005). Agricultural practices, such as the application of organic fertilizers and pesticides, have been implicated as a major source of heavy metals in soils (Schulin et al. 2007), and atmospheric deposition of industrial, traffic, and household emissions also contribute significantly to heavy metal pollution in urban areas (Khalil et al. 2013; Schulin et al. 2007). Heavy metals entering soil can be transferred to the other ecosystem components, such as underground water or crops, and can affect human health through the water supply and food web (Micó et al. 2006).

Regional soil environmental quality is a rapidly growing area of research in the environmental sciences and the establishment of soil environmental standards is becoming an important practice (Zheng et al. 2008). Research is increasingly focused on heavy metal contamination in urban soils and its effect on the urban environment and ecology (Chen et al. 2005; Wang and Qin 2007; Taghipour et al. 2013; Hofer et al. 2013; Liu et al. 2013; Khalil et al. 2013). Analyses of heavy metal concentrations in urban soils will contribute to the establishment of soil quality standards and the management of the regional environment (Zheng et al. 2008), and will also provide scientific guidance for policy making aimed at reducing heavy metal inputs to soil; this will contribute to maintaining or improving soil functions (Micó et al. 2006).

The West Development Policy being implemented in China has brought forth important and positive developments, however it has also caused significant changes in land use and land cover, and deterioration of the environment across the west of the country. Investigations of heavy metal contamination of urban soils have been carried out in the south and northeast of China (Lu et al. 2003; Zhang and Ke 2004; Guo et al. 2005; Duzgoren-Aydin et al. 2006; Wang and Qin 2007; Li and Huang 2007; Lu et al. 2007a, b; Shi et al. 2008; Wu et al. 2008; Zheng et al. 2008; Li et al. 2009; Sun et al. 2010), while there is a lack of information on soils in northwestern China, particularly at the Loess Plateau (Fig. 1). The aims of this study were: 1 to characterize the spatial variability of soil properties involved in trace element chemistry (soil pH, electrical conductivity (EC), organic matter content, and total element concentrations) 2 and to assess the levels of certain toxic metals in the topsoil (Cu, Pb, Zn, Cr, Cd, and Ni); 3 to evaluate the extent of soil contamination and to compare these values with those in other cities.

2 Materials and methods

2.1 Study area

This study was conducted in the city of Yan'an (35°21′ to 37°31′N, 107°41′ to 110°31′E), located in the northern province of Shaanxi, China (Fig. 1). Yan'an covers an area of 37 037 km^2, comprises one district and 12 counties, and has a total population of 2,270,000 (according to the census of 2011). It is characterized by a plateau continental monsoon climate; the north is a semi-arid region and the south is a semi-humid region. The four seasons are quite distinct with cold and dry winters, and hot and rainy summers. Spring is characterized by frequent sand dust storms, frost, and gales. The mean annual temperature is about 9.2 °C and the area averages 170 frost-free days annually. Mean annual precipitation is about 550 mm with over 80% between June and August. Severe loss of soil and water has had devastating effects on the environment of this area. The natural forest protection project, the three north shelterbelt program, and the converting farmland to forest program have been implemented in this area in an effort to mitigate these problems.

2.2 Soil sampling and preparation

In August and September 2012 under dry and warm weather conditions, 40 soil samples were collected from seven districts and one control district of Yan'an (Fig. 1). Control samples

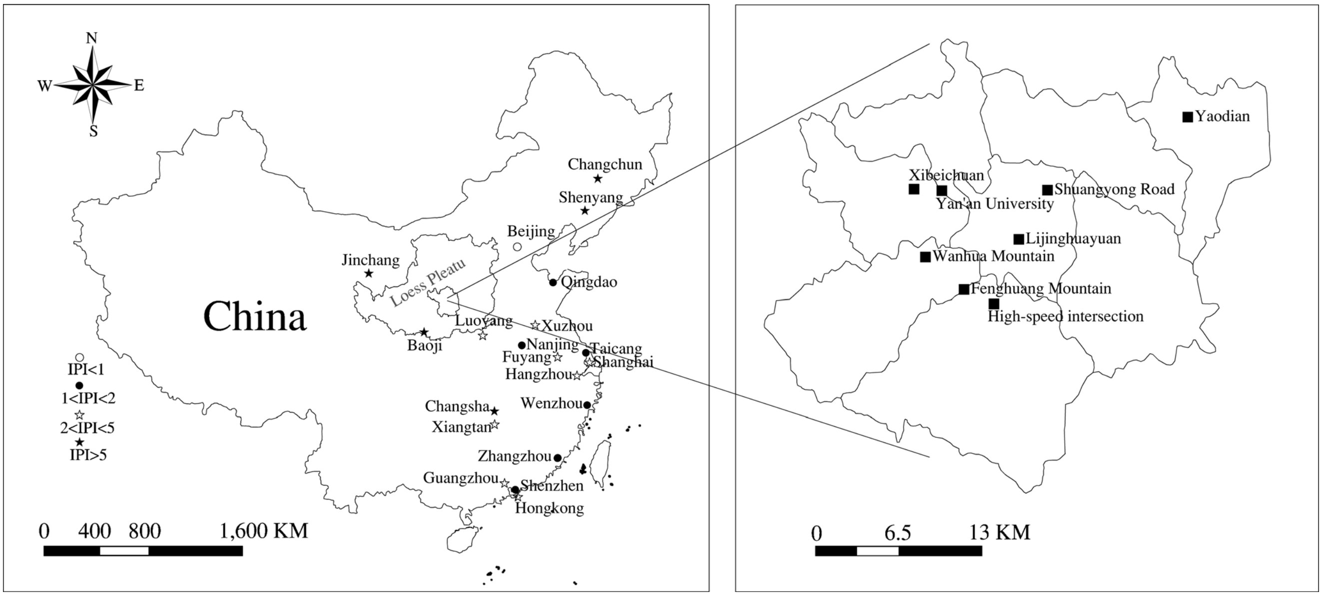

Fig. 1 Heavy metal contamination in urban soils of China (from Wei and Yang (2010)) and in the study area

were collected from Wanhua Mountain (WH) near the study area, where human activity is very limited. The districts were classified into seven different sections including industrial region, main road, farmland, public square, residential area, park, and education area (Table 1). All seven sections are characterized by dense populations and high potential risk of human exposure to pollutants. At each site, six sampling points (depth of 0–20 cm) at a distance of 20 cm apart were arranged in a quincunx method, and five sites were positioned in each section with more than 100 m between them (Šichorová et al. 2004). The six subsamples were taken and mixed thoroughly, and the quadripartite method was then used to obtain a bulk sample (about 0.5 kg). Collected samples were stored in plastic bags while being transferred to the laboratory.

After the removal of stones, large particles, and organic debris, the soil samples were air dried for 72 h, crushed, homogenized, and sieved through a 2-mm nylon sieve. The subsamples were then ground with an agate grinder and sieved through a 150-μm nylon sieve (100 mesh). All treated samples were stored in plastic bags and refrigerated at 4 °C before the final analysis (Mapanda et al. 2005; Sharma et al. 2007; Li et al. 2009).

2.3 Chemical analyses and wet digestion

The coarse particles (2 mm) were used to determine pH and EC, and the fine particles were used for analysis of soil organic matter and selected heavy metals. The soil pH was measured in a suspension of 1:5 soil to deionized water (Sharma et al. 2007) using an Artorius PB-10 Standard pH meter after 0.5 h agitation. EC was measured in a 1:5 soil to water suspension using a Model DDS-307 Conductometer (Shanghai Precision & Scientific Instrument Co. Ltd) after equilibration for 0.5 h and subsequent filtering (Slycken et al. 2013). The soil organic carbon (total organic carbon (TOC)) was determined by wet oxidation at 185 °C with a mixture of potassium dichromate and titration with ferrous ammonium sulfate; a conversion factor of 1.724 was used to convert organic carbon to organic matter (Burgos et al. 2008; Li et al. 2009). The concentrations of Cd, Cu, Pb, Ni, Cr, and Zn in digested solutions were determined by a flame atomic absorption spectrophotometer (WFX-120, Beijing Rayleigh Analytical Instrument Corp., Beijing, China) (Sun et al. 2010). Blanks and replicates were included in the sample batches for quality control (Duzgoren-Aydin et al. 2006).

Dried soil samples weighing 0.5 g (accurate to 0.0001 g) were placed in a 100-ml pyrex digestion tube; 15 ml of a 1:3 concentrated nitric-hydrochloric acid mixture (Micó et al. 2006) was added to the tube and gently mixed; then small, torticollis, short-stemmed funnels were placed in the mouths of the tubes, and allowed to stand overnight. The tubes were heated in a block-digester with an airing chamber, and the temperature was slowly increased to 155 °C to avoid spouting of the solution. The tubes were then kept at 155 °C for approximately 8 h, then 5 ml of concentrated perchloric acid was added and the solution was heated carefully and gradually until the soil was completed digested. When dense white fumes of perchloric acid appeared in the tubes and the sediment became white, the temperature was slowly upgraded (up to 450 °C) and the digestion continued. Before the residues dried, the tubes were moved out of the block-digester to cool for a few minutes, then 10 ml of 5% HNO_3 was added. The tubes were sealed and heated in a water bath at 60 °C for a specific period of time, allowed to settle, then diluted to a specific volume. Two blank tubes (containing only liquid) were included with each batch of tubes to estimate background metal contamination from the digestion procedure. The concentrations of heavy metals in digested solutions were determined by a flame atomic absorption spectrophotometer (AA-7000A, Beijing East & west Analytical Instrument Inc., Beijing, China).

2.4 Statistical treatment

All statistical analyses were performed using Microsoft Excel 2003 and SPSS 17.0 for Windows.

Table 1 The mean and standard deviation of pH, EC, TOC, and TOM in the soil samples from the study area

Location	Abbreviation	Functional section	pH	EC (μs/cm)	TOC/%	TOM/%
Yaodian District	YD	Industrial region	8.07±0.06	70.80±5.70	0.34±0.20	0.58±0.35
Shuangyong Road District	SY	Main road	8.11±0.04	72.10±5.97	0.19±0.13	0.33±0.22
High-speed Intersection District	HS	Farmland	7.98±0.09	73.63±7.36	0.61±0.15	1.06±0.26
Xibeichuan District	XB	Public square	8.13±0.27	62.40±3.73	0.23±0.02	0.39±0.04
Lijinghuayuan District	LJ	Residential area	8.06±0.06	57.10±3.27	0.33±0.07	0.56±0.12
Fenghuang Mountain District	FH	Park	7.89±0.04	60.84±2.74	0.41±0.16	0.71±0.27
Yan'an University District	YU	Education area	7.96±0.05	55.29±2.09	0.39±0.20	0.67±0.34
Wanhua Mountain District	WH	Suburb (CK)	8.19±0.08	51.12±3.39	0.48±0.24	0.82±0.42
Mean±SD			8.05±0.10	62.91±8.43	0.37±0.13	0.64±0.23
Background values in Loess Plateau (CEPA 1990)			8.50		0.49	0.85

3 Results and discussion

3.1 Soil characteristics

The mean pH, EC, TOC, and total organic material (TOM) values of soils in the study area are given in Table 1. As show in Table 1, the pH of the soil samples ranged from 7.89 to 8.19 with a mean values 8.05 (SD±0.10), which are lower than the background values of Loess Plateau (8.50). There were some differences in pH between the various land use types. This indicates that the soil of the study area was alkaline and had different degrees of soil acidification. Chemical and physical properties of both the soil and the heavy metals determine their potential mobility in soil (Šichorová et al. 2004). Different soil compositions, such as grain-size distribution and mineralogy, affect the natural heavy metal concentrations (Wang and Qin 2007), while the soil pH can influence the mobilization of heavy metals in soil (Liu et al. 2013). It has been confirmed that in alkaline soil (pH>8.0), the mobilization of heavy metals will be limited and plant uptake effect could be decreased (Sharma et al. 2007). However, soil acidification can destroy soil structure and increase the water solubility of heavy metals, which would make heavy metals available for plant uptake, and increase the pollution risk (Harter 1983; Li et al. 2009; Taghipour et al. 2013). Therefore, the causes of soil acidification and methods to reduce it will be important areas of future research in Yan'an.

The soil EC can be used to characterize soil properties, pollution, and the degree of soil salinization (Yuan and Zhang 2010). The minimum, maximum, and mean EC values of soil samples were 51.12, 73.63, and 62.91 (SD±8.43) μs/cm, respectively. Onweremadu (2008) found that in the university farm of Imo State, Nigeria, EC was positively correlated with Fe, Mn, and B, and was not significantly correlated with Cd, Pb, Cu, Zn, and Ni. The soil EC may dependent on a number of factors, such as soil particle and ion types, different land use and use times, pollution, and environmental factors (Yuan and Zhang 2010).

In this study, a conversion factor of 1.724 was used to convert organic carbon to organic matter. The results indicated a minimum, maximum, and mean, respectively, of 0.19, 0.61, and 0.37% (SD±0.13) for TOC and 0.33, 1.06, and 0.64% (SD±0.23) for TOM; the control forest soil had TOC and TOM values of 0.48 and 0.82%. Maximum value of organic carbon was observed in the high-speed intersection district, and the minimum value was observed in the Shuangyong Road district; there were no great differences of the value among the other districts. Soils surrounding the high-speed intersection area are used for agriculture, so the use of agricultural fertilizer, biological fertilizer, and straw returning could significantly improve soil structure and increase soil nutrient levels. Organic matter plays an important role in physical, biological, and chemical properties of soil, and it can affect soil structure stability, porosity, nutrient availability, and cation exchange capacity (Bellanger et al. 2004). Therefore, to improve the quality of urban greening, more attention should be given to the use of organic fertilizer and microbial fertilizer, which can improve soil properties and promote soil microbial breeding.

3.2 Heavy metals concentrations in the soils

The mean and standard deviation of Cu, Zn, Pb, Ni, Cr, and Cd are presented in Table 2. Additionally, to facilitate comparison of the values, the results of published reports from other areas in China are shown in Table 3. The background values of the metals in these studies are derived from the Chinese Environmental Protection Administration (CEPA 1990). As shown in Table 2, there was a narrow range in the concentrations of heavy metals. The concentrations of Cu at the individual sites were in the following order: HS>YD>FH>SY>WH>XB>YU>LJ, and the mean concentration of Cu was 23.65 (±2.80) mg/kg. The mean Cu value in Yan'an was lower than that of other cities in China but higher than the world mean value (Table 3). Cu, Pb, Cd, and Zn are considered to be related to specific human activities; for example, Cu and Zn are associated with specific agronomic practices, and Pb is derived from car exhausts. Cr and Ni, however, are often derived from parent rocks (Facchinelli et al. 2001; Micó et al. 2006). In addition, the intensive application of metal-containing agrochemicals and organic composts derived from a variety of wastes and sludge during long-term vegetable production also significantly contribute to soil heavy metal pollution (Li et al. 2009). The influence of traffic was characterized by Zn and to a lesser extent by Cu and Pb (Miguel et al. 1997). Copper compounds are used in a wide variety of applications, such as pesticide, fungicide, batteries, electroplating solutions, and as catalysts for dye. In the long-term or in the past use of pesticide, chemical fertilizers, and livestock manures have led to an increase in Cu concentrations in HS, FH, and SY district soils, especially in agricultural soils (HS). YD contains newly emerging industrial areas; the high Cu concentrations in YD district soils may be attributed to frequent human activities, industrial wastes, and effluents. The distribution of heavy metals is more complex in urban soils, in which the heavy metal content could be reduced through the application of foreign soil backfill (Wu and Pan 2005). There was significant moving of soils from some anthropogenic activity, which could be owed to higher concentrations of Cu in WH than XB, YU, and LJ.

The minimum, maximum, and mean Zn values in soils from the study area were 62.01, 83.77, and 71.20 (SD±8.33) mg/kg, respectively. Mean concentrations at individual sites were in the following order: FH>YD>HS>SY>XB>YU>WH>LJ. The mean Zn concentration in topsoils of Yan'an was higher than both the global mean concentration

Table 2 The mean and standard deviation of heavy metal concentrations (Cu, Zn, Pb, Ni, Cr, and Cd) in the soil samples from the study area (milligrams per kilogram in dry weight)

Location	Cu	Zn	Pb	Ni	Cr	Cd
YD	27.31±2.78	82.15±11.2	23.97±0.86	38.01±8.92	73.88±4.03	0.11±0.04
SY	22.97±1.63	67.53±9.00	21.75±2.04	42.88±6.25	73.89±5.35	0.14±0.03
HS	27.44±2.33	68.83±9.28	23.76±0.59	30.77±7.73	72.99±6.32	0.10±0.04
XB	22.10±6.65	67.21±3.26	20.35±0.35	40.39±4.14	59.82±5.88	0.09±0.04
LJ	20.76±1.22	62.01±10.67	15.84±0.96	37.79±17.96	52.01±8.39	0.09±0.01
FH	24.17±3.16	83.77±0.80	20.49±0.57	32.13±2.15	70.89±7.91	0.10±0.01
YU	20.83±2.15	66.89±15.15	15.13±2.86	40.95±5.71	60.04±6.74	0.10±0.02
Mean±SD	23.65±2.80	71.20±8.33	20.18±3.51	37.56±4.54	66.22±8.81	0.10±0.02
WH	22.17±1.43	65.59±5.61	18.51±1.25	29.82±2.5	61.16±3.01	0.09±0.09

(60 mg/kg) and the mean concentration in Beijing (65.6 mg/kg), but was significantly lower than that of other cities in China (Table 3). Anthropogenic sources of Zn in soils are fertilizers, sewage sludge, and atmospheric industrial dust (Taghipour et al. 2013). Municipal wastes such as decorative materials, pipe material, and batteries which contain Zn and Pb are considered to be the main sources of heavy metal pollution in urban centers (Wu et al. 2003). Fertilizers, pesticide, tourism activities, and waste may increase Zn in soils of FH, and sewage sludge and corrosion of metal pipelines underground (Wu and Pan 2005) might contribute to Zn contamination in the soils of YD.

As shown in Table 2, the mean concentration of Pb in the study area was 20.18 (±3.51), and mean concentrations at individual sites were in the following order: YD>HS>SY>FH>XB>WH>LJ>YU. As presented in Table 3, mean Pb concentrations in soils from Yan'an were lower than both mean concentrations in other cities in China and the global average. Considerable traffic may cause atmospheric deposition of Pb, leading to increases in the Pb levels of urban soil (Turer et al. 2001); wastes from commodities also contributes to Pb pollution in soils (Chen et al. 1997). Wu et al. (2003) found that Pb concentrations in the urban soils of Nanjing reached up to 700 mg/kg in the surface and subsurface soils near the garage. Emissions from the city from vehicular traffic and coal burning for heating are considered to be responsible for the increased Pb concentrations observed in the urban soils. In addition, larger values observed in YD and HS may be the result of car washing parks nearby, and soil transportation and backfill may be the reason for the lower values observed in LJ and YU.

The mean concentrations of Ni in the study area was 37.56 (±4.54) mg/kg and mean Ni concentrations at individual sites were in the following order: SY>YU>XB>YD>LJ>FH>HS>WH. The mean concentration of Ni from the non-control sites in the study area was higher than that at the control site. As indicated in Table 3, the mean Ni concentration in the topsoil of Yan'an as higher than the global average value (20 mg/kg) and the average values of other Chinese cities (Beijing, 27.8 mg/kg; Guangzhou, 25.57 mg/kg; Hangzhou, 24.1 mg/kg; and Shanghai, 31.14 mg/kg), except for two heavy industrial cities (Changchun, 73.5 mg/kg; and Baoji, 72.1 mg/kg). As indicated in Tables 2 and 3, the mean Ni concentration in WH (29.82 mg/kg) was also significantly higher than that of many other cities in China (e.g., Beijing, Guangzhou, Hangzhou) and higher than the global average.

Table 3 Average concentration of heavy metals (milligrams per kilogram) in urban soils from different cities in the world

Places	Cu	Zn	Pb	Ni	Cr	Cd
Yan'an (present study)	23.65	71.20	20.18	37.56	66.22	0.10
Beijing (Zheng et al. 2008)	23.7	65.6	28.6	27.8	35.6	0.15
Nanjing (Lu et al. 2003)	66.1	162.6	107.3	–	84.7	–
Guangzhou (Lu et al. 2007a)	62.57	169.24	108.55	25.57	–	0.50
Changchun (Guo et al. 2005)	41.85	109.69	54.81	73.5	–	2.92
Baoji (Li and Huang 2007)	112.14	1,964.12	25,380.55	72.1	102.4	–
Shanghai (Shi et al. 2008)	59.25	301.4	70.69	31.14	107.9	0.52
Xuzhou (Sun et al. 2010)	38.2	144.1	43.3	–	–	0.54
Hangzhou (Zhang and Ke 2004)	41.0	148	75.7	24.1	47.5	1.30
Luoyang (Lu et al. 2007b)	85.40	215.75	65.92	–	71.42	1.71
China (mean) (Wei and Yang 2010)	115.07	266.4	1,350.51	99.48	78.43	1.58
World (mean) (Athar and Vohora 2005)	23	60	30	20	60	0.5

The comparison between different regions of the world is difficult because of substantial differences in the composition of the parent materials; differences in sampling and digestion methods may also affect the analysis results (Chen et al. 2004; Zheng et al. 2008). Moreover, there are greatly changes in the nickel content of the soil as a result of the great influence of parent rock; thus it can be assumed that the observed concentration is determined by the sources of Ni, including both natural (parent rock) and anthropogenic (waste from traffic and commodity, combustion of coal used for heating, and discarded Ni batteries).

The mean concentration of Cr in surface soil was 66.22 (±8.81) mg/kg, and the mean concentrations at individual sites were in the following order: SY>YD>HS>FH>WH>YU>XB>LJ. As shown in Table 3, the mean Cr concentrations in the study area were lower than those of some Chinese cities (Nanjing, 84.7 mg/kg; Luoyang, 71.42 mg/kg; Shanghai, 107.9 mg/kg; Baoji, 102.4 mg/kg) and higher than those of others (Beijing, 35.6 mg/kg; Hangzhou, 47.5 mg/kg and global mean value, 60 mg/kg). Besides weathering of parent rock, wastewater from industry is likely a major source of Cr entering into the soil; however research is needed to obtain more accurate information about the sources of Cr in the soil in the study area.

The concentration of Cd in the soil in the study area is presented in Table 2, and a comparison between the study area and other cities in China is shown in Table 3. The mean concentrations of Cd was determined to be 0.10 (±0.02) mg/kg, and the mean concentrations of Cd in soils in individual sites were in the following order: SY>YD>HS=FH=YU>XB=LJ=WH sequence. As shown in Table 3, the mean concentration of Cd in soil from Yan'an was lower than both the mean concentrations of other cities of China and the global mean soil Cd concentration. Burning of fossil fuels (coal and petroleum), incineration of municipal solid waste, wearing of vehicle tires, and consumption of vehicle lubricating oil are the main sources of Cd in soils.

In China, the concentration ranges of Cr, Cu, Pb, Zn, Ni, and Cd in urban soils were observed to be 23.1–194.7, 23.3–1226.3, 28.6–25380.55, 65.6–1964.12, 27.8–910.3, and 0.15–8.59 mg/kg, respectively; the concentrations of Cd, Cu, Pb, and Zn exceed the background levels in all cities (Wei and Yang 2010). By contrast, the concentrations of heavy metals in urban soils of Yan'an are significantly lower than the mean concentrations across China (Table 3). The concentrations of Pb and Cd in Yan'an are lower than the minimum values (28.6 and 0.15, respectively) observed in cities with large populations, which have more mining, industry, heavy traffic, and in which there is rapid of development and expansion (Wei and Yang 2010). To some degree, mean concentrations of heavy metals in urban soils of China are not comparable to those of small and medium sized cities. It is therefore necessary to assess the metal contamination in the topsoil of typical medium-sized cities; we suggest that city size be carefully considered during the calculation of national average values.

3.3 Assessment of pollution risk

Pollution index (PI) and integrated pollution index (IPI) are commonly used to assess environmental quality (Lu et al. 2009), and have been proposed to assess the degree of soil contamination (Chen et al. 2005; Sun et al. 2010; Taghipour et al. 2013). The PI is defined as the ratio of the heavy metal concentration to the geometric means of background concentration (Chen et al. 2005). PI was calculated as:

$$\mathrm{PI} = C_i/S_i$$

Where PI is the evaluation score corresponding to each sample, C_i is the measured concentration of the examined metals in the soils, and S_i is the geochemical background concentration of the metals (in this study, the geometric mean concentrations of soils in the control district was used as the natural background concentration). The PI value of each metal was calculated and classified as either low contamination ($\mathrm{PI} \leq 1.0$), moderate contamination ($1.0 < \mathrm{PI} \leq 3.0$), or high contamination ($\mathrm{PI} > 3.0$) (Chen et al. 2005; Sun et al. 2010; Taghipour et al. 2013). IPI was defined as the mean values for all PI values of all of the considered metals (Taghipour et al. 2013), then classified as either low ($\mathrm{IPI} \leq 1.0$), moderate ($1.0 < \mathrm{IPI} \leq 2.0$), high ($2.0 < \mathrm{IPI} \leq 5.0$), or extremely high contamination ($\mathrm{IPI} > 5$) (Chen et al. 2005; Lu et al. 2009).

The PIs and IPIs, calculated according to the control values of heavy metals in soils of Yan'an, varied little between the metals and the soil samples (Table 4). The Cu and Cr values of PI varied from 0.94 to 1.24 and 0.85 to 1.21, respectively. XB, LJ, and YU had low contamination, and YD, SY, HS and FH had moderate contamination. The mean PI value of Cu was 1.07 and Cr was 1.08, indicating moderate Cu and Cr pollution of soils in Yan'an. For Zn, there was moderate pollution,

Table 4 Pollution index (PI) and integrated pollution index (IPI) of heavy metals in soil from Yan'an

Location	PI						IPI
	Cu	Zn	Pb	Ni	Cr	Cd	
YD	1.23	1.25	1.29	1.27	1.21	1.22	1.25
SY	1.04	1.03	1.18	1.44	1.21	1.56	1.24
HS	1.24	1.05	1.28	1.03	1.19	1.11	1.15
XB	1.00	1.02	1.10	1.36	0.98	1.00	1.08
LJ	0.94	0.95	0.86	1.27	0.85	1.00	0.98
FH	1.09	1.28	1.11	1.08	1.16	1.11	1.14
YU	0.94	1.02	0.82	1.37	0.98	1.11	1.04
Mean	1.07	1.09	1.09	1.26	1.08	1.16	1.13

with a mean PI value of 1.09, in spite of low contamination (PI=0.95) in LJ. The PI values of Pb varied from 0.82 to 1.29 with a mean value of 1.09, indicating moderate pollution. YU and LJ, in which there is very low vehicular traffic, had low contamination, while other regions had moderate pollution. The PI values for Ni varied from 1.03 to 1.44 with a mean value of 1.26, indicating moderate pollution. This result varied from other published reports; for example, Zheng et al. (2008) found there was no obvious pollution of Ni in park soil samples from Beijing, Taghipour et al. (2013) observed that the pollution index of Ni values indicated low pollution in the suburban area on the Tabriz, and in a review of heavy metal contamination in urban soils by Wei and Yang (2010), Ni appears to be the least contaminated elements in all cities in China. However, more studies are needed to explore the exact reason of low Ni pollution in the future. Finally, moderate pollution was observed for Cd throughout most of the study area with a mean PI value of 1.16. LJ and XB had low pollution (PI=1.00), while the other sites had moderate contamination.

The IPI values in individual districts were in the following order: YD>SY>HS>FH>XB>YU>LJ, and the mean IPI was 1.13, indicating moderate pollution. Land use greatly influences the physical, chemical, and biological proprieties of soils, resulting in a wide spatial diversity of soil quality (Wang and Gong 1998; Khalil et al. 2013). Urban soils are transformed significantly to depths greater than 50 cm by human activities such as mixture, importation, and exportation (Norra and Stüben 2003). The IPI value of LJ was less than 1.0 (low contamination) and XB and YU were close to 1.0 (1.04 and 1.08, respectively), which may be influenced by the method and depth of soil backfill. The results above indicate that the topsoils of Yan'an may be significantly influenced by vehicular emissions, industrial waste, waste from auto repair shops and auto wash shops, waste incineration, urban effluent, sewage sludge, burning of fossil fuels (coal, petroleum), domestic heating, discarded batteries, incinerating of municipal solid waste, wearing of vehicle tires and parts, and the application of pesticides, and fertilizers.

4 Conclusions

The soil in the Yan'an area was alkaline, while most of the regions have varying degrees of soil acidification. The EC, TOC, and TOM values were very similar in comparison with findings from other studies in the Loess Plateau. There was a narrow range in the concentrations of the heavy metals (Cu, Zn, Pb, Ni, Cr, and Cd) among the seven regions in the study area. The average concentrations of the heavy metals were greater than those in the control soil (WH). By comparison, the average concentrations of the heavy metals were lower than the mean values of China and higher than the global average values, with the exception of Pb and Cd. The PI values in the area indicate moderate levels of heavy metal pollution, and the IPIs indicate moderate contamination in the different regions except LJ, which had low contamination.

These findings can be applied to save costs and improve the efficiency of remediation strategies. Soil backfill may change the spatial distribution of some soil chemical properties and heavy metal contents to some extent; additional research is required to confirm this. If this is the case, deep digging and backfill can be effectively used for the remediation of heavy metal contaminated soil and sediments.

With the rapid developments of new cities, local governments should consider the following: (1) increasing investments in environment pollution monitoring and management, (2) strictly controlling and reducing the sources of pollutants and improving facilities for waste classified recovery and disposal techniques, and (3) providing resources to educate the public to increase awareness about environmental protection.

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