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ASSESSMENT OF SPATIAL DISTRIBUTION AND POLLUTION WITH HEAVY METALS IN ROADSIDE SOILS ALONG XI'AN-BAOJI HIGHWAY IN NORTHWEST CHINA

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Abstract

Xi'an-Baoji Highway is one of the oldest and most important highways in northwest China. In this study, the concentrations (0-20 cm) of Pb, Zn, Cu and Cr at 5-1000 m distances in the roadside soils along Xi'an-Baoji Highway were experimentally determined to analyze their spatial distribution and evaluate their contamination levels. The spatial distribution ($mg \cdot kg^{-1}$) of Pb, Zn, Cu and Cr at 5-1000 m distances from the both roadsides (North/South) is, respectively, 23.81-38.45/24.54-36.90, 72.79-121.98/ 76.91-130.60, 24.58-41.60/23.82- 37.31, and 63.83-85.26/64.30-85.94 at Chencang District section, while it is 23.41-45.76/20.95- 42.50, 74.62-135.54/75.15-127.25, 23.94-35.71/22.04-36.91, and 63.82-85.84/64.33-88.53, respectively, at Caijiapo section. Regarding the Pb, Zn, Cu and Cr at Mei County section, it is 25.47-40.89/23.56-32.72, 74.15-131.24/72.67-118.15, 24.00-37.61/25.68-44.99, and 64.00- 89.22/61.90-85.58, respectively. Integrated evaluation via the contamination factor (C_f), contamination degree (C_d) and pollution level index (*PLI*) showed the moderate pollution level. While geoaccumulation index (I_{geo}) revealed that all evaluated metals were almost unpolluted ($0 < I_{geo}$), only part heavy metal of individual sampled sites were unpolluted to moderately polluted ($0 \leq I_{geo} < 1$). The correlation analysis shown these metals are significantly associated with each other. Interelement correlation is as follows: Pb–Cr > Pd-Cu > Zn-Cu > Pd–Zn > Zn–Cr > Cu–Cr. Moreover, the hierarchical cluster analysis suggested that Pb and Zn might be from the identical anthropogenic and natural source while Zn and Cr might have the same original source in the roadside soils along Xi'an-Baoji Highway in Northwest China.

Key words: geoaccumulation index, heavy metals, highway, roadside

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1. Introduction

Heavy metal contamination is serious in water bodies and soils in China and has become an important factor to restrict further development of industry and agriculture (Wei and Yang, 2010; Zhang et al., 2008). More significantly, it is likely to become more widespread in the relative near future (He et al., 2013). According to numerous studies, heavy metal pollution originates from many different sources. These include: 1) traffic emission (vehicle exhaust particles, tire wear particles, weathered pavement surface particles, brake lining wear particles and lubricating oil consumption etc.) (Ahmed and Ishiga, 2006; Duong and Lee, 2011; Johansson and Westerlund, 2001; Plesničar and Zupančič, 2005); 2) industrial emission (power plants, coal combustion, metallurgical industry, auto repair shop, chemical plants etc.) (Yaylali-Abanuz, 2011; Zhou et al., 2008; Zhang et al., 2012); 3) weathering of building and pavement surface (Kong et al., 2011); 4) atmospheric deposited etc. (Sezgin et al., 2004; Soriano et al., 2012; Wei and Yang, 2010). Among them, vehicle pollution is one of the major sources of heavy metal contamination, which leads to the pollution of roadside soils, plants and even

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residents along the roadsides (Chen et al., 2010; Werkenthin et al., 2014). Research has showed that the major heavy metals from the traffic pollution are Pb, Cd, Cr, Zn and Cu since they are included in petrol, engines, tires, lubricant oil and galvanized parts of the vehicles (Okunola et al., 2011; Saeedi et al., 2009; Yan et al., 2012). Accordingly, the most frequently reported heavy metals with regards to potential hazards and the occurrence in contaminated soils are Cd, Cr, Pb, Zn and Cu. As these metals are not biodegraded and are largely immobile in roadside soil system, they tend to accumulate and persist in urban soils for a long time (Akoto et al., 2008). They are regarded as serious pollutants because of their environmental persistence, toxicity and ability to be incorporated into food chains, causing complex pollution (Kishe and Machiwa, 2003). It is a confirmed fact that 75-80% of heavy metals can get into human body with vegetable diet when plants take them from the soil (Grigalavičienė et al., 2005).

Highways play an important role in the transportation of productions and lives with the development of the economy. However, the roadside soil and residential area have been polluted seriously due to the rapid increasing flow of motor vehicles along highways (Qian et al., 2011). In recent years, considerable attention has been paid to the vehicular exhaust and road dust, the pollution of the roadside soils by heavy metals from automobile source is a serious environmental issue (Aslam et al., 2011; Lu et al., 2012; Ma et al., 2009; Qian et al., 2011; Xi et al., 2010). Nowadays, in line with the fact in China that the increased road traffic and associated problems of automobile exhaust emissions become more evident, it is highly desirable and important to have more studies about the heavy metal accumulation on roadside soils and their potential ecological risk assessment. Gu et al. (2012a) investigated the health risk of heavy metals (Cd, Cu, Pb, Zn, Ni and Cr) in the roadside soils in two sampling transects of Wanliu and Xiaowangzhuang on the Zhengzhou-Shangqiu section along the Lianyungang-Horgas highway. Their results showed that the heavy metal concentrations and the health risks increased with the increase in operation time, the highest concentration and the highest health risk occurred between 15-50 m from the highway roadbed. Both the sampling sites were possibly carcinogenic risk. Li et al. (2008) reported that the highway traffic would cause the accumulation and distribution of the heavy metals (Ni, Pb, Cr, Zn, Cu and Cd) in roadside soils of Zhengzhou-Shangqiu section of the Lianyungang-Horgas highway. The results showed that the heavy metal has caused serious accumulation along the highway on both sides.

Unfortunately, few studies were reported about the heavy metal behaviour in the soil of Shaanxi section of Lianyungang-Horgas highway, i.e. Xi’an-Baoji Highway, which is a key section of Lianyungang-Horgas Highway in China. Therefore, the present study was undertaken to study heavy metal (Pb, Zn, Cu and Cr) contamination in roadside soils along Xi’an-Baoji Highway. The relationship between heavy metals pollution and distance off the highway was investigated and discussed in great detail. In addition, assessment was made to evaluate the heavy metal contamination levels.

2. Materials and methods

2.1. Study area

Xi’an-Baoji Highway is an important part of Lianyungang-Horgas highway. It was opened to traffic in December 25, 1995 with 152 km in length, passing through three major cities of Xi'an, Xianyang and Baoji of Shaanxi province. Many important agricultural fields are distributed in the vicinity of the highway. It has been reported that the traffic capacity was 17669 cars in 2007 while it was increased to 28755 cars in 2008 (SINA NEW, 2008). The transportation discharge increases continuously, so the contamination endangers to aggravate increasingly. Baoji section is one of the sections of Xi’an-Baoji Highway. The heavy metals in soils along the highway were the main focus of this study. Soil samples were collected by Multisampler in April 2012 with the specific locations shown in Fig. 1 and the corresponding coordinates shown in Table 1. The coordinates of the sample locations were recorded with a GPS. The area around the sampling section must be open and flat, and no industrial pollution sources within 3 km radius.

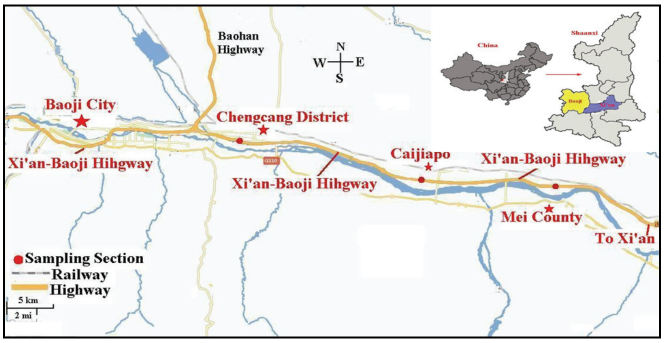

Fig. 1. Location of the sampling transects

Table 1. Sampling section and the corresponding coordinates

Sample ID	*N*	*E*
Chencang District	34.344°	107.370°
Caijiapo	34.309°	107.563°
Mei County	34.301°	107.737°

2.2. Sampling strategy and sample processing method

The soil samples were collected from 3 sections in roadside soils along Xi’an-Baoji Highway. The samples of each section were collected from the upper 0-20 cm of soil, at 5 m, 10 m, 20 m, 50 m, 100 m, 200 m, 300 m and 1000 m distances from the both roadsides. The site at 1000 m from the railroad was used as the control site. To obtain representative and uniform sample, 3 samples were collected by Multisample from each sampling site. After sampling, the samples were stored in clean polyethylene bottles and transferred to the laboratory.

All samples were air-dried indoor at room temperature. The three samples of the same sites were mixed as one analysis sample. The impurities such as stones and tree leaves from the soil samples were removed and the samples were ground with an agate mortar, allowing passed through a 0.15 mm nylon screen sieve for analysis.

2.3. Sample digestion and analysis method

The heavy metals (Pb, Zn, Cu and Cr) content of the soil samples were extracted using the wet-acid digestion method. The digestion procedure was as following: A small portion of each pretreatment sample (0.5 g) was transferred into a tetrafluoroethylene beaker (100mL) for digestion with 10mL HNO_3 (GR), 10mL HF (GR), and 10 mL $HClO_4$ (GR). The solution was heated for 5-10 min at 200-280^{0}C. The plastics crucible was then removed from the heater and allowed for cooling. 5.0 mL HNO_3 (GR), 5.0 mL HF (GR), and 5.0 mL $HClO_4$ (GR) were added to the beaker again, and the solution was heated at 200-280^{0}C until the residual volume was 2-3 mL.

The plastics crucible was then removed from the heater and allowed for cooling again. The solution was then transferred from the plastics crucible to a volumetric flask (50 mL), and the wall of the plastics was washed 2-3 times with dilute nitric acid (GR, 10%). Thereafter, the solution was made up to the mark of the volumetric flask (50 mL) with dilute nitric acid (GR, 10%) and used for laboratory analysis. The concentrations of Pb, Zn, Cu and Cr in the volumetric flask (50 mL) were determined using an Atomic Absorption Spectrophotometer (AA-6800, SHIMADZU, Japan). All heavy metals were analyzed in the flame mode. Data were subjected to analysis by SPSS software package version 19.0, Microsoft Excel 2003, Origin 7.5 and statistica 5.5 to determine the differences in the concentration of each metal between different sections.

2.4. Quality control

All the reagents were of guarantee reagent (GR) grade. Double-distilled water was used throughout the study. Glassware was properly cleaned. The accuracy of instrumental methods and analytical procedures were validated using the certified reference materials obtained from the National Research Center for CRMs (Beijing, China) according to the trace elements in soil (GBW07409). Accuracy of the analytical method was given as percentage recovery for each of the elements: Pb, 99%; Zn, 99%; Cu, 98%; Cr, 101%. Furthermore, each analytical batch contained at least a blank. Standard solutions were analyzed after every 10 sample solutions as a check on instrument performance. Heavy metals concentration in soil are given as mg·kg^{-1} dry weight.

3. Results and discussion

3.1. Content of heavy metals and distribution

The regional variations of heavy metals (Pb, Zn, Cu and Cr) concentration in roadside soils of different sections along Xi'an-Baoji Highway are shown in Table 2. The observed concentration (mg·kg^{-1}) ranges of the metals at 5-1000 m distances from the both roadsides (North/South) were 23.81-38.45/24.54-36.90, 72.79-121.98/76.91-130.60, 24.58-41.60/23.82-37.31, and 63.83-85.26/64.30-85.94 for Pb, Zn, Cu, Cr, respectively, at Chencang District section; 23.41- 45.76/20.95-42.50, 74.62-135.54/75.15-127.25, 23.94-35.71/22.04-36.91, and 63.82 -85.84/64.33-88.53, respectively, at Caijiapo section; 25.47-40.89/23.56-32.72, 74.15-131.24/72.67-118.15, 24.00-37.61/25.68-44.99, and 64.00-89.22/61.90-85.58, respectively, at Mei County section.

The horizontal distribution of the heavy metal concentrations are shown in Fig. 2. It shows that the concentrations of total Pb, Zn, Cu and Cr varied significantly with the different distance along with the highway. The values of total Pb, Zn, Cu and Cr showed a similar trend, which increased at first and then decreased with the distance increases from the highway edge. Several studies on the pollution in soils along highways showed the similar trends (Gu et al., 2012b; Lagerwerff and Specht, 1970; Li et al., 2007; Motto et al., 1970; Turer and Maynard, 2003).

The highest concentrations of heavy metals in roadside soils appeared at 30-50 m for Pb and Cu, at 80-90 m for Cr and at 120-138 m for Zn. This is related to soil type, wind direction, road exposure, road distance, and particle size of the pollutants. There is usually dense vegetation that is close to the road, which could restrain the low-level pollutants. So, the accumulations of heavy metals close to the road were lower. Airborne particulate transport of metals can take place largely unhindered in the air, which were influenced by factors like wind would spread to a certain distance and then deposit and accumulate in soil. Airflow is the predominant transport path of metal distribution. Airborne pollutant transport depends on many factors e.g. geomorphological position of the road, wind direction, wind velocity, vegetation cover, and atomic masses of the metals (Werkenthin et al., 2014).

3.2. Contamination analysis of heavy metals

The level of contamination expressed by the contamination factor (C_f) (Fan et al., 2010; Fan, 2011; Nasr et al., 2006) can be calculated as follows (Eq. 1):

$$C_f = C_i / B_n \qquad (1)$$

where: C_i is the measured concentration of the examined metal in the soil, mg·kg^{-1}; B_n is the geochemical background concentration of the same metal, mg·kg^{-1}, which was background values of Shaanxi (Pb=21.4, Zn=69.4, Cu=21.4, and Cr=62.5) (CSEMC, 1990). The contamination factor can be classified into four groups: $C_f < 1$ refers to the low contamination factor; $1 \le C_f < 3$ represents the moderate contamination factor; $3 \le C_f < 6$ implies the considerable contamination factor; and $C_f \ge 6$ refers to the very high contamination factor. The values of C_f are shown in Table 3.

Table 2. Heavy metal concentrations in roadside soils of Xi'an-Baoji Highway (mg·kg^{-1} dry weight)

Sampling Section	***Element***	***Position***	***Min***	***Max***	***Mean***	***SD***	***CV%***
Chencang District	Pb	North	23.81	38.45	29.04	4.70	6.18
		South	24.54	36.90	30.05	4.59	6.55
	Zn	North	72.79	121.98	91.44	16.83	5.43
		South	76.91	130.60	91.83	17.97	5.11
	Cu	North	24.58	41.60	32.79	6.00	5.46
		South	23.82	37.31	29.90	4.70	6.37
	Cr	North	63.83	85.26	71.84	7.10	10.12
		South	64.30	85.94	71.88	7.94	9.06
Caijiapo	Pb	North	23.41	45.76	29.87	6.88	4.34
		South	20.95	42.50	30.26	6.28	4.82
	Zn	North	74.62	135.54	90.90	20.05	4.53
		South	75.15	127.25	88.63	16.99	5.22
	Cu	North	23.94	35.71	31.22	3.90	8.00
		South	22.04	36.91	30.20	4.44	6.80
	Cr	North	63.82	85.84	71.91	7.58	9.49
		South	64.33	88.53	73.38	8.87	8.27
Mei County	Pb	North	25.47	40.89	31.70	5.20	6.10
		South	23.56	37.00	29.27	4.27	6.86
	Zn	North	74.15	131.24	93.43	21.36	4.37
		South	72.67	124.05	92.53	19.82	4.67
	Cu	North	24.00	37.61	30.65	4.96	6.18
		South	25.68	44.99	31.30	6.09	5.14
	Cr	North	64.00	89.22	73.42	8.28	8.87
		South	61.90	85.58	74.41	7.50	9.92

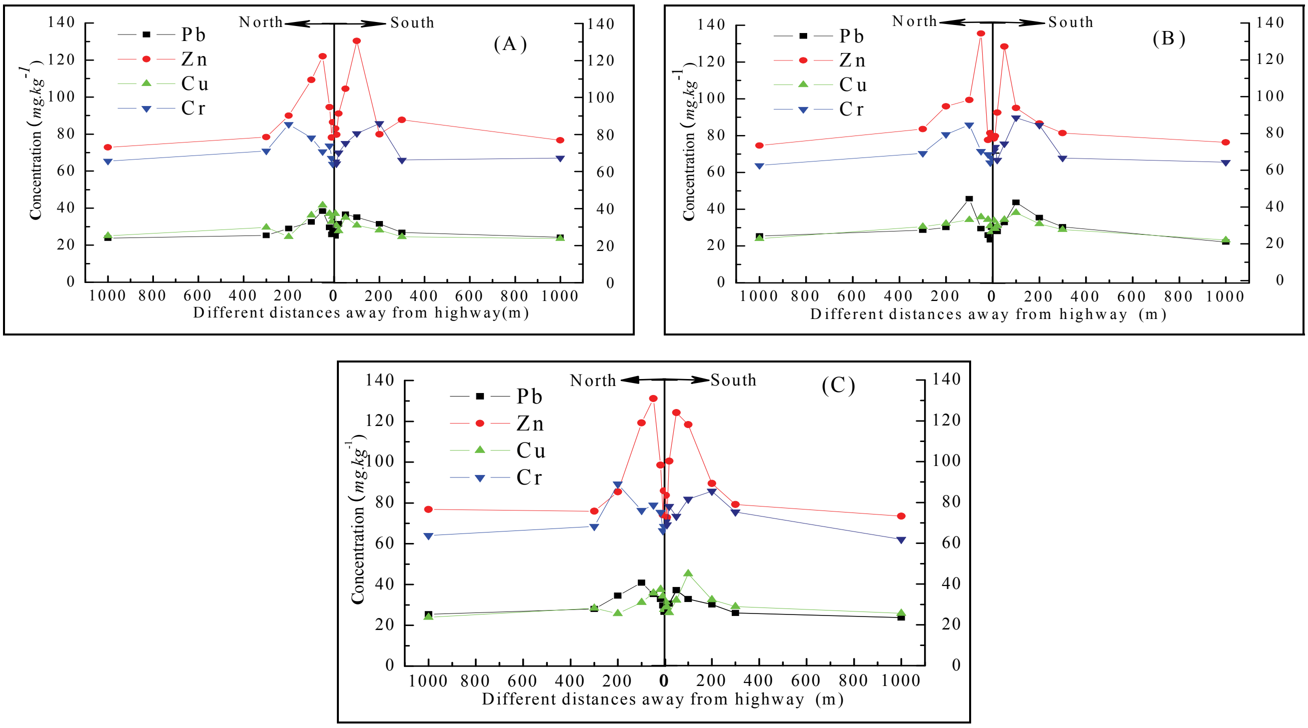

Fig. 2. The horizontal distribution situations of heavy metal concentrations in different sampling sites.
(A): Chencang section; (B): Caijiapo section; (C): Meixian section

Table 3. The C_f values of heavy metals in roadside soils of Xi'an-Baoji Highway

Sampling Section	*Element*	*Position*	*5 m*	*10 m*	*20 m*	*50 m*	*100 m*	*200 m*	*300 m*	*1000m*
Chencang District	Pb	North	1.30	1.20	1.38	1.79	1.52	1.35	1.18	1.11
		South	1.18	1.3	1.48	1.72	1.65	1.48	1.27	1.14
	Zn	North	1.24	1.13	1.36	1.76	1.57	1.30	1.13	1.05
		South	1.20	1.15	1.31	1.51	1.88	1.21	1.27	1.11
	Cu	North	1.66	1.52	1.82	1.76	1.55	1.43	1.38	1.17
		South	1.74	1.44	1.3	1.64	1.44	1.32	1.15	1.11
	Cr	North	1.02	1.07	1.18	1.13	1.25	1.36	1.13	1.05
		South	1.04	1.03	1.12	1.20	1.29	1.34	1.06	1.08
Caijiapo	Pb	North	1.41	1.09	1.21	1.37	1.62	1.40	1.33	1.19
		South	1.29	1.37	1.25	1.48	1.80	1.60	1.36	0.98
	Zn	North	1.14	1.17	1.12	1.59	1.43	1.38	1.20	1.07
		South	1.11	1.13	1.32	1.37	1.35	1.14	1.16	1.08
	Cu	North	1.29	1.44	1.61	1.67	1.60	1.50	1.43	1.12
		South	1.53	1.32	1.39	1.55	1.72	1.44	1.29	1.03
	Cr	North	1.09	1.04	1.12	1.14	1.26	1.34	1.13	1.02
		South	1.13	1.16	1.05	1.19	1.29	1.4	1.07	1.03
Mei County	Pb	North	1.24	1.39	1.54	1.65	1.86	1.61	1.31	1.19
		South	1.32	1.23	1.42	1.73	1.53	1.4	1.21	1.1
	Zn	North	1.24	1.07	1.42	1.89	1.72	1.23	1.09	1.11
		South	1.20	1.05	1.44	1.79	1.70	1.29	1.14	1.05
	Cu	North	1.66	1.52	1.82	1.76	1.55	1.43	1.38	1.17
		South	1.74	1.44	1.30	1.64	1.44	1.32	1.15	1.11
	Cr	North	1.02	1.07	1.18	1.13	1.25	1.36	1.13	1.05
		South	1.04	1.03	1.12	1.20	1.29	1.34	1.06	1.08

Contamination degree (C_d) of sampling sites defined by Håkanson (1980) can be determined as essential calculations for assessment of sediment pollution. It represents the sum of contamination factors for all metals（Eq. 2）：

$$C_d = \sum_{i=1}^{n} C_f \tag{2}$$

The description of contamination degree for analyzed element is as follows: $C_d < 6$, low contamination degree; $6 \le C_d < 12$, moderate contamination degree; $12 \le C_d < 24$, considerable contamination degree; and $C_d \ge 24$, very high contamination degree. The values of C_d are shown in Table 4. Furthermore, each site was evaluated for the extent of metal pollution by employing the method based on the pollution load index (*PLI*) developed by Thomilson et al. (1980) (Eq. 3):

$$PLI = \sqrt[n]{C_f^1 ' \ C_f^2 ' \ C_f^3 ' \ \ldots ' \ C_f^n} \tag{3}$$

where: *n* is the number of metals studied (four in this study), and C_f^n is the contamination factor as described in Eq. (1). The *PLI* provides simple but comparative means for assessing a sample site quality. The rank of values of *PLI* and its implication is as follows: $PLI < 1$, unpolluted; $1 \le PLI < 2$, moderately polluted; $2 \le PLI < 3$, strongly polluted; and $PLI \ge 3$, extremely polluted. The values of *PIL* are shown in Table 5.

The values of C_f for each of the metal on 3 sections in roadside soils along Xi'an-Baoji Highway are illustrated in Table 3 and Fig. 3. It shows that the C_f of Pb, Zn, Cu and Cr is situated between 1 and 3, representing moderate contamination on 3 sections of in roadside soils along Xi'an-Baoji Highway.

Table 4 and Fig. 4 show the degrees of contamination for four heavy metals along roadside soils on 3 sections along Xi'an-Baoji Highway. The C_d values of four heavy metals are all less than 6, in addition to individual sampling points, belong to low contamination degree.

Table 4. The C_d values of heavy metals in roadside soils of Xi'an-Baoji Highway

Sampling Section	*Position*	*5 m*	*10 m*	*20 m*	*50 m*	*100 m*	*200 m*	*300 m*	*1000 m*
Chencang District	North	5.23	4.92	5.74	6.44	5.89	5.43	4.83	4.37
	South	5.16	4.92	5.22	6.08	6.26	5.36	4.75	4.44
Caijiapo	North	4.93	4.75	5.05	5.78	5.91	5.63	5.09	4.40
	South	5.05	4.98	5.00	5.59	6.16	5.58	4.88	4.12
Mei County	North	5.16	5.05	5.96	6.43	6.38	5.63	4.92	4.51
	South	5.31	4.74	5.29	6.36	5.96	5.35	4.56	4.34

Table 5. The *PIL* values of heavy metals in roadside soils of Xi'an-Baoji Highway

Sampling Section	*Position*	*5 m*	*10 m*	*20 m*	*50 m*	*100 m*	*200 m*	*300 m*	*1000 m*
Chencang District	North	1.29	1.22	1.42	1.58	1.47	1.36	1.20	1.09
	South	1.27	1.22	1.30	1.51	1.55	1.34	1.18	1.11
Caijiapo	North	1.22	1.18	1.25	1.43	1.47	1.41	1.27	1.10
	South	1.25	1.24	1.24	1.39	1.52	1.39	1.21	1.03
Mei County	North	1.27	1.25	1.47	1.58	1.58	1.40	1.22	1.13
	South	1.30	1.17	1.32	1.57	1.48	1.34	1.14	1.09

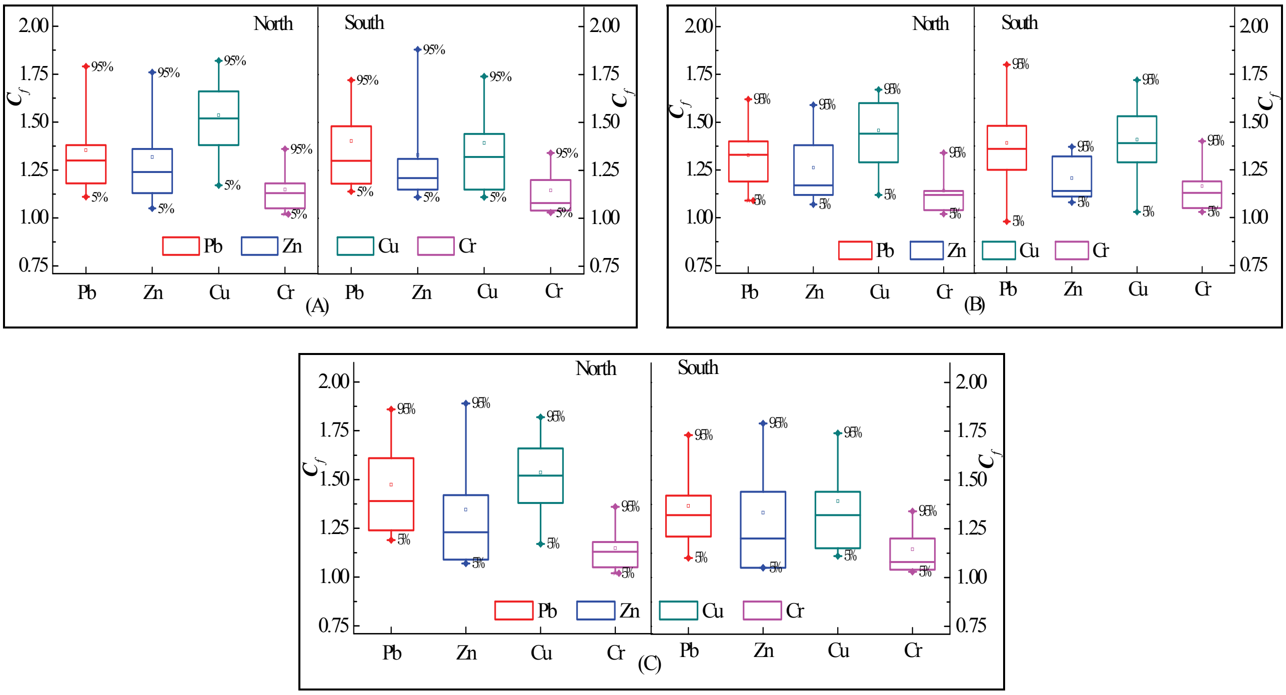

Fig. 3. Contamination factors (C_f) for heavy metals along roadside soils for each sample section: (A): Chencang section; (B): Caijiapo section; (C): Meixian section

The individual sampling points were more than 6, which belong to moderate contamination degree, in addition to Cu and Pb a number of monitoring points were more than 6. In addition, the values of *PLI* from the sample sections in roadside soil are shown in Table 5 and Fig. 5.

The values are between 1 and 2, which were moderately polluted. Overall, the evaluation results with C_f, C_d and *PLI* are in good agreement. All evaluated metals on each section in roadside soils along Xi'an-Baoji Highway are basically in moderately polluted.

3.3. Geoaccumulation index of heavy metals

Geoaccumulation index (I_{geo}) defined by Müller (1969) can be calculated as follows (Eq. 4):

$$I_{geo} = log_2\left[\frac{C_n}{1.5 \times B_n}\right] \tag{4}$$

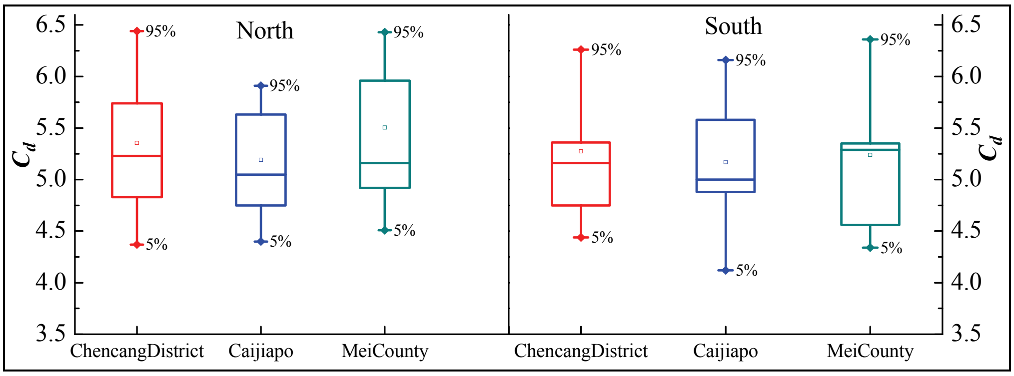

Fig. 4. Degree of contamination of the three sections for each heavy metal evaluation from roadside soil

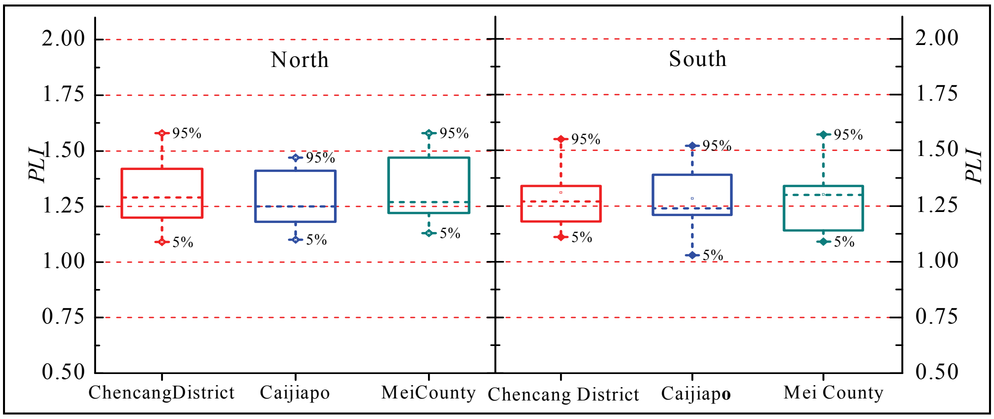

Fig. 5. Pollution Level Index (*PLI*) from the sample sections in roadside soil

where: C_n is the measured concentration of the examined metal in the soil. B_n is the geochemical background concentration of the same metal, which was background values of Shaanxi (Pb=21.4, Zn=69.4, Cu=21.4, and Cr=62.5) (CSEMC, 1990). Factor 1.5 is the background matrix correction factor due to lithogenic effect. I_{geo} is associated with a qualitative scale of pollution intensity. It includes seven grades ranging from unpolluted ($I_{geo}<0$) to extremely polluted ($I_{geo}\geq5$).

Samples may be classified as unpolluted to moderately polluted ($0\leq I_{geo}<1$), moderately polluted ($1\leq I_{geo}<2$), moderate to strongly polluted ($2\leq I_{geo}<3$), strongly polluted ($3\leq I_{geo}<4$), and strongly to extremely polluted ($4\leq I_{geo}<5$). The values of I_{geo} are shown in Table 6. Values of I_{geo} from this study are illustrated in Table 6 and Fig. 6. It shows that almost all evaluated metals in addition to individual sampling points were almost unpolluted ($I_{geo}<0$).

However, the I_{geo} values in some sampling points were between 0 and 1, indicating unpolluted to moderately polluted. These sections are: 1) Chencang district north (Pb in 50 m and 100 m area; Zn in 50 m and 100 m area; Cu in <100 m area); 2) Chencang district south (Pb in 50 m and 100 m area; Cu in <50 area); 3) Caijiapo district north (Pb in 100 m area; Zn in 50 m; Cu in 100 m, 50 m and 20 m area); 4) Caijiapo district south (Pb in 100 m and 200 m area; Cu in 5 m, 50 m and 100 m area); 5) Mei County district north (Pb in 200 m, 100 m, 50 m and 20 m area; Cu in 5 m, 50 m and 100 m area; Zn in 100 m and 50 m; Cu in <100 m area); 6) Mei County district south (Pb in 50 m and 100 m area; Zn in 50 m and 100 m area; Cu in 5 m and 50 m area).

Table 6. The I_{geo} values of heavy metals in roadside soils of Xi'an-Baoji Highway

Sampling Section	***Element***	***Position***	***5 m***	***10 m***	***20 m***	***50 m***	***100 m***	***200 m***	***300 m***	***1000 m***
Chencang District	Pb	North	-0.20	-0.32	-0.12	0.26	0.02	-0.15	-0.34	-0.43
		South	-0.35	-0.21	-0.02	0.20	0.14	-0.02	-0.24	-0.39
	Zn	North	-0.27	-0.41	-0.14	0.23	0.07	-0.21	-0.41	-0.52
		South	1.37	1.32	1.51	1.71	2.02	1.39	1.45	1.26
	Cu	North	0.15	0.02	0.28	0.23	0.05	-0.07	-0.12	-0.36
		South	0.22	-0.06	-0.2	0.13	-0.05	-0.18	-0.38	-0.43
	Cr	North	-0.56	-0.48	-0.35	-0.41	-0.27	-0.14	-0.41	-0.52
		South	-0.52	-0.54	-0.42	-0.32	-0.22	-0.16	-0.50	-0.48
Caijiapo	Pb	North	-0.09	-0.46	-0.31	-0.13	0.11	-0.10	-0.17	-0.34
		South	-0.22	-0.13	-0.27	-0.02	0.26	0.09	-0.14	-0.62
	Zn	North	-0.40	-0.36	-0.42	0.09	-0.07	-0.12	-0.32	-0.48
		South	-0.43	-0.41	-0.19	-0.13	-0.15	-0.39	-0.38	-0.47
	Cu	North	-0.22	-0.05	0.10	0.15	0.09	0	-0.07	-0.43
		South	0.03	-0.19	-0.11	0.05	0.20	-0.06	-0.21	-0.55
	Cr	North	-0.47	-0.52	-0.43	-0.39	-0.25	-0.17	-0.41	-0.56
		South	-0.41	-0.37	-0.52	-0.33	-0.22	-0.10	-0.49	-0.54
Mei County	Pb	North	-0.27	-0.11	0.04	0.14	0.31	0.10	-0.2	-0.34
		South	-0.19	-0.29	-0.08	0.20	0.03	-0.10	-0.32	-0.45
	Zn	North	-0.28	-0.49	-0.08	0.33	0.20	-0.28	-0.46	-0.44
		South	-0.32	-0.52	-0.06	0.25	0.18	-0.22	-0.40	-0.51
	Cu	North	0.15	0.02	0.28	0.23	0.05	-0.07	-0.12	-0.36
		South	0.22	-0.06	-0.20	0.13	-0.05	-0.18	-0.38	-0.43
	Cr	North	-0.56	-0.48	-0.35	-0.41	-0.27	-0.14	-0.41	-0.52
		South	-0.52	-0.54	-0.42	-0.32	-0.22	-0.16	-0.50	-0.48

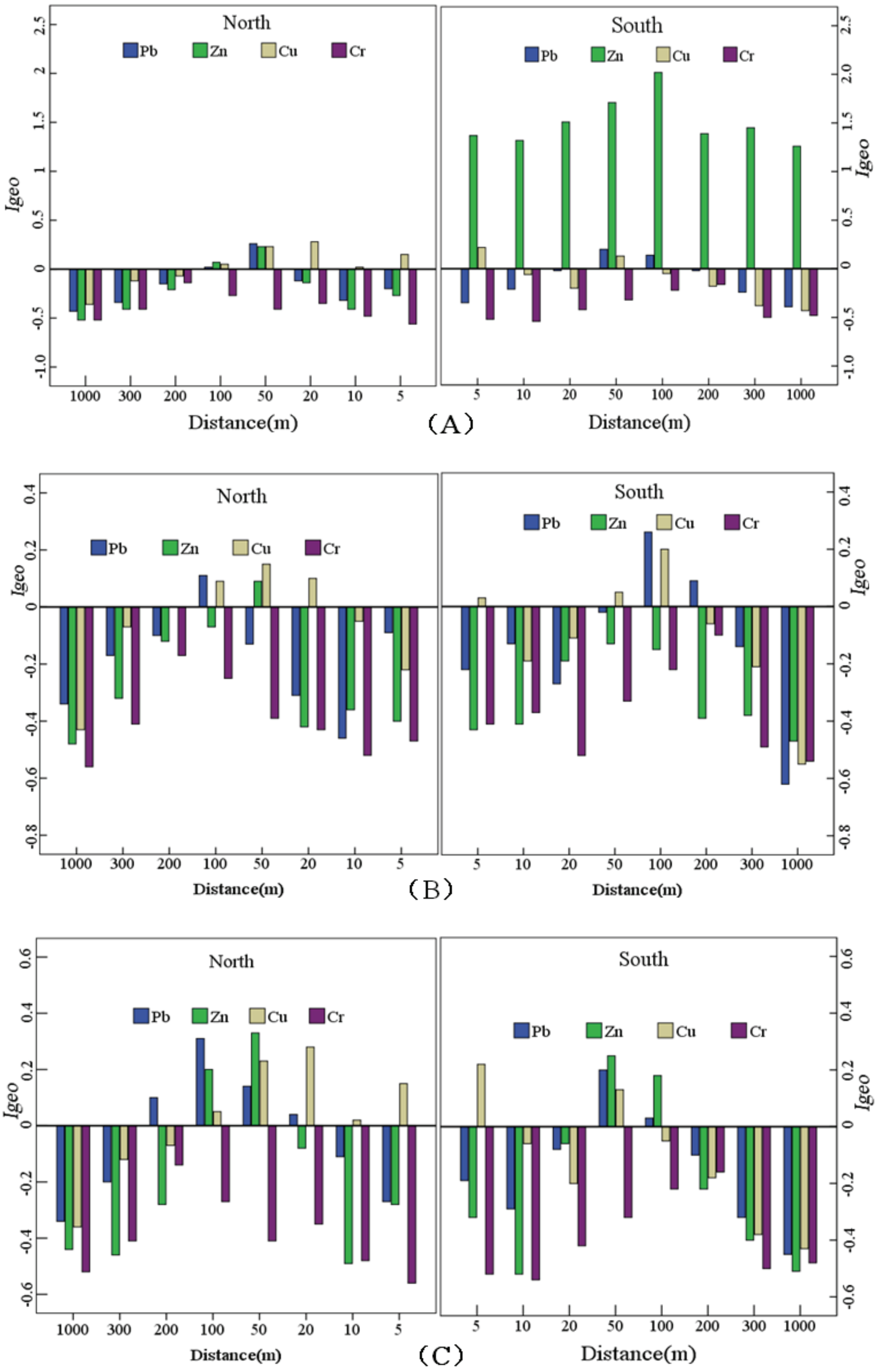

Fig. 6. Geoaccumulation index of heavy metals along roadside soils for each sample section：(A): Chencang section; (B): Caijiapo section; (C): Meixian section

In addition, Zn was between 1 and 2, belong to unpolluted to moderately polluted in Chencang district south.

3.4. Correlation analysis and cluster analysis

Scatter plotting of the mean value of the heavy metals in analysed soils between pairs of variables of Pd vs. Zn, Pd vs. Cu, Pb vs. Cr, and Zn vs. Cu together with their coefficient of correlation are shown in Fig. 7. According to the grade classification of the coefficient of correlation (Wang, 2011), Pd–Zn, Pd–Cu, Pb–Cr and Zn–Cu are moderately correlated (r = 0.68, r = 0.71, r = 0.76, and r = 0.69, respectively), while Zn–Cr and Cu–Cr are less correlated (r = 0.44, and r = 0.31, respectively). Moreover, the results showed the inter-element correlation being as follows: Pb–Cr＞Pd-Cu＞Zn-Cu＞Pd–Zn＞Zn–Cr＞Cu–Cr.

Agglomeration schedule of cluster analysis was performed on the data using nearest neighbour linkage and Euclidean distance as a measure of proximity between samples. The results of the hierarchical cluster analysis are illustrated in Fig. 8. Extrapolating from these results, it reveals two groups of metals having close similarities. Pb and Cu could be sorted into a single group while Zn and Cr are in the other group.

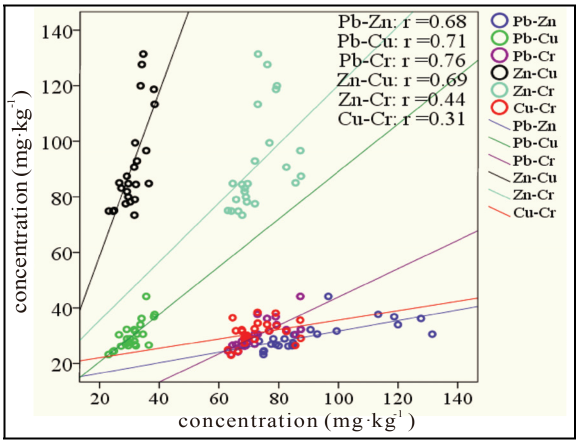

Fig. 7. Scatter plots of heavy metals mean content in analysed soils between pairs of variables: Pd - Zn, Pd - Cu, Pb - Cr, Zn - Cu, Zn - Cr, Cu - Cr

This result suggests that Pb and Cu have the same source of contamination in roadside soils along Xi'an-Baoji Highway. The main reasons were that Pb and Cu stemmed largely from vehicle exhausts and dust of tyre wear. Pb was primarily the result of leaded gasoline emissions. Cu was primarily the result of wear and tear of automobile tires which is mainly because Cu is hardness additive of automobile tires. While Zn and Cr have another same source of contamination. They may originate from other anthropogenic source or natural source.

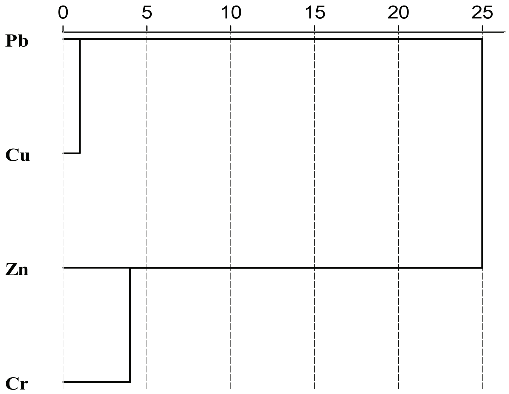

Fig. 8. Dendrogram of hierarchical cluster analysis of heavy metals mean content in analysed soils

4. Conclusions

This study investigated the heavy metal (Pb, Zn, Cu, Cr) concentrations and their horizontal distributions in roadside soils along Xi'an-Baoji Highway, Northwest China. Soil samples from 3 sections along Xi'an-Baoji Highway were collected and analyzed. The results indicated that the heavy metals concentrations of Pb, Zn, Cu and Cr in roadside soil matrix increased at first and then decreased with the distance increases from the highway edge.

The highest concentrations of heavy metals in roadside soils appeared at 30-50 m for Pb and Cu, at 80-90 m for Cr and at 120-138 m for Zn. The reason was that the heavy metals from the highway influenced by factors like wind would spread to a certain distance and then deposit and accumulate in soil. It also shows that the Pb and Cu contents imply these heavy metal elements originate from the same source or they have similar geochemical behaviors, Zn and Cr have other factors.

The evaluation results with the contamination factor (C_f), contamination degree (C_d) and pollution level index (*PLI*) are in good agreement. All evaluated metals were basically in moderately polluted. While geoaccumulation index (I_{geo}) revealed that all evaluated metals were almost unpolluted ($I_{geo} < 0$), only part heavy metal of individual sampled sites were unpolluted to moderately polluted ($0 \leq I_{geo} < 1$). The hierarchical cluster analysis suggested that Pb and Cu might have identical anthropogenic and natural sources while Zn and Cr might have the same source. Pb and Cu stemmed largely from vehicle exhausts and dust of tyre wear. Pb was primarily the result of leaded gasoline emissions. Cu was primarily the result of wear and tear of automobile tires which is mainly because Cu is hardness additive of automobile tires

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