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ORIGINAL ARTICLE

Analysis of trace elements (heavy metal based) in the surface soils of a desert–loess transitional zone in the south of the Tengger Desert

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Abstract It is very important to strengthen the research about the heavy metal pollution of soil in vulnerable ecological regions of the south-central arid area of Northwest China for regulating and guiding local industrial and municipal activities and for protecting the environment. In this study, 48 surface soil samples were collected in the desert–loess transitional zone in the south of the Tengger Desert. The distributions of elements (heavy metal based) and the differences between urban and natural soils were analyzed. We observed that As, Pb, Cu, Zn and S were clearly enriched in the Baiyin area, and Ni and Cr were mainly enriched in the Zhongwei area. V, Mn, Ti, Bi, Co and W were enriched in the southeast margin of the Tengger Desert, where there is relatively little human activity. Over the entire study area, Ce, La and Nd were widely distributed across regions whether with strong or weak human activity. Based on the distributions of elements, we suggest that in the desert–loess transitional zone in the south of the Tengger Desert, the distribution and abundances of element As, Pb, Cu, Zn, S, Ni and Cr are strongly related to the human activities in the area, but the elements V, Mn, Ti, Bi, Co, W, Ce, La and Nd are derived mainly from natural sources.

Keywords Tengger Desert · Heavy metals · Desert–loess transitional zone · Contour

Introduction

Heavy metals are persistent, potentially harmful contaminants that can accumulate in the tissues of organisms and cause severe environmental damage (Loizidous et al. 1991; Savvides et al. 1995). Cities are the centers of human activity, and thus heavy metals may find their way into urban soil in many ways. Environmental and health concerns have led to studies of heavy metals in the urban soils of many cities, e.g., Hamburg (Lux 1993), Berlin (Birke and Rauch 2000) and Rostock (Kahle 2000) in Germany; Madrid (De Miguel et al. 1998) and Seville (Madrid et al. 2002) in Spain; Palermo (Manta et al. 2003) and Naples (Imperato et al. 2003) in Italy; Hong Kong (Chen et al. 1997; Li et al. 2001), Beijing (Chen et al. 2005), Xi'an (Han et al. 2006), Shanghai (Deng et al. 2010) and Quanzhou (Hu et al. 2011) in China. These studies have advanced the understanding of heavy metal contamination, distribution, movement, prevention and control, and, in particular, the studies have helped to manage the metal pollution of urban soil. Study on heavy metals in urban soils and soils in vast country side, especially those less affected by human activities, would help improve our understanding and promote our ability to deal with the heavy metal pollution of urban soil. The desert–loess transitional zone in the south of the Tengger Desert is located in an arid area of Northwest China, where the natural environment is quite vulnerable and could easily be affected by various contaminants, especially heavy metal pollutants generated by human activity. The increasing population and the "Go West" campaign initiated by the

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Chinese government over the course of the last decade have led to the rapid rise of towns in the desert–loess transitional zone, which has brought considerable economic benefits to the area. However, various contaminants, including heavy metals, have also entered the environment as a result of the economic activity, and the contamination has had unprecedented negative impacts on the vulnerable local ecology. Advancing research on the heavy metal pollution of soil in vulnerable ecological regions is important for guiding and regulating local industrial and municipal activities and for developing strategies to protect the environment.

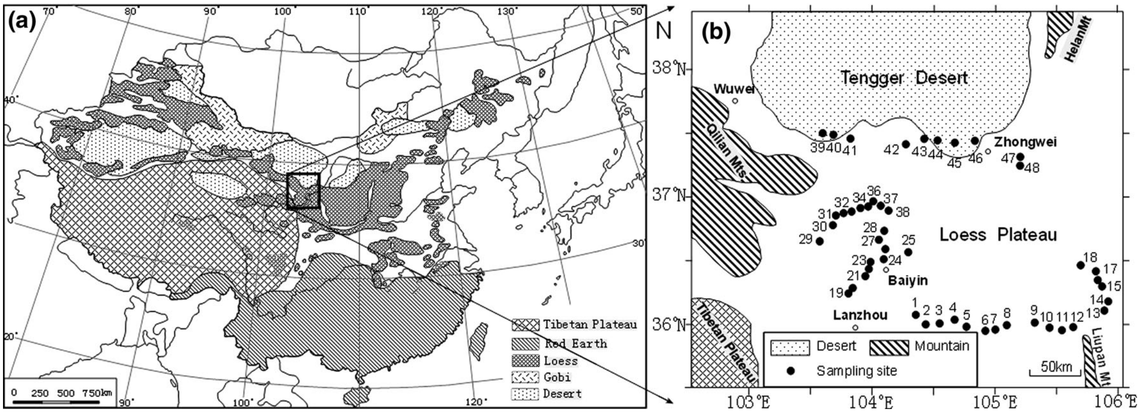


Fig. 1 **a** Map showing the location of the study area. **b** Locations of surface soil samples (*solid black spots*)

Table 1 Element concentrations (ppm) in natural surface soils of the desert–loess transitional zone in the south of the Tengger Desert

Element	Range	Mean	Standard deviation	Coefficient of variation	Background concentration[a]
As	0–9.6	0.44	1.77	4.00	11.5
Hf	0–2.8	1.35	0.57	0.42	7.51
Nb	4–7.3	6.37	0.61	0.10	–
Y	0–8.5	6.65	1.54	0.23	23.2
Pb	0–34.9	8.99	7.86	0.88	18.2
Cu	0–53.4	10.37	10.65	1.03	20.3
Ni	3–31.4	14.99	3.72	0.25	33
Bi	5.4–135.6	23.19	22.10	0.95	0.3
Nd	19.9–55.9	38.42	8.81	0.23	23.8
Rb	29–44.8	39.32	3.21	0.08	94
La	25.2–60.1	40.55	7.78	0.19	30.2
Zn	6.6–136.2	42.66	28.07	0.66	61.3
Co	29.80–259.8	72.32	42.01	0.58	10
Ce	53.8–108.2	79.19	13.82	0.17	59.9
Cr	38.1–504.4	91.18	61.93	0.68	59.3
V	27.3–111.2	92.12	13.66	0.15	70.8
Zr	62.6–181.4	114.87	18.90	0.16	208
Sr	56.2–201.1	116.24	23.59	0.20	231
W	24–852.4	125.71	136.81	1.09	2.18
Cl	77.9–313.2	164.04	68.55	0.42	–
Ba	249.2–307.5	273.32	14.91	0.05	476
S	0–2,110.9	285.60	298.69	1.05	–
P	205.5–962.6	665.96	119.26	0.18	–
Mn	270–838	709.86	93.09	0.13	478
Ti	1,983.3–5,063.1	4,255.82	509.95	0.12	3,500

[a] CNEMC (1990)

Surface soil samples were collected in the desert–loess transitional zone in the south of the Tengger Desert. The distributions of elements and the differences between urban and natural soils were studied. We determined the effects of human activity on particular elements (especially heavy metals) in the vulnerable ecological regions of the desert–loess transitional zone.

Materials and methods

Forty-eight surface samples were collected from the area west of the Helan-Liupan Mountains, east of the Qilian Mountains, south of the southern border of the Tengger Desert and north of Lanzhou City (Fig. 1). Samples were analyzed in the Key Laboratory of Western China's Environmental System (Ministry of Education), Lanzhou University. The treatment procedures were the same as those described by Guan et al. (2008). Sample preparation involved air-drying samples completely and grinding them to yield grain sizes smaller than 75 μm. Up to 4 g of sample was weighed and poured into the center of a column apparatus, together with boric acid, and the apparatus was pressurized to 30 t/m^2 for 20 s. The potential contamination during the experiment may easily and obviously distort the real result. To avoid the potential contamination, all the collected samples were sealed in clean plastic bags. The grinding container was rinsed with distilled water then air dried before being used to grind each sample. The column apparatus for sample compaction was also pre-cleaned by absorbent cotton with alcohol and then air dried. The processed sample, measuring approximately 4 cm in diameter and 8 mm in thickness, was analyzed by a Philips Panalytical Magix PW2403 X-ray fluorescence spectrometer. (The soil samples were selected as the standard samples and the standard deviation was approximately 2 % based on repeat sample analysis). Analytical results are reported in elemental form for trace elements.

Results and discussion

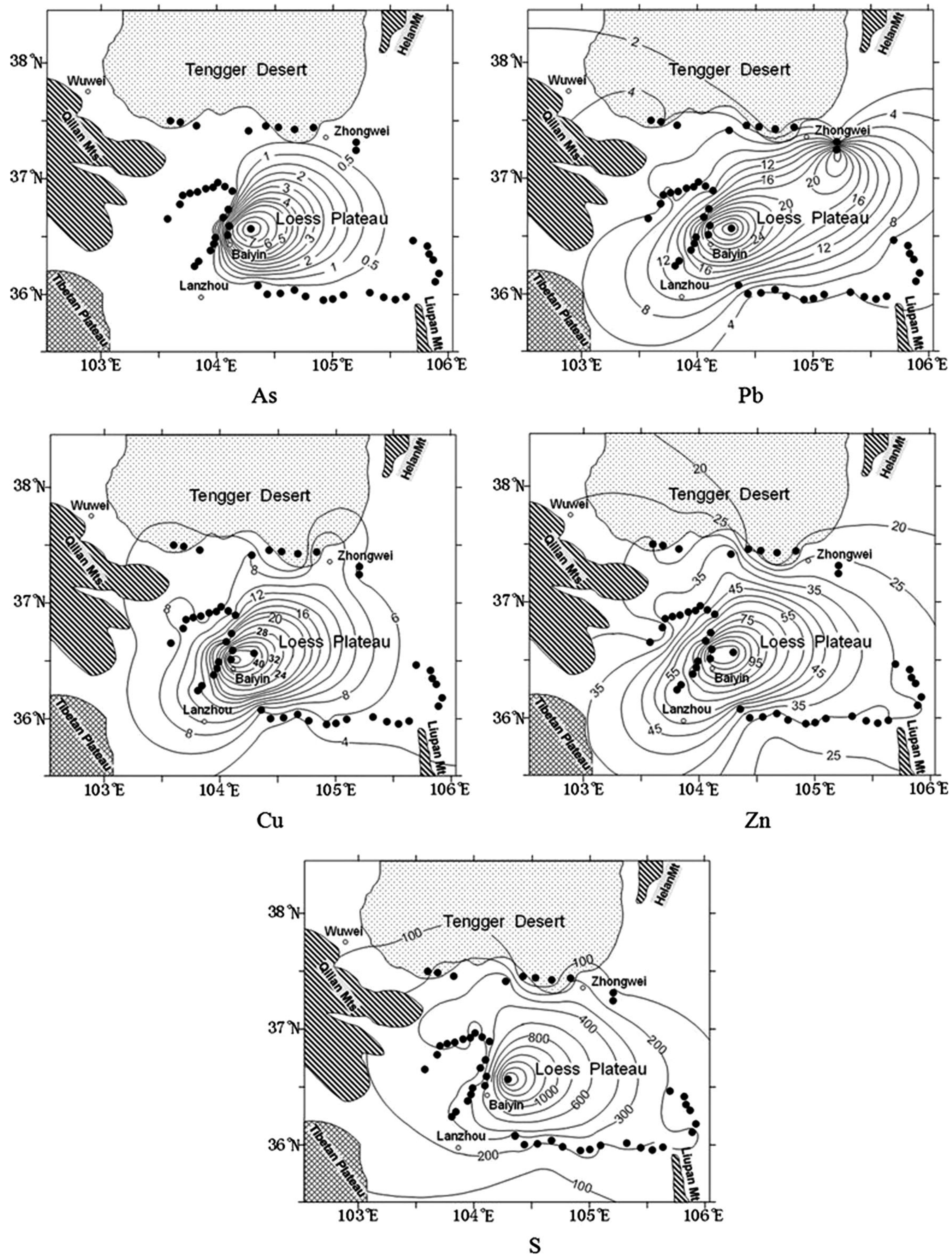
Element concentrations

The analysis results for trace elements in the surface soil samples are presented in Table 1, in the order of decreasing mean concentration. As indicated, As has the lowest mean concentration (approximately 0.44 ppm) of all of the trace elements. The mean concentrations of Hf, Nb, Y and Pb are between 1 and 9 ppm. For Cu, Ni, Bi, Nd, Rb, La and Zn, the mean concentrations gradually increase from 10.37 to 42.66 ppm. The mean concentration range of Co,

Table 2 Correlation coefficient matrix for surface sediments in the desert–loess transitional zone in the south of the Tengger Desert ($n = 48$)

	As	Pb	Cu	Ni	Bi	Nd	La	Zn	Co	Ce	Cr	V	W	S	Mn	Ti
As	1.00															
Pb	0.73***	1.00														
Cu	0.82***	0.88***	1.00													
Ni	0.12	0.33*	0.29*	1.00												
Bi	−0.10	−0.22	−0.24	−0.56***	1.00											
Nd	0.02	0.13	0.05	0.08	−0.41**	1.00										
La	0.06	0.16	0.05	−0.12	−0.10	0.43**	1.00									
Zn	0.79***	0.91***	0.96***	0.37*	−0.31*	0.15	0.08	1.00								
Co	−0.11	−0.21	−0.26	−0.51***	0.98***	−0.37*	−0.07	−0.32*	1.00							
Ce	−0.12	0.02	−0.08	−0.33*	0.35*	0.08	0.38**	−0.08	0.35*	1.00						
Cr	−0.01	−0.02	0.02	0.76***	−0.09	−0.19	−0.25	0.01	−0.05	−0.23	1.00					
V	0.17	0 35*	0.30*	0.70***	−0.87***	0.40**	0.12	0.41**	−0.81***	−0.27	0.19	1.00				
W	−0.10	−0.23	−0.24	−0.58***	0.99***	−0.41**	−0.12	−0.31**	0.97***	0.34*	−0.10	−0.88***	1.00			
S	0.79***	0.65***	0.67***	0.21	−0.30*	0.03	0.07	0.70***	−0.34*	−0.06	−0.03	0.33*	−0.29*	1.00		
Mn	0.15	0.43**	0.39**	0.63***	−0.84***	0.47**	0.14	0.51***	−0.78***	−0.11	0.11	0.86***	−0.85***	0.32*	1.00	
Ti	0.13	0.45**	0.39**	0.66***	−0.80***	0.49***	0.17	0.52***	−0.74***	−0.06	0.11	0.85***	−0.81***	0.32*	0.95***	1.00

Significant correlations: * ($p < 0.05$), ** ($p < 0.01$), *** ($p < 0.001$)



As

Pb

Cu

Zn

S

Fig. 2 Contour figures for elements As, Pb, Cu, Zn and S

Ce, Cr and V is 72–93 ppm, whereas the range is 114–165 ppm for Zr, Sr, W and Cl. The mean concentrations of Ba and S are approximately 300 ppm, and those of P and Mn are approximately 700 ppm; the highest concentration recorded is that of Ti, at more than 4,200 ppm. Among elements with mean concentrations above their background values, Nd, La, Ce, Cr, V, Mn and Ti show concentrations 1.22–1.61 times greater than their background values, and Co, W and Bi show concentrations 7.23, 57.67 and 77.3 times their background values, suggesting that surface soils in certain regions of the study area have been contaminated by these three elements.

According to the relationship between element concentrations and their corresponding background values, we classified the analyzed elements of the 48 samples into three categories: (1) Bi, Co and W, with concentrations higher than their background values in all sites. (2) As, Hf, Y, Ni, Rb, Zr, Sr and Ba, with concentrations below their background values in all sites. (3) Pb, Cu, Nd, Ld, Zn, Ce, Cr, V, Mn and Ti, with background values within their concentration ranges. These groupings suggest that Bi, Co and W have accumulated throughout the entire topsoil of the study area and that Pb, Cu, Nd, Ld, Zn, Ce, Cr, V, Mn and Ti have accumulated in certain regions. Compared to their background values, the concentrations of As, Hf, Y, Ni, Rb, Zr, Sr and Ba indicate a loss state.

When elements are derived mainly from natural sources, the coefficients of variation are small, whereas when they are controlled by anthropogenic sources, the coefficients of variation are large (Han et al. 2006; Tume et al. 2008). The coefficients of variation of As, Pb, Cu, Bi, Zn, Co, Cr, W and S are relatively high, all >0.5 (As has the highest coefficient of variation, 4), suggesting that there is significant spatial variation in the distributions of these elements across the study area and that these elements may be strongly affected by human activities.

We selected 15 elements (with coefficients of variation >0.5 and mean concentrations greater than their background values) to analyze the effects of human activity on the element distributions in the topsoil of the study area. It was noted that the mean concentration of Ni is less than half of its background value, and the coefficient of variation is only 0.25; nevertheless, we also selected this element for analysis based on the following two considerations: the maximum content of Ni is close to its background value, and Ni has attracted much attention in research on the heavy metal pollution of soils (Woitke et al. 2003; Chen et al. 2005; Farkas et al. 2007; Tume et al. 2008; Emam and Saad-Eldin 2013).

Correlation coefficient results

Statistical analyses performed on the dataset enabled the identification of shared characteristics, e.g., behavior, origin, etc. among the heavy metals in the sediments (Jonathan et al. 2004; Farkas et al. 2007; Hu et al. 2011; Emam and Saad-Eldin 2013). Based on the correlation matrices obtained for individual elements, five clearly distinct group associations may be distinguished: As, Pb, Cu, Zn and S [r (correlation coefficient) = 0.65–0.96]; Ni and Cr ($r = 0.76$); Ni, V, Mn and Ti ($r = 0.63$–0.95); Bi, Co and W ($r = 0.97$–0.99); and Nd and La ($r = 0.434$) (Table 2). In the first four groups, the elements in each group show a strong positive relationship among one another ($p < 0.001$). In the last group, the correlation between Nd and La illustrates a moderate positive relationship ($p < 0.01$). These groupings suggest that elements in the same group share common sources.

Element contour figures

Using Surfer 8.0 (Golden Software), we converted the concentrations of the 16 selected elements in the 48 sampling sites into contour figures (Figs. 2, 3, 4, 5). Based on the shapes of the contour lines, the selected 16 elements were classified into four groups: (1) As, Pb, Cu, Zn and S were clearly enriched in the Baiyin area (Fig. 2). (2) Ni, Cr

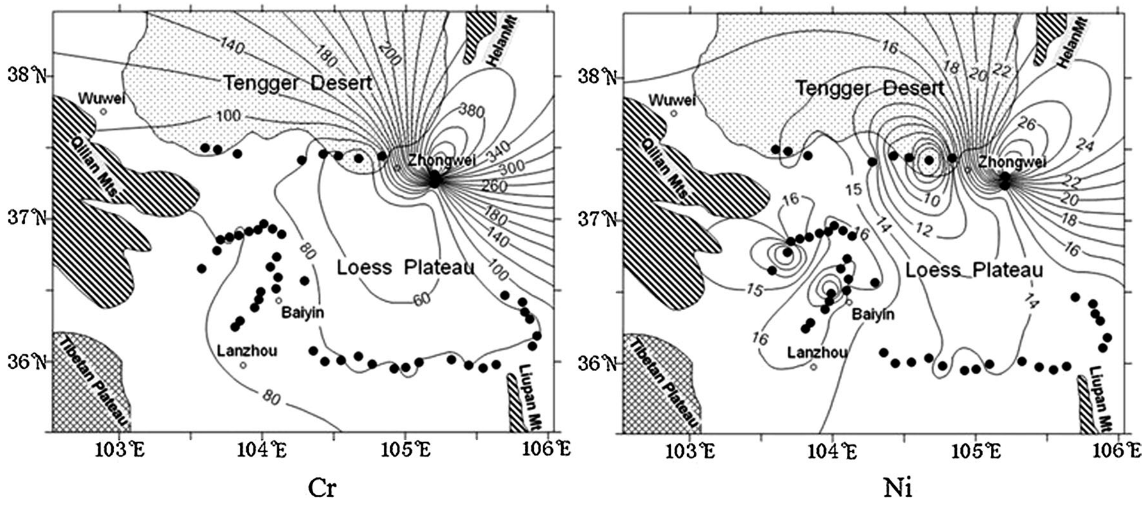


Fig. 3 Contour figures for elements Cr and Ni

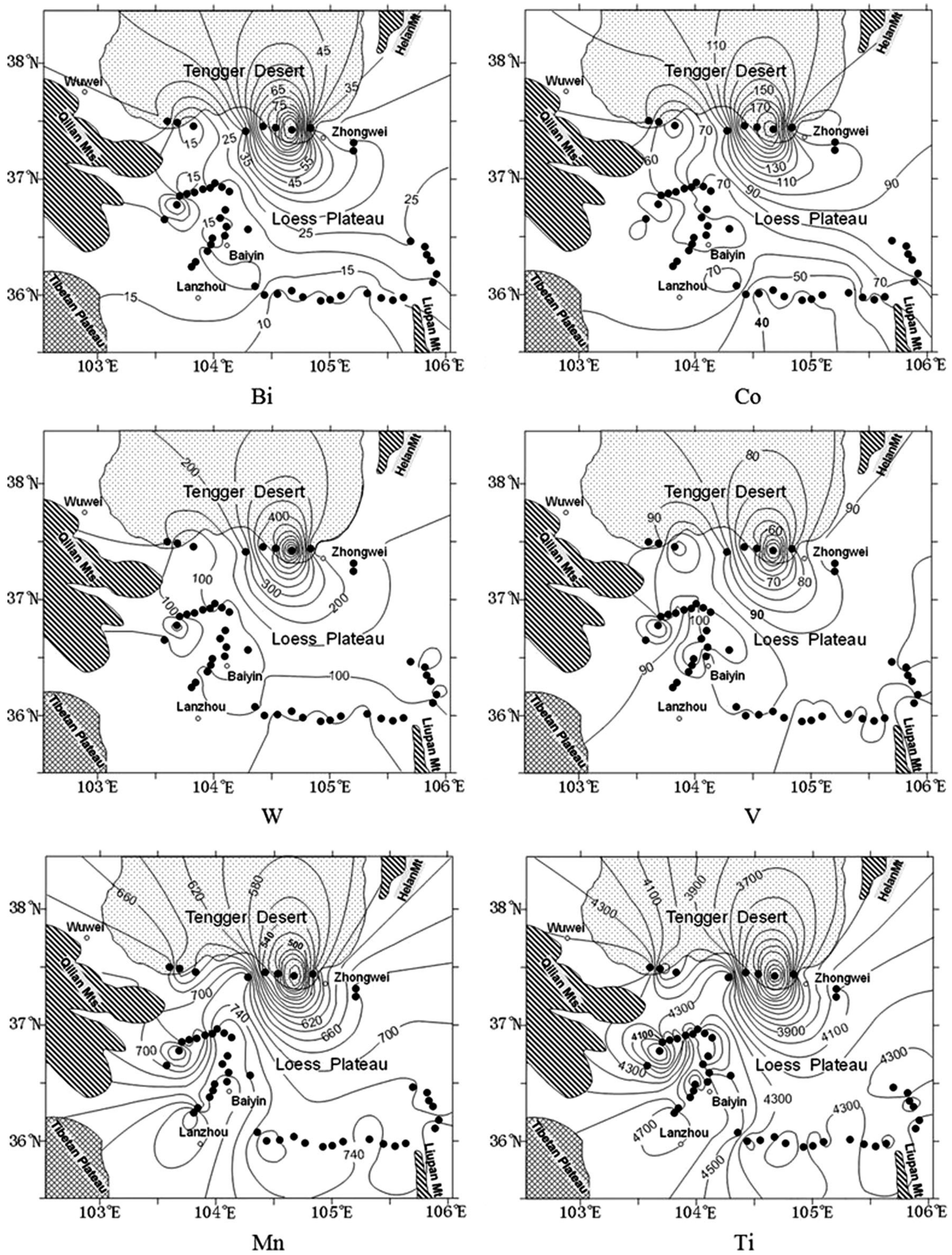


Fig. 4 Contour figures for elements Bi, Co, W, V, Mn and Ti

and Pb showed clear enrichment in the Zhongwei region (Fig. 3). (3) Bi, Co, W, V, Mn and Ti exhibited closed contour lines along the southeast margin of the Tengger Desert (the contour lines for the former three elements are closed with high values, whereas those for the latter three elements are closed with low values, Fig. 4). (4) Nd, La and Ce showed closed contour lines in many regions (Fig. 5).

Mining and smelting are the major sources of metals that contaminate the environment (Lee and Stuebing

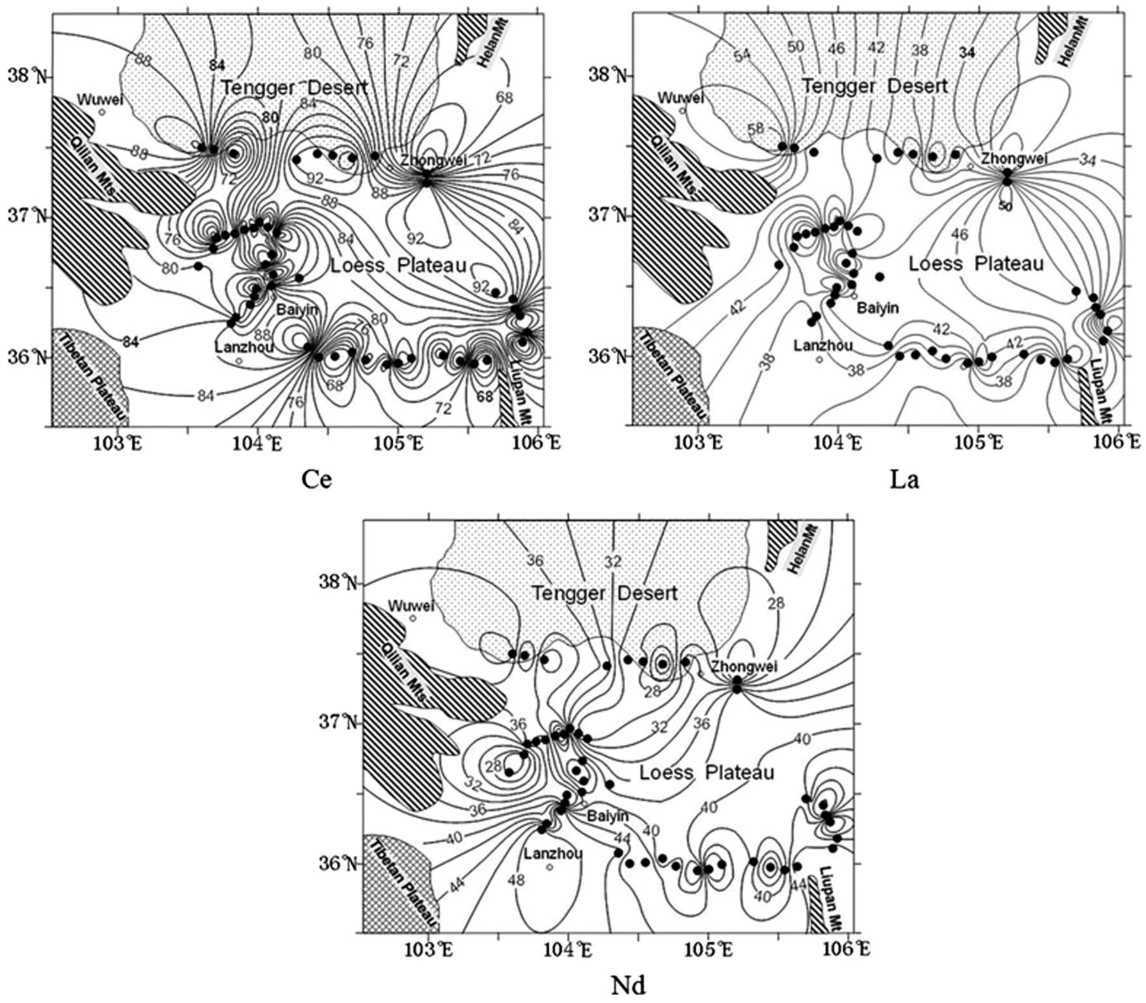


Fig. 5 Contour figures for elements Ce, La and Nd

1990). Baiyin, a typical industrial city, covers an area of 501 km^2 in Gansu Province, China. The city has been a center of non-ferrous metal mining and smelting in China since the 1950s. The total yield of non-ferrous metals was 3.0×10^5 t in 1962 and 3.15×10^6 t in 2004, and the yield of copper in 2004 was 1.45×10^6 t. The city currently produces Zn and Pb products for China (Li et al. 2006; Wang et al. 2012). More than 38,000 workers were engaged in the mining, smelting and transport services associated with mining activities (Li et al. 2006). Investigations have shown that the soil in Baiyin is severely polluted by heavy metals (Nan and Zhao 2000; Li et al. 2006). The contour maps of As, Pb, Cu, Zn and S show closed contour lines with high values strongly associated with the Baiyin area (Fig. 2); these contour lines indicate high concentrations of these elements, which are mostly produced by human activity, especially the types of industrial activities practiced in the Baiyin area. These elements have been released into the environment and have seriously contaminated the local surface soils. Zhongwei is the main production center for smelting and electrolytic metals in the Ningxia Autonomous Region. In Zhongwei, the annual chromium output of a company, for example, can reach up to 360,000 t. The 11th meeting of Chinese Chromium Alloy Chain Conferences and Forums (G12) was assembled in Zhongwei on October 17th, 2012. A nickel project with an annual output of approximately 300,000 t was completed and put into operation in 2012 in Zhongwei. Like Baiyin, Zhongwei has become a major industrial base in the desert–loess transitional zone in the south area of the Tengger Desert. Therefore, Zhongwei's industrial activities are responsible for the strong enrichment of Cr, Ni and Pb in the nearby surface soils (Fig. 2, 3).

The contour maps of Bi, Co, W, V, Mn and Ti show distinct closed contour lines at the southeast margin of the Tengger Desert (Fig. 4), where there is only a highway that passes through, without any traces of human activity from towns, villages, plants, mines or farmlands. Thus, we can assume that these six elements in the area are not affected by human activity. There are areas of exposed bedrock that form low mountains near the sampling sites (44, 45 and 46) that showed closed contour lines (Fig. 4). We suggest that the concentrations of Bi, Co, W, V, Mn and Ti may be largely controlled by the local geology.

The contour maps of Ce, La and Nd show closed contour lines indicating not only strong human activity around the city, country and farmland but also weak human activity in such areas as the desert margin (Fig. 5). Throughout the entire study area, the mean concentrations of the three metals are only 1.3–1.6 times their background values. Among those in all of the sample sites, the coefficients of variation of Ce, La and Nd are relatively small: 0.17, 0.19 and 0.23, respectively. The closed contour line zones of Ce, La and Nd exhibit a broad regional distribution associated either with strong human activity or areas with low activity, such as the desert margin. Therefore, we suggest that the concentrations of Ce, La and Nd in the desert–loess transitional zone in the south of the Tengger Desert are less affected by human activities. Instead, they may be mostly controlled by local regional geological factors.

Conclusions

Through analyzing element concentrations in the desert–loess transitional zone in the south of the Tengger Desert, comparing the concentrations to regional background values, studying the correlation coefficients of 16 selected elements and creating contour maps of the element concentrations, we determined that As, Pb, Cu, Zn, S, Ni and Cr mostly originate from the cities of Baiyin (the former five elements) and Zhongwei (the latter two elements). V, Mn, Ti, Bi, Co and W are mostly derived from the southeast margin of the Tengger Desert, where there is relatively little human activity, and Ce, La and Nd are associated not only with areas of strong human activity but are also detected in desert margin areas with little human activity. Based on the distribution characteristics of these elements, we suggest that, in the desert–loess transitional zone in the south of the Tengger Desert, there are strong anthropogenic sources (mainly industrial production and municipal activities) for As, Pb, Cu, Zn, S, Ni and Cr. In contrast, V, Mn, Ti, Bi, Co, W, Ce, La and Nd are primarily derived from natural sources.

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