Received: 19 January 2018 | Revised: 27 November 2018 | Accepted: 28 November 2018

DOI: 10.1111/sum.12470

RESEARCH PAPER

WILEY Soil Use and Management

Anthropogenically disturbed potentially toxic elements in roadside topsoils of a suburban region of Bishkek, Central Asia

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Funding information
Strategic Priority Research Program of Chinese Academy of Sciences, Grant/Award Number: XDA20060303; West Light Foundation of Chinese Academy of Sciences, Grant/Award Number: 2016-QNXZ-A-4; National Natural Science Foundation of China, Grant/Award Number: 41471173

Abstract

The ecological environment in Central Asia is vulnerable to pressure from human activity due to the physical geography and climatic fragility of this region. A set of indicators suitable for the future assessment of this pressure needs to be proposed. Thirty-six topsoil samples (0–5 cm) were collected from roadsides in a suburban region of Bishkek, the capital of the Kyrgyz Republic in Central Asia, and a risk assessment of anthropogenically disturbed potentially toxic elements (PTEs) was systematically conducted with classic statistical methods. The results of detrended correspondence analysis and principal component analysis clearly showed that topsoil samples with high contents of PTEs (Pb, Zn and Cu) were strongly affected by traffic within a distance threshold of 200 m and that anthropogenic effects decreased significantly with increasing distance from the highway. The enrichment factor and anthropogenic contribution for Pb were the highest among the three PTEs, with average values of 2.0% and 47.4%, respectively, suggesting enrichment. However, the results of the human health risk assessment also indicated that noncarcinogenic risks did not occur for any of the anthropogenic PTEs. The reported method provides a new systematic pathway to reveal anthropogenic influences on the geochemical composition of soil. The conclusions of this work will be highly valuable as important guidelines for agriculture, and the results of the PTE contents will provide a scientific basis for soil collection in future studies.

KEYWORDS

anthropogenic factors, Central Asia, human health risk, potentially toxic elements, roadside soils

1 | INTRODUCTION

The ecological environments in Central Asia are fragile, unstable (Li, Chen, Li, Deng, & Fang, 2015; Qi & Kulmatov, 2008) and vulnerable to the potential effects of human activities. Researchers have focused on the influence of human activities on land use and land cover changes combined with global climate change in Central Asia (Chen et al., 2013; Klein, Gessner, & Kuenzer, 2012; Lioubimtseva, Cole, Adams, & Kapustin, 2005). The geochemical components of soils, especially potentially toxic elements (PTEs) that are associated with potential toxicity or ecotoxicity (Duffus, 2002), depend on both the natural environment where the land is formed and the degree of influence from anthropogenic activity (Karim, Qureshi, Mumtaz, & Qureshi, 2014; Saaltink, Griffioen, Mol, & Birke, 2014; Smith et al., 2015). Soil that is polluted by PTEs increases human health risks via ingestion, inhalation and dermal absorption (Chen, Teng, Lu, Wang, & Wang, 2015; Tóth, Hermann, Da Silva, & Montanarella, 2016). Therefore, the pollution of soils with PTEs is a significant environmental issue.

For long-term comprehensive risk assessments of PTE pollution, the gradients of background concentrations and environmental variables are usually assumed to be uniform at small scales (Wu, Zhou, & Li, 2011); therefore, many researchers have focused only on pollution and the assessment of potentially toxic elements but have not given any consideration to the possibility of spatial variability in the field (Mamat, Haximu, Zhang, & Aji, 2016; Tang et al., 2015; Zhang, Juying, Mamat, & QingFu, 2016). Soil is a valuable natural resource in the arid zone of Central Asia. The lands on both sides of roads have been the main areas of agricultural farming due to convenient transportation. However, it is unclear whether the soils on the roadsides have been affected. If these soils have been affected, what is the enrichment pattern of PTEs on the roadsides? In this paper, based on the assessment of the geochemical elemental characteristics of surface soils collected from the Bishkek suburbs in Kyrgyzstan (Central Asia), multivariate statistical analyses and potential ecological risk calculations were applied to examine the topsoil samples and the responses of their elemental compositions to anthropogenic factors. In particular, whether human traffic and transportation activities have altered the geochemical compositions of topsoils and caused PTE pollution was investigated. This research will provide a scientific basis for the prevention and control of soil heavy metal pollution in the future.

2 | MATERIALS AND METHODS

2.1 | Sampling and laboratory analysis

Bishkek is the capital of Kyrgyzstan, which is located in the eastern part of Central Asia (Figure 1). The soils in the study area are characterized as Calcisols (FAO, 2012) based on the soil classification in the Harmonized World Soil Database (v 1.2). Corn crops are planted in this region. Fertilizer use in all Kyrgyzstan was just 18.8 kilograms per hectare of arable land (Light, 2007; Swinnen, Van Herck, & Sneyers, 2011). After field research, no fertilizer was used in this region. The soils, which are often used to evaluate the influences of regional anthropogenic factors (Li, Wan, Ben, Fan, & Hu, 2017; Salako, Hauser, Babalola, & Tian, 2006), were collected at depths of 0–5 cm at each location using a corer with a cutting ring (with an inner diameter of 50 mm and a depth of 50 mm). Based on the chessboard stationing method with a 50 m interval, 36 sampling points (4 × 9) were placed at a given distance from highway M39. Although Kyrgyzstan is a low-income developing country, the number of registrations reached 444.1 thousand motor cars in Bishkek, equivalent to 1 unit per two persons (Kadyraliev, 2011). Since there is no official traffic data for

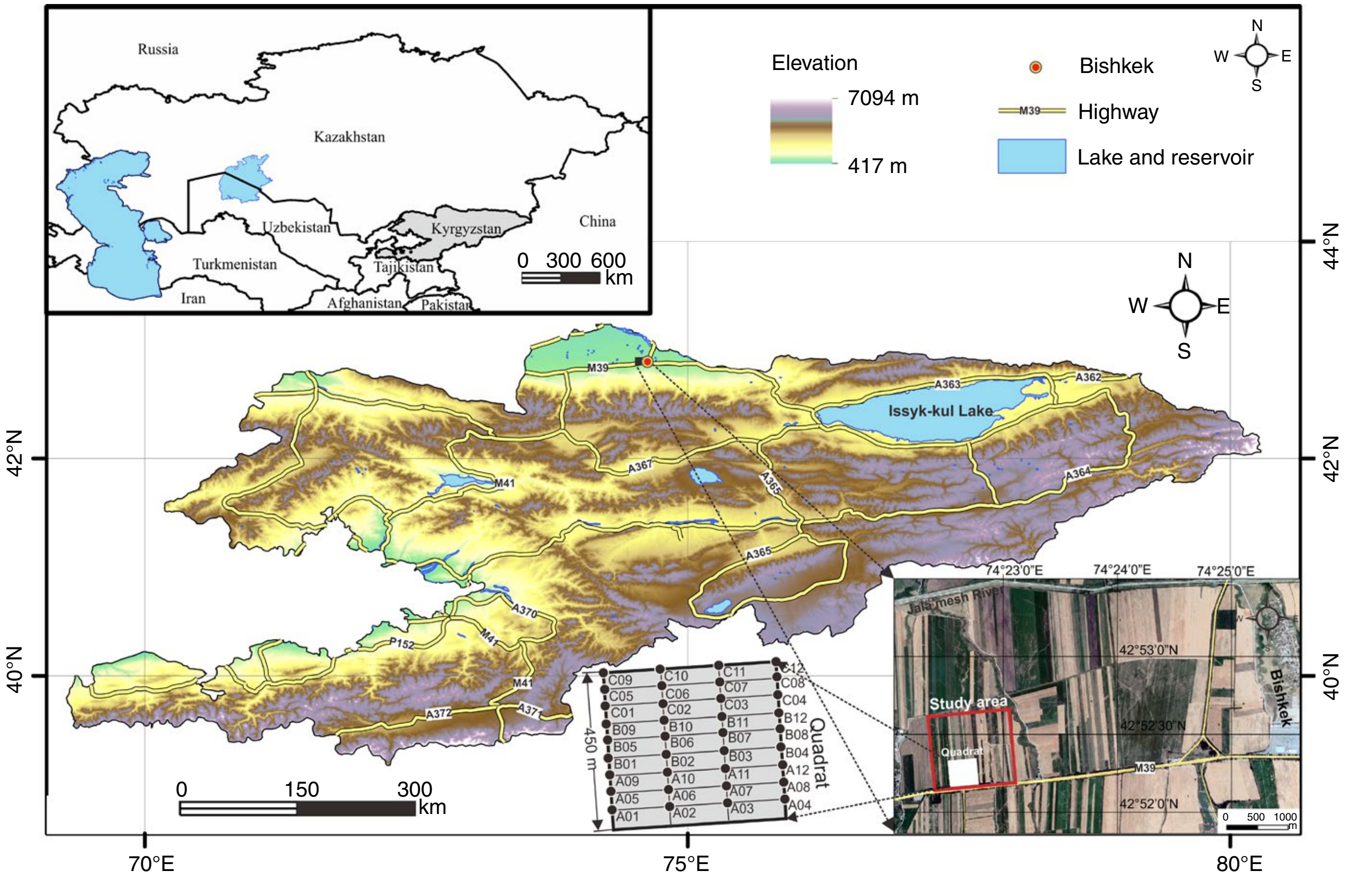

FIGURE 1 Location of the study area and design of quadrat-based sampling in the Bishkek suburbs

highway M39, we recorded traffic data on 24 October 2018, which reached 65 units per minute at 13:00 hr. The criteria were that the samples had to be within 150 m (A01–A12), 200–300 m (B01–B12) and 350–450 m (C01–C12) of the side of the highway, which allowed a direct comparison of the effects of traffic on soil composition. In this paper, in order to separate the PTEs that are affected by the natural background, we analysed PTEs (Co, Cr, Cu, Ni, Pb, V and Zn) and major elements (Al, Na, K, Ca, Mg, Fe, Mn and Ti). Following the elemental analysis method (Liu, Wu, & Pan, 2016; Ma, Wu, & Abuduwaili, 2013), surface soil samples were dried, and subsamples weighing ~0.125 g were ground through a 200 μm mesh, digested with $HF–HNO_3–HClO_4$ and prepared for geochemical analysis using an American Leeman Labs profile inductively coupled plasma atomic emission spectrometer with a relative individual elemental concentration error of <5%.

2.2 | Classic statistical methods

Principal component analysis (PCA) was used to identify the potential factors influencing elemental variation (Kelepertzis, 2014; Micó, Recatalá, Peris, & Sánchez, 2006). Detrended correspondence analysis (DCA), which aided in the identification of interrelationships among soil samples, was used to separate topsoils that had anthropogenic contamination from the samples (Hill & Gauch, 1980; Peet, Knox, Case, & Allen, 1988). Detrended correspondence analysis has proven to be a highly reliable and useful tool for data exploration and is widely used in ecological and environmental studies (Nilsson, Jansson, & Zinko, 1997; Smol et al., 2005; Stephansen, Nielsen, Hvitved-Jacobsen, Pedersen, & Vollertsen, 2016).

2.3 | Methods for the assessment of pollution and anthropogenic contributions to potentially toxic elements

Enrichment factors (EFs) have been widely used to calculate the extent of anthropogenic contributions (ACs) using a normalizing element (i.e., conservative metals) such as Al (Varrica, Aiuppa, & Dongarrà, 2000), Fe (Chakraborty, Bhattacharya, Singh, & Maity, 2014), Ti (Taboada, Cortizas, García, & García-Rodeja, 2006), Mn (Huang et al., 2014) and K (Nesbitt, Markovics, & price, 1980). The EF for element X is defined as follows:

$$\mathrm{EF}_X = \frac{[X/R]_\mathrm{S}}{[X/R]_\mathrm{B}} \tag{1}$$

The anthropogenically derived source ($[X]_\mathrm{anth}$) is defined as follows:

$$[X]_\mathrm{anth} = [X]_\mathrm{s} - [R]_\mathrm{s} \times [X/R]_\mathrm{B} \tag{2}$$

The parts with an anthropogenic contribution (AC; $[X\%]_\mathrm{anth}$) are defined as follows:

$$[X\%]_\mathrm{anth} = \left(1 - \frac{1}{\mathrm{EF}_X}\right) \times 100 \tag{3}$$

In Equations 1–3, R is the reference element, $[X/R]_\mathrm{S}$ is the concentration ratio of X to R in the topsoil samples, and $[X/R]_\mathrm{B}$ is the concentration ratio of X to R in the natural background materials. EF < 1 suggests that there is no enrichment; 1 < EF < 3 suggests that there is minor enrichment; 3 < EF < 5 suggests that there is moderate enrichment; and EF > 5 suggests that there is severe enrichment (Sakan, Đorđević, Manojlović, & Predrag, 2009).

A widely used model for the health risk assessment (Jiang et al., 2017; Li, Ma, van der Kuijp, Yuan, & Huang, 2014; Olawoyin, Oyewole, & Grayson, 2012), developed by the United States Environmental Protection Agency (USEPA, 1996), is selected to calculate the potential noncarcinogenic risks of the PTEs to human health. For the contaminated soils, three exposure pathways of PTEs are considered: (a) ingestion: direct ingestion of soil particles and indirect consumption of crops grown on contaminated soils; (b) dermal contact with PTEs; and (c) inhalation of resuspended particles by nose or mouth (Jiang et al., 2017; Wu et al., 2015).

The average daily intake (ADD) of a PTE via ingestion ($\mathrm{ADD}_\mathrm{ing}$) is calculated as follows:

$$\mathrm{ADD}_\mathrm{ing}(\mathrm{mg\ kg^{-1}\ day^{-1}}) = C \times \frac{\mathrm{IngR} \times \mathrm{ExF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \times 10^{-6} \tag{4}$$

The average daily intake of the PTE via inhalation ($\mathrm{ADD}_\mathrm{inh}$) is calculated as follows:

$$\mathrm{ADD}_\mathrm{inh}(\mathrm{mg\ kg^{-1}\ day^{-1}}) = C \times \frac{\mathrm{InghR} \times \mathrm{ExF} \times \mathrm{ED}}{\mathrm{PEF} \times \mathrm{BW} \times \mathrm{AT}} \tag{5}$$

The average daily intake of the PTE via dermal absorption ($\mathrm{ADD}_\mathrm{derm}$) is calculated as follows:

$$\begin{aligned}&\mathrm{ADD}_\mathrm{derm}(\mathrm{mg\ kg^{-1}\ day^{-1}}) = \\ &C \times \frac{\mathrm{SA} \times \mathrm{SL} \times \mathrm{ABS} \times \mathrm{ExF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \times 10^{-6}\end{aligned} \tag{6}$$

The hazard quotient (HQ), which is designed as a measurement of noncarcinogenic hazards, is calculated as follows:

$$\mathrm{HQ}_i = \mathrm{ADD}_i / \mathrm{RfD}_i \tag{7}$$

The hazard index (HI), which represents mixed pollution, is calculated as follows:

$$\mathrm{HI} = \sum_{i=1}^{3} \mathrm{HQ}_i \tag{8}$$

In Equations 4–8, C is the content of the potentially toxic element ($\mathrm{mg\ kg^{-1}}$). The ingestion rate (IngR) is 200 mg $\mathrm{day^{-1}}$ (Ferreira-Baptista & De Miguel, 2005). The inhalation rate (InhR) is 12.8 m^3 day^{-1} (Qing, Yutong, & Shenggao, 2015). The exposure frequency (ExF) is 350 day $year^{-1}$ (Gu, Gao, & Lin, 2016). The exposure duration (Ed) is 30 a. Body weight (BW) is 70 kg (Gu et al., 2016). The exposure time (AT) is AT = 365 × ED. The particle emission factor (PEF) is 1.36×10^9 m^3 kg^{-1} (Ferreira-Baptista & De Miguel, 2005). The exposed skin area (SA) is 4350 cm^2 (Qing et al., 2015). The skin adherence factor (SL) is 0.2 mg cm^{-2} day^{-1} (Ferreira-Baptista & De Miguel, 2005). The dimensionless dermal absorption factor (ABS) is ABS = 0.001 (Ferreira-Baptista & De Miguel, 2005). The corresponding reference dose for exposure pathway i is denoted as RfD_i (USEPA, 1996). The average daily intake of PTEs for exposure pathway i is denoted as ADD_i. If HI < 1 or HQ < 1, there is no noncarcinogenic risk. If HI > 1 or HQ > 1, noncarcinogenic effects may occur (Lu, Zhang, Li, & Chen, 2014).

3 | RESULTS AND DISCUSSION

3.1 | Geochemical features and factors influencing roadside soils in the suburban region in Bishkek

The geochemical components of soil, especially PTEs, depend on both the natural environment where the land is formed and the degree of influence from anthropogenic activity (Dung et al., 2013; Saaltink et al., 2014). However, it is undeniable that the PTEs can undergo chemical phase changes and spatial migration with changes in time and regional environments (irrigation, crop planting, soil properties, soil erosion, atmospheric dust fall, etc.; Bi, Zhou, Chen, Jia, & Bao, 2018; Caporale & Violante, 2016; Han et al., 2003; Shi et al., 2018). To minimize the impacts of time and regional environments on the content distribution of PTEs, a small spatial scale study was conducted. The contents of major elements and PTEs are shown in Figure 2. The results of the PCA showed that three factors accounted for 86% of the total variance (Table 1). The first factor (F1) was the main factor influencing the major and trace elements (Al, Fe, Mn, Ti, Co, Cr, Ni and V; Table 2). Al (Varrica et al., 2000), Fe (Chakraborty et al., 2014), Mn (Huang et al., 2014; Loska, Cebula, Pelczar, Wiechuła, & Kwapuliński, 1997) and Ti (Sabbioni, 1995; Taboada et al., 2006) are extremely immobile and are regarded as typical lithogenic elements. This relationship suggested that these elements were released by the weathering of local bedrock (Wilcke, Müller, Kanchanakool, & Zech, 1998). Therefore, these elements mainly represent a lithogenic origin from the weathering and erosion of rocks and soil parent materials in this region.

The second factor (F2) controlled the variations in the elements Al, Na, K, Ca and Mg; Ca and Mg had high negative loadings on F2 (Table 2). The soil in this study area, which is classified as a Calcisol, formed at an early stage of weathering due to carbonate leaching (Mavris et al., 2010). The second factor reflected the gradient of weathering intensity. The percentage changes in the major immobile elements (Al, Na and K) are influenced by typical mobile elements (Ca and Mg) during pedological weathering (Chen, Ji, Qiu, & Lu, 1998).

The third factor (F3) dominated PTEs (Pb, Zn and Cu) with high loadings (from 0.89 to 0.94). The third controlling factor was significantly different from the natural factors (F1 and F2; Table 2). The PTEs (Pb, Zn and Cu) were influenced by anthropogenic traffic contributions. Vehicle emissions represented a major source of anthropogenic Pb prior to the use of unleaded gasoline (Cao et al., 2014; Ewing et al., 2010). High Zn concentrations in our analysed topsoil samples were highly attributable to the attrition of rubber from motor vehicle tires, which was exacerbated by poor-quality road surfaces in the region. Lubricating oils often included Zn as one of the many different additives (Okunola, Uzairu, & Ndukwe, 2007). Copper contamination may have occurred due to the wearing out of engine parts, such as thrust bearings, bushings and metal bearings, which are commonly found along roadsides in this study area (Okunola et al., 2007).

Using PCA, anthropogenically influenced elements were revealed; however, it was unknown whether there was spatial variability in the study area or how large the impacts of the anthropogenic factors were. Due to the large dimensional differences in the geochemical data, a logarithmic transformation was conducted before analysis. In addition, DCA was used to reveal the influences of natural processes and anthropogenic factors on the soil samples.

The DCA results from the soil data suggested that axes 1 and 2 accounted for 46.61% and 24.06% of the total variation, respectively. The two axes explained 70.67% of the variance in the soil data, which showed strong gradients (Figure 3). The elements Ca, Mg, Na, K and Al had strong positive/negative loadings with axis 1, and axis 2 separated the elements Pb, Zn and Cu from the elemental group with positive loadings. The first axis strongly indicated that chemical weathering was the underlying gradient. The second axis strongly indicated anthropogenic influence, which was consistent with the above-mentioned PCA analysis. The results suggested that the soils in quadrants I and II (Figure 3) at a range of 200 m were strongly influenced by traffic and transportation; however, the topsoil samples A01 and A04 were not influenced by anthropogenic factors. In a study at the beginning of this century, the enrichment factors for Pb, Cu, Cd, Zn, Ni and Cr became negligible beyond a distance of 5 m from the roadside of a major French highway (Pagotto, Rémy, Legret, & Le Cloirec, 2001). In Nigeria, heavy metals rapidly decreased with distance, reaching the natural background levels at a distance of 50 m from the road (Fakayode

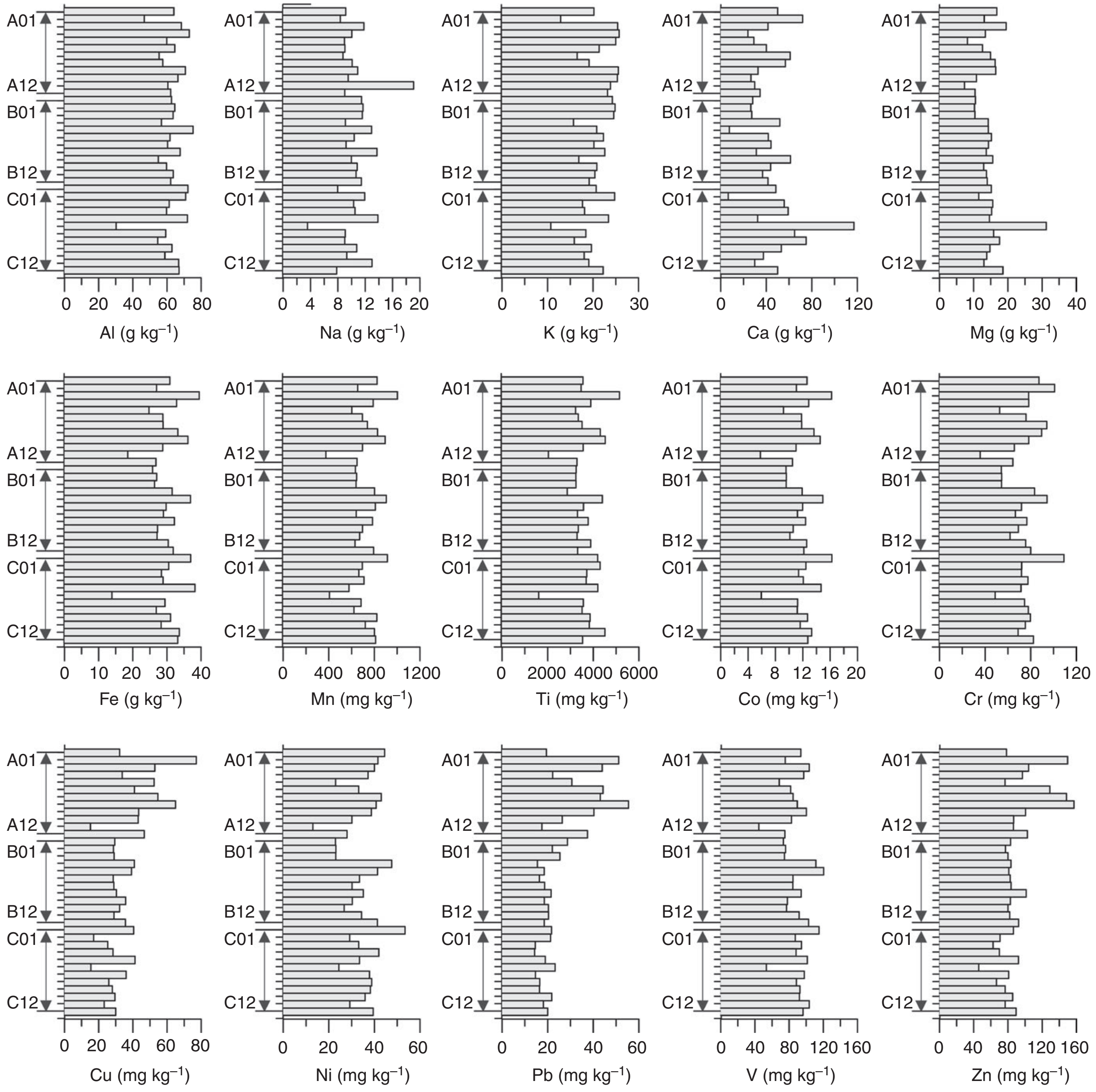

FIGURE 2 The contents of the major and potentially toxic elements

& Olu-Owolabi, 2003). The influences of heavy metal pollution (Zn, Pb and Cd) induced by traffic in the vicinity of a highway (A31, France) can reach up to 320 m, but the maximum contamination is observed between 5 and 20 m (Viard, Pihan, Promeyrat, & Pihan, 2004). In the city of Kavala (Greece), pollution decreased sharply with distance and reached a natural background level at approximately 50 m (Yassoglou, Kosmas, Asimakopoulos, & Kallianou, 1987). In Chinese pollution assessments of PTEs in farmland soils adjacent to a superhighway, Cu, Pb and Zn concentrations decreased with increasing distance from the superhighway within a 320 m range (Qin, Lou, Jiang, & Liang, 2009; Ruan & Jiang, 1999), which suggested possible differences in the traffic environments.

3.2 | Risk assessment of potentially toxic element pollutants affected by human activities

The analytical results of the PCA confirmed that Fe is a conservative element; therefore, the major element Fe was designated as the reference element. The contents of Fe and the anthropogenically influenced PTEs Pb, Zn and Cu in

TABLE 1 Eigenvalues and the total and cumulative % of variance

	Initial eigenvalues			Rotation sums of squared loadings		
Factors	**Total**	**% of variance**	**Cumulative %**	**Total**	**% of variance**	**Cumulative %**
1	6.50	43.35	43.35	6.07	40.44	40.44
2	3.96	26.37	69.72	3.97	26.46	66.90
3	2.40	16.02	85.74	2.83	18.84	85.74
4	0.71	4.72	90.46			
5	0.51	3.37	93.84			
6	0.26	1.70	95.54			
7	0.19	1.25	96.79			
8	0.18	1.23	98.02			
9	0.12	0.80	98.81			
10	0.07	0.49	99.31			
11	0.05	0.31	99.62			
12	0.03	0.18	99.80			
13	0.02	0.14	99.94			
14	0.01	0.04	99.98			
15	0.00	0.02	100.00			

Note. Extraction method: principal component analysis.

TABLE 2 Rotated component matrix (PCA loadings >0.5 are shown in bold)

Elements	**F1**[a]	**F2**[a]	**F3**[a]
Al	**0.59**	**0.77**	−0.12
Na	−0.04	**0.77**	−0.13
K	0.08	**0.88**	−0.01
Ca	−0.20	−0.93	0.05
Mg	0.17	−0.80	−0.18
Fe	**0.93**	0.29	0.11
Mn	**0.89**	0.07	0.15
Ti	**0.82**	0.33	0.16
Co	**0.97**	0.12	0.13
Cr	**0.82**	−0.32	0.33
Cu	0.26	−0.09	**0.89**
Ni	**0.83**	−0.42	0.17
Pb	−0.01	−0.02	**0.94**
V	**0.96**	0.01	−0.12
Zn	0.17	0.04	**0.93**

[a] Extraction method: principal component analysis. Rotation method: varimax with Kaiser normalization. Rotation converged in five iterations.

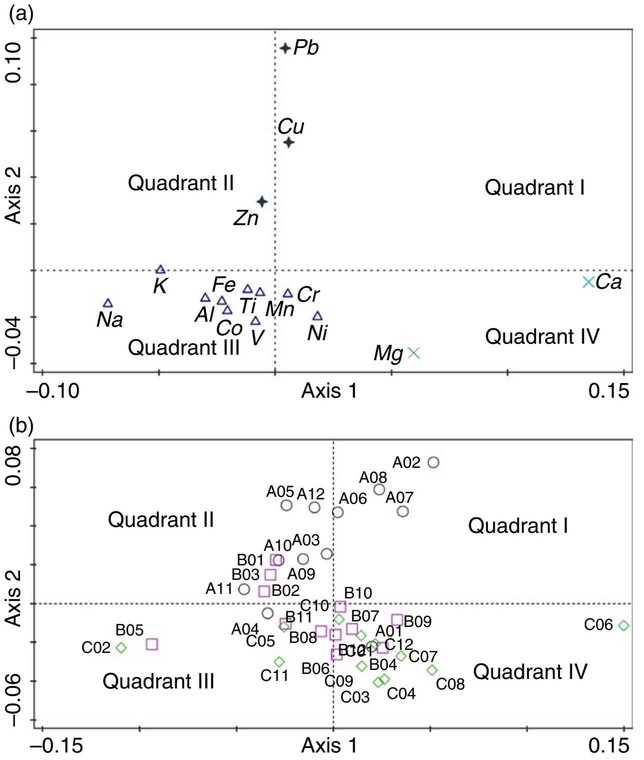

FIGURE 3 The factors influencing the samples and elements derived from a detrended correspondence analysis

quadrants III and IV (Figure 3) were used as the natural background values. The calculated results in Table 3 show that the EF and AC of Pb were the highest, with average values of 2.0 and 47.4%, respectively, suggesting significant enrichments in PTEs (Pb, Zn and Cu). Based on the risk assessment for potentially toxic element pollutants, the HQs of Zn, Cu and Pb (regarding the ingestion of surface soils) were higher than those for inhalation and dermal absorption, and the HQs of Pb were the highest. The highest HI values for Pb, Zn and Cu were 4.5×10^{-2}, 1.5×10^{-3} and 5.4×10^{-3}, respectively

TABLE 3 The ratios of anthropogenic contributions and the hazard index (HI) for potentially toxic elements in surface soils

Samples	EF_{Cu}	EF_{Pb}	EF_{Zn}	Cu_{auth} %	Pb_{auth} %	Zn_{auth} %	HI_{Cu}	HI_{Pb}	HI_{Zn}
A02	2.8	3.1	2.1	64.7	67.5	52.4	5.4×10^{-3}	4.1×10^{-2}	1.4×10^{-3}
A03	1.3	1.8	1.0	24.5	44.5	0.0	3.7×10^{-3}	3.5×10^{-2}	9.7×10^{-4}
A05	2.1	2.0	1.2	52.2	50.0	14.4	3.6×10^{-3}	2.5×10^{-2}	7.1×10^{-4}
A06	1.4	2.5	1.7	28.7	59.8	40.9	2.8×10^{-3}	3.6×10^{-2}	1.2×10^{-3}
A07	1.9	2.4	1.9	46.5	58.5	48.5	3.8×10^{-3}	3.5×10^{-2}	1.4×10^{-3}
A08	1.9	2.7	1.8	48.3	63.0	44.2	4.5×10^{-3}	4.5×10^{-2}	1.5×10^{-3}
A09	1.2	1.8	1.1	15.6	44.5	4.9	3.0×10^{-3}	3.2×10^{-2}	9.4×10^{-4}
A10	1.5	1.5	1.1	32.4	32.7	12.1	3.0×10^{-3}	2.1×10^{-2}	8.1×10^{-4}
A11	0.8	1.5	1.8	-	34.6	43.2	1.1×10^{-3}	1.4×10^{-2}	8.1×10^{-4}
A12	1.7	2.3	1.4	41.9	55.8	31.0	3.2×10^{-3}	3.0×10^{-2}	9.6×10^{-4}
B01	1.1	1.8	1.2	11.1	44.4	17.8	2.0×10^{-3}	2.3×10^{-2}	7.8×10^{-4}
B02	1.0	1.3	1.1	4.6	24.4	7.3	2.0×10^{-3}	1.8×10^{-2}	7.2×10^{-4}
B03	1.1	1.6	1.1	7.9	35.7	12.7	2.0×10^{-3}	2.0×10^{-2}	7.5×10^{-4}
Average	1.5	2.0	1.4	31.5	47.4	25.3	3.1×10^{-3}	2.9×10^{-2}	9.9×10^{-4}
Maximum	2.8	3.1	2.1	64.7	67.5	52.4	5.4×10^{-3}	4.5×10^{-2}	1.5×10^{-3}
Minimum	0.8	1.3	1.0	4.6	24.4	0.0	1.1×10^{-3}	1.4×10^{-2}	7.1×10^{-4}

(Table 3). The HI values suggested that there were no noncarcinogenic risks for any of the anthropogenic PTEs.

Through the above analysis, two important arguments can be made. One argument is derived from the geochemical survey. Soil investigations of geochemical baselines (Salminen & Gregorauskien, 2000), which are fundamental and valuable for the assessment of PTE contamination (Okedeyi, Dube, Awofolu, & Nindi, 2014; Wu et al., 2015; Zahra, Hashmi, Malik, & Ahmed, 2014), should avoid sampling within 200 m of the highway in this region. The other argument can be made for food cultivation. Despite the difference in transfer coefficients describing the transfer of PTEs from soil to plant, crops grown in contaminated soils accumulate higher amounts of PTEs than those grown in uncontaminated soils (Intawongse & Dean, 2006; Tasrina Rc & Ali, 2015). The absorption of PTEs through foods may lead to the disruption of biological processes in the human body (Jolly, Islam, & Akbar, 2013). According to the research results in this area, farmlands should be far from the road, at least 200 m away.

4 | CONCLUSIONS

With mathematical methods and a model for health risk assessment, anthropogenically disturbed PTEs and anthropogenically influenced topsoils in a suburban region in Bishkek were revealed. The results were as follows:

1. Major elements and PTEs (Al, K, Na, Ca, Mg, Fe, Mn, Ti, V, Cr and Ni) were affected by natural processes. The PTEs (Pb, Zn and Cu) were strongly affected by human traffic and transportation activities.
2. Topsoil samples collected within a distance threshold of 200 m from the highway had high contents of PTEs (Pb, Zn and Cu) and were strongly affected by the presence of traffic, and the anthropogenic effects decreased significantly with increasing distance from the highway.
3. Among the PTEs (Pb, Zn and Cu), the EF and AC of Pb were the highest, with average values of 2.0% and 47.4%, respectively, suggesting significant enrichment. However, the HIs were less than one, suggesting that there were no noncarcinogenic risks for any of the anthropogenic PTEs.

ACKNOWLEDGEMENTS

This study was supported by the Strategic Priority Research Program of Chinese Academy of Sciences (Grant No. XDA20060303), West Light Foundation of Chinese Academy of Sciences (Grant No. 2016-QNXZ-A-4) and National Natural Science Foundation of China (Grant No. 41471173). The authors also gratefully acknowledge the Youth Innovation Promotion Association, Chinese Academy of Sciences.

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How to cite this article: Ma L, Abuduwaili J, Li Y, Liu W. Anthropogenically disturbed potentially toxic elements in roadside topsoils of a suburban region of Bishkek, Central Asia. *Soil Use Manage*. 2019;00:1–10. https://doi.org/10.1111/sum.12470