

Original Research

Health Risk Assessment and Source Analysis of Toxic Element Pollution In Cultivated Soils of the Weigan and Kuqa Rivers Oasis in Xinjiang, China

Kawuqiati Baishan¹, Xuemei Wang^{1,2*}, Xiaoyu Huang¹, Mamattursun Eziz^{1,2}

¹College of Geographic Science and Tourism, Xinjiang Normal University, Urumqi 830054, China

²Xinjiang Arid Lake Environment and Resources Laboratory, Urumqi 830054, China

Received: 27 February 2023

Accepted: 15 May 2023

Abstract

Given the importance of exploration on current toxic element contamination in dryland soils and its health risks for preventing toxic element pollution, this paper studied the Weigan and Kuqa rivers oasis in the Xinjiang Uygur autonomous region, China, and investigated 98 plow soil samples of different land-use types, to explore the accumulation characteristics of risk element (As) and five heavy metals (Cr, Cd, Zn, Pb, Cu) in soils. Specifically, pollution index (P_i), Nemerow composite pollution index (P_n), and geo-accumulation index (I_{geo}) were used to understand the spatial distribution of six elements; while correlation, principal component, and cluster analysis to evaluate the health risk. Results show the average concentrations ($\text{mg}\cdot\text{kg}^{-1}$) of six elements in the cultivated layer: Zn (71.09), Cr (52.24), Cu (24.74), Pb (15.57), As (11.67), and Cd (0.15), among which As, Cr, Cd, and Zn were higher than the background value of Xinjiang soils by 1.04, 1.06, 1.25, and 1.03 times, respectively. Such pollution mainly troubles the eastern and northeastern parts, i.e., around the city of Kuqa, and the pollution indices from large to small were Cd, Cr, As, Zn, Cu, and Pb. Besides, despite the absence of non-carcinogenic risk, cancer risk is above the acceptable level, with children being the more vulnerable group. The non-carcinogenic risk can be largely explained by Zn and the carcinogenic risk by Cr, so the toxic element pollution mostly results from the petroleum processing industry and vehicular traffic, followed by input from other anthropogenic sources and natural soil formation.

Keywords: toxic element pollution, spatial distribution features, health risk assessment, source analysis, Weigan and Kuqa Rivers Oasis

Introduction

Toxic elements in soils have become an environmental concern [1] with the increasingly severe pollution caused by booming industrialization and excessive anthropogenic activities, such as nonferrous metal mining and smelting, industrial activities, fertilizer and herbicide applications, wastewater irrigation, and vehicular traffic [2]. These persistent and complex, metals are difficult to mitigate, and can evolve into a global concern for ecosystem and human life when accumulating [3, 4]. Besides, those adsorbed on the surface of airborne particles and enriched in surface soils threaten ecological and human health through exposure routes such as oral ingestion, dermal absorption, and inhalation [5, 6]. The extensive studies in the past 2 decades on the characteristics of soil toxic element pollution, spatial and temporal differentiation, pollution traceability and risk transmission, ecological risk, toxicology, and health effect [7] contribute much to the in-depth identification of their risks to human and environment, and facilitate the creation and maintenance of a greener, safer, and healthier living surroundings and natural environment. Such studies usually use enrichment factor (EF), pollution index (PI), pollution load index (PLI), and geo-accumulation index (I_{geo}) [8-10], and models including chemical mass balance (CMB) [11], principal component analysis/cluster analysis-multiple linear regression (PCA/FA-MLR) [12], positive definite matrix factorization (PMF), UNMIX [13] isotope ratio, etc. [14]. Besides, the health risk assessment, which has been developed since the 1980s, quantitatively describes the harm of environmental pollution to human health [15].

Weigan and Kuqa rivers oasis, the study area, which has long engaged in cotton and agricultural production using early artificial irrigation, is home to copper, medium-and-small coal mines, and several other mining sites [16]. It's proved that industrial activities can release toxic elements into the surrounding environment, which, in turn, produces certain amount of toxic elements [17-19]. Accordingly, risk element (As) and heavy metal elements (Cr, Cd, Zn, Pb, and Cu) are widely found in the cultivated layer of soil in South of Xinjiang because of its thriving petrochemical industry and unreasonable use of pesticides and fertilizers [20]. What's worse, such elements are highly toxic, carcinogenic and difficult to degrade. Once inside human body, the toxic elements in high concentration undermine physiological functions, biochemical reactions, and human health. To be specific, pesticides, insecticides, herbicides, veterinary drugs, and human medications contain As, higher exposure to which cripples the immune system and cause organ and skin diseases [21]; Cr accumulated in the body causes skin ulcers and eczema, Liver damage, respiratory tract cancer, glomerular necrosis, and pneumonia [22]; high exposure to Cd caused by inhaled dust and fumes leads to obstructive lung disease and Cd pneumonia [23]; Zn is a trace element in the body, both high and

low level of which incur related diseases [24], because the lack of Zn results in skin damage, nervous system disorders, and decreased immunity, while too much Zn brings about zinc poisoning and symptoms such as vomiting and diarrhea [25]. High concentration of Pb disrupts normal physiological process and neurological development [26]. And Cu explains the chronic toxicity in the form of neurological weakness, metabolic disorders, cellular carcinogenesis, and brain tissue damage [22]. The above demonstrates the practical significance of researches on the spatial distribution of toxic elements and the health risk assessment in the oasis area of South Xinjiang. In reality, the toxic element contamination of the soil in this oasis caused by the petrochemical industry, transportation, and agricultural activities, and the derived health risks, remain unknown. Therefore, this paper studies the geological accumulation of the risk element (As) and five heavy metals (Cr, Cd, Zn, Pb, Cu) there through soil samples collection to clarify the status quo of soil toxic element pollution, elucidates the contamination degree and the health risk using pollution index (P_i), Nemerow Composite Pollution Index (P_n), geo-accumulation index (I_{geo}), and human health risk assessment. Meanwhile, the sources of the six elements are analyzed based on correlation analysis, principal component analysis, and cluster analysis to unveil the causes of toxic element pollution in cultivated soils, which will provide a scientific basis for the prevention and control of toxic element pollution in dryland soil, and clarify its importance for ecological cities and human health.

Materials and Methods

Study Area

The Weigan and Kuqa rivers oasis in Xinjiang, China, located at 39°30'-42°40'N, 81°27'-84°07'E, is a fan-shaped plain oasis that consists of Kuqa, Shaya, and Xinhe counties in the Aksu region of Xinjiang (Fig. 1). It is endowed with unique geomorphology featuring frequent occurrence of yellow sand; while the elevation is from high to low in the order of northern, inner plains, and southern desert areas [27]. In terms of climate, an arid continental climate dominates, which means a huge difference in daily temperature, hot and dry summers, cold and dry winters, and lower temperature in the north and higher temperature in the south caused by topography. Besides, its long distance from the sea blocks water vapor, leading to low precipitation and rapid evaporation.

Sample Collection and Preparation

In mid to late July 2019, 98 points evenly distributed among the Weigan and Kuqa rivers oasis were selected according to land-use type. Soil samples were taken at the center of each 50 m×50 m sample square in the

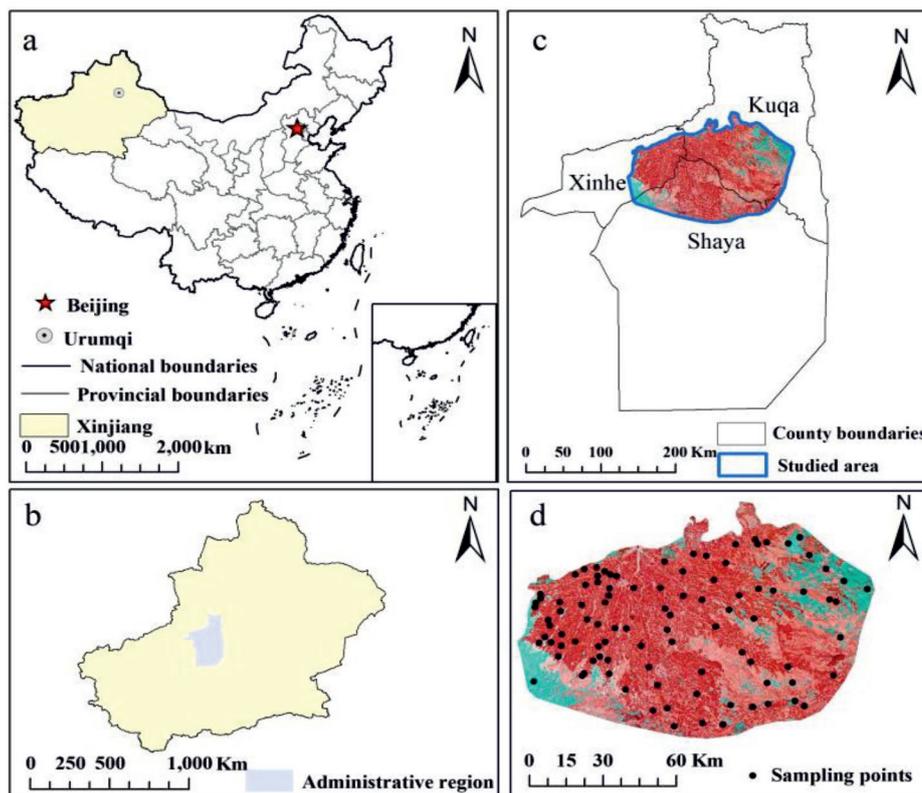


Fig. 1. Location of the study area and sample collecting points.

top soil layer of 0-20 cm, with a soil weight of 500 g per sample point. To minimize heterogeneity and uncertainty, a plume-shaped sampling method was employed, during which gravel and plant roots were removed. The samples were sealed in polyethylene self-sealing bags, labeled, and transported back to the laboratory, which were then dried naturally at room temperature, ground with a ball mill, passed through a 100-mesh- nylon sieve, and stored in a grinding brown bottle for later use. All samples were sent to Xinjiang Uygur Autonomous Region Institute of Analysis and Testing for tests as per relevant specifications. Specifically, As was determined by atomic fluorescence photometry, Cr, Cd, Zn, and Pb by flame atomic absorption spectrophotometry, while Cu by an inductively coupled plasma emission spectrometer. The element content was determined based on the National Soil Standard Reference Material GBW07426 (GSS-12) and the quality control of duplicate samples, which revealed the recoveries of the six elements to be within 90%~105% and acceptable.

Assessment Methods

The Pollution Index (P_i) and Nemerow Composite Pollution Index (P_n)

This paper takes the background value for Xinjiang soil [28] as reference. With one-factor index and Nemerow composite pollution index [29], the toxic

element pollution of a single element and a combination of multiple pollutants were evaluated, respectively. The formulae are as follows:

$$P_i = C_i / S_i \tag{1}$$

$$P_n = \sqrt{\frac{P_{i\max}^2 + P_{i\text{ave}}^2}{2}} \tag{2}$$

In Formula (1), P_i , C_i , and S_i respectively refers to the single factor pollution index, content value, and reference ratio of heavy metal I. In Formula (2), P_n stands for the comprehensive pollution index, while $P_{i\max}$ and $P_{i\text{ave}}$ the maximum value of the single factor pollution index and the arithmetic mean value of multiple single factor pollution indices, respectively. Besides, P_i and P_n were graded into 5 levels: <0.7 suggests non-polluting, 0.7~1.0 alert value, 1.0~2.0 light pollution, 2.0~3.0 moderate pollution, while >3.0 heavy pollution.

Index of Geo-Accumulation, I_{geo}

The Index of Geo-accumulation (I_{geo}), first proposed by Müller (1969) [30], is a frequently adopted quantitative approach for studies concerning heavy metal accumulation in soil. The formula is:

$$I_{geo} = \text{Log}_2[C_i / (K \times C_n^i)] \quad (3)$$

where I_{geo} represents the ground accumulation index for heavy metals; while C_i and the measured content and the reference background value for heavy metal I , respectively. In this paper, the Xinjiang soil environmental background values were taken as reference background values [31]. To eliminate possible differences among background values caused by local geology (K is generally constant to be 1.5), I_{geo} pollution scale is categorized into 7 levels: ≤ 0 , no pollution; $0 < I_{geo} \leq 1$, light pollution; $1 < I_{geo} \leq 2$, moderate pollution; $2 < I_{geo} < 3$, moderate to heavy pollution; $3 \leq I_{geo} < 4$, heavy pollution; $4 \leq I_{geo} < 5$, heavy to extreme pollution; and $I_{geo} \geq 5$, serious pollution.

Health Risk Assessment

The US EPA's Integrated Risk Information System (IRIS) and International Agency for Research on Cancer (IARC) validate the harm of trace amounts of heavy metals and other carcinogenic risk factors in the soil for human health [32]. Among which, US EPA only mentions oncogenes slope (SF) values for As, Cr, and Cd. Therefore, this paper explores the carcinogenic risk of As, Cr, and Cd, which are more toxic, to clarify the health risk characterization of children and adults near or in contact with the area. Soil toxic elements can enter the human body through multiple routes, including ingestion, dermal, and inhalation, and humans with chemical exposure may suffer from non-carcinogenic or carcinogenic risks [33]. The average daily exposure of adults and children to the six soil toxic elements under the three routes are calculated according to the specific formulae below:

$$\text{ADD}_{ing} = \frac{c \times IRG \times CF \times EF \times ED}{BW \times AT} \quad (4)$$

$$\text{ADD}_{inh} = \frac{c \times IRG \times EF \times ED}{PEF \times BW \times AT} \quad (5)$$

$$\text{ADD}_{derm} = \frac{c \times CF \times SA \times AF \times ABS \times EF \times ED}{BW \times AT} \quad (6)$$

Where ADD_{ing} , ADD_{inh} , and ADD_{derm} refer to the average daily exposure to ingestion, inhalation, and dermal, respectively (unit: $\text{mg} \cdot (\text{kg} \cdot \text{d})^{-1}$); while c is the concentration of heavy metals in the sample. The parameters like average weight and exposure duration are not fixed considering the physiological characteristics and behaviors of adults and children. Table 1 demonstrates all parameters.

All six elements present chronic non-carcinogenic health risks, while As, Cr, and Cd bring carcinogenic risks. Non-carcinogenic Risk Quotient (HQ) and Total Non-carcinogenic Risk Index (HI) for heavy metals were calculated as follows:

$$\text{HQ} = \frac{\text{ADD}}{\text{Rfd}} \quad (7)$$

$$\text{HI} = \sum \text{HQ} = \text{HQ}_{ing} + \text{HQ}_{inh} + \text{HQ}_{derm} \quad (8)$$

where ADD denotes the average daily exposure to non-carcinogenic heavy metal, while RfD (reference dose value) the reference dose for exposure pathways to non-carcinogenic heavy metals. HQ or HI < 1 indicates negligible non-carcinogenic health risk from heavy soil metals, and HQ or HI > 1 supports the presence of such risk [37].

Table 1 Health Risk Assessment Parameters.

Parameters	Physical Significance	Unit	Reference value		References
			Adults	Children	
<i>ED</i>	Exposure duration	<i>a</i>	24	6	[33]
<i>EF</i>	Exposure frequency	<i>d/a</i>	350	350	[34]
<i>BW</i>	Body weight	<i>kg</i>	55.9	15	[35]
<i>AT</i> (Non carcinogenic)	Average time	<i>d</i>	8760	2190	[34]
<i>AT</i> (Carcinogenic)	Average time	<i>d</i>	27740	27740	[34]
<i>AF</i>	Adherence factor to skin	<i>mg/(cm²·d)</i>	0.07	0.20	[33]
<i>REG</i>	Daily intake of soil particles	<i>mg/d</i>	100	200	[33]
<i>IRH</i>	Daily air-breathing volume	<i>m³/d</i>	14.5	7.5	[34]
<i>SA</i>	Skin surface area exposed	<i>cm²/d</i>	4350	1600	[36]
<i>ABS</i>	Dermal absorption factor	non-dimensional	0.001	0.001	[33]
<i>CF</i>	Internal conversion coefficient	<i>kg/mg</i>	1×10^{-6}	1×10^{-6}	[33]
<i>PEF</i>	Particle emission factor	<i>m³/kg</i>	1.36×10^9	1.36×10^9	[33]

Table 2. Toxic elements Risk Reference Slope coefficient (SF) and Reference Dose Value (RfD).

Elements	RfD (mg·kg ⁻¹ ·d ⁻¹)			SF respiratory intake	Reference
	Diet intake	Skin intake	Respiratory intake		
As	3×10 ⁻⁴	1.23×10 ⁻⁴	3.01×10 ⁻⁴	1.50	[39]
Cr	3×10 ⁻³	6×10 ⁻⁵	2.86×10 ⁻⁵	42.00	[40]
Cd	1×10 ⁻³	1×10 ⁻⁵	1×10 ⁻³	7.05	[40]
Zn	0.3	0.06	0.3	—	[40]
Pb	3.50×10 ⁻³	5.25×10 ⁻³	3.52×10 ⁻³	—	[40]
Cu	4×10 ⁻²	1.20×10 ⁻²	4×10 ⁻²	—	[39]

Potential Carcinogenic Risk Value (CR) and Total Carcinogenic Risk Value (TCR) for heavy metals [38] were determined as follows:

$$CR = ADD \times SF \quad (9)$$

$$TCR = \sum CR = CR_{ing} + CR_{inh} + CR_{derm} \quad (10)$$

where CR represents the carcinogenic risk value of a single heavy metal, and SF the carcinogenic risk reference slope factor. $CR/TCR < 10^{-6}$ indicates an acceptable risk of cancer, $10^{-6} < CR/TCR < 10^{-4}$ certain risk, while $10^{-4} < CR/TCR$ carcinogenic risk. Table 2 describes the SF and RfD of the heavy metals.

Results and Analysis

This paper investigated the toxic elements in the cultivated soils of the Weigan and Kuqa rivers oasis using the single-factor index, Nemero comprehensive pollution index, and ground accumulation index, and introduced the human health risk evaluation method to evaluate the pollution and risk of the heavy metals. Besides, the sources of such elements were analyzed

by correlation analysis, principal component analysis, and cluster analysis, and the causes of heavy metal pollution there were explored.

Analysis and Spatial Distribution of Toxic Elements in the Soil

Table 3, which demonstrates the characteristics of the six elements in the cultivated soil, shows their average contents (mg·kg⁻¹), that is, As (11.67), Cr (52.24), Cd (0.15), Zn (71.09), Pb (15.57), and Cu (24.74), among which Zn and Cr account for above 70% of the total, while Cd the lowest. Besides, deviation coefficient is an index that reveals the distribution pattern of the data, and the larger its absolute value, the greater the skewness of the distribution pattern [20]. As can be seen, the deviation coefficients of these elements were 1.08 (As), 0.34 (Cr), -0.19 (Cd), -0.41 (Zn), -0.09 (Pb), and 0.12 (Cu), with As being the largest. As for Kurtosis coefficient, an index that reveals the distribution steepness of all values, the larger its absolute value, the greater the distribution steepness, and the greater the difference between the steepness of the distribution and the normal distribution [41]. As shown in Table 3, As exhibited the largest Kurtosis coefficient, while Pb

Table 3. Statistical analysis of soil toxic elements in the study area.

Items	As	Cr	Cd	Zn	Pb	Cu
Minimum (mg·kg ⁻¹)	4.35	15	0.06	21	9.20	8
Maximum (mg·kg ⁻¹)	22.80	86	0.25	105	23.30	42
Average (mg·kg ⁻¹)	11.67	52.24	0.15	71.09	15.57	24.74
Standard deviation (mg·kg ⁻¹)	2.99	13.31	0.04	15.58	3.10	7.03
Coefficient of variation/%	25.70	25.49	29.69	21.91	19.91	28.41
Skewness	1.08	0.34	-0.19	-0.41	-0.09	0.12
Kurtosis	3.44	0.33	-0.79	0.77	-0.15	0.25
Agricultural land screening value (mg·kg ⁻¹)	25	250	0.6	300	170	100
Background value of Xinjiang soil (mg·kg ⁻¹)	11.20	49.30	0.12	68.80	19.40	26.70
The agricultural land control value (mg·kg ⁻¹)	100	1300	4	—	1000	—

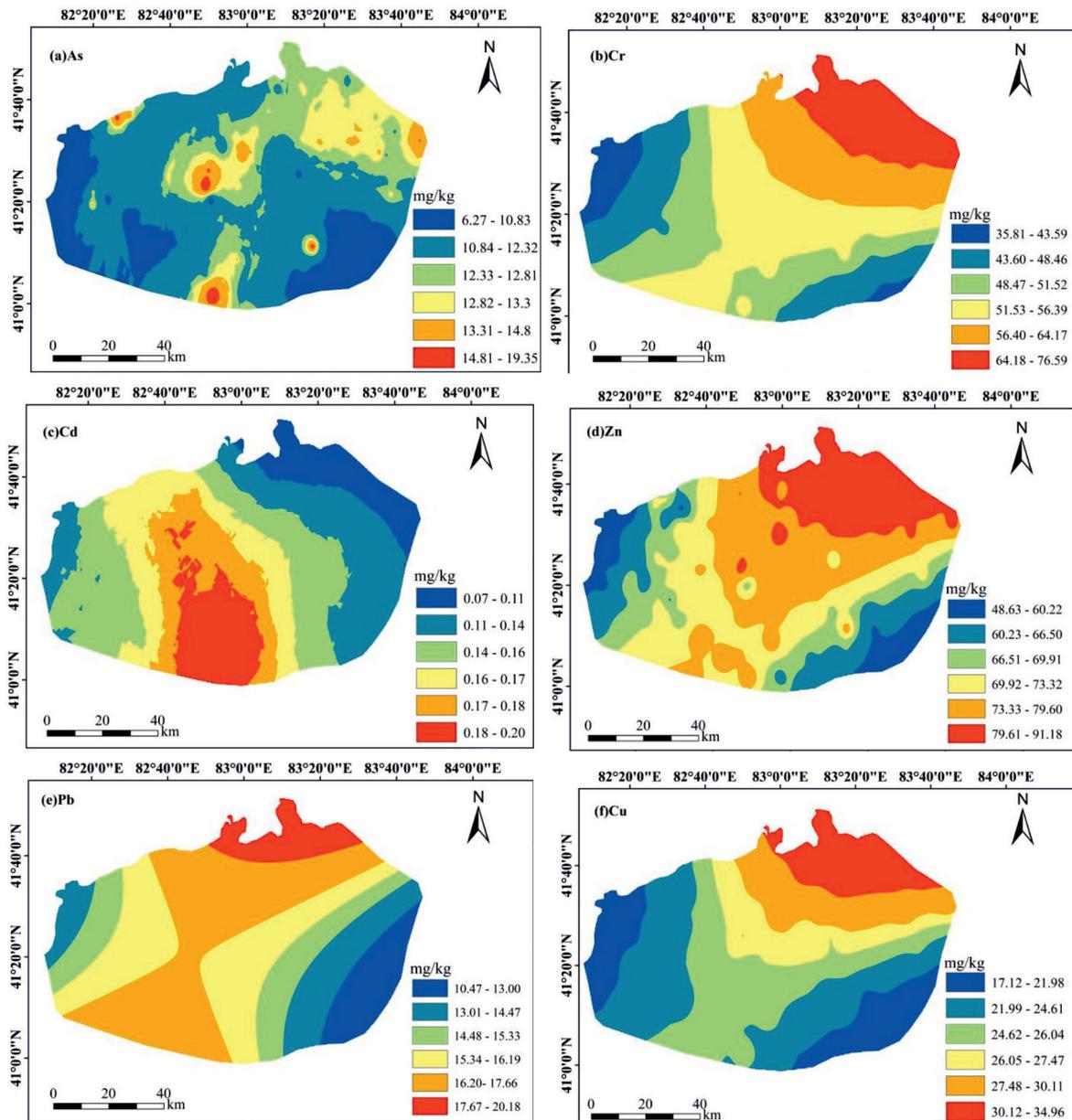


Fig. 2. Spatial distribution map of toxic soil elements in the study area.

the smallest. Accordingly, As performed high deviation coefficient and Kurtosis coefficient, indicating its high content and accumulation in the samples. Meanwhile, the deviation coefficient and Kurtosis coefficient of Pb are both small, proving its near-normal distribution in topsoil, and so do the other four heavy metals. In terms of the coefficient of variation (CV), which reflects the average variation degree in the heavy metal content at various points, a CV value greater than 50% suggests the uneven spatial distribution of heavy metal content, and the possible existence of point source pollution caused by exogenous substances [28]. The CV of these elements from large to small is Cd (29.69), Cu (28.41), As (25.70), Cr (25.49), Zn (21.91), and Pb (19.91), ranging from 20% to 50%, which validates the relative uniform spatial distribution of their contents and their certain immunity to external environment.

To elaborate the geospatial distribution of toxic elements, the Kriging interpolation method was employed to analyze the spatial interpolation of toxic elements in the soil, thus obtaining their spatial distribution (Fig. 2). According to the results, Cr, Zn, Pb, and Cu are found in small amounts in the western and southern regions, and in large amounts in the eastern and northeastern regions, which can be explained by the thriving urbanization in the latter parts, including oil processing plants and pollutants discharged by related industries, such as waste gas and sewage. As and Cd, whose spatial distribution patterns are swayed by natural factors including soil parent materials, topographic conditions, and hydrology, abound in the central and southern regions. Cr and Zn present similar spatial distribution patterns, bringing slight pollution to most sectors. Specifically, Cr containing pollutants

and 59.18% of the total, respectively. (Fig. 3) reveals the relatively low pollution of Pb and Cu (accounting for 69.39% and 48.98%) compared with the background value, which lies in the range of "alert". Besides, the evaluation of P_n supports the light pollution of all samples.

According to Fig. 3b) and Table 5, the I_{geo} indices are, in descending order of magnitude, Cd (-0.33), Cr (-0.55), As (-0.57), Zn (-0.58), Cu (-0.76), and Pb (-0.93), among which the last three perform low contamination with 97.96%, 100%, and 97.96% of no contamination, respectively. When it comes to Cd, I_{geo} illustrates that 74.49% of sample sites display no pollution, while 25.51% light pollution.

Human Health Risk Assessment

(Table 6, 7) elucidate the non-carcinogenic and carcinogenic risks for adults and children through health risk assessment model. The pathways (HQ) connecting soil toxic elements and sufferers are dominated by ingestion, followed by dermal and inhalation. Children are generally more prone to non-carcinogenic risk than adults, which can be attributed to their developing organs (consistent with earlier studies) [43, 44], their more exposure to soil particles contaminated with toxic elements caused by their play areas, unhealthy eating habits, and more sensitive reaction to environmental pollution [45]. HI shows that the non-carcinogenic risks to adults from six elements are in the descending order of Zn, Cu, Cr, Pb, As, and Cd, and the same is true for children, which exposes the huge threat of Zn, Cu, and Cr, calling for more attention and human protection measures. On the other hand, HI of the six elements are less than 1 for both adults and children,

which is acceptable. The CR of the six elements for adults and children in the descending order is Cr, As, and Cd. Among them, As and Cd are within the acceptable range, while Cr has some carcinogenic risk, which shares the results of [37]. The TCR of adults and children deserves more attention and measures from relevant departments.

Source Analysis of Toxic Elements in Soil

The Spearman correlation coefficient is adopted to analyze the relation between source and migration for toxic elements in soil (Fig. 4), which visually reflects the closeness between the elements. The high correlation ($P < 0.001$) between As, Cr, Zn, and Cu indicates a possible homology, which means their common anthropogenic and natural sources of pollution. In addition, the low correlation between As and Cd, combined with no significant correlation between Cr and Cd, Zn and Cd, Cu and Cd, and Pb and Cr ($P > 0.05$), proves the different sources of these heavy metals and Cd. Furthermore, the toxic elements are elaborated through principal component analysis and cluster analysis to accurately identify their sources.

The toxic elements in soil mainly source from natural and anthropogenic activities, the former of which involves soil-forming parent material, while the latter is the mode and intensity of anthropogenic disturbance. This paper carried out the principal component analysis and cluster analysis for the one risk element and five heavy metals, obtaining the KMO and Bartlett's spherical results of 0.781 and 655.490 ($df = 15, p < 0.01$). In view of the cumulative contribution of variance of toxic elements based on maximum variance rotation (Table 8), the eigenvalues of the three

Table 6. Health Risk Assessment of toxic elements in Weigan and Kuqa Rivers Oasis

Elements	Adult				
	HQ _{ing}	HQ _{inh}	HQ _{dermal}	HI	CR
Zn	3.59E-04	3.82E-08	2.18E-07	3.59E-04	
Pb	9.16E-07	9.83E-11	4.19E-09	9.20E-07	
Cu	1.66E-05	1.77E-09	1.52E-08	1.66E-05	
As-Non carcinogenic risk	5.88E-08	6.29E-12	7.35E-11	5.89E-08	
As-Carcinogenic risk	9.91E-08				9.91E-08
Cr-Non carcinogenic risk	2.63E-06	2.68E-12	1.60E-10	2.63E-06	
Cr-Carcinogenic risk	1.24E-05				1.24E-05
Cd-Non carcinogenic risk	2.54E-09	2.71E-13	7.73E-14	2.54E-09	
Cd-Carcinogenic risk	6.03E-09				6.03E-09
Total	HQ _{ing}	HQ _{inh}	HQ _{dermal}	HI	TCR
Non carcinogenic risk	3.79E-04	4.01E-08	2.38E-07	3.79E-04	
Carcinogenic risk					1.25E-05

Table 7. Health Risk Assessment of toxic elements in Weigan and Kuqa Rivers Oasis.

Elements	Children				
	HQ _{ing}	HQ _{inh}	HQ _{dermal}	HI	CR
Zn	2.67E-03	7.37E-08	8.55E-07	2.67E-03	
Pb	6.83E-06	1.89E-10	1.64E-08	6.85E-06	
Cu	1.24E-04	3.42E-09	5.95E-08	1.24E-04	
As-Non carcinogenic risk	4.39E-07	1.21E-11	2.88E-10	4.39E-07	
As-Carcinogenic risk	4.77E-08				4.77E-08
Cr-Non carcinogenic risk	1.96E-05	5.16E-12	6.28E-10	1.96E-05	
Cr-Carcinogenic risk	5.98E-06				5.98E-06
Cd-Non carcinogenic risk	1.89E-08	5.22E-13	3.03E-13	1.89E-08	
Cd-Carcinogenic risk	2.90E-09				2.90E-09
Total	HQ _{ing}	HQ _{inh}	HQ _{dermal}	HI	TCR
Non-carcinogenic risk	2.82E-03	7.73E-08	9.32E-07	2.82E-03	
Carcinogenic risk					6.03E-06

common factors recorded 3.505, 1.135, and 1.053 in order, with a cumulative contribution of 94.881%, which clarifies most information concerning these metals. The variance contribution of the first principal factor (PC1) was 58.417%, the highest among the three. Specifically, metals such as As, Cr, Zn, and Cu displayed larger positive loads of 0.850, 0.957, 0.926, and 0.945, respectively, and their significant positive correlation ($P < 0.001$) was observed, which confirmed their similar spatial patterns. The variance contribution of the second principal factor (PC2) was 18.911%, and Pb exhibited

a positive load of 0.928, indicating its unique spatial pattern (Table 9), which supports the findings in Fig. 2. The variance contribution of the third principal factor (PC3) was 17.554%, and Cd displayed a positive load of 0.990 (Table 9). The cluster analysis was performed based on the Pearson correlation coefficient of toxic elements to decide whether their sources were similar to other heavy metals. The six elements are categorized into 3 clusters in Fig. 5. As can be seen, cluster 1 includes Zn, Cu, Cr, and As, cluster 2 contains Pb, and cluster 3 contains Cd, which consolidates the findings of principal component analysis, and validates the common pollution source among metals in the same cluster.

Relevant studies show that Zn, Cu, Cr, and As mainly come from industrial plants, enter into soil by atmospheric deposition, and accumulate gradually [46]. In the paper, the small CV of As in the cultivated soil exhibits a more even spatial distribution, suggesting the limited role of anthropogenic activities. In this way, As is concluded to be a natural source element, which is largely affected by parent soil-forming material. Zn is generally employed in automobile tire lubricant, detergents, additives, and antioxidant, which brings Zn-containing dust into the soil [46]. The northern part of the study area is home to oil processing plants, mining, and coal resources around Kuqa, which requires toxic elements as catalysts for petroleum processing [47]. Accordingly, the toxic element pollution in the northeast region worsens, and the dust and waste gas from activities such as mining, smelting, and electroplating accumulate through atmospheric deposition and rain leaching, increasing the amount of Zn in the soil [48]. According to previous studies, Cr mainly derives from metal corrosion and deceleration activities of automobiles [40], and accumulates in the surrounding

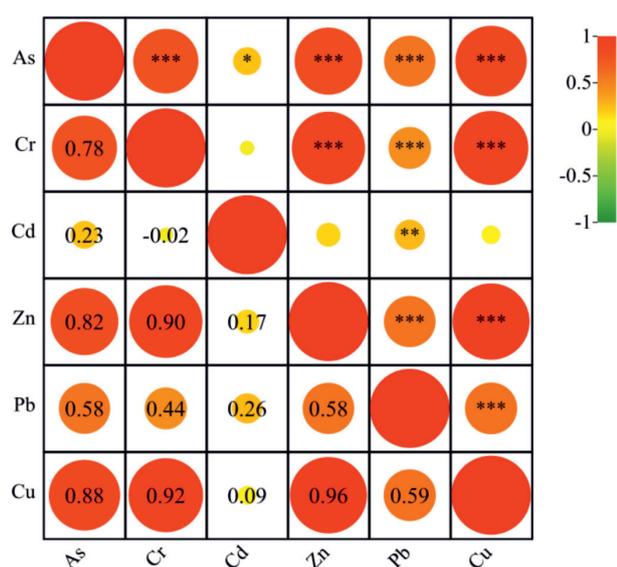


Fig. 4. Pearson correlation analysis between elements. Note: * indicates statistical significance with $P \leq 0.05$, ** indicates statistical significance with $P \leq 0.01$, *** indicates statistical significance with $P \leq 0.001$

Table 8. Characteristic values and cumulative contribution rates of toxic elements in soil.

Element	Initial eigenvalue			Extract the sum of the squares of load and load			Rotational load sum of squares loaded		
	Eigenvalue	Variance /%	Cumulative Variance/%	Characteristic value	Variance /%	Cumulative Variance/%	Eigenvalue	Variance /%	Cumulative Variance/%
1	4.062	67.706	67.706	4.062	67.706	67.706	3.505	58.417	58.417
2	1.086	18.108	85.814	1.086	18.108	85.814	1.135	18.911	77.327
3	0.544	9.067	94.881	0.544	9.067	94.881	1.053	17.554	94.881
4	0.207	3.454	98.335	—	—	—	—	—	—
5	0.074	1.237	99.572	—	—	—	—	—	—
6	0.026	0.428	100.000	—	—	—	—	—	—

Table 9. Principal component factor load of toxic elements in soil.

Elements	Component matrix			Rotational component matrix		
	PC1	PC2	PC3	PC1	PC2	PC3
As	0.914	0.047	0.087	0.850	0.297	0.188
Cr	0.910	-0.287	0.165	0.957	0.125	-0.089
Cd	0.202	0.934	0.287	0.039	0.116	0.990
Zn	0.962	-0.063	0.102	0.926	0.269	0.098
Pb	0.691	0.327	-0.642	0.340	0.928	0.141
Cu	0.977	-0.138	0.060	0.945	0.289	0.016

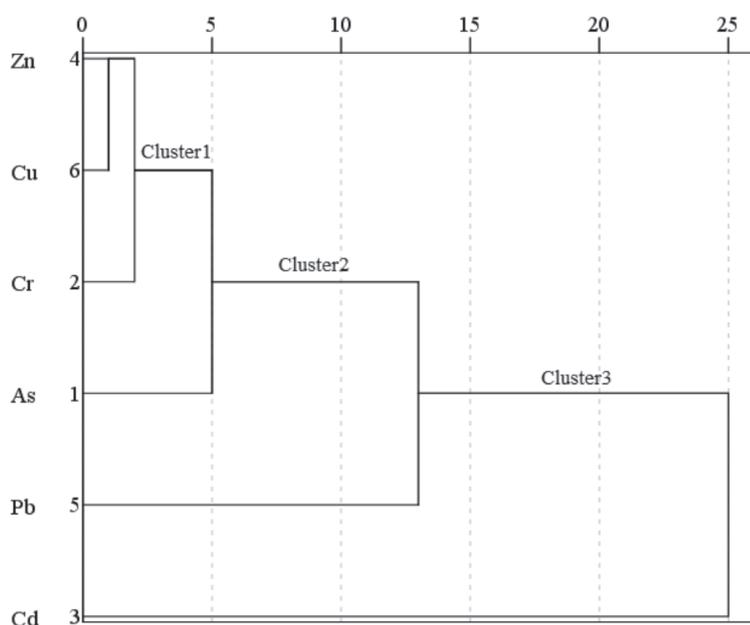


Fig. 5. Analysis of six elements content in the soil.

environment of roads with high traffic density [49]. This paper takes mining, smelting, and processing as essential sources of Cr in the study area based on its load of (PC1). Fig. 2 demonstrates the similar spatial distribution of Zn, Cu, and Cr in the study area, with

a high value in the northeastern part. Therefore, the PC1 may be a mixture of industrial and transportation sources. The load of (PC2) Pb is 0.928, as previously mentioned. Tuerhong et al. [50] considered vehicle emissions to be a vital source of Pb in soil, and heavy

vehicles, in particular, give rise to enormous Pb emissions into the soil. What's worth mentioning is that most sample sites are in proximity to highways, which consolidates the view that the (PC2) Pb mainly derives from traffic pollution. The (PC3) Cd also presents a larger load despite its high variability. The P_i and I_{geo} are evaluated at light pollution levels and no pollution, respectively. The spatial distribution pattern of Cd, which is shaped by natural factors covering regional soil-forming parent material, topographic conditions, and hydrology, reveals high value concentrated in the central and southern parts, validating the commanding role of soil substrate and anthropogenic activities in its sources.

Discussion

Heavy metals in soil enter into the human body through diverse pathways and accumulate to the extent of excess, posing huge threat to health. In this study, the Analysis of six elements content reveals higher average value of As, Cr, Cd, and Zn in the cultivated soil than the background value of Xinjiang soil (Table 3), as well as the lower average value of Pb and Cu, which calls for more attention to the first four elements. Oral ingestion is the most direct route connecting heavy metals in soil and human body, as reported by previous studies [51]. Besides, this paper demonstrates That children are more vulnerable to health risk and metal exposure than adults, which shares the results of related studies [52-54]. It's also confirmed that such higher No-narcinogenic risks in children can be explained by their lower body weight, more outdoor activities, direct dust exposure, high dust intake, and lower pollutant tolerance [5].

The Weigan and Kuqa Rivers Oasis, situated in an area with industrial system consisting of coal mining, petrochemical industry, and oil and gas chemical industry, generates plenty of gas waste that enters the soil through atmospheric dry and wet deposition, and solid waste during landfill and accumulation, owing to natural and human factors. The high value of Cr, Zn, Pb, and Cu in the cultivated soils is mostly observed in the northeastern part of the study area, which mainly comes down to the high traffic flow in the center of Kuqa, the national and rural roads passing through, and industrial emissions. Besides, the high value of Pb, Cr, Zn, and Cu in the northwestern part is attributed to frequent human activities and transportation. Guo et al. have argued that the concentration of Pb, Cu, and Zn is influenced by anthropogenic behavior, While that of As is almost related to natural sources [56]. Han et al. [57] showed that Pb, Zn, and Cu are heavy metal pollutants originating from transportation, Pb mainly sources from fuel combustion in transportation, vehicle engines, and tire friction, while Zn is indispensable in automobiles manufacturing. Adimalla et al. [1] reported that copper and zinc originate directly or indirectly from industrial activities, such as metal processing,

smelting, and waste incineration. Xiao et al. [58] demonstrated that Cd is an enriched element in different soil-forming parent materials, which is consistent with the results of this study. Despite their higher average contents than the background values, As, Cr, Cd, and Zn lies in light pollution range based on their individual ecological risk index calculated by combining the ecological and environmental effects of heavy metals. Cd is the only one among the six with higher ecological risk. In addition, 25.51% soil sample sites are lightly contaminated in the paper, which is consistent with Zheng et al. [59], who evaluated the heavy metal contamination in the soil of polluted irrigation area of Linfen section of the Fen River.

Accurate analysis of soil toxic element sources and their hazards to human health is of great significance for the prevention and control of toxic element pollution in dryland soils. In future research, more detailed collection and analysis of soil toxic element samples under industrial and agricultural production activities will be added, and more scientific soil toxic element risk evaluation and its source analysis will be applied, so as to provide a reference for soil green development and human health.

Conclusions

The pollution degree, health risk, and sources of six elements in the soil, that is, As, Cr, Cd, Zn, Pb, and Cu, are identified in the paper by exploring their spatial distribution among 98 soil samples in the Weigan and Kuqa Rivers Oasis, Xinjiang. The following conclusions are drawn: six elements covering As, Cr, Cd, and Zn, whose average values surpassed the background values of Xinjiang soil, were lightly polluted, while Cu and Pb presented alert pollution with lower average values. Among the six elements, chromium should be mostly blamed for carcinogenic risk faced by both adults and children, followed by Cu and Cr. HI for the six elements is less than 1 for both adults and children. In addition, the toxic elements that cause the most pollution do not necessarily pose the greatest health risk. According to health risk assessment, the carcinogenic risks of As and Cd are within the acceptable range, while that of Cr for children deserves further research. Children are more prone to carcinogenic and non-carcinogenic risks caused by soil toxic elements, and relevant departments with more corresponding measures should notice the TCR of adults and children. Among the heavy metals, Zn contributes most to non-carcinogenic risk, while Cr carcinogenic risk, and the contamination is mainly concentrated in the northeast region and associated with Cr, Zn, Pb and Cu. Furthermore, through correlation analysis, principal component analysis, and cluster analysis, the main sources of As, Cr, Zn, Pb and Cu in the cultivated soils are identified to be a mixture of local industry, traffic, and anthropogenic activities, the main source of Pb is traffic pollution, while that of Cd is

natural soil-forming parent material and anthropogenic activities.

Acknowledgments

This research was funded by National Natural Science Foundation of China, grant number 41561051 and by Natural Science Foundation of Xinjiang Uygur Autonomous Region, China, grant number 2020D01A79. We acknowledge Xinjiang Uygur Autonomous Region analysis and testing Institute of China for measuring the content of soil.

Conflict of interest

The authors declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work.

References

- ADIMALLA N. Heavy metals pollution assessment and its associated human health risk evaluation of urban soils from Indian cities: a review. *Environmental geochemistry and health*, **42** (1), 173, **2020**.
- WANG Y., GUO G., ZHANG D., LEI M. An integrated method for source apportionment of heavy metal (oids) s in agricultural soils and model uncertainty analysis. *Environmental Pollution*, **276**, 116666, **2021**.
- KIM J.J., KIM Y.S., KUMAR V. Heavy metal toxicity: An update of chelating therapeutic strategies. *Journal of Trace Elements in Medicine and Biology*, **54**, 226, **2019**.
- ALUKO T., NJOKU K., ADESUYI A., AKINOLA M. Health risk assessment of heavy metals in soil from their mines of Itakpe and Agbaja, Kogi State, Nigeria. *Pollution*, **4** (3), 527, **2018**.
- HOOKER P.J., Nathanail C.P. Risk-based characterisation of lead in urban soils. *Chemical Geology*, **226** (3-4), 340, **2006**.
- DELIBAŠIĆ Š., ĐOKIĆ-KAHVEDŽIĆ N., KARIĆ M., KESKIN I., VELISPAHIĆ A., HUREMOVIĆ J., HERCEG K., SELIMO VIĆ A., SILAJDŽIĆ S., ŽERO S., SALIMOVIĆ S., PARTIĆ A., PAŠALIĆ A. Health risk assessment of Heavy metal contamination in street dust of federation of Bosnia and Herze govina. *Human and Ecological Risk Assessment: An International Journal*, **27** (5), 1296, **2020**.
- ZANG F., LI P., XUE S.Y., WANG S.L., NAN Z.R. Source apportioning of heavy metal concentration in atmospheric dustfall in Lanzhou City. *Journal of Lanzhou University (Natural Sciences)*, **52**, 357, **2016**.
- GUAN Q., WANG F., XU C., PAN N., LIN J., ZHAO R., YANG Y., LUO H. Source apportionment of heavy metals in agricultural soil based on PMF: A case study in Hexi Corridor, northwest China. *Chemosphere*, **193**, 189, **2018**.
- WANG Z., TIAN H., LIN M., MEGHARAJ M., TAN X., WANG F., JIA H., HE W. Soil enzyme kinetics indicate ecotoxicity of longterm arsenic pollution in the soil at field scale. *Ecotoxicology and Environmental Safety*, **191**, 110215, **2020**.
- WU Q., HU W., WANG H., LIU P., WANG X., HUANG B. Spatial distribution, ecological risk and sources of heavy metals in soils from a typical economic development area, Southeastern China. *Science of the Total Environment*, **780**, 146557, **2021**.
- GU Y.G., GAO Y.P. Bioaccessibilities and health implications of heavy metals in exposed-lawn soils from 28 urban parks in the megacity Guang Zhou inferred from an invitrophy sociologically based extraction test. *Ecotoxicology and Environmental Safety*, **148**, 747, **2018**.
- LI J., YANG Z.W., TAN W., YUAN W.Z., JIANG J.Y. Comparative Study on the Simulation Effect of Two Receptor Models in Apportioning the Sources of Soil Heavy Metals. *Research of Environmental Sciences*, **1001**, 6929, **2020**.
- LUO X., XUE Y., WANG Y., CANG L., CANG L., XU B., DING J. Source identification and apportionment of heavy metals in urban soil profiles. *Chemosphere*, **127**, 152, **2015**.
- AI J.C., WANG N. Source Apportionment of Soil Heavy Metals in Jiapigou Goldmine Based on the UNMIX Model. *Environmental Science*, **35** (9), 3530, **2014**.
- SUN S.Q., HU G.H., WANG Y.Z., LI C. Water environmental health risk assessment of Xiangjiang River. *Journal of Safety and Environment*, **6**, 12, **2006**.
- ZHOU J., WANG G., WANG Q., MA H.C., FAN L.S., ZHAO J.H. Preliminary analysis of the geoecological environment of the Gobi Oasis in Xinjiang: a case study of the Weigan and Kuqa river oasis. *Xinjiang Geology*, **37**, 469, **2019**.
- RAHMAN M.S., KHAN M.D., JOLLY Y.N., KABIR J., AKTER S., SALAM A. Assessing risk to human health for heavy metal contaminat ion through street dust in the South-east Asian Megacity: Dhaka, Bangladesh. *Science of The Total Environment*, **660**, 1610, **2019**.
- RAJESHKUMAR S., LIU Y., ZHANG X., RAVIKUMAR B., BAI G., LI X. Studies on seasonal pollution of heavy metals in water, sediment, fish and oyster from the Meiliang Bay of Taihu Lake in China. *Chemosphere*, **191**, 626, **2018**.
- ISLAM M.S., AHMED M.K., AL-MAMUN M.H., EATON D.W. Human and ecological risks of metals in soils under different land-use types in an urban environment of Bangladesh. *Pedosphere*, **30** (2), 201, **2020**.
- WANG Z.J., LIU S.J., ZHENG J., HENG J., YU L.F. Ecological risk assessment of heavy metals in soils of Caohai watershed. *Ecology and Environmental Sciences*, **28** (12), 2438, **2019**.
- KUMAR D., MALIK D.S., PATEL S.L., GUPTA V. Human health risk assessment and mitigation of heavy metal pollution in agriculture and environment. *Contaminants in Agriculture and Environment: Health Risks and Remediation*, **1**, 66, **2019**.
- YANG Y.R., ZHONG Y., LI S.D., DENG M.L. Research progress on the harm of heavy metals to human body in aquatic products. *Agricultural Technology & Equipment*, **55**, 56, **2020**.
- NEMERY B. Metals and the respiratory tract. In *Handbook on the Toxicology of Metals*. Academic Press, **3** (2), 202, **1990**.
- BAI L., HE Z. J., CHEN W.Y., LI N., QIN J., SHEN M.N. Characteristics and source analys is of heavy metal pollution in human hair in different regions of China. *Environmental Monitoring in China*, **36** (01), 105, **2020**.
- ZHANG Y., LIU S.F. Trace element Zn and human health. *Science & Technology Information*, **17**, 253, **2019**.

26. ISLAM M. S., HOSSAIN M. B., MATIN A., SARKER M. S. I. Assessment of heavy metal pollution, distribution and source apportionment in the sediment from Feni River estuary, Bangladesh. *Chemosphere*, **202**, 25, **2018**.
27. TAN J., DING J.L., CHEN W.Q., ANEWAR M., LI X., ZHOU Q.Q. Groundwater Depth Prediction Based on Multivariate Time Series Model-A Case Study on Weigan and Kuqa Rivers Delta Oasis. *Water Saving Irrigation*, **55**, 59, **2017**.
28. EZIZ M., MAMUT A., MOHAMMAD A., MA G.F. Assessment of heavy metal pollution and its potential ecological risks of farmland soils of oasis in Bosten Lake Basin. *Acta Geographica Sinica*, **72** (09), 1680, **2017**.
29. NEMEROW N.L. *Stream, Lake, Estuary, and Ocean Pollution*. New York: Van Nostrand Reinhold Publishing Co, **1985**.
30. MULLER, G. M. M. G. M. G. M. G. P. Index of geoaccumulation in sediments of the Rhine River. *Geojournal*, **2**, 108, **1969**.
31. LIU M.M., GAO F.J., HAN J., WANG X. Ecological risk and source analysis of soil heavy metals in a Mollisol watershed of China. *Journal of China Agricultural University*, **25** (11), 12, **2020**.
32. USEPA. *Exposure factors handbook, volume 1: General factors*. Washington, DC: U.S. Environmental Protection Agency, Office of Research and Development, **1997**.
33. USEPA. *Risk assessment guidance for superfund, vol I, Human health evaluation manual (Part A) Office of Emergency and Remedial Response*, Washington, DC, **1989**.
34. XU X.T., HAN Q., WANG M.S., SHEN J., GUO X.M. Pollution characteristics and health risk assessment of Heavy Metals in Soil of Large Industrial Areas and Surrounding Communities in Anyang City. *Earth and Environment*, **49**, 551, **2021**.
35. DUAN X.L. *Outline of Chinese Population Exposure Parameters (Adult's volume)*. Beijing: Environmental Science Press, **2016** [In Chinese].
36. DUAN X.L. *Outline of Chinese Population Exposure Parameters (Children's volume)*. Beijing: Environmental Science Press, **2016** [In Chinese].
37. YU F., WANG W., YU Y., WANG D.H., LIU S.B. Distribution Characteristics and Ecological Risk Assessment of Heavy Metals in Soils from Jiulong Li-BeMinig Area, Western Sichuan Province, China. *Rock and Mineral Analysis*, **40** (03), 408, **2021**.
38. HOSSAIN M.A., CHOWDHURY A.I.H., MULLICK M.R.A., HOQUE A. Heavy metal pollution status and health risk assessment vicinity to Barapukuria coal mine area of Bangladesh. *Environmental Nanotechnology. Monitoring & Management*, **16**, 100469, **2021**.
39. ZHENG N., LIU J.S., WANG Q.C., LIANG Z.Z. Health risk assessment of heavy metal exposure to street dust in the zinc smelting district northeast of China. *Science of the Total Environment*, **408** (4), 726, **2010**.
40. YANG X.Y., EZIZ M., ISMAYIL A., HAYRAT A. Assessment of Pollution and Health Risks of Heavy Metals in Surface Dust in Changji City, Xinjiang. *Environmental Science & Technology*, **44** (05), 211, **2021**.
41. THORPE A., HARRISON R.M. Sources and properties of non-exhaust particulate matter from road traffic: a review. *Science of the total environment*, **400** (1-3), 270, **2008**.
42. LI J., LI K.M., WEI J., ZANG F., YANG Y.Q. Contaminations and Health Risks of Heavy Metals from the Roadside Greenbelt Soils and Dust along the BRT Platform in Lanzhou. *Earth and Environment*, **50** (02), 228, **2022**.
43. EL FADILI H., ALI M. B., TOUACH N., EL MAHI M. Ecotoxicological and pre-remedial risk Assessment of heavy metals in municipal solid wastes dumpsite impacted soil in Morocco. *Environmental Nanotechnology. Monitoring & Management*, **17**, 100640, **2022**.
44. QU C., SUN K., WANG S., HUANG L., BI J. Monte carlo simulation-based health risk assessment of heavy metal soil pollution: A case study in the Qixia mining area, China. *Human and ecologic risk assessment: an international journal*, **18** (4), 733, **2012**.
45. JI C., HOU D.W., LI F.Z., BAO G.J., DENG A.P., SHEN H.J., SUN H. Assessment and Spatial Characteristics Analysis of Human Health Risk of Heavy Metals in Cultivated Soil. *Environmental Science*, **41** (3), 1140, **2020**.
46. LI F., LIU S.Y., LI Y., SHI, Z. Spatiotemporal variability and source apportionment of soil heavy metals in an industrially developed city. *Environmental Science*, **40** (2), 934, **2019**.
47. ZHANG Z., LU R., WU S.Y., JIA Z.B., WANG N. Heavy Metal Pollution and Health Risk Assessment of Mine Soil in Yangtze River Economic Belt. *Environmental Science*, **43** (7), 3763, **2022**.
48. WANG X.M., YU M.T., MAO D.L. Hyperspectral estimation of chromium heavy metals in oasis soils of arid zones in the cultivated layer. *Ecology and Environmental Sciences*, **30** (10), 2076, **2021**.
49. CHEN X.D., LU X.W., YANG G. Sources identification of heavy metals in urban topsoil from inside the Xi'an Second Ringroad, NW China using multivariate statistical methods. *Catena*, **98**, 73, **2012**.
50. TUERHONG A., LI X.G., LI Z., LI B., EZIZ M. Distribution characteristics and sources of heavy metals in the soil profile of lakeside zone on the west bank of Boston lake. Xinjiang. *Ecological Science*, **38** (06), 53, **2019**.
51. JIANG H.H., CAI L.M., HU G.C., WEN H.H., LUO J., XU H.Q., CHEN L.G. An integrated exploration on health risk assessment quantification of potentially hazardous elements in soils from the perspective of sources. *Ecotoxicology and Environmental Safety*, **208**, 111489, **2021**.
52. ROY S., GUPTA S.K., PRAKASH J., HABIB G., BAUDH K., NASR M. Ecological and human health risk assessment of heavy metal contamination in road dust in the National Capital Territory (NCT) of Delhi, India. *Environmental Science and Pollution Research*, **26**, 30413, **2019**.
53. BHAT N.A., BHAT A.A., GUHA D.B., SINGH B.P. Vertical distribution of heavy metals in Karewa deposits of South Kashmir: environmental contamination and health risk assessment. *International Journal of Environmental Science and Technology*, **1**, 14, **2022**.
54. SAWUT R., KASIM N., MAIHEMUTI B., HU, L., ABLIZ A., ABDUJAPPAR A., KURBAN M. Pollution characteristics and health risk assessment of heavy metals in the vegetable bases of northwest China. *Science of the Total Environment*, **642**, 864, **2018**.
55. QADEER A., SAQIB A., AJMAL Z., XING Z., KHALIL S.K., USMAN M., LIU, M. Concentrations, pollution indices and health risk assessment of heavy metals in road dust from two urbanized cities of Pakistan: Comparing two sampling methods for heavy metals concentration. *Sustainable cities and society*, **53**, 101959, **2020**.
56. GUO G., WU F., XIE F., ZHANG A. Spatial distribution and pollution assessment of heavy metals in urban soils

- from southwest China. *Journal of environmental sciences*, **24** (3), 410, **2012**.
57. HAN Z.X., WANG X.Q., CHI Q.H. Analysis of heavy elemental content and sources of soils in the Alluvial plains of the Pearl River Delta. *China Environmental Science*, **38**, 3455, **2018**.
58. XIAO G.Q., CHEN J., BAI B., LI Y. B. Content characteristics and risk assessment of heavy metals in soil of typical high geological background areas, Yunnan Province. *Geology and Exploration*, **57**, 1077, **2021**.
59. ZHENG F., GUO X., TANG M. Y., ZHU D., DONG S. J., KANG L., CHEN B. Distribution Characteristics and Ecological Risk Assessment of Soil Heavy Metals in Baiyangdian Lake. *Environmental Science*, **43**, 4556, **2022**.