Environ Sci Pollut Res
DOI 10.1007/s11356-015-4625-1

RESEARCH ARTICLE

Evaluation of the pollution and human health risks posed by heavy metals in the atmospheric dust in Ebinur Basin in Northwest China

Jilili Abuduwailil[1] · Zhang Zhaoyong[2] · Jiang Fengqing[1]

Received: 8 December 2014 / Accepted: 27 April 2015

Abstract Recently, a large amount of research assessing pollution levels and the related health risks posed by atmosphere dust has been undertaken worldwide. However, little work has been done in the oases of the arid regions of Northwest China. In this paper, we studied the pollution and health risks over a year of seven heavy metals in the atmospheric dust of Ebinur Basin, a typical oasis in Northwest China. The results showed the following: (1) The annual amount of atmospheric deposition in Ebinur Basin was 298.23 g m^{-2} and the average monthly atmospheric deposition was 25.06 g m^{-2}. The average and maximum values of the seven heavy metals measured were all below the National Soil Environmental Quality Standards (2nd). (2) Heavy metals of Cu, Cr, and As in the atmospheric deposition mainly originated from the natural geological background, while Zn came from human activity. This study also showed that among the seven measured heavy metals, the ratios of the no-pollution status of Pb, Cd, and Hg were higher than those of others with moderate degrees of pollution also accounting for a certain ratio. (3) The carcinogenic risks from As, Cd, and Cr were all lower than the corresponding standard limit values, and these metals are considered not harmful to the health of the basin. However, there is a relatively high risk of exposure for children from hand-to-mouth intake, which is worthy of attention. This research showed that both human activity and natural factors, such as wind and altitude, influenced the heavy metal contents in the atmospheric dust of the study area. Furthermore, recent human activity in the study area had the most negative influence on the accumulation of the heavy metals and the corresponding health risks, especially for Hg, Pb, and Cd, which is worthy of attention.

Keywords Atmospheric deposition · Heavy metals · Pollution assessment · Health risk evaluation · Ebinur Basin · Northwest China

Introduction

Atmospheric dust serves as a carrier and reaction bed for many pollutants. For example, heavy metals can loosely bind to the surface of the dust particles, which leads to instability of the heavy metals and potential biological activities (Akhter and Madany 1993; Al-Khashman 2004; Christoforidis and Stamatis 2009; Li 2013; Zhang et al. 2013). Heavy metals can accumulate in the environment, and enrichment of heavy metals through the food chain into the soil and plant system may endanger human health. In addition, heavy metal accumulation and settling in soil, water, and natural environment can persist and harm the ecological environment (Yang et al. 2003, 2010; Dai et al. 2014). In recent years, scholars worldwide have studied the pollution status of different heavy metals in urban areas, as well as the ecological and health risks (De-Miguel et al. 1997; Al-Khashman 2004; Chen and Luan 2011; Dai et al. 2013; Wu et al. 2014). Banerjee (2003) studied the pollution statuses of Cr, Ni, and Cu in the industrial areas of Delhi and India, and found that levels of these metals were all very high and closely related, and they were mainly originated from industrial waste emissions. Christoforidis

---

Responsible editor: Gerhard Lammel

✉ Zhang Zhaoyong
baiyangdian313@163.com

[1] State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China

[2] College of Resources and Environmental Science, Xinjiang University, Key Laboratory of Oasis Ecology of the Ministry of Education, Urumqi 830046, China

and Stamatis (2009) studied the sources and pollution statuses of Pb, Cu, Zn, Ni, Cr, Cd, As, and Hg in the main road dust, and found that they were mainly influenced by the local transportation vehicular fuel and high phosphorus in fertilizers from emissions from nearby agricultural and petrochemical factories. Akhter and Madany (1993) researched the health risks posed by Pb, Zn, Cd, Cr, and Ni in the street dust of Bahrain, and found Pb reached significant levels of pollution and toxicity both indoors and outdoors and, therefore, was a significant threat towards the health of children.

Despite these studies, research in China about the health risks of the heavy metals remains limited, and the studies are all about heavy metal pollution and sources and health risks from the dust, which all focus on the eastern and central parts of China, which have undergone rapid economic development. One such study, performed by Liu et al. (2012), evaluated the pollution status and ecological risks posed by Cd, Hg, Pb, Zn, and Cu in the street dust of Luoyang city, Henan province, in the eastern part of China. They determined that the heavy metal contents were all significantly higher than the background values of Henan province and the soil quality standards of China with Cd being the largest pollutant. Wang et al. (2011) studied the heavy metal pollution and health risks from Cd, Hg, Pb, Zn, and Cu in the land dust from children parks of Kaifeng, Henan province, in Eastern China, and found that hand-to-mouth was the primary routes of exposure to heavy metals in this area with Pb and Cr posing the greatest health risks. Zheng et al. (2010) researched the risk of heavy metals Hg, Pb, Cd, Zn, and Cu in the street dust of a zinc mining area of Huludao in Northeast China, and they found heavy metal smelting and the large density of road traffic heavily contributed to the heavy metal pollution in this area. Furthermore, according to the calculated risks index of HI, hand-to-mouth made the heavy metals have no-cancer risks, which was the primary route of exposure for both children and adults, followed by skin contact, and the risk to adults mainly came from Pb and Cd.

Located in the Eurasia hinterland, Ebinur Basin is an ecologically protected area on the northern slope of the Tianshan Mountains in the Xinjiang oases in Northwest China. Because of the combined influences of climate changes and human activities, this area is now undergoing desertification and a decline in soil fertility. This has made the area's ecological environment fragile, leading to typical ecological degradation and serious sandstorms in Xinjiang in arid areas of Northwest China (Jilili et al. 2007; Liu et al. 2009). However, the research on the pollution and health risks posed by heavy metals in the atmospheric dust of this area are still lacking. In this study, the atmospheric dust of this area was collected monthly from August 2013 to July 2014 and the concentrations of Zn, Cr, Hg, As, Pb, Cd, and Cu were tested. Classical statistical analysis methods combined with enrichment factor evaluation, geo-accumulation index (I_{geo}), and health risk assessment methods were used to evaluate the distribution characteristics of the atmospheric dust of Ebinur Basin, as well as the pollution status of and health risks from heavy metals contained within the dust. Using these methods, we aimed to answer the following questions:

(1) How much is the annual atmospheric precipitation flux in Ebinur Basin, and what are the spatial and temporal distribution characteristics of the atmospheric dust?
(2) What are the human health risks posed by heavy metals in the atmospheric dust of Ebinur Basin, and should close attention be paid to any of these heavy metals?

Materials and methods

Study area

Ebinur Basin is a closed basin located in the inland area of Xinjiang in Northwest China (43°38′–45°52′N, 79°53′–85°02′E) (Fig. 1). It has a total area of 50,621 km^2. As suggested by the arid desert climate, there is little rainfall with the average annual amounts totaling only 100–200 mm and a potential evaporation of up to 1500–2000 mm (Jilili et al. 2013). The flora is primarily that of Central Asia and Mongolia. There are a total of 385 plant species belonging to 53 families and 191 genera. The soil types are mainly *Piedmont psephitic* and *Gypsum desert soil*, the vegetative cover is mainly *H. ammodendron desert* and *Ephedra desert*, and plant growth consists of *Populus euphratica forest*, *Phragmites australis*, and lowland meadow. During the past 50 years, the rapid land-use changes in Ebinur Basin, humans have significantly affected and modified the natural landscape on multiple scales in this area. These changes mostly occurred as the population density increased and agriculture intensified (Liu et al. 2011). The increasing amounts of land being converted to agricultural land as well as other driving forces in land-use changes were the factors that lead to excessive use of water resources in this area. This excessive water use led to a significant reduction in the surface water resources of Ebinur Basin and a decrease in the surface water area by one third that left only 500 km^2. Furthermore, this large bared area of the dry lake bottom has become a huge salt dust storm source in Northwest China and central Asia, threatening this area with serious sand dust storms (Liu et al. 2011).

Setting of sampling sites

First, we performed a basic analysis of the land-use types and topography of Ebinur Basin. Then, we used ArcGIS 10.0

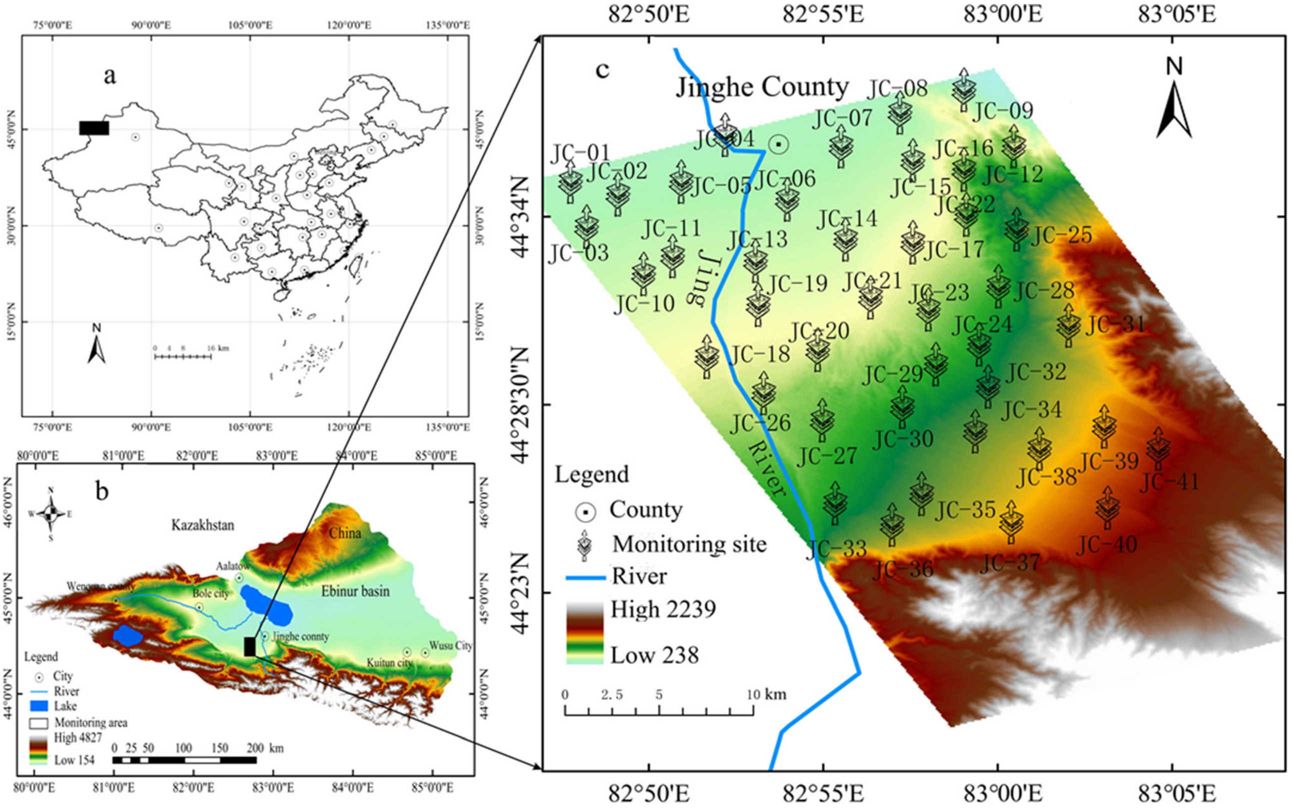

Fig. 1 Locations of the study area and sampling sites

software to lay out a grid of sampling points on a digital map of 3×3 km in the southeast region of Ebinur Basin, which is located in the piedmont plain of the basin. This eventually resulted in 41 atmospheric dust samples. During sampling sets, we adjusted the sample sites based on the actual environment, which eventually resulted in the sampling map shown in Fig. 1. The atmospheric deposition collection was performed using a Standard Atmospheric Precipitation Sampling Device (WEN-162; NSRO Company, Beijing, China) with a cylindrical vessel (20 cm radius×20 cm height).

Sample collection and analysis

From August 2013 through July 2014, we collected the monthly atmospheric deposition in Ebinur Basin. The collection was the sum of both dry and wet atmospheric depositions. Upon collecting the samples, a clean brush was first used to brush the dust into clean sample bags, which were numbered and sealed. These samples were then taken to the laboratory, and rinsed thoroughly by deionization to obtain the reine quantitat of the atmospheric deposition for that month. After the sediment samples were taken back to the laboratory, they were air dried and pushed through a 20-mesh nylon sieve (0.84 mm) to eliminate plant residue and stones. Agate was then used to grind the soil samples through 100 mesh nylon sieves (0.25 mm) to prevent contamination, and the samples were stored in plastic bottles.

The amount of each heavy metal in the samples was measured as follows: 0.5 g sample was placed into an Anton PVC digestion tank (Multiwave 3000; Anton Parr, Austria) along with HCl-HF-HNO_3^-. An inductively coupled atomic spectrum emission spectrometer (ICAP 7500; Dionex Corporation, USA) was used to measure the Pb, Cd, Cu, Zn, and Cr contained in the samples. An atomic fluorescence spectrometer (AFS) was used to measure As and Hg.

First, standard curves were obtained using separate solutions containing known concentrations of each heavy metal (GSS series, China) that had been diluted with deionized water. Next, these standard curves were used to optimize the machine as well as measure the heavy metals. Finally, in order to verify the accuracy of our heavy metal measurements, 30 % of the samples were retested. Based on this, the consistency of the repeated heavy metal measurements was determined to be 95.71 %. The standard solutions of the heavy metals were used to compare our samples to national standards (GSS series, China). The recovery of each heavy metal in all the samples was 97.31–106.394 %. To prevent contamination during the testing process, all glasswares were soaked in 5 % HNO_3 for 24 h, rinsed, and then dried. All reagents were of analytical grade and were used without further purification, and all solutions were prepared with Milli-Q water. Blanks and duplicates were regularly employed during testing.

Enrichment factor (EF) method

EF is an important indicator used to quantitatively evaluate pollution levels and the sources of certain pollutants. This method is performed by choosing an element in a reference system to serve as the reference element. The EF is then obtained by getting the ratio of the percentage of the quality of a polluting element and the percentage of the reference element in the samples (Rahn 1976; Huang et al. 2008). The equation used was as follows:

$$\mathrm{EFs} = \left(\frac{C_i}{C_n}\right)_{\text{test}} \Big/ \left(\frac{C_i}{C_n}\right)_{\text{background}} \qquad (1)$$

In this study, EF is the enrichment factor of certain heavy metal, $(C_i)_{\text{test}}$ is the measured concentration of i heavy metal in the dust, $(C_n)_{\text{test}}$ is the measured concentration of the reference element, $(C_i)_{\text{background}}$ is the background value of a certain heavy metal locally, and $(C_n)_{\text{background}}$ is the background concentration of the reference element in the soil locally. In this study, when EF is less than or close to 1, it indicates that there was no enrichment of these heavy metals compared to the local soil, and these metals were mainly derived from the natural environment. When $1<\mathrm{EF}<5$, it suggests that there was a low level of enrichment of these heavy metals, and apart from the soil sources, they were also influenced by man-made sources. When $5<\mathrm{EF}<10$, there was moderate enrichment of these heavy metals, indicating that they were significantly influenced by pollutants from human activity. When $\mathrm{EF}>10$, this indicates a strong enrichment of these heavy metals, where the primary source was man-made pollutants (Huang et al. 2008).

Geo-accumulation index (I_{geo})

I_{geo} is a quantitative indicator proposed by Müller (1979) that is used to estimate the heavy metal pollution status of sediments in a water environment. This index can directly reflect the degree of enrichment of heavy metals, and is now also widely used to evaluate the pollution status of soil, atmospheric dust, and sediments in water. The equation used is as follows:

$$I_{geo} = Log_2[C_i/1.5B_i] \qquad (2)$$

In this study, C_i is the measured concentration of the heavy metal in the dust, B_i is the geochemical background value of a particular heavy metal, and 1.5 is the CV that may be a result of movement of the earth and rock formation (Zhong et al. 2010). Here, we chose the average values of global shale as the background reference values. The values of As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn were 13, 0.3, 90, 45, 0.017, 26.7, 26.6, and 19.4 mg kg^{-1}, respectively (Wang et al. 2007).

The I_{geo} criteria of heavy metals in the atmospheric dust in this work are shown in Table 1, which are based on related literature (Müller 1979; Wang et al. 2007).

Health risk assessment

Exposed quantity

Currently, the health risk assessment method of heavy metals in the dust that has been internationally adopted is the Soil Health Risk Model put forward by the U.S. Environmental Protection Agency (U.S. EPA 1989, 2002). These assessments tend to proceed as follows: first, each heavy metal is calculated for medium exposure levels, and then the health risks are calculated according to the model parameters selected (Wang et al. 2011; Dong et al. 2014; Guo et al. 2014). From this study and related literature, we can conclude that in the atmospheric dust of Ebinur Basin, Cd, Cu, Cr, Pb, and Zn have no chronic risk of cancer induction, while As, Cd, and Cr have a risk of cancer induction. We hypothesized that exposure to heavy meals in atmospheric dust was mainly through hand-to-mouth, contact with skin, and respiration. Based on relevant publications, the intake of heavy metals through each route of exposure was calculated as follows (Dong et al. 2014; Guo et al. 2014; Li et al. 2014):

$$ADD_{ing} = \frac{(C \times R_{ing} \times CF \times EF \times ED \times AT)}{BW} \qquad (3)$$

$$\mathrm{ADD}_{\mathrm{inh}} = \frac{(C \times R_{inh} \times BF \times ED)}{PEF} \times BW \times AT \qquad (4)$$

$$ADD_{derm} = \frac{C \times SA \times CF \times SL \times ABS \times EF \times ED}{BW \times AT} \qquad (5)$$

$$LADD_{inh} = \frac{C \times EF}{PEF \times AT} \times \left(\frac{R_{inh\,child}}{BW_{child}} \times ED_{child} + \frac{R_{inh\,adult}}{BW_{adult}}\right) \times ED_{adult} \qquad (6)$$

where $\mathrm{ADD}_{\mathrm{ing}}$ is the daily average quantity of heavy metals exposed to from dust by hand-to-mouth (mg(kg day)$^{-1}$), $\mathrm{ADD}_{\mathrm{inh}}$ is the daily average quantity of heavy metals exposed to from dust through respiration (mg(kg day)$^{-1}$), $\mathrm{ADD}_{\mathrm{derm}}$ is

Table 1 Contamination levels and classification based on I_{geo} of heavy metals

I_{geo}	≤0	0–1	1–2	2–3	3–4	4–5	>5
Classification	0	1	2	3	4	5	6
Pollution level	Clean	Slight	Partially moderate	Moderate	Partially serious	Serious	Severe

the daily average quantity of heavy metals exposed to from dust through contact with skin (mg(kg day)$^{-1}$), and $\mathrm{LADD_{inh}}$ is the lifetime average daily exposure levels for a risk of cancer from heavy metals from dust through inhalation (mg(kg day)$^{-1}$. The values of the other parameters were chosen based on the relevant literature (Table 2).

Health risk characterization

The no-cancer risk of heavy metals was often used to represent as the reference dose of chronic poisoning of heavy metals. It indicates the dose humans need to be exposed to for chronic poisoning of heavy metals within the reference dose, and we think there is no harm of them. By contrast, if the human exposure dose that leads to chronic poisoning by heavy metals exceeds the reference dose, then we think they pose a risk. Based on related published literature, the formulas used to calculate the no-cancer risk and cancer risks of heavy metals are as follows (Wang et al. 2011; Dong et al. 2014):

$$HQ_{ij} = \frac{ADD_{ij}}{RfD_{ij}} \tag{7}$$

$$HI = \sum_{i=1}^{n} \times \sum_{j=1}^{m} \times HQ_{\mathrm{ij}} \tag{8}$$

$$Risk = LADD \times SF \tag{9}$$

In this study, $\mathrm{HQ_{ij}}$ is the no-cancer risk quantity of certain heavy metals through specific exposure routes, $\mathrm{RfD_{ij}}$ is the maximum dose of a single heavy metal pollutant over a unit of time and a unit of weight that will not cause a negative bodily reaction, HI is the total cancer risk for multiple routes of exposure and is the sum of the cancer risk for all polluting elements through all routes of exposure, and $\mathrm{HQ_{ij}}$ is the cancer risk entropy of single heavy metal through certain route of exposure. In this study, when $\mathrm{HQ_{ij}}$ or HI<1, there is a low risk, but when $\mathrm{HQ_{ij}}$ or HI>1, there is no-cancer risk of heavy metals. SF is the slope coefficient and represents the maximum probability; there will be a carcinogenic effect when humans are exposed to a certain quality of a certain heavy metal. Risk is the risk of cancer, represents the probability of cancer occurring, and is the ratio of people with cancer within a unit quantity. When the risk ranges from 10^{-6} to 10^{-4}, it suggests that the heavy metal poses a carcinogenic risk (Guo et al. 2014; Li et al. 2014).

Ordinary Kriging (OK) method

OK is a commonly used linear spatial interpolation method that estimates variables at unsampled locations by using information from neighboring points and assigning weights to these points based on their distance from the point and the spatial variability structure (Neto et al. 2006).

The OK method can be formulated as follows:

$$Z^{*}_{\mathrm{OK}}(x_0) = \sum_{i=1}^{n} w_i Z(x_i) \tag{10}$$

where $Z^{*}_{\mathrm{OK}}(x_0)$ is the OK estimate at an unsampled location (x_0), n is the number of samples in a search neighborhood, and w_i is the weight assigned to the ith observation, $Z(x_i)$. Weights are assigned to each sample such that the estimation or Kriging variance $E[\{Z^*(x_0)-Z(x_0)\}^2]$ is minimized and the estimates are unbiased (Mamat et al. 2014). Weights are determined after computing a semivariogram that models spatial correlation and covariance structure between data points for each variable using Eq. 11.

Table 2 Parameters and the values of models for exposure to heavy metals

Items	Parameters	Implication	Units	For children	For adult	Literature
	C	Concentration of heavy metals	mg kg^{-1}	95 % UCL	95 % UCL	This research
	EF	Exposure frequency	day a^{-1}	180	180	(Dong et al. 2014)
Exposure factor	ED	Exposed fixed number of year	a	6	24	(Li et al. 2014)
	AT	The average exposure time	day	365×ED (no-cancer) 365×70 (carcinogenesis)	365×ED (no-cancer) 365×70 (carcinogenesis)	(U.S. EPA 1989)
	BW	Average weight	kg	15	70	(U.S. EPA 2002)
	CF	Unit converter	mg kg^{-1}	1×10^{-6}	1×10^{-6}	(U.S. EPA 1989)
Hand-to-mouth	R_{ing}	Consumption rate of dust	mg day^{-1}	200	100	(U.S. EPA 2002)
Respiration	R_{inh}	Respiratory rate	m^3 day^{-1}	7.63	12.8	(Li et al. 2014)
	PEF	Particulate emission factor	kg m^{-3}	1.36×10^{-9}	1.36×10^{-9}	(U.S. EPA 1989)
Skin contact	SL	Skin adhesion degrees	mg cm^{-2}	0.2	0.07	(U.S. EPA 1989)
	SA	Exposed skin area	cm^2 day^{-1}	956	1528	This research
	ABS	Skin factor	–	0.001	0.001	(U.S. EPA 1989)

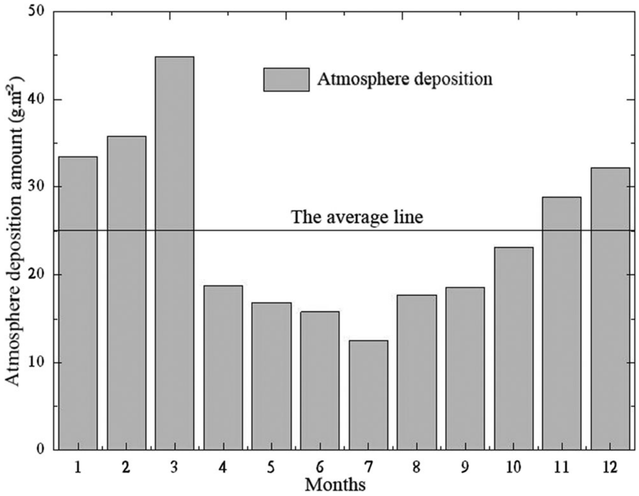

Fig. 2 Atmospheric dust deposition in Ebinur Basin

$$\gamma(h)=\frac{1}{2N(h)}\sum_{i=1}^{N}\left[Z(x_i+h)-Z(x_i)\right]^2 \tag{11}$$

where $\gamma(h)$ is the semivariance between two observation points $Z(x_i)$ and $Z(x_i+h)$, separated by a distance h, and N is the number of observation pairs at the distance h.

In this study, Matlab 7.0 software was used to calculate the EF and I_{geo}. The OK of the pollution status of the seven heavy metals in the atmospheric dust of Ebinur Basin was extrapolated with Arcgis 10.0 software.

Results and analysis

Statistical characteristics of the heavy metal content and changes in the atmospheric dust

As shown in Fig. 2, the annual settling flux from August 2013 to July 2014 of Ebinur Basin was 298.23 g m^{-2}, and the monthly settling flux ranged from 12.4 to 44.8 g m^{-2}, with a mean value of 25.06 g m^{-2}. The maximum value occurred in March 2014 at 25.06 g m^{-2}, while the minimum value was in August 2013 at 13.45 g m^{-2}. Overall, the winter half of the year running from August 2013 to February 2014 was significantly higher, 1.42 times, than in the summer half of the year from March 2014 to July, 2014.

We used the background values of Xinjiang (CSEPA 1990) and the Secondary National Soil Quality Standards of China (EPDPRC 1995) as the standards against which to evaluate the heavy metal contents in the atmospheric dust of Ebinur Basin. The results in Table 3 show that the average and maximum values of the tested heavy metals were all below the Secondary National Soil Quality Standards of China, and, besides As, all the values were below the soil background values of Xinjiang and the National Soil Environmental Quality Standards (2nd) (GB15618-1995) (EPDPRC 1995). The average values of Pb, Cd, and Hg all exceeded the soil background values of Xinjiang by 28.5, 41.3, and 25.4 %, respectively. Meanwhile, the maximum values of Zn, Cu, and Cr, all exceeded the background values of Xinjiang by 20.4, 27.8, and 15.9 %, respectively, but did not exceed the values of the Secondary Soil Environmental Quality Standards of China.

A coefficient of variation (CV) is the ratio between the standard deviation and the average of certain elements, and this indicator can be used to compare indexes with different dimensions (Abuduwaili et al. 2015). In this study, the average CVs of Cu, Zn, and Cr ranged from 36.7 to 55.9 %, displaying a medium variation. The CV of As was 18.6 %, displaying a low variation in amounts of As between different samples. By comparison, the average CVs of Pb, Hg, and Cd were all higher than 100 % and reached 186.7, 151.9, and 122.5 %, respectively. They all had high variation, indicating that there were large differences in the contents of these three heavy metals between samples. Based on their average skewness, we can order the metals as Pb>Cd>Hg>Cu>Zn>Cr>As. The values of Pb, Cd, and Hg are large, indicating that they were influenced by the economic development in the study area.

Table 3 Heavy metal content in atmospheric deposition in Ebinur Basin

Elements	Ranges (mg kg^{-1})	SD (mg kg^{-1})	GM (mg kg^{-1})	CV (%)	Over-limit ratio (%)	BV (mg kg^{-1})	NSS (mg kg^{-1})	Skewness	Kurtosis
Zn	26.25–227.51	5.14	157.16	36.7	20.4	110.6	300	34.6	28.1
Pb	11.14–124.17	1.02	16.32	186.7	28.5	13.5	350	75.7	84.7
Cu	15.12–62.27	3.11	24.52	47.1	27.8	32.5	100	38.4	29.5
Hg	0.01–0.79	0.24	0.038	151.9	25.4	0.017	1.0	42.5	32.5
As	0.22–2.16	0.71	1.05	18.6	0	8	25	17.6	11.7
Cd	0.004–0.48	0.037	0.34	122.5	41.3	0.12	0.6	61.4	62.4
Cr	58.15–169.25	3.57	102.17	55.9	16.9	96.2	250	29.9	22.7
Al	12.56–36.57		28.61		/	/	/	/	/

SD standard deviation, *GM* geometric means of heavy metals, *CV* variable coefficient, *BV* background values of the heavy metals, *NSS* secondary national soil standard values

Enrichment factor (EF) of heavy metals in the atmospheric dust

In this study, we calculated the average enrichment factors (EFs) of heavy metals in the atmospheric dust of Ebinur Basin (Formula 2, Fig. 3) using Al as a reference. Based on the calculated EFs, the seven tested heavy metals can be ordered as Pb>Cd>Hg>Zn>Cu>Cr>As, and divided into three categories. The first category consists of Cu, Cr, and As with EFs lower than 1 and no significant enrichment. This indicates that they were not polluting the atmospheric dust of Ebinur Basin and mainly originated from the natural environment, such as soil particles and soil parental materials (Huang et al. 2008; Eichler et al. 2014). The second category consists of Zn, which had an EF of 1.28. It was slightly enriched, and belonged to low pollution levels. By combining our study with related literature, we conclude that the levels of Zn were influenced by both the natural environment and pollution emitted by human activities in the basin. The third category consists of Pb, Cd, and Hg with average EFs all higher than 13. Specifically, the EFs of Pb, Cd, and Hg were 13.6, 23.64, and 24.46, respectively, showing that Cd and Hg were extremely enriched and indicating that these heavy metals were mainly influenced by the pollutants emitted by human activities in the basin (Huang et al. 2008, 2012; Eichler et al. 2014).

The spatial distribution of the EFs of Pb, Cd, and Hg in the atmospheric dust of all samples showed higher values in the northern and central parts of the study area, while Zn, Cu, Cr, and As were higher in the southern and surrounding areas (Fig. 4).

Geo-accumulation index (I_{geo}) of heavy metals in atmospheric dust

The average monthly geo-accumulation indexes (I_{geo}) and the average pollution classifications of the heavy metals in the atmospheric dust samples are shown in Table 4. Based on our analysis, the tested heavy metals can be ordered by pollution levels as Cd>Pb>Hg>Cu>Zn>Cr>As. Overall, the I_{geo} of Zn in all months tested, as well as the I_{geo} for all the other metals in August 2013, March 2014, and May 2014 fell at a no-pollution status, while in other months of the research period, the heavy metals fell at low levels of pollution status. The average values of I_{geo} of Pb in September 2013, October 2013, November 2013, and the whole year all belonged to low pollution status, while in the other monitoring months, they all belonged to low pollution levels. The average values of I_{geo} of Cu was at low pollution levels throughout the year, while Hg in September 2013, October 2013, November 2013, and the whole year fell at moderate pollution levels, but in the other months, fell at low pollution levels and had a heavier pollution status. In all atmospheric dust samples, the average values of I_{geo} of Cr in September 2013, March 2014, June 2014, July 2014, and the whole year all belonged to no-pollution status. Similarly, in all atmospheric dust samples, the average I_{geo} of As in September 2013, March to July 2014, and the whole year all belonged to no-pollution status. While these two heavy metals in the other months and the whole year all belonged to low pollution levels and have relatively light pollution (Table 4).

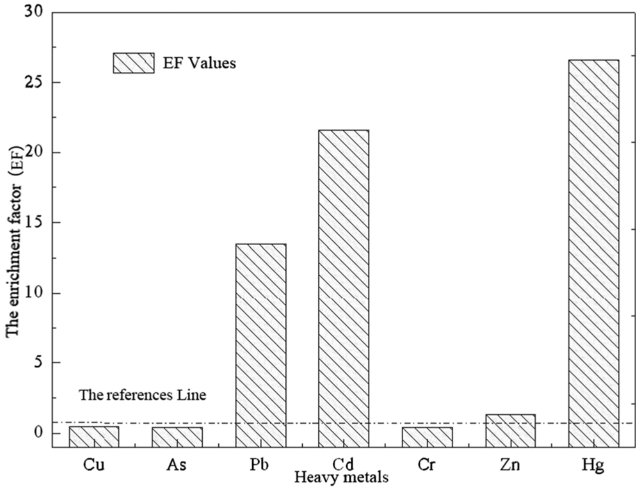

Fig. 3 EFs of the heavy metals in the atmospheric deposits

From the distribution of the heavy metal contents, we determined that the environmental risks posed by the seven heavy metals in the atmospheric dust of Ebinur Basin were significantly influenced by the season. For example, the pollution levels of Cd, Hg, and Pb in the winter months of September 2013 through March 2014 were significantly higher than those in the other months and were at relatively heavier pollution levels.

From the spatial distribution of the average I_{geo} of the atmospheric dust in the study area, we found that the I_{geo} values of Pb, Cd, and Hg were higher in the northern and central parts of the study area, while Zn, Cu, Cr, and As were higher in the southern and surrounding parts (Fig. 5). This is consistent with the distribution of the EFs of heavy metals in the atmospheric dust in the study area.

Assessment of health risk posed by heavy metals in atmospheric dust

Exposure levels to heavy metals in atmospheric dust

Based on the pollution levels we obtained for the heavy metals in the atmospheric dust of Ebinur Basin, we evaluated the health risk posed by these heavy metals through different routes of exposure using Formulas 3–6. As shown in Table 5, the order of the exposed quantity of no-cancer risk for the heavy metals for the three routes of exposure was Cd>Cu>Cr>As>Zn>Hg>Pb. This analysis also showed that the daily exposure levels were significantly higher in children than in

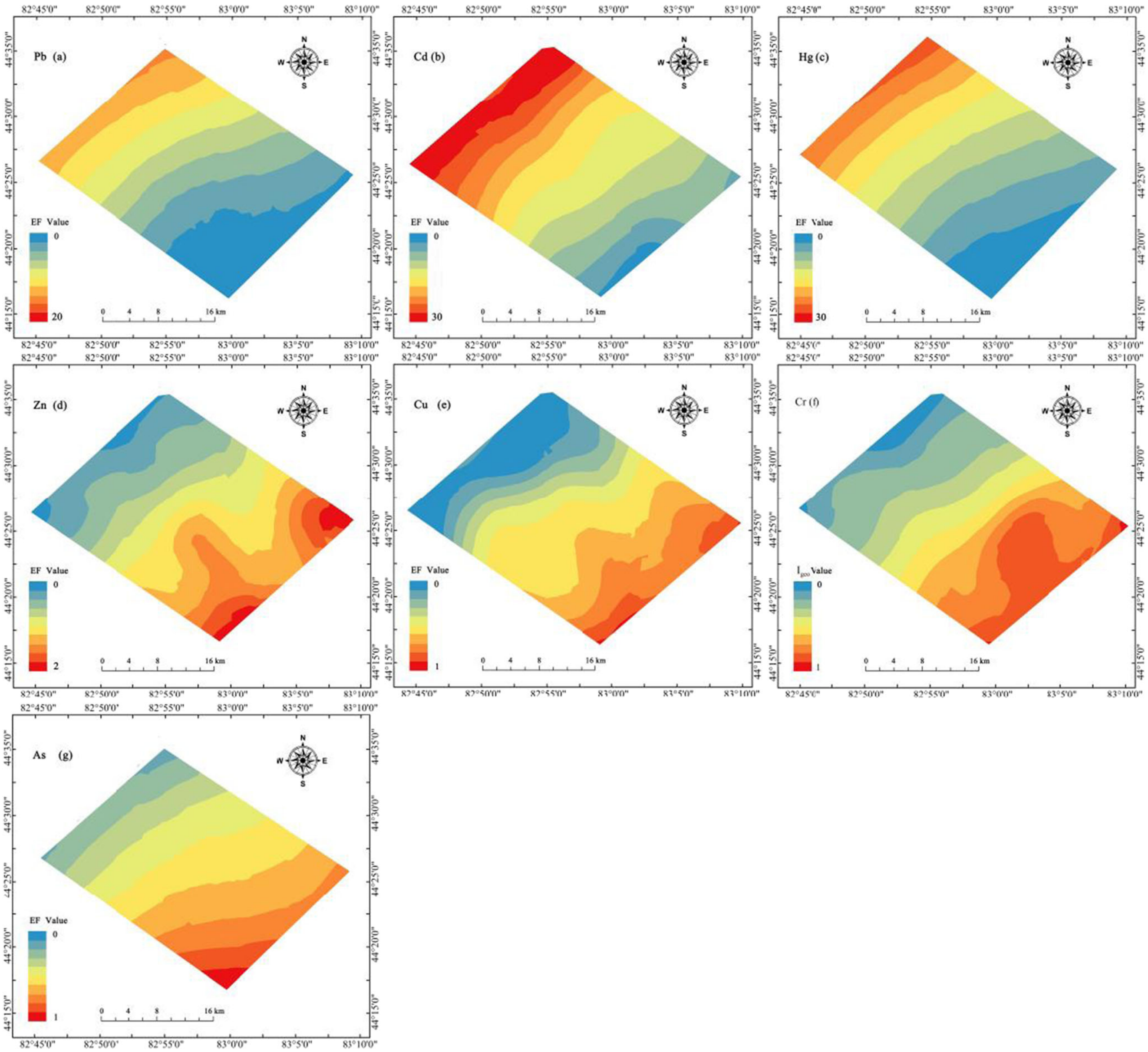

Fig. 4 Spatial distribution of the EFs of heavy metals in the atmospheric deposits

Table 4 Monthly accumulation indexes and classification of heavy metals in Ebinur Basin

Month	August 2013	September 2013	October 2013	November 2013	December 2013	January 2014	February 2014	March 2014	April 2014	May 2014	June 2014	July 2014	Annual average
Zn	−0.11(0)	0.19 (1)	0.09 (1)	0.11 (1)	0.15 (1)	0.28 (1)	0.06 (1)	0 (0)	0.11 (1)	0 (0)	0.19 (1)	0.06 (1)	0 (0)
Pb	0.97 (1)	1.21 (2)	1.41 (2)	1.57 (2)	0.38 (1)	0.27 (1)	0.76 (1)	0.78 (1)	0.66 (1)	0.76 (1)	0.81 (1)	0.67 (1)	1.16 (2)
Cu	0.11 (1)	0.18 (1)	0.29 (1)	0.11 (1)	0.38 (1)	0.21 (1)	0.17 (1)	0.17 (1)	0.24 (1)	0.11 (1)	0.11 (1)	0.04 (1)	0.38 (1)
Hg	0.74 (1)	0.81 (1)	1.01 (2)	1.26 (2)	0.54 (1)	0.38 (1)	0.49 (1)	0.51 (1)	0.42 (1)	0.39 (1)	0.52 (1)	0.31 (1)	1.14 (2)
Cd	0.81 (1)	1.14 (2)	1.19 (2)	1.45 (2)	0.11 (1)	0.32 (1)	0.19 (1)	0.39 (1)	0.41 (1)	0.54 (1)	0.47 (1)	0.67 (1)	1.35 (2)
Cr	0.15 (1)	0 (0)	0.12 (1)	0.09 (1)	0.17 (1)	0.42 (1)	0.47 (1)	0 (0)	0 (0)	0.11 (1)	0 (0)	0 (0)	0 (0)
As	0.15 (1)	0 (0)	0.05 (1)	0.09 (1)	0.15 (1)	0.64 (1)	0.45 (1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

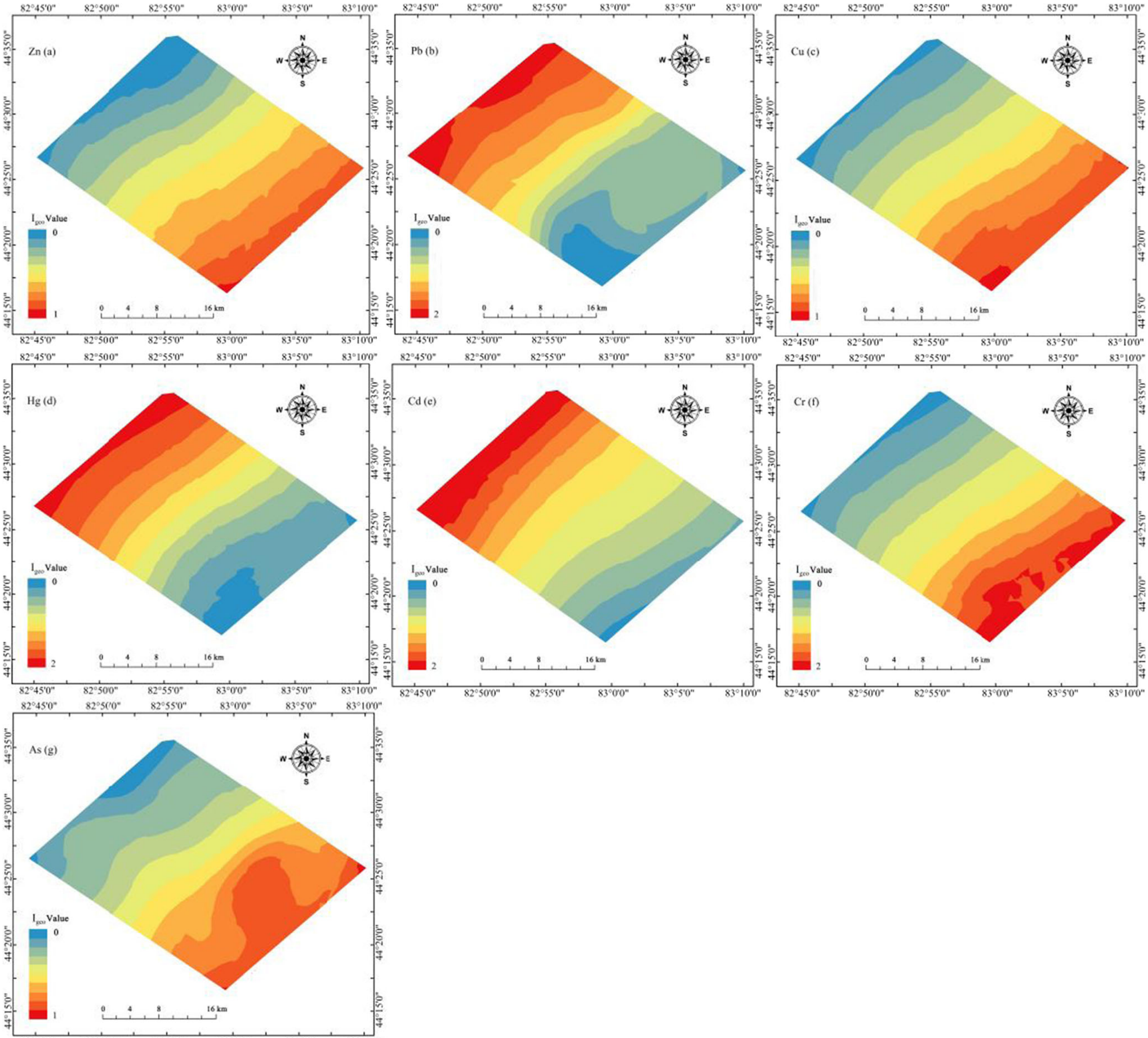

Fig. 5 I_{geo} spatial distribution of the heavy metals in the atmospheric deposits

Table 5 Daily doses for each heavy metal and routes of exposure

Elements	ADD$_{ing}$		ADD$_{inh}$		ADD$_{derm}$		LADD$_{inh}$
	C	*A*	*C*	*A*	*C*	*A*	
Zn	1.84×10^{-3}	3.23×10^{-3}	4.85×10^{-7}	4.24×10^{-8}	2.71×10^{-9}	3.79×10^{-9}	
Pb	1.29×10^{-4}	2.59×10^{-4}	2.99×10^{-8}	1.51×10^{-8}	1.49×10^{-9}	1.24×10^{-9}	7.31×10^{-9}
Cu	9.05×10^{-3}	3.34×10^{-3}	3.34×10^{-6}	2.81×10^{-7}	2.28×10^{-8}	8.82×10^{-9}	
Hg	1.36×10^{-3}	3.51×10^{-4}	3.87×10^{-7}	2.77×10^{-8}	1.87×10^{-9}	1.72×10^{-9}	6.27×10^{-10}
Cd	10.15×10^{-3}	7.06×10^{-3}	4.42×10^{-6}	3.61×10^{-7}	2.94×10^{-8}	1.51×10^{-8}	4.27×10^{-9}
Cr	5.07×10^{-3}	3.12×10^{-3}	1.79×10^{-6}	8.46×10^{-8}	6.87×10^{-9}	6.58×10^{-9}	
As	3.71×10^{-3}	3.17×10^{-3}	10.21×10^{-7}	5.56×10^{-8}	4.81×10^{-9}	4.32×10^{-9}	

C children, *A* adults

adults. For both children and adults, hand-to-mouth was the primary source of exposure, skin was the secondary source exposure, and respiration was the tertiary route of exposure.

Assessment of the health risks posed by heavy metals in the atmospheric dust

Based on the quantity of heavy metals in the atmospheric dust of Ebinur Basin and Formulas 7–9, we calculated the no-cancer exposed risks of the atmospheric dust of Ebinur Basin. As shown in Table 6, the no-cancer exposed risks of the seven heavy metals were tested for three routes of exposure, and it was found that the risk of exposure was higher in children than in adults. The no-cancer risk was highest for exposure through hand-to-mouth. Specifically, the percent of the no-cancer risks for the total cancer risk posed by heavy metals in children through hand-to-mouth intake was 92.4 %, while for adults, it was 91.7 %.

Based on the total no-cancer risks (HI) for adults, the metals can be ordered as Cd>Pb>Hg>Cr>Cu>Zn>As. For children, the metals can be ordered as Cd>Pb>Hg>Cu>Cr>Zn>As. By comparing the RfD_{ing} values of heavy metals taken in by hand-to-mouth, we can get that the risk posed by exposure of children to Pb through hand-to-mouth was the highest. The exposure risks (HQ) for the three routes of exposure for the seven tested heavy metals in the atmospheric dust of Ebinur Basin were all lower than the limit value of the one proposed by the U.S. Environmental Protection Agency (U.S. EPA 2002). Meanwhile, the overlay no-cancer risks of the seven heavy metals through the three routes of exposure in the atmospheric dust of Ebinur Basin did not exceed 1 (Table 6), indicating that the no-cancer risks of Ebinur Basin were relatively low and not significantly harmful to the area.

By calculating the risk of cancer posed by As, Cd, and Cr taken in via respiration, we can get that the SFs of As, Cd, and Cr in the atmospheric dust of Ebinur Basin were 5.8, 4.9, and 3.7, and the carcinogen exposure risks of these three heavy metals were 2.56×10^{-8}, 8.89×10^{-9}, and 2.17×10^{-9}, respectively (Table 6). These values are significantly lower than the limits of 10^{-6}–10^{-4} as recommended by the U.S. Environmental Protection Agency (U.S. EPA 2002), indicating that these metals posed no-cancer risk and did not harm the residents in the study area (Dong et al. 2014; Li et al. 2014).

Based on the calculation of the no-cancer risks from relevant literature, we calculated the cancer risks of As, Cd, and Cr from intake through respiration (U.S. EPA 1989, 2002; Dong et al. 2014; Li et al. 2014). From this, we determined that the SFs of As, Cd, and Cr were 5.8, 4.9, and 3.7 with exposure risks of 2.56×10^{-8}, 8.89×10^{-9}, and 2.17×10^{-9}, respectively. These results show that in Ebinur Basin, the cancer risks posed by As, Cd, and Cr were in the range of 10^{-8}–10^{-9} for exposure through respiration, which are within the standard limits and, therefore, represent little cancer risk (U.S. EPA 2002).

Discussion

The influence of meteorological and human activity on heavy metals in the atmospheric dust of Ebinur Basin

Influence of human factors on heavy metal pollution in the atmospheric dust in Ebinur Basin

In this study, consistent results were achieved with EF and I_{geo} when studying the heavy metal pollution of dust from Ebinur Basin. We found that the EFs and I_{geo}s of Hg, Pb, and Cd in the dust from the northern, central, and northeastern parts of the study area (Figs. 4 and 5) were much higher than those in the western, southern, and surrounding parts. The northern and central parts of the research area were close to Jinghe county and significantly influenced by human activities,

Table 6 Hazard quotient and risk for each heavy metal and exposure pathway

Elements	RfD_{ing}	RfD_{inh}	RfD_{derm}	*C*				*A*			
				HQ_{ing}	HQ_{inh}	HQ_{derm}	HI	HQ_{ing}	HQ_{inh}	HQ_{derm}	HI
Zn	3.45×10^{-3}	4.96×10^{-4}	5.13×10^{-5}	1.15×10^{-2}	3.71×10^{-7}	0.18×10^{-4}	2.81×10^{-2}	1.61×10^{-3}	1.45×10^{-7}	1.4×10^{-5}	4.32×10^{-3}
Pb	2.19×10^{-1}	1.28×10^{-2}	3.41×10^{-3}	2.31×10^{-1}	1.61×10^{-5}	1.45×10^{-3}	1.48×10^{-1}	2.61×10^{-2}	6.14×10^{-5}	2.6×10^{-4}	2.27×10^{-2}
Cu	3.28×10^{-3}	5.74×10^{-4}	1.29×10^{-5}	4.61×10^{-2}	1.09×10^{-7}	2.14×10^{-4}	3.34×10^{-2}	7.31×10^{-3}	3.18×10^{-6}	1.7×10^{-5}	7.15×10^{-3}
Hg	0.88×10^{-2}	0.65×10^{-3}	0.27×10^{-4}	1.64×10^{-1}	3.11×10^{-5}	3.18×10^{-2}	0.67×10^{-1}	3.17×10^{-2}	2.74×10^{-5}	3.4×10^{-4}	1.28×10^{-2}
Cd	1.81×10^{-2}	1.37×10^{-3}	2.66×10^{-4}	1.37×10^{-1}	4.61×10^{-5}	1.34×10^{-2}	1.74×10^{-1}	6.51×10^{-2}	1.71×10^{-6}	1.2×10^{-4}	4.17×10^{-2}
Cr	6.21×10^{-3}	1.34×10^{-4}	2.17×10^{-5}	2.04×10^{-2}	2.12×10^{-7}	4.74×10^{-5}	4.77×10^{-2}	4.34×10^{-3}	0.68×10^{-7}	3.4×10^{-5}	6.62×10^{-3}
As	2.83×10^{-3}	4.37×10^{-4}	2.77×10^{-5}	1.85×10^{-2}	2.34×10^{-6}	4.07×10^{-4}	1.64×10^{-2}	4.71×10^{-3}	0.78×10^{-7}	5.1×10^{-5}	2.54×10^{-3}
Total				2.32×10^{-1}	4.14×10^{-3}	1.61×10^{-3}	0.74×10^{-1}	0.97×10^{-1}	0.88×10^{-4}	4.1×10^{-3}	1.35×10^{-1}

C children, *A* adults

such as traffic on the main state road of China S303, pollution from the burning of coal in winter, and other industrial and agricultural activities. This suggests that the heavy metal pollution emitted from these activities had a significant influence on the heavy metal content in the atmosphere and eventual deposition in the study area. Therefore, the pollution status and the health risks posed by Hg, Pb, and Cd were significantly higher in the northern, central, and northeastern parts of the research area. In previous studies, Leung et al. (2008) showed that human activities, including industrial, urban, and traffic related, caused pollution of the atmosphere, dust and soil, which can significantly influence the chemical fractions of the dust. In this study, we found that in the northern, central, and northeastern parts of the research area, the amounts of the heavy metals in the dust were mainly influenced by the polluting emissions from industrial, urban, and vehicular emissions. These heavy metals were then transferred into the atmosphere and eventually deposited on land. This is also consistent with studies by Akhter and Madany (1993) on heavy metals in the dust in the streets and indoors in Bahrain city in Bahrain, by Arslan (2001) on the heavy metal pollution of the dust on industrial park roads in Kayseri city in Turkey, and by De-Miguel et al. (1997) on the heavy metal pollution of the street dust of Madrid, Spain, and of Oslo, Norway.

In this study, the distributions of Cd, Hg, and Pb were found significantly higher during the colder months from September 2013 to March 2014. The background values during these periods in the study area combined with the fact that heating increases during the winter time from September 2013 through March 2014 in Ebinur Basin, suggesting that Cd and Pb were released into the atmosphere, where they accumulated in the condensed nucleus and then eventually settled on land.

The influence of wind and altitude on the distribution of heavy metals in Ebinur Basin

Alataw Pass is the widest and flattest part of Northwest China, and is located on the Kazakhstan border. Due to its long, narrow, and flat topography, it forms a famous windy pass. In this area, there are approximately 300 windy days annually with up to 165 days annually with high speed winds >17.5 m s^{-1}. The maximum instantaneous wind speed reaches 55 m s^{-1} and grade 17. Previous work by Liu et al. (2011) found that the strong wind of the lake basin contributes to the distribution of heavy metals in the soil of Ebinur Basin. Furthermore, because of blockage by the high altitude of the mountains, lower altitude areas had much higher amounts of atmospheric dust deposition than the higher altitude areas (Fig. 6). For example, samples JC-02 and JC-04, which were taken from the lower altitude areas in the north of the research area, had annual atmospheric dust accumulations of 34.59 and 36.18 g m^{-2}, respectively. Meanwhile, samples JC-38 and JC-41, from higher altitude areas in the south of the study area, had annual atmospheric dust accumulations of 27.18 and 26.25 g m^{-2}, respectively. This suggests that the strong winds from Alataw Pass that travel from the north to the south can significantly influence the atmospheric dust deposition, which may eventually influence the heavy metal contents. In low altitude site sample JC-02 and JC-04, and high altitude site sample JC-38 and JC-41, the Pb, Hg, and Cd contents were 27.8, 0.12, and 0.035 mg kg^{-1}; 25.6, 0.14, and 0.041 mg kg^{-1}; 21.3, 0.04, 0.021; and 18.1, 0.03, and 0.019 mg kg^{-1}, respectively. This is consistent with data published by Liu et al. (2011) showing that the annual deposition in the plain of Ebinur Basin is much higher than that in the mountains surrounding the basin.

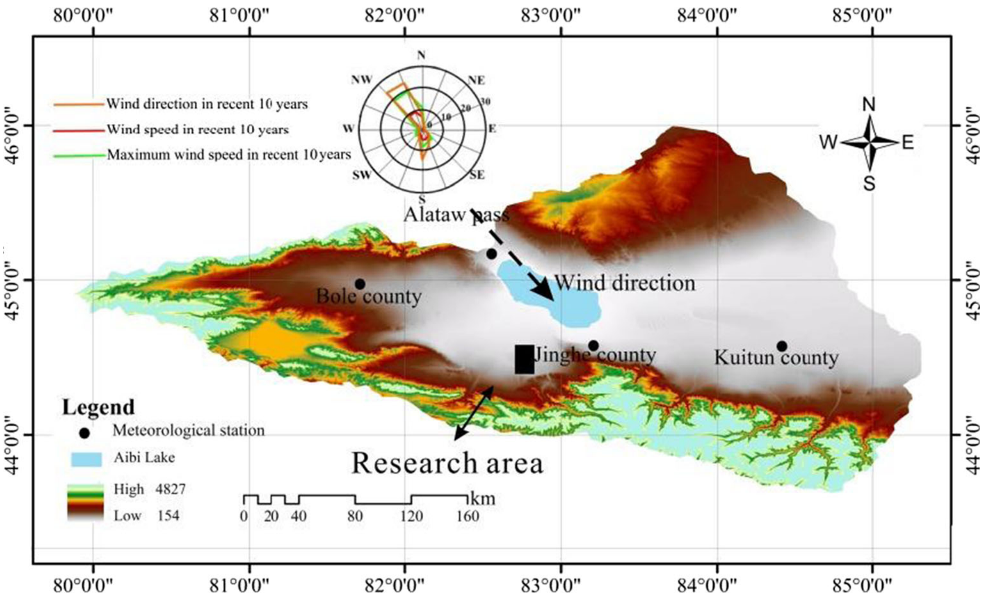

Fig. 6 The annual wind direction in Ebinur Basin

Choose of parameters for evaluation of health risk of cancer and no-cancer of heavy metals in the atmosphere dusts

In this study, in order to compare with the similar research in the world, when calculating the risk of cancer and no-cancer of heavy metals in Ebinur Basin using health evaluation models, we chose the parameters mainly from the Soil Health Risk Model put forward by the U.S. Environmental Protection Agency (U.S. EPA 1989, 2002). But this may make the evaluated results higher than the actual values. Previous studies have found that the skin surface area of Chinese adults is averagely lower by 10–13 % than that of American and European (Tang et al. 2012), so choosing parameters of skin exposure from the calculation models of the U.S. Environmental Protection Agency can cause higher calculation results of risk of cancer and no-cancer of heavy metals in the atmosphere of the research area. Duan et al. (2012) also found that choosing the parameters of skin exposure from the U.S. Environmental Protection Agency resulted in higher results in the health risks assessment of heavy metals in China by 5–20 %, which increased the uncertainty of the research results. So it is very important to choose suitable parameters for the health risk evaluation of heavy metals in the atmospheric dust of the research area and to further choose suitable health risk assessment model for evaluation of the actual situation of arid areas in China, and it is also important to compare the calculated results of different parameters between different health risk assessment models both at home and abroad, to reveal the otherness and the influential factors in the research.

Comparison of levels of heavy metals in the dust around the world

A comparison of heavy metals in dust from cities and other areas in China and other regions in the world found that among the seven heavy metals tested in our study, Hg, As, Cr, Ni, and Zn were present at much lower levels than in studies of the city streets of other areas in many countries of the world such as Bahrain city in Bahrain (Akhter and Madany 1993), Jackson Port in Australia (Birch and Scollen 2003), Karak in Jordan (Al-Khashman 2004), Kavala in Greece (Christoforidis and Stamatis 2009), Delhi in India (Benin et al. 1999), and France (Pagotto et al. 2001). They were also lower than the dust from cities in China, such as Gui yu town in Southern China (Leung et al. 2008), Baoji city in Northern China (Lu et al. 2010), Hongkong city in Eastern China (Li et al. 2001), Baotou city in Northern China (Guo et al. 2011), Nanjing city in Eastern China (Huang et al. 2008), and Peking in Eastern China (Dai et al. 2013) (Table 7). These differences indicate that the environment in Ebinur Basin is clean and the heavy metal contents are relatively low. However, this work also revealed that recent economic development of Ebinur Basin has negatively influenced the amounts of heavy metals in the atmospheric dust. Pb, Cd, and Hg levels were much higher than other heavy metals. Additionally, the risk of exposure to Pb in atmospheric dust by children through

Table 7 Heavy metal content in dust around the world

Regions	Heavy metals (mg kg^{-1})							References
	As	Hg	Cd	Zn	Cu	Cr	Pb	
Bahrain, Bahrain	1.21	–	0.38	–	26.51	–	22.15	Akhter and Madany 1993
Jackson Port, Australian	1.08	0.05	–	167.51	–	128.61	–	Birch and Scollen 2003
Karak, Jordan	–	–	0.32	–	33.77	ND	23.53	Al-Khashman 2004
Ulsan, Korea	–	0.07	–	199.54	–	133.51	–	Duong and Lee 2011
Delhi, India	1.39	–	0.63	–	68.82	–	26.61	Benin et al. 1999
France	0.29	0.05	–	268.41	–	ND	24.16	Pagotto et al. 2001
Guiyu, Southern China	–	–	0.49	274.61	32.79	–	–	Leung et al. 2008
Hongkong, Eastern China	1.27	–	0.71	212.54	37.94	95.43	33.61	Li et al. 2001
Baoji, Sorthern China	–	0.05	ND	187.61	–	–	–	Lu et al. 2010
Baotou, Northern China	1.07	–	0.61	–	66.51	80.54	38.75	Guo et al. 2011
Nanjing, Eastern China	–	0.06	–	171.42	–	ND	–	Huang et al. 2008
Peking, Eastern China	1.03	–	0.37	–	–	–	48.61	Dai et al. 2013
Ebinur Basin	1.07	0.04	0.21	166.89	22.74	99.32	17.81	This research

ND not detected

intake from hand-to-mouth is also high, which deserves attention.

Conclusion

From a study on the atmospheric dust deposition in Ebinur Basin, and the associated pollution and health risks from heavy metals in the dust, we have drawn the following conclusions:

(1) This research found that the contents of heavy metals of the atmospheric deposition in most places of Ebinur Basin are all very lower than those in the urbanized and the industrially developed countries, and also in Eastern China.
(2) From the review of the research of the no-cancer and carcinogenic risks of related heavy metals showed, they were all lower and not harmful to the health of the basin.
(3) "In normal view, we mostly think that the environment of the Xinjiang oases in the arid regions of Northwest China is very good, and the heavy pollution of the environment is very little. However, recent literatures and our research have showed that with the rapid progress of the economy of Xinjiang oases, the water, soil, and the atmosphere dusts of some places have brought some pollution phenomenon, such as the water, soil, and atmosphere pollution in Urumqi city, and the soil and water pollution in Kashgar city. This deserves attention, because the environment of Xinjiang oases is very fragile, and once suffered from the pollution of heavy metals, it will be very hard to recover. In the further, effective measures should be made to maintain the coordination and the sustainability of the rapid economic development and ecological environment protection of this area. In addition,the government should also focus on the heavy metal pollution of Xinjiang oases, which under rapid progress of the economy driven by the *Development of the Western Regions of China* and the *One Belt and One Road Economy Construction of China*" these years.

Acknowledgments This study was supported by the National Natural Science Foundation of China (No. 41471098) and the National Natural Science Foundation of China-Xinjiang Joint Fund (No. U1138301). The authors are extremely thankful for the advice and comments from the reviewers.

References

Abuduwaili J, Zhang ZY, Jiang FQ (2015) Assessment of the distribution, sources and potential ecological risk of heavy metals in the dry surface sediment of Aibi Lake in Northwest China. Plos One 10(3), e0120001

Akhter MS, Madany IM (1993) Heavy metals in street and house dust in Bahrain. Water Air Soil Pollut 66(1–2):111–119

Al-Khashman O (2004) Heavy metal distribution in dust, street dust and soils from the work place in Karak Industrial Estate, Jordan. Atmos Environ 38(39):6803–6812

Arslan H (2001) Heavy metals in street dust in Bursa, Turkey. J Trace Microprobe Technol 19(3):439–445

Banerjee AD (2003) Heavy metal levels and solid phase speciation in street dusts of Delhi, India. Environ Pollut 123(1):95–105

Benin AL, Sargent JD, Dalton M, Roda S (1999) High concentrations of heavy metals in neighborhoods near ore smelters in northern Mexico. Environ Health Perspect 107(4):279

Birch GF, Scollen A (2003) Heavy metals in road dust, gully pots and parkland soils in a highly urbanised sub-catchment of Port Jackson, Australia. Aust J Soil Res 41(7):1329–1342

Chen ZX, Luan WL (2011) Distribution characteristics and genetic analysis of heavy metals in near-surface atmospheric dust fall in Tangshan. Geophys Geochem Explor 35(06):833–836 **(In Chinese)**

China's State Environmental Protection Agency (CSEPA) (1990) China's soil element background values. China Environmental Science Press, Beijing **(In Chinese)**

Christoforidis A, Stamatis N (2009) Heavy metal contamination in street dust and roadside soil along the major national road in Kavala region, Greece. Geoderma 151(3):257–263

Dai SD, Ma KM, Bao L, Zhang T, Zhang D (2013) Distribution of particle matters and contamination of heavy metals in the foliar dust of *Sophora japonica* in parks and their neighboring roads in Beijing. Acta Sci Circumst 33(01):154–162 **(In Chinese)**

Dai JR, Zhu DC, Pang XG, Wang X (2014) Geochemical characteristics and pollution sources identification of the near-surface atmosphere dust-fall in Jining City. China Environ Sci 41(01):40–48 **(In Chinese)**

De-Miguel E, Llamas JF, Chacón E, Berg T, Larssen S, Røyset O, Vadset M (1997) Origin and patterns of distribution of trace elements in street dust: unleaded petrol and urban lead. Atmos Environ 31(17): 2733–2740

Dong T, Li TX, Zhao XG, Cao SZ, Wang BB, Ma J, Duan XL (2014) Source and health risk assessment of heavy metals in ambient air PM_{10} from one coking plant. Environ Sci 35(04):1238–1244 **(In Chinese)**

Duan XL, Huang N, Wang BB, Zhao XG, Nie J, Qian Y, Wang XL, Zhang JL (2012) Development of exposure factors research methods in environmental health risk assessment. J Environ Health 29(2):99–103 **(In Chinese)**

Duong TTT, Lee BK (2011) Determining contamination level of heavy metals in road dust from busy traffic areas with different characteristics. J Environ Manag 92(3):554–562

Eichler A, Tobler L, Eyrikh S, Malygina N, Papina T, Schwikowski M (2014) Ice-core based assessment of historical anthropogenic heavy metal (Cd, Cu, Sb, Zn) emissions in the Soviet Union. Environ Sci Technol 48(5):2635–2642

Environmental Protection Department of the People's Republic of China (EPDPRC) (1995) Environmental quality standard for soils (GB 15618–1995). Ministry of Environmental Protection of People's Republic of China, Beijing **(In Chinese)**

Guo W, Zhao RX, Zhang J, Bao YY, Wang H, Yang M, Jin F (2011) Distribution characteristic and assessment of soil heavy metal pollution in the iron mining of Baotou in Inner Mongolia. Environ Sci 32(10):3099–3105 **(In Chinese)**

Guo JT, Zhou J, Hu BB, Meng WQ, Wang ZW, Wang ZL (2014) Health risk assessment on heavy metals in dust of urban parks in Tianjin. Chin J Ecol 33(02):415–420 **(In Chinese)**

Huang SS, Hua M, Jin Y, Wu XM, Liao QL, Zhu BW, Pan YM (2008) Concentrations and sources of heavy metal in atmospheric dustfall in Nanjing city, East China. Earth Sci Front 15(05):161–166 **(In Chinese)**

Huang XX, Zhu XF, Tang L, Ji HB, Jin YS (2012) Studies on the distribution and chemical speciation of heavy metals in iron mine soil of the upstream area of Miyun Reservoir, Beijing. China Environ Sci 32(09):1632–1639 **(In Chinese)**

Jilili A, Xu JR, Mu GJ, Xu M, Gabchenko MV (2007) Effect of soil dust from Ebinur on soil salts and landscape of surrounding regions. J Glaciol Geocryol 29(06):928–939 **(In Chinese)**

Jilili A, Hu RJ, Wang YJ, Ma L, He Q, Zhang ZY (2013) Lakes of arid land and salt-dust storms. China Environmental Science Press, Beijing, pp 1–301 **(In Chinese)**

Leung AO, Duzgoren-Aydin NS, Cheung KC, Wong MH (2008) Heavy metals concentrations of surface dust from e-waste recycling and its human health implications in southeast China. Environ Sci Technol 42(7):2674–2680

Li XY (2013) Influence of season change on the level of heavy metals in outdoor settled dusts in different functional areas of Guiyang City. Environ Sci 34(6):2407–2415 **(In Chinese)**

Li X, Poon C, Liu PS (2001) Heavy metal contamination of urban soils and street dusts in Hong Kong. Appl Geochem 16(11):1361–1368

Li P, Xue LY, Nan ZR (2014) Pollution evaluation and health risk assessment of heavy metals from atmospheric deposition in Lanzhou. Environ Sci 35(03):1021–1028 **(In Chinese)**

Liu DW, Jilili A, Mu GJ, Xu JR (2009) Chemical components and transport mechanics of wind-erodible playa sediments, Ebinur Lake, Xinjiang, China. China Environ Sci 29(2):157–162 **(In Chinese)**

Liu DW, Jilili A, Lei JQ, Wu GY (2011) Saline dust storm and its ecological effects. J Desert Res 31(01):168–173 **(In Chinese)**

Liu DH, Wang FY, Zhou WL, Yang YJ (2012) Heavy metal pollution in street dusts from different functional zones of Luoyang City and its potential ecological risk. Environ Sci 33(1):253–259 **(In Chinese)**

Lu X, Wang L, Li LY, Lei K, Huang L, Kang D (2010) Multivariate statistical analysis of heavy metals in street dust of Baoji, NW China. J Hazard Mater 173(1):744–749

Mamat Z, Yimit H, Ji RZA, Eziz M (2014) Source identification and hazardous risk delineation of heavy metal contamination in Yanqi basin, northwest China. Sci Total Environ 493:1098–1111

Müller G (1979) Heavy-metals in sediment of the Rhine-changes since 1971. Umsch Wiss Tech 79(24):778–783

Neto JAB, Gingele FX, Leipe T, Brehme I (2006) Spatial distribution of heavy metals in surficial sediments from Guanabara Bay: Rio de Janeiro, Brazil. Environ Geol 49(7):1051–1063

Pagotto C, Remy N, Legret M, Le Cloirec P (2001) Heavy metal pollution of road dust and roadside soil near a major rural highway. Environ Technol 22(3):307–319

Rahn KA (1976) The chemical composition of the atmospheric aerosols. Technical report, Graduate School of Oceanography, University of Rhode Island

Tang RL, Ma KM, Zhang YX, Mao QZ (2012) Health risk assessment of heavy metals of street dust in Beijing. Acta Sci Circumst 32(8): 2006–2015 **(In Chinese)**

U.S. EPA (1989) Risk assessment guidance for superfund. volI. Human health evaluation manual. Office of Emergency and Remedial Response, Washington, DC

U.S. EPA (2002) Environmental protection agency. Supplemental guidance for developing soil screening levels for super fund sites. Office of Solid Waste and Emergency Response, Washington, DC, pp 1–106

Wang J, Chen ZL, Wang C, Ye MW, Shen J, Nie ZL (2007) Heavy metals accumulation in river sediments of Chongming Island, Shanghai city, and its environmental risk. Chin J Appl Ecol 18(07):1518–1522 **(In Chinese)**

Wang X, Ma J, Hou Q, Duan H (2011) Accumulation and health risk assessment of heavy metals in kindergarten surface dust in the city of Kaifeng. Acta Sci Circumst 31(3):583–593 **(In Chinese)**

Wu D, Wei HT, Zhao RR, Zhang R, Liu JB (2014) Magnetic properties of indoor dust fall at different heights in Lanzhou. Environ Sci 35(01): 79–84 **(In Chinese)**

Yang Q, He Q, Li HJ, Lei JQ (2003) Study on the sand-dust climate change trend and jump in Ebinur Lake area. J Desert Res 23(05): 27–32 **(In Chinese)**

Yang S, Liu G, Zhang A, Wang Y, Yang Z (2010) Analysis on accumulation characters of 5 kinds of heavy metals in orchard topsoil in typical production zone in China. Acta Ecol Sin 30(22):6201–6207 **(In Chinese)**

Zhang ZY, Abuduwaili J, Jiang FQ (2013) Determination of occurrence characteristics of heavy metals in soil and water environments in Tianshan Mountains, Central Asia. Anal Lett 46(13):2122–2131

Zheng N, Liu J, Wang Q, Liang Z (2010) Health risk assessment of heavy metal exposure to street dust in the zinc smelting district, Northeast of China. Sci Total Environ 408(4):726–733

Zhong XL, Zhou SL, Li JT, Zhao QG (2010) Evaluation of soil heavy metals accumulation in the fast economy development region. Environ Sci 31(06):1608–1616 **(In Chinese)**