Microchemical Journal 93 (2009) 147–152

Contents lists available at ScienceDirect

Microchemical Journal

journal homepage: www.elsevier.com/locate/microc

Spatial distribution and contamination assessment of heavy metals in urban road dusts from Urumqi, NW China

Binggan Wei [a,b], Fengqing Jiang [a,*], Xuemei Li [a,b], Shuyong Mu [a]

[a] Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, Xinjiang, PR China
[b] Graduate University of Chinese Academy of Sciences, Beijing 100049, PR China

ARTICLE INFO

Article history:
Received 25 May 2009
Accepted 2 June 2009
Available online 12 June 2009

Keywords:
Spatial distribution
Contamination assessment
Heavy metal
Road dust
Urumqi

ABSTRACT

This study reports the spatial distribution pattern and degree of heavy metal pollution (Cd, Cr, Cu, Ni, Pb, Mn, Be, Co, Zn and U) in 169 urban road dust samples from urban area of Urumqi city. The spatial distribution pattern shows that Cu, Pb, Cr and Zn have similar patterns of spatial distribution. Their hot-spot areas were mainly associated with main roads where high traffic density was identified. Ni and Mn show similar spatial distributions coinciding with the industrial areas, while the spatial distribution patterns of Co and U show hot-spot areas were mainly located in the sides of the urban area where the road dust was significantly influenced by natural soils. The spatial distributions of Be and Cd were very different from other metals. The geo-accumulation index suggests that road dust in Urumqi city was uncontaminated to moderately contaminated with Cd, Cu, Ni, Pb, Mn, Be, Zn and U. The integrated pollution index shows IPIs of all road dust samples were higher than 1, suggesting that the road dust quality of Urumqi city has clearly been polluted by anthropogenic emission of heavy metals. Moreover, the spatial distribution pattern of IPIs also shows several distribution trends in the studied region.

© 2009 Elsevier B.V. All rights reserved.

1. Introduction

In recent decades, more and more attention has been paid to heavy metal pollution in urban road dust in that heavy metals exert considerable impacts on human health and ecosystem. For example, low-level lead exposure can be harmful to enzyme systems, brain and blood production for human body; and high Pb level may affect blood Pb level and intelligence [1,2]. Long-term exposure to lead can increase the probability of mentally retarded children and slow down the mentality development of children [3].

Since industrial revolution started in the mid-1800s, the biogeochemical cycle of inorganic contaminants (e.g. metals) naturally present in the environment has been greatly accelerated by human activities [3,4]. According to numerous studies, the anthropogenic sources of heavy metals can be generally classified into three categories: 1) “urban” elements; 2) “natural” elements; and 3) elements of a mixed origin, meaning that some kinds of metal pollutants experience geochemical reaction and their major attributes have been altered [5]. In the urban area, motor vehicles, industry and weathered materials were the three main sources of heavy metals [2,6–11]. Moreover, atmospheric pollution was one of the sources of heavy metal contamination in road dust. Heavy metals can accumulate in topsoil from atmospheric deposition by sedimentation, impaction and interception [2]. Ahmed and Ishiga reported that increases in anthropogenic trace metals in the environment can most likely be attributed to rapid urbanization and industrialization and increased vehicle emissions to the atmosphere [3].

At present, air pollution has become a major environmental issue in many developing countries, including China. In several cities of China, studies about heavy metal contamination in urban road dust have been conducted recently [12–16]. With regard to Urumqi city — a rapidly developing arid city in economy located at the inner continent, several studies have reported that the air and soil environment were significantly polluted, and Urumqi city was one of those cities heavily polluted in the world [17–19]. However, it is still not understood about the spatial distribution patterns and contamination levels of heavy metals in road dust in Urumqi city.

Therefore, to obtain and learn more information on spatial distribution patterns and contamination levels of heavy metal in Urumqi city, the objectives of this paper is to: 1) identifying the patterns spatial distribution of Cd, Cr, Cu, Ni, Pb, Mn, Be, Co, Zn and U; and 2) assessing the contamination levels of these metals by geo-accumulation index (I_{geo}) and integrated pollution index (IPI).

2. Materials and methods

2.1. Study region

Urumqi city (86°37′33″–88°58′24″E, 42°45′32″44°08′00″N), the capital of Xinjiang Uygur Autonomous Region of China, locates at the north-west of China, the hinterland of continent. The temperature

* Corresponding author. Xinjiang Institute of Ecology and Geography, Chinese Academy of Science, 818 South Beijing Road, Urumqi 830011, Xinjiang, PR China. Tel.:+86 991 7885421; fax: +86 991 7885300.
E-mail address: jiangfq@ms.xjb.ac.cn (F. Jiang).

0026-265X/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.microc.2009.06.001

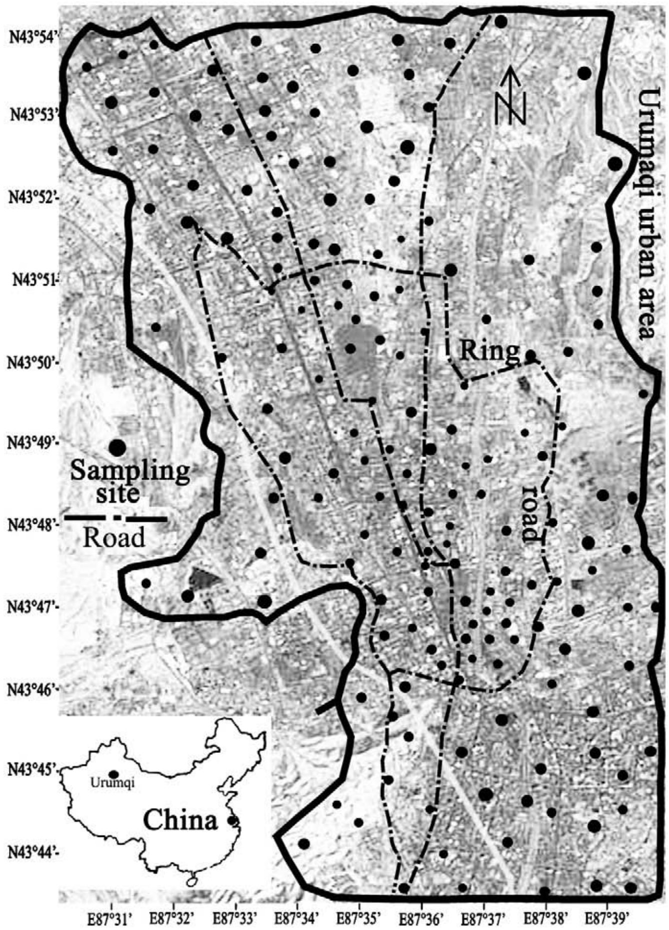

Fig. 1. Sampling sites in Urumqi city.

of Urumqi was characterized by middle-temperate continental and arid climate. The urban area of Urumqi was surrounded by Tianshan Mountain in the south, west and east direction with peaks up to 5000 m. The mean altitude of Urumqi city was about 800 m a.s.l (Fig. 1). The total population increased from 164 millions in 2000 to more than 194 millions in 2005. There were more than 0.23 million motor vehicles in the city in 2006. In 2006, 11.4 million tons of coal was consumed in Urumqi, about 4 million tons more than that in 2000. Most of industries and automobile service businesses were located around the urban area of Urumqi. Machine shops, tire factories, rubber factories, cement factories were located in the northern Urumqi; in the eastern Urumqi, there were paper mill, firepower plant, textile mill, automobile factory, chemical plant and other manufactories. In recent years, the population and number of vehicles increase sharply with rapidly developing economy in Urumqi. However, environment comes to be heavily polluted by various pollutants. In 1998, Urumqi was evaluated by Word Health Organization (WHO) and was ranked as one of the ten (ranked the fourth) most polluted cities over the world [17,18]. Heavy environment pollution in Urumqi urban may be due to exhausts emissions from vehicles, firepower plants, domestic heating, industrial discharging, building materials weathering.

2.2. Road dust sampling

A total of 169 road dust samples were collected from different roads (i.e. highway, primary roads, minor roads, residential roads and park roads) within the city of Urumqi during August 2007 in order to investigate spatial distribution and contamination levels of the heavy metals in these roads. The sampling points are shown in Fig. 1. Each sample point was situated at the side of road, and about 100–200 g dust sample was collected and gathered into self-sealing polyethylene bag by using a clean plastic dustpan and a brush, from each area of 1 m^2 measured by a ruler. The exact location (longitudes and latitudes) of each sample point was measured by GPS instrument. Finally, the road dust samples were transferred to the laboratory for further analysis.

2.3. Sample processing

All the samples were air-dried in room, and then these dried samples were sieved through nylon sieve with diameter of ≤0.149 mm. 0.1 g of the sieved dust samples were digested with a mixture 5:2:1 of HNO_3–H_2SO_4–HF and left over night. Then, the solution was heated at 120 °C for 30 min, at 150 °C for 30 min, at 200 °C for 30 min, and at 260–270 °C for 60 min in turn. Finally, the digested samples were diluted to 50 ml with deionized water [2,9,20]. Ten heavy metals, i.e., Cd, Cr, Cu, Ni, Pb, Mn, Be, Co, Zn and U were determined by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS, ELANDRCII, PerkinElmer). Quality controls involved: 1) analysis of 12 random samples and 4 national standard samples; and 2) random selection of samples to ensure that the mean deviation be less than 3%.

2.4. Geostatistic methods and mapping of metal concentration

All statistical analyses were performed by using the Microsoft Excel 2007 and SPSS V13.0 for Windows. Moreover, the maps of spatial distribution of heavy metal concentrations were generated by Kriging interpolating data from 169 road dusts by using Surfer 8.0.

2.5. Methods of heavy metal pollution assessment

The geo-accumulation index (I_{geo}) introduced by Muller has been used since the late 1960s, and has been widely employed in European trace metal studies [21]. The I_{geo} was used to assess heavy metal contamination in urban soils by comparing current and pre-industrial concentrations, although it is not always easy to reach pre-industrial sediment layers. It was also used to assess heavy metal pollution in road dust. Geoaccumulation index is expressed as follows [23]:

$$I_{geo} = \log_2(C_n / 1.5B_n) \quad (1)$$

where C_n is the concentration of element in urban soil, B_n is the background value. In this study, the background geochemical compositions of the city soil types [22] were chosen as the background values for calculating the I_{geo} values. The constant 1.5 allows us to analyze natural fluctuations in the content of a given substance in the environment and to detect very small anthropogenic influences [23].

The geo-accumulation index consists of 7 classes (Table 1). Class 6 is an open class and comprises all values of the index higher than grade 5. The elemental concentrations in grade 6 may be hundred fold greater than the background value [23].

To further assess the road dust quality, a pollution index (PI) of each metal and an integrated pollution index (IPI) of the metals were attributed to each metal. The PI of each element was defined as the ratio of the heavy metal concentration in the study to the background

Table 1
Six classes of the geo-accumulation index.

Class	Value	Urban soil quality
0	$I_{geo} \leq 0$	Practically uncontaminated
1	$0 < I_{geo} < 1$	Uncontaminated to moderately contaminated
2	$1 < I_{geo} < 2$	Moderately contaminated
3	$2 < I_{geo} < 3$	Moderately to heavily contaminated
4	$3 < I_{geo} < 4$	Heavily contaminated
5	$4 < I_{geo} < 5$	Heavily to extremely contaminated
6	$5 < I_{geo}$	Extremely contaminated

Table 2
Heavy metal concentrations (mg/kg) and IPIs of urban road dusts in Urumqi.

Elements	No. of samples	Concentration			Std. dev.	Background values[a]	Geoaccumulation index		
		Min.	Mean	Max.			Min.	Mean	Max.
Cd	169	0.11	1.17	14.57	2.00	0.12	−0.2	0.8	1.9
Cr	169	20.23	54.28	174.57	19.73	49.3	−0.6	−0.1	0.4
Cu	169	33.63	94.54	252.17	42.39	26.7	−0.1	0.4	0.8
Ni	169	19.40	43.28	95.55	11.91	26.6	−0.3	0.0	0.4
Pb	169	13.87	53.53	99.45	18.20	19.4	−0.3	0.3	0.5
Mn	169	535.10	926.60	1458.34	139.06	688	−0.3	0.0	0.2
Be	169	1.55	2.75	11.56	0.84	1.65	−0.2	0.0	0.7
Co	169	6.69	10.97	25.46	2.15	15.9	−0.6	−0.3	0.0
Zn	169	69.26	294.47	846.15	129.11	68.8	−0.2	0.5	0.9
U	169	1.54	2.13	3.78	0.35	2.8	−0.4	0.0	0.0

[a] CNEMC (1990).

concentration of the corresponding metal of the city as the following formulation [24–26]:

$$PI = C_n / B_n \tag{2}$$

where C_n and B_n are the measured and the background concentrations of element n respectively in road dust.

The integrated pollution index (IPI) is defined as the mean value of the pollution index (PI) of an element. It is classified as: IPI ≤ 1 low level of pollution; 1 < IPI ≤ 2 middle level of pollution; IPI > 2 high level of pollution [24–26].

3. Results and discussions

3.1. Heavy metal concentrations

The minimum and maximum concentrations, the mean values and standard deviations for each analyzed heavy metal were presented in Table 2. In addition, the background values of the metals in Urumqi soil were also shown in Table 2. Table 2 shows, in general, the concentrations of heavy metals varied widely in the studied region. The mean concentrations of Cr, Cu, Ni, Pb, Mn, Be and Zn, particularly Cd, were higher than their background values, suggesting than these metals in road dust from Urumqi city were influenced by anthropogenic sources.

3.2. Geo-accumulation index

The minimum, maximum and mean values of I_{geo} for each element were shown in Table 2. Based on the I_{geo} data and the Muller's geo-accumulation index listed in Table 1, the main mean I_{geo} value was in the range from 0 to 1 except for Cr and Co that showed I_{geo} value lower than 0, which indicates that road dust in Urumqi city was uncontaminated to moderately contaminated with Cd, Cu, Ni, Pb, Mn, Be, Zn and U. The highest I_{geo} value for each element also shown that the road dust was uncontaminated to moderately contaminated by the metals except for Cd. The highest I_{geo} value for Cd was 1.9, which may suggest that Cd in the road dust was most significantly impacted by anthropogenic sources.

3.3. Spatial distribution of metals

The spatial distribution of metal concentrations is a useful aid to assess the possible sources of enrichment and to identify hot-spot area with high metal concentration [27,28]. Distribution patterns of the studied elements in the whole urban area of Urumqi are represented in Fig. 2.

Similar patterns of spatial distribution were observed for Cu, Pb, Cr and Zn. For these elements, they had relatively high spatial variability. Their hot-spot areas were mainly associated with main roads where high traffic density was identified. The features suggest these metals are probably due to vehicular emission.

Ni and Mn show similar spatial distributions coinciding with the industrial areas, which suggest the two metals may be derived from industrial sources in the study region, although several studies have shown the elevated Mn concentration in road dust mainly attributed to natural sources [2,29–31].

Co and U also show similar spatial distributions. The mean concentrations of the two metals are lower than their background concentrations in soil, reflecting Co and U may be not polluted by anthropogenic activities. The spatial distribution patterns of Co and U show hot-spot areas were mainly located in the sides of the urban area where the road dust was significantly influenced by natural soils, which suggest that Co and U are mainly due to input of soil parent material.

With regard to Be and Cd, the spatial distributions were very different from other metals. The spatial distribution of Be was relatively even, while the only one hot-spot area located in the south-western of the city was associated with the railway station of Urumqi. It seems that, in the study region, the activities in the railway station may emit significant quantities of Be into road dust. However, the spatial distribution pattern of Cd concentration presented less variability. The hot-spot areas were located in the south area closed to the old centre of Urumqi city and the east area closed to the petrochemical factory, textile mill and Shuimogou Park. The main utilization types of these areas were commerce centre, industrial estate and vegetable field. In this study, therefore, anthropogenic inputs of Cd into road dust may be attributed to commercial activities, industrial activities, application of organic manures and phosphatic fertilizer in the Park. Other authors reported that numerous human activities, such as mining, smelting, waste disposal, wastewater irrigation and phosphate fertilizer application had resulted in the release of significant quantities of Cd to the environment [32–36].

3.4. Metal pollution index

The IPIs of all analyzed samples varied from 1.1 to 14.4. Fig. 3 represents the spatial distributions of IPIs in Urumqi city. The assessment of the data shows that the IPIs of all road dust samples were higher than 1, suggesting that the road dust quality of Urumqi city has clearly been polluted by anthropogenic emission. Approximately 4.1% of all samples had extremely high pollution levels with IPI higher than 5. These road dust sample sites with extremely high pollution levels were all located in the areas closed to manufactories such as petrochemical factory, power plant, tire manufacturing plant, cement plant, textile mill or others. Therefore, the road dusts in these sites may be significantly impacted by heavy metals from the manufactories emission. Moreover, about 60% of all samples had high pollution levels with IPI in the range from 2 to 5, while low pollution levels with IPI lower than 2 accounted for about 35.9% of all samples.

There are several clear trends in the distribution of the IPI values in the studied region. In the old urban area, most of the road dust

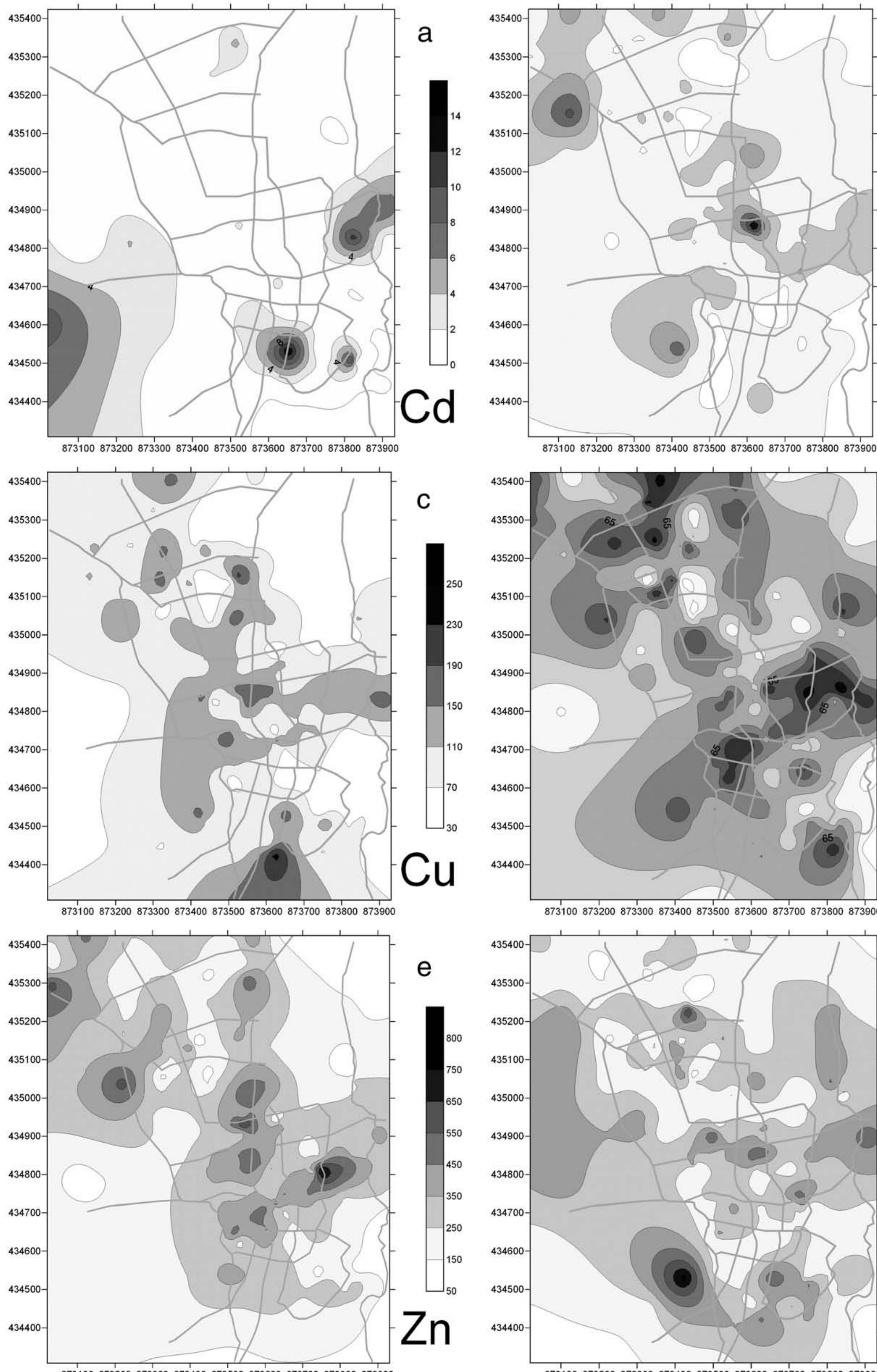

Fig. 2. Spatial distribution of the concentrations of heavy metals in the studied area.

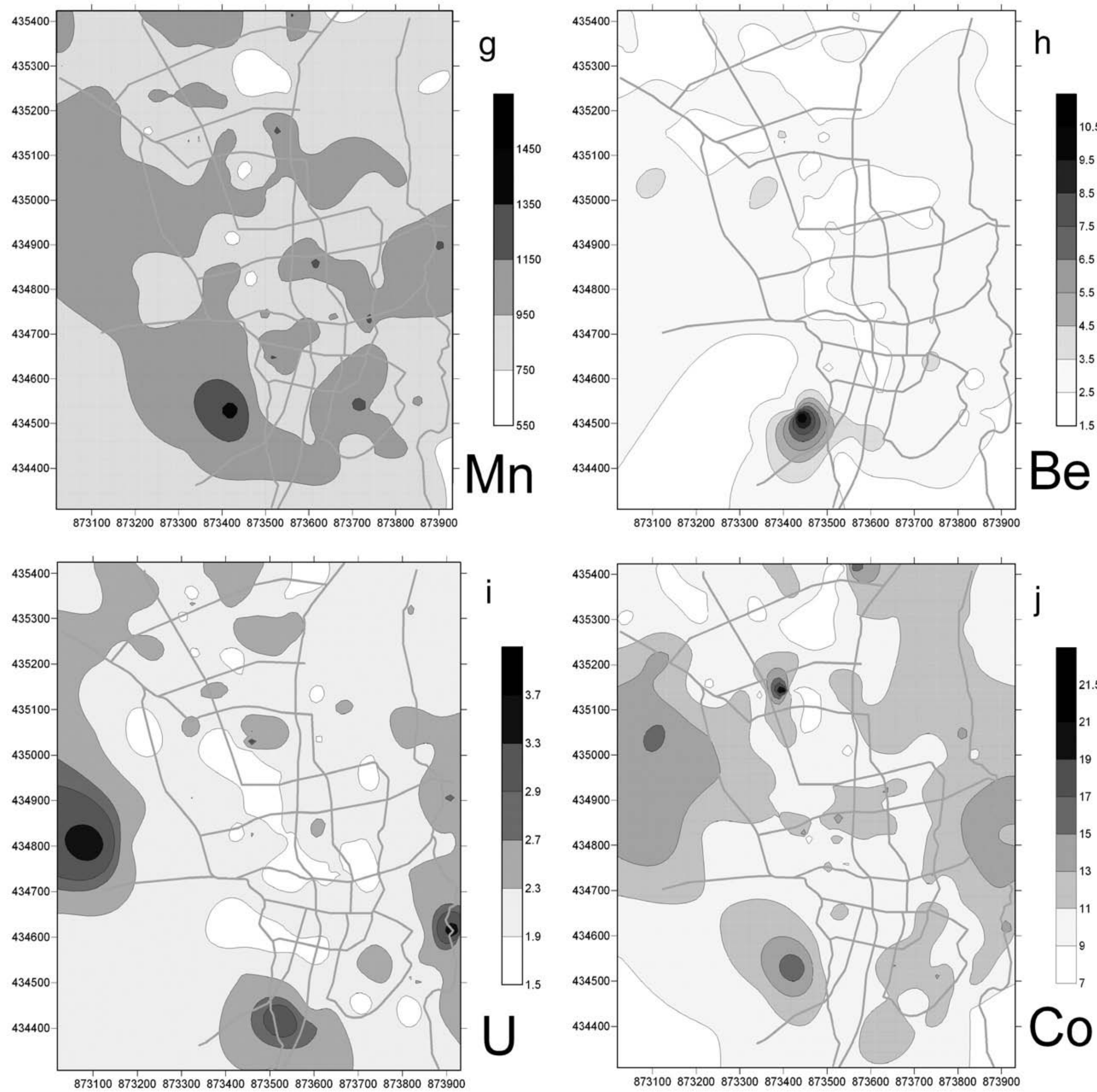

Fig. 2 (*continued*).

samples were in high levels of pollution, which can be attributed to significantly traffic emission and long-term accumulation of heavy metals. Contrary, most of the road dust samples were in low levels of pollution in the new urban area and city side. Moreover, the areas closed to manufactories were also in high levels of pollution. These trends can be attributed to urbanization, distribution of industrial areas and commercial areas.

4. Conclusions

A total 169 samples of road dust collected in Urumqi city were analyzed for Cd, Cr, Cu, Ni, Pb, Mn, Be, Co, Zn and U using ICP-MS. The concentrations of these elements were generally higher than their background values. The spatial distribution of the metals shows that similar patterns of spatial distribution were observed for Cu, Pb, Cr and Zn. Their hot-spot areas were mainly associated with main roads where high traffic density was identified. Ni and Mn show similar spatial distributions coinciding with the industrial areas, which suggest that the two metals may be derived from industrial sources in the study region. The spatial distribution patterns of Co and U show that hot-spot areas were mainly located in the sides of the urban area where the road dust was significantly influenced by natural soils, which suggest that Co and U are mainly due to input of soil parent material. However, the spatial distributions of Be and Cd were very different from other metals. The only one hot-spot area of Be located in the south-western of the city was associated with the railway station of Urumqi. It seems that the activities in the railway station may emit significant quantities of Be into road dust. The hot-spot areas of Cd were located in the south closed to the old urban area of Urumqi city and the east closed to manufactories and one park. The anthropogenic inputs of Cd into road dust may be attributed to commercial activities, industrial activities, application of organic manures and phosphatic fertilizer in the parks.

The pollution level of the elements for Urumqi city was estimated using I_{geo} and IPI, it was found that the pollution level of this city is in the category of "uncontaminated to moderately contaminated level". The spatial distribution pattern of IPIs indicate that about 60% of the collected samples had high pollution levels with IPI ranging from 2 to 5, while low pollution levels with IPI lower than 2 accounted for about

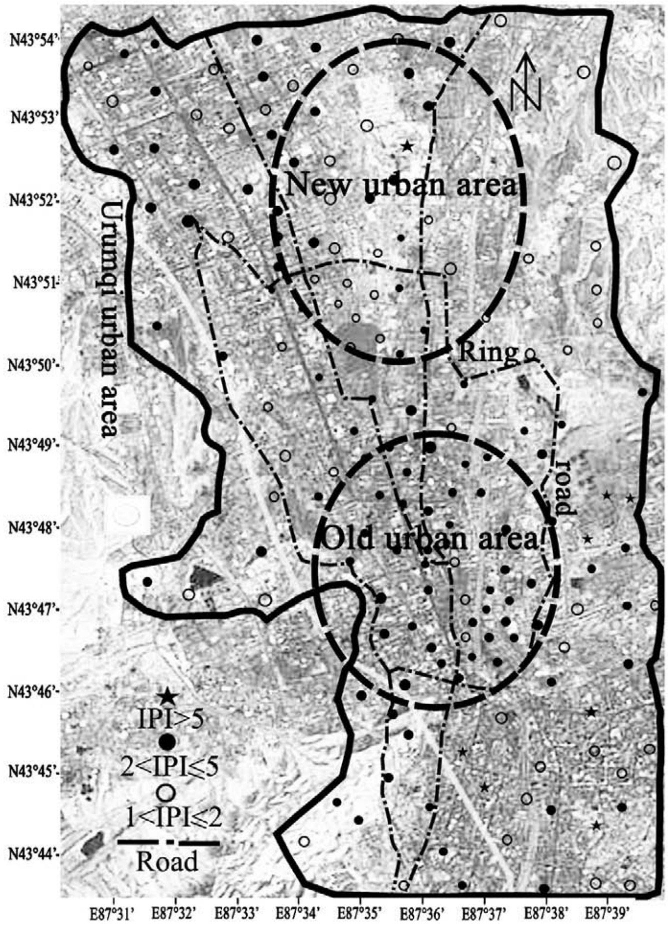

Fig. 3. Spatial distribution of the integrated pollution index (IPI) in the studied area.

35.9% of all samples. In the old urban area, most of the road dust samples were high levels of pollution, which can be attributed to significantly traffic emission and long-term accumulation of heavy metals. Contrary, most of the road dust samples were low levels of pollution in the new urban area and city side.

Acknowledgements

The work described in this paper was financially supported by the Key Laboratory of Oasis Ecology and Desert Environment, Xinjiang Institute of Ecology and Geography, CAS (project no. 0571041).

References

[1] X.D. Li, C.S. Poon, P.S. Liu, Heavy metal contamination of urban soils and street dusts in Hong Kong, Applied Geochemistry 16 (2001) 1361–1368.
[2] N. Sezgin, H.K. Ozcan, G. Demir, S. Nemlioglu, C. Bayat, Determination of heavy metal concentrations in street dusts in Istanbul E-5 highway, Environment International 29 (2003) 979–985.
[3] F. Ahmed, H. Ishiga, Trace metal concentrations in street dusts of Dhaka city, Bangladesh, Atmospheric Environment 40 (2006) 3835–3844.
[4] S. Davydova, Heavy metals as toxicants in big cities, Microchemical Journal 79 (2005) 133–136.
[5] E. De Miguel, J.F. Llamas, E. Chacon, T. Berg, S. Larssen, O. Royset, M. Vadset, Origin and patterns of distribution of trace elements in street dust: unleaded petrol and urban lead, Atmospheric Environment 31 (1997) 2733–2740.
[6] R.M. Harrison, D.P.H. Laxen, S.J. Wilson, Chemical associations of lead, cadmium, copper and zinc in street dusts and road side soils, Environmental Science and Technology 15 (1981) 1376–1383.
[7] M.G. Gibson, J.G. Farmer, Multi-step chemical extraction of heavy metals from urban soils, Environ Pollut B 11 (1986) 117–135.
[8] S.M. Akhter, I.M. Madany, Heavy metals in street and house dust in Bahrain, Water, Air, and Soil Pollution 66 (1993) 111–119.
[9] O.A. Al-Khashman, Heavy metal distribution in dust, street dust and soils from the work place in Karak Industrial Estate, Jordan, Atmospheric Environment 38 (2004) 6803–6812.
[10] O.A. Al-Khashman, The investigation of metal concentrations in street dust samples in Aqaba city, Jordan, Environ Geochem Health 29 (2007) 197–207.
[11] F. Douay, H. Roussel, H. Fourrier, C. Heyman, G. Chateau, Investigation of heavy metal concentrations on urban soil, dust and vegetables nearby a former smelter site in Mortagne du Nord, Northern France, Journal of Soil and Sediments 7 (2007) 143–146.
[12] Y.Z. Sun, H.J. Zhang, Z.C. Du, Q.X. Li, Z.X. Li, Organic pollution of street dust in the Handan City, China, Environmental Contamination and Toxicology 70 (2003) 422–429.
[13] Y.M. Han, P.X. Du, J.J. Cao, Posmentier, multivariate analysis of heavy metal contamination in urban dusts of Xi'an, Central China, Science of the Total Environment 355 (2006) 176–186.
[14] Y.H. Ling, M. Hu, X.F. Huang, Y.H. Zhang, B.D. Yu, D.Q. Liu, Chemical characterization of fine particles from on-road vehicles in the Wutong tunnel in Shenzhen, China, Chemosphere 62 (2006) 1565–1573.
[15] L.H. Han, G.S. Zhuang, S.Y. Cheng, Y. Wang, J. Li, Characteristics of re-suspended road dust and its impact on the atmospheric environment in Beijing, Atmospheric Environment 41 (2007) 7485–7499.
[16] S. Xue, Y.Q. Wang, Some characteristics of the distribution of heavy metals in urban topsoil of Xuzhou, China, Environmental Geochemistry and Health 29 (2007) 11–19.
[17] Q.C. Zhao, Y. Qian, C.X. Zheng, W.J. Liu, The space–time distribution characters of TSP and lead of low altitude air on the two sides of traffic ways in Urumqi, Journal of Xinjiang Agricultural University 29 (2006) 71–75.
[18] J. Li, G.S. Zhuang, K. Huang, Y. Lin, C. Xu, S.L. Yu, Characteristics and sources of air-borne particulate in Urumqi, China, the upstream area of Asia dust, Atmospheric Environment 42 (2008) 776–787.
[19] Y.Y. Liu, M. Liu, H.F. Liu, Distribution of heavy metal in urban soil of Urumqi City, Arid Land Geography 30 (2007) 120–123.
[20] S. Charlesworth, M. Everett, R. McCarthy, A. Ordonez, E. De Miguell, A comparative study of heavy metal concentration and distribution in deposited street dusts in a large and a small urban area: Birmingham and Coventry, West Midlands, UK, Environment International 29 (2003) 563–573.
[21] G. Muller, Index of geo-accumulation in sediments of the Rhine River, Geojournal 2 (1969) 108–118.
[22] CNEMC (China National Environmental Monitoring Centre), The Background Values of Chinese Soils, Environmental Science Press of China, Beijing, 1990.
[23] Y.Q. Ji, Y.C. Feng, J.H. Wu, T. Zhu, Z.P. Bai, C.Q. Duan, Using geo-accumulation index to study source profiles of soil dust in China, Journal of Environmental Sciences 20 (2008) 571–578.
[24] X. Lu, L. Wang, K. Lei, J. Huang, Y. Zhai, Contamination assessment of copper, lead, zinc, manganese and nickel in street dust of Baoji, NW China, J. Hazard. Mater. (2008), doi:10.1016/j.jhazmat.2008.04.052.
[25] T.B. Chen, Y.M. Zheng, M. Lei, Z.C. Huang, H.T. Wu, H. Chen, K.K. Fan, K. Yu, X. Wu, Q. Z. Tian, Assessment of heavy metal pollution in surface soils of urban parks in Beijing, China, Chemo 60 (2005) 542–551.
[26] Y. Faiz, M. Tufail, M.T. Javed, M.M. Chaudhary, N. Siddique, Road dust pollution of Cd, Cu, Ni, Pb and Zn along Islamabad Expressway, Pakistan, Microchemical Journal (2009), doi:10.1016/j.microc.2009.03.009.
[27] P. Burgos, M. Madejón, A. Pérez-de-Mora, F. Cabrera, Horizontal and vertical variability of soil properties in a trace element contaminated area, International Journal of Applied Earth Observation & Geoinformation, 10 (2008) 11–25.
[28] J. Li, Y. Lu, W. Yin, H. Gan, C. Zhang, X. Deng, J. Lian, Distribution of heavy metals in agricultural soils near a petrochemical complex in Guangzhou, China, Environ Monit Assess (2008), doi:10.1007/s10661-008-0363-x.
[29] L. Ferreira-Baptista, E. De Miguel, Geochemistry and risk assessment of street dust in Luanda, Angola: a tropical urban environment, Atmospheric Environment 39 (2005) 4501–4512.
[30] S.R. Oliva, A.J.F. Espinosa, Monitoring of heavy metals in topsoils, atmospheric particles and plant leaves to identify possible contamination sources, Microchemical Journal 86 (2007) 131–139.
[31] X. Wang, Y. Qin, Some characteristics of the distribution of heavy metals in urban topsoil of Xuzhou, China, Environmental Geochemistry and Health 29 (2007) 11–19.
[32] B.J. Alloway, Heavy metals in soils, 2nd Ed. Blackie, London, 1995.
[33] G.C. Kisku, S.C. Barman, S.K. Bhrgava, Contamination of soils and plants with potentially toxic elements irrigated with mixed industrial effluent and its impact on the environment, Water, Air, & Soil Pollution 120 (2000) 121–137.
[34] Y. Li, Y.B. Wang, X. Gou, Y.B. Su, G. Wang, Risk assessment of heavy metals in soils and vegetables around non-ferrous metals mining and smelting sites, Baiyin, China, Journal of Environmental Sciences 18 (2006) 1124–1134.
[35] D. Montagne, S. Cornu, H. Bourennane, D. Baize, C. Ratié, D. King, Effect of agricultural practices on trace-element distribution in soil, Communications in Soil Science and Plant Analysis, 38 (2007) 473–491.
[36] T. Sabiha-Javied, M.M. Mehmood, M. Chaudhry, N. Tufail, Irfan, heavy metal pollution from phosphate rock used for the production of fertilizer in Pakistan, Microchemical Journal 91 (2009) 94–99.