Review

The Pollution Character Analysis and Risk Assessment for Metals in Dust and PM_{10} around Road from China*

CHEN Rong Hui, WANG Bao Qing#, WANG Ze Bei, and YAO Shu

INTRODUCTION

In recent years, with the gradual improvement of road construction, the rapid increase of the number of motor vehicles, vehicle emissions and the current poor vehicle performance, poor vehicle maintenance, higher emission factor[1] and so on, air pollution caused by the traffic issues becomes the focus of people attention[2-6]. The harmful substances are gradually accumulated to atmosphere particles surrounding roads due to dust particles (soil dusts, road dusts, construction dusts), coal emissions, industrial emissions, vehicle emissions, biomass burning, secondary particles[7], which has a certain harmful influence to the atmosphere, soil and plants surrounding roads. Component matters of atmospheric particulates are rather complex and are mainly affected by source and industry, agriculture, geography, climate and other conditions[3], in which heavy metals attached to particles, due to their chemical stability and hard degradation characteristics, are the most dangerous hazards to the environment and exposed population.

Heavy metals in surface dust leaves and vehicle exhaust emissions have good correlation and Poisson analysis showed the correlation coefficients of Zn, Fe, and Cr are greater than 0.8; the correlation coefficients of Mn and Cu are greater than 0.7; the correlation coefficients of Pb and Ni are greater than 0.6 for the contents of road dusts on the leaves[8]. The traffic emission plays a significant role in atmospheric particulate matters from roads surrounding the effective distance[9]. The concentrations of Pb, Cu, Zn, Ni, Cr, Cd, As, Hg in the road dust and soil in several different functional areas of caneva demonstrated that the distribution of heavy metals in road dusts is similar for the soil, indicating that transport activities can make the concentrations of heavy metals in soil surrounding roads to increase by impacting road dusts[3]. The contents of different size fine particles in Beijing typical roads environment with the Enrichment Factor Analysis and Factor Analysis showed that sources of elements such as Cu, S, Zn, Pb, As, Br are motor vehicles emission, coal and biomass burning, industrial emissions, etc[10].

Some of atmospheric particles with heavy metals transfer to road surface by dry sedimentation and become road dusts, others still suspend in the atmosphere and can be inhaled particulate matters (PM_{10})[11]. However, due to the different of the terrain, climate, and the level of urbanization, the proportion of deposition particulate matters accounted for the total particulate matters is also different[12-13].

Heavy metals in road dusts are gradually accumulated in the soil surface so that the contents of heavy metals in the soil change and pollute the environment[14-16]. Heavy metals adsorbed on fine particles[17-23] are easy into the human body with respiration and continue to accumulate in the body, which resulting that function of the human body impaired and causing disease. Heavy metals such as PGEs, Cd would be gradually accumulated in the body from the liver to the kidneys in the study of heavy metals pollution caused by traffic, which making height, weight, and kidney function of the mice decline[24]. Heavy metals such as As, Cd, Co, Cr, Ni adsorbed on $PM_{2.5}$ have a carcinogenic risk to human health[25].

Heavy metals (Pb, Cd, Cu, Zn, Ni, Cr) in road dusts and PM_{10} that people have been concerned[26-27] at the most of Chinese cities. However, the quantitative data on heavy metals transmission and sources, concentrations and their contamination levels, the degree of pollution to environment and health have not been systematically gathered and intercompared.

doi: 10.3967/bes2015.005

*This work was financially supported by National Major Scientific Instrument Equipment Development Special (2011YQ060111).

College of Environmental Science and Engineering, Nankai University, Tianjin 300071, China

Therefore, this paper focuses on heavy metals contamination in dusts and PM_{10} around roads in China and first analyzes briefly the sources, the transportation of particulates and the ways of evaluation of pollution levels, then reviews the effect of six metals (Pb, Cd, Cu, Zn, Ni, and Cr) related traffic particulate (PM_{10}) and dust to environment and health.

TRANSPORTATION OF PARTICLES

There are two approaches of diffusion of particulate matters, including natural approach and anthropogenic activities. Natural approach refers to particles spread due to natural phenomena (climatic and meteorological factors) with air, water, soil, organisms[28-31].

In an early study of particles diffusion pollution, it is likely to cause water pollution that particulate matters containing hazardous substances easily go into the water. Besides it can attract the attention of many researchers because of its short time and great harm[32-34]. Currently, scholars have begun to gradually conduct research about particulate matters that enter into the soil and atmospheric on account of food safety and air pollution problems frequently, in which atmospheric pollution of particulates has been more attention[28,35]. Because it can transfer with the movement of wind, boundary unlimited and serious harm on downwind areas, besides its diffusion time is short. The chemical compositions of fly ash particles from several to 20 μm in diameter emitted in Northeast Asia showed the same characteristics with Japan and Korea, China, and Taiwan particles using discriminant analysis. And it illustrated most of these compositions were probably transported from Chinese industrial regions through wind[36]. Due to atmospheric suspended particles (usually in the particle size range<60 μm) can be spread in the wind, it has important influence on the downwind regions and countries. So the pollution characters of particulate matter have become a hot issue concerned by the world[37-41].

In order to recognize the activities of diffusion of atmospheric particulate matters, people specialize in models to simulate its activities, including simple box models, Lagrangian or Eulerian models, Gaussian models, and computational fluid dynamics (CFD) based models[42-45]. Computing characterisation of the fine particle dispersion in the wake of an isolated wheel of vehicle by CFD methods, it showed easily velocity field of the air flow around a rotating wheel and to determine the trajectories for different particle sizes[46]. The analysis results of ambient monitored data at Santiago using box models showed the concentrations of particles were concerned with humidity, wind speed, and direction[47]. Lagrangian particle dispersion model was developed to simulate total fine particulate carbon in rural areas, using readily available meteorological and emission inputs[48]. Anthropogenic activities mainly refer to particulates diffusion due to human activities, agricultural activities, manufacturing activities, mining activities, etc[49-52].

SAMPLING COLLECTION AND ANALYSIS METHOD

Sampling Site and Sample Collection

Sampling Site and Sample Collection of Road Dust Samples sites in 16 Chinese cities (Shenyang, Huludao, Urumqi, Beijing, Hefei, Jinan, Xi'an, Nanjing, Wuhu, Hangzhou, Shanghai, Baoji, Guiyang, Kunming, Guangzhou, and Hong Kong) typical roads were selected in literatures. The choice of sampling site and collection cities surveyed is based on road dust samples specification issued EPA AP-42 manual and Technical Specifications for Urban Fugitive Dust Pollution Prevention and Control (HJ/T 393-2007) published the environmental protection administration of china. Because of the different amount of various urban road dust, sampling areas of every city are different in order to reach the lower limit of detection of heavy metal. In addition to take the vacuum cleaner sample in Beijing, the rest of the cities road dust samples were collected using a clean plastic dustpan and brushes. The road dust samples were dried thoroughly and then sieved through a <2 mm sieve in order to wipe off stones, plant residues, etc. Then, the sieved road dusts samples would be sieved through 100 mesh nylon sieve and dried in clean plastic bags to subsequent experiments.

Sampling Site and Sample Collection of PM_{10} PM_{10} sampling data from typical roads of seven cities (Beijing, Harbin, Urumqi, Kaifeng, Nanchang, Huainan, Chengdu) in China and four highways (the section of Changjiu highway from Nanchang to Jiujiang, the section of Changzhang highway from Nanchang to Zhangshu, Jiangsu section of State Road 104 and Kaifeng section of State Road G310) were discussed. The sampling sites in urban and highway were less than 5 m and 30 m from the typical road edge. The choice of PM_{10} sampling collection cities surveyed is based on Manual methods for ambient air quality monitoring (HJ/T 194-2005) published the environmental protection administration of china. The sampling instrument of PM_{10} was a large flow TSP sampler that was equipped with a cutting head of PM_{10}.

Sampling Analysis Method

Acid digestion is typically used to extract particle-bound metals from traffic assistants. Heavy metals were usually acidified in the laboratory by a or two certain kinds of combinations of HCl, H_2SO_4, HF, HNO_3, $HClO_4$, and H_3BO_3[53-56]. The aqueous extracts can then be subjected to a suite of chemical analysis, including atomic absorption spectrophotometry (AAS)[57] (if concentrations of heavy metals are high, the way of chemical analysis is flame atomic absorption spectrometry; if low, the way is graphite furnace atomic absorption spectrometry), atomic fluorescence spectrometry (AFS)[58], inductively coupled plasma mass spectrometry (ICP-MS)[59], inductively coupled plasma-atomic emission spectrometry (ICP-AES)[60], inductively coupled plasma atomic emission spectroscopy (ICP-OES)[60], and X-ray fluorescence spectrometry (XFR)[61]. The total concentrations of Pb, Zn, Cd, Cu, Ni, and Cr in road dusts of cities surveyed were determined by ICP, ICP-MS, ICPAES, ICP-OES, AAS, GF-AAS, or XRF.

CONCENTRATION OF HEAVY METAL

The concentrations of heavy metals (Pb, Zn, Cd, Cu, Ni, Cr) in road dusts, PM_{10} around urban roads and PM_{10} around highways are shown in Tables 1, 2, and 3, respectively.

Concentrations of Heavy Metals in Road Dust

Table 1 shows that the mean concentrations of Pb, Zn, Cd, Cu, Ni, and Cr in urban road dusts from China are 172.54, 769.46, 7.53, 129.44, 43.71, and 85.11 mg/kg, respectively; The heavy metal concentration ranges are observed to be 14.18-533.2, 162.33-5271, 0.285-72.84, 51.89-264.4, 21.47-86, and 36-167 mg/kg, respectively. Nowadays there are on normal because road dust concentration is influenced by many aspects. So we use elements background values in soil of China (China B) and maximum permissible concentrations of potential toxic elements for agricultural soils of China (PTE-MPC) to reflect the element pollution levels of road dust. Besides, it is obvious that the concentrations of six heavy metals in the urban road dusts in all the cities exceed their background values, in which the concentrations of Zn, Cd, and Cu indeed exceed their maximum permissible concentrations of potential toxic elements. Therefore the current heavy metals pollution in road dusts in urban from China is very serious.

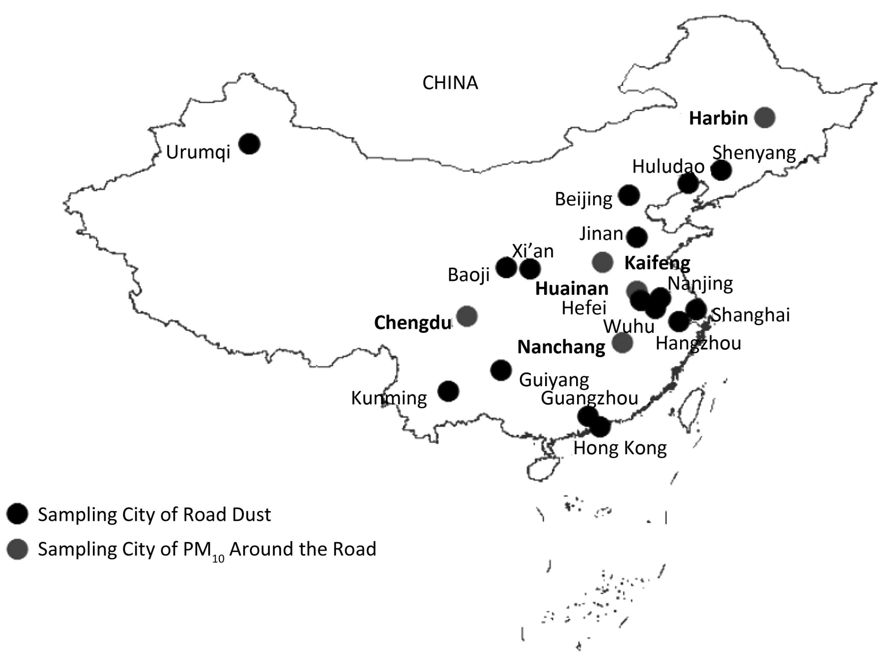

Figure 1. The sampling site of heavy metals in road dust and PM_{10} in China.

Comparing the mean concentrations of heavy metals in urban road dusts from China and foreign (given in Table 1), it shows that Pb (172.54 mg/kg) pollution is lower than Greece (300.9 mg/kg), Japan (200 mg/kg) and Australia (487 mg/kg), but is higher than Korea (118 mg/kg) and America (73 mg/kg); Zn (769.46 mg/kg) pollution is lower than Japan (1300 mg/kg), but higher than surveyed other countries; Cd (7.53 mg/kg) pollution is highest among surveyed countries; Cu (129.44 mg/kg) pollution is lower than Korea (148 mg/kg), Japan (510 mg/kg), Australia (164 mg/kg) and higher than Greece (123.9 mg/kg), America (105 mg/kg); Ni (43.71 mg/kg) pollution is higher than Australia (27 mg/kg), Korea (16.9 mg/kg), and lower than Greece (57.5 mg/kg). Cr (85.11 mg/kg) pollution is higher than Australia (34 mg/kg) and lower than surveyed other countries. Overall, the level of Cd pollution in road dusts from China is considered to be more serious; other heavy metals pollution are in the medium level.

Heavy metals concentrations in the survey areas of the cities showed that the concentrations of heavy metals in road dusts in Huludao region are far more than the maximum allowable emissions concentrations and background values. It is that because there are a lot of galvanizing and other metallurgical industries there that release heavy metals by refining zinc ore and so on, besides the development of traffic in recent years also increase concentrations of heavy metals. In addition, observing the concentration of heavy metals in road dust, heavy metals concentrations were lower in Guiyang than other cities. It is likely that there are higher vegetation coverage in Guiyang that have some protective effect on heavy metals pollution in road dusts. The average concentrations of six heavy

Table 1. Heavy Metals Concentrations in Urban Road Dust (mg/kg)

City	Pb	Zn	Cd	Cu	Ni	Cr	Reference
Shenyang	106.26	334	4.35	81.33	NG	NG	[62]
Huludao	533.2	5271	72.84	264.4	NG	NG	[63]
Urumqi	53.53	294.47	1.17	94.54	43.28	54.28	[64]
Beijing-1	69.6	248.5	0.71	78.3	41.1	85	[65]
Beijing-2	50.79	NG	0.47	NG	23.43	77.36	[66]
Jinan	59.23	200.56	NG	51.89	NG	57.67	[67]
Hefei	83.34	700.41	2.11	58.68	NG	75.59	[68]
Xi'an	231	422	NG	95	NG	167	[69]
Nanjing	103.4	394	1.094	122.9	55.9	125.5	[70]
Wuhu	95.21	257.7	5.85	162.78	24.73	46.19	[71]
Hangzhou	202.16	321.4	1.59	116.04	25.88	51.29	[72]
Shanghai-1	294.9	733.8	1.23	196.8	83.98	159.3	[73]
Shanghai-2	264	673	NG	182	86	NG	[74]
Baoji	408.41	715.1	NG	123.17	48.83	NG	[75]
Guiyang	14.18	162.33	0.285	54.8	46.95	36	[76]
Kunming	97.49	316.53	NG	168.8	21.47	79.41	[77]
Guangzhou	240	586	2.41	176	23	78.8	[78]
Hong Kong	181	1450	3.77	173	NG	NG	[79]
Mean	172.54	769.46	7.53	129.44	43.71	85.11	
China B.	26	100	0.097	22.6	26.9	61	[80]
PTE-MPC	300	250	0.3	100	50	200	[81]
Ulsan (Korea)	118	130	1.48	148	16.9	NG	[82]
Kavala (Greece)	300.9	271.6	0.2	123.9	57.5	196	[3]
Massachusetts (USA)	73	240	NG	105	NG	95	[83]
Tokyo (Japan)	200	1300	2	510	NG	130	[84]
Sydney (Australia)	487	523	NG	164	27	34	[85]

Note. China B. refers to background values in soil of China; PTE-MPC refers to maximum permissible concentrations of potential toxic elements for agricultural soils of China.

metals are followed a descending orders: Zn>Pb>Cu>Cr>Ni>Cd, and it is similar to the study of Han[53].

Heavy Metals Concentrations In PM_{10} Around Urban Roads

Table 2 shows that the mean concentrations of Pb, Zn, Cd, Cu, Cr, and Ni in PM_{10} around urban roads from China are respectively 0.352, 0.663, 0.037, 0.118, 0.122, and 0.019 μg/m^3; Heavy metals concentrations ranges are observed to be 0.064-1.168, 0.243-1.931, 0.001-0.110, 0.039-0.389, 0.004-0.367, and 0.009-0.133 μg/m^3, respectively. The average concentrations of six heavy metals are followed a descending orders: Zn>Pb>Cr>Cu>Cd>Ni. Compared with the concentrations of heavy metals in PM_{10} around urban road at abroad, the concentrations in China are very greater, indicating that it is time that we should carefully assess the impact of heavy metals in PM_{10} from china to human health.

Heavy Metals Concentrations In PM_{10} Around Highways From China

Table 3 shows that the mean concentrations of Pb, Zn, Cd, Cu, Cr, and Ni in PM_{10} road around highways from China are 2.05, 3.83, 0.10, 0.35, 0.24, and 0.11 μg/m^3, respectively; The heavy metals concentrations ranges are observed to be 1.42-2.71, 0.81-6.60, 0.03-0.19, 0.133-0.35, 0.099-0.12 μg/m^3, respectively. The average concentrations of six heavy metals are followed a descending orders: Zn>Pb>Cu>Cr>Ni>Cd, and it shows the different trend with heavy metals concentrations in PM_{10} around urban roads. Compared with heavy metals concentrations in PM_{10} around urban roads, heavy metals concentrations in PM_{10} around highways are higher. It illustrates that heavy metals concentrations in PM_{10} are mainly influenced by vehicle speed[100].

HEALTH AND ENVIRONMENTAL IMPACT

Considering the applicability of the evaluation methods to environment and health, different assessment methods to heavy metals in road dusts and PM_{10} around urban roads from China are discussed.

The Sources And Impact to Environment of Heavy Metals

Multivariate Statistical Analysis of Heavy Metals Taking into account data abundant, the surveyed cities are as follows: Urumqi, Beijing-1, Nanjing, Wuhu, Hangzhou, Shanghai-1, Guangzhou, and multivariate statistical analysis to sources of heavy metals in roads dust by SPSS is carried.

The sources of heavy metals in particulate matters are mainly divided into two categories. One is from the vehicle itself, including direct emissions from motor vehicle emissions[26], road surface abrasion and resuspension in the wake of passing traffic[101], brake wear, tyre wear[26,102-104], the use of

Table 2. Heavy Metals Concentrations in PM_{10} around Urban Road from China (μg/m^3) and Foreign (ng/m^3)

City	Pb	Zn	Cd	Cu	Cr	Ni	Reference
Beijing-1	0.682	0.567	NG	0.389	0.291	0.133	[86]
Beijing-2	0.186	0.525	NG	0.067	0.067	0.028	[87]
Harbin	0.295	0.519	NG	0.111	0.367	NG	[88]
Urumqi	0.064	NG	0.002	0.124	NG	NG	[89]
Kaifeng	0.479	0.620	NG	0.069	0.043	0.027	[90]
Nanchang	0.121	0.243	0.110	0.046	0.004	0.009	[91]
Huainan	0.155	0.14	NG	0.039	0.013	0.012	[92]
Chengdu	1.168	1.931	0.001	0.372	0.241	NG	[93]
Mean	0.352	0.663	0.037	0.118	0.122	0.019	
Frankfurt (Germany)	32.6	105.6	0.3	101.5	16.3	7.3	[94]
Birmingham ($PM_{7.2}$) (UK)	9.6	33	0.21	10	NG	0.93	[95]
Palermo (Italy)	17.5	52.5	NG	58.5	7.1	6.15	[96]
Barcelona (Spain)	57.1	97.3	0.7	48.5	8.2	7.3	[97]
Stockholm (Sweden)	7.2	41	0.12	57.6	6.1	2.9	[26]

lubricating and crude oil containing heavy metals[104-106]. For example, the combustion of diesel or gasoline can cause concentrations of Ni and Cu to rise in the study of heavy metals in Taiwan some roads[21]; The brake wear and fuel combustion can make Cu, Co contents increase by calculating emission factors of heavy metals in surrounding roads particulates[26]. The other is anthropogenic activities, including industries[107] and agricultural activities. For the concentrations of heavy metals in Harbin road dusts, there are significant differences in different urban functions streets, which the concentrations of heavy metals in Daqing road dusts are higher than other roads and it is because there are many industries around Daqing road[108]. Csavina[28] also confirmed that concentrations of heavy metals in particulate matter around the mining industry are higher than other areas.

Correspondence analysis Pearson correlation coefficient for each metal in the urban road dusts using SPSS is shown in Table 4. It is clear that Pb, Zn and Pb, Cu have both a good correlation, Pearson correlation coefficients were 0.902 and 0.833, respectively. Besides, the correlation of Zn and Cu is very significant. So it illustrates that the sources of Pb, Zn, and Cu in urban road dusts are similar and mainly attributed to vehicular traffic and industrial discharges[109-110]. The concentrations of Ni and Cr also show a significant correlation, while there was a negative correlation between Ni, Cd and Cr, Cd, which the correlation coefficients are -0.478 and -0.249, respectively. It explains that the sources of Ni, Cr are similar and mainly attributed to soil parent material[111], which have adverse influence on the source of Cd that is effected by industrial activities[112].

Hierarchical cluster analysis Hierarchical Cluster Analysis is a multivariate statistical method that can classify unknown phenomenon and principle is that the same classes of individuals are similar (small difference), individuals in different classes are different. It can easily analysis the source of heavy metals by Hierarchical Cluster Analysis using SPSS, which results in Figure 2. Figure 2 shows that Hierarchical Cluster Analysis put the sources of heavy metals divide into three categories from dendrogram, heavy metals of the first category source include Pb, Zn, and Cu; the second category includes Ni and Cr; the third category is Cd, which is similar to the correlation analysis.

Contamination Levels of Heavy Metals in Urban Road Dusts Based on the limited experimental data, the geo-accumulation index was used to evaluate the pollution levels of heavy metals in urban road dusts from China. The geo-accumulation index is provided in 1969 by scientists at Heidelberg University in Germany sediments Muller Institute[113]. The geo-accumulation index is calculated using the following equation:

$$I_{geo} = \log_2\left(\frac{C_n}{1.5B_n}\right) \quad (1)$$

Where C_n is the content of elements n in sediments ($mg \cdot kg^{-1}$); B_n refers to geochemical background values in sediments ($mg \cdot kg^{-1}$); 1.5 is a constant that

Table 3. Heavy Metals Concentrations in PM_{10} around Highways from China ($\mu g/m^3$)

Highway	Pb	Zn	Cd	Cu	Cr	Ni	Reference
Changjiu highway	2.20	6.60	0.10	0.65	NG	NG	[43]
Changzhang highway	1.42	4.09	0.03	0.45	NG	NG	[43]
State Road 104	1.85	0.81	0.065	0.040	0.133	0.099	[98]
State Road G310	2.71	NG	0.19	0.24	0.35	0.12	[99]
Mean	2.05	3.83	0.10	0.35	0.24	0.11	

Table 4. Correspondence Analysis for Heavy Metals in the Urban Road Dusts

Metal	Pb	Zn	Cd	Cu	Ni	Cr
Pb	1	-	-	-	-	-
Zn	0.902**	1	-	-	-	-
Cd	0.103	-0.018	1	-	-	-
Cu	0.833*	0.835**	0.529	1	-	-
Ni	0.230	0.482	-0.478	0.164	1	-
Cr	0.588	0.785*	-0.249	0.545	0.781*	1

Note. *: Correlation is significant at the 0.05 level (2-tailed). **: Correlation is significant at the 0.01 level (2-tailed).

was presented due to the changes of background value. According to I_{geo}, the pollution levels of heavy metals are divided into seven classes which are uncontaminated (I_{geo}≤0); uncontaminated to moderately contaminated (0<I_{geo}≤1); moderately contaminated (1<I_{geo}≤2); moderately to heavily contaminated (2<I_{geo}≤3); heavily contaminated (3<I_{geo}≤4); heavily to extremely contaminated (4<I_{geo}≤5); extremely contaminated (I_{geo}≥5). The I_{geo} values for the metals in road dusts are shown in Table 5.

The mean I_{geo} values for Pb, Zn, Cd, and Cu in urban road dust are 1.67, 1.68, 3.79, and 1.78, while the mean I_{geo} values for Ni and Cr is -0.05 and -0.27, respectively. From the all cities pollution average values, it shows that Cd contamination level belongs to heavily contaminated; Pb, Zn, and Cu are moderately contaminated; Ni and Cr are uncontaminated. It is similar to the study of Wang[114]. The pollution levels of Pb, Zn, Cu, Cd are higher than other cities because of lots of metal smelting industries in Huludao. Observing the all cities (in addition to Huludao) pollution levels of Pb and Cd, Pb pollution concentrates in the developed cities such as Xi'an, Shanghai, Guangzhou and the industrial city (Baoji); Cd pollution is more serious in the industrial cities (Shenyang and Wuhu) and the developed cities (Guangzhou and Hong Kong). So the sources of Pb, Cd in urban road dusts are mainly traffic and industry activities, respectively.

The Impact to Health of Heavy Metals

The changes of heavy metals in PM_{10} around roads in Beijing 2000 and 2009 are shown in Figure 3.

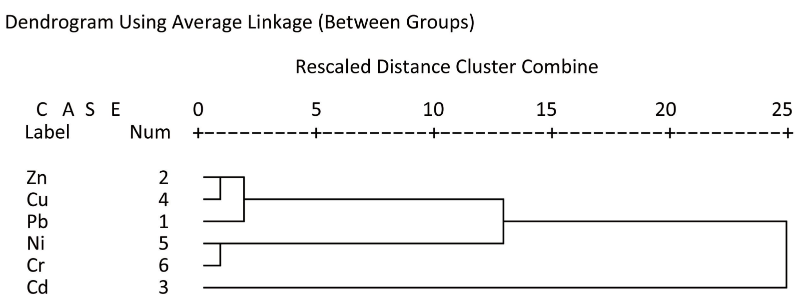

Figure 2. Hierarchical Cluster Analysis of heavy metals.

Table 5. Geo-accumulation Index of Heavy Metals in Urban Road Dusts from China

City	Pb	Zn	Cd	Cu	Ni	Cr
Shenyang	1.45	1.15	4.90	1.26	NC	NC
Huludao	3.77	5.14	8.97	2.96	NC	NC
Urumqi	0.46	0.97	3.01	1.48	0.10	-0.75
Beijing-1	0.84	0.73	2.29	1.21	0.03	-0.11
Beijing-2	0.38	NC	1.69	NC	-0.78	-0.24
Jinan	0.60	0.42	NC	0.61	NC	-0.67
Hefei	1.10	2.22	3.86	0.79	NC	-0.28
Xi'an	2.57	1.49	NC	1.49	NC	0.87
Nanjing	1.41	1.39	2.91	1.86	0.47	0.46
Wuhu	1.29	0.78	5.33	2.26	-0.71	-0.99
Hangzhou	2.37	1.10	3.45	1.78	-0.64	-0.84
Shanghai-1	2.92	2.29	3.08	2.54	1.06	0.80
Shanghai-2	2.76	2.17	NC	2.42	1.09	NC
Baoji	3.39	2.25	NC	1.86	0.28	NC
Guiyang	-1.46	0.11	0.97	0.69	0.22	-1.35
Kunming	1.32	1.08	NC	2.32	-0.91	-0.20
Guangzhou	2.62	1.97	4.05	2.38	-0.81	-0.22
Hong Kong	2.21	3.27	4.70	2.35	NC	NC
Mean	1.67	1.68	3.79	1.78	-0.05	-0.27

Note. NC: Not calculated because of lacking data.

Figure 3 shows that the total concentrations of heavy metals in PM_{10} around roads in 2009 are significantly lower than that of 2000, this is because Beijing implemented traffic control measures during the 2008 Olympic Games, including vehicle restrictions, sealed part of the bus and increasing road cleaning, etc[10]. Thus, the temporary control of the motor vehicle can directly decrease metals emissions. The risk assessment based on the data in Beijing refers to the Beijing-2.

Heavy metals adsorbed on respirable particulate matter (PM_{10}) is mainly into the human body with respiration. According to USEPA Risk assessment guidance for Superfund[115], the daily exposure dose equation is as follows:

$$ADD = \frac{C \times IR \times EF \times ED}{BW \times AT} \tag{2}$$

Where *ADD* is the average daily dose ($mg \cdot kg^{-1} \cdot d^{-1}$); *C* is the exposure concentration of metals in PM_{10} ($mg \cdot m^{-3}$); *IR* is a daily ingestion rate ($m^3 \cdot d^{-1}$), in which the values[68] of Children and Adults are 7.63 ($m^3 \cdot d^{-1}$) and 12.8 ($m^3 \cdot d^{-1}$); *EF* is the exposure frequency in a day ($d \cdot a^{-1}$) and the value[117] is 180 ($d \cdot a^{-1}$) in this essay; *ED* is the exposure duration (a) and the values[116] of Children and Adults are 6 years and adults 24 years; *BW* is the average body weight (kg) and the values of Children and Adults are 44 kg and adults 63 kg based on 2010 National Physique Monitoring Bulletin; *AT* is the averaging time (d) and the values[115] of Non-carcinogenic metals and carcinogenic metals are ED×365 and 70×365 in this essay.

Heavy metals of Zn, Pb, and Cu have chronic non-cancer risk on humans, while Cd, Cr, and Ni are carcinogenic metals in this study.

Non-carcinogenic hazard index for each element[115-116] is:

$$HQ = \frac{ADD_i}{RfD_i} \tag{3}$$

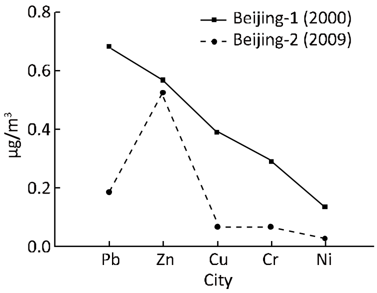

Figure 3. Changes in the heavy metals concentration in Beijing 2000 and 2009.

Non-carcinogenic hazard index for several elements[115-116] is:

$$HI = \sum_{i=1}^{n} \frac{ADD_i}{RfD_i} \tag{4}$$

Carcinogenic hazard index for each element[115] is:

$$R = ADD_i \times SF_j \tag{5}$$

Where *HQ* is non-carcinogenic hazard index for each element; RfD_i is reference dose of metal *i* with respiration ($mg \cdot kg^{-1} \cdot d^{-1}$); *HI* is non-carcinogenic hazard index for several elements; *R* is lifetime excess risk of certain carcinogenic metal; SF_i is carcinogenic potency index ($kg \cdot d \cdot mg^{-1}$). According to the data of the U.S. Environmental Protection Agency Integrated Risk Impact System (IRIS), RfD_{Cu}=0.04, RfD_{Zn}=0.3, RfD_{Pb}=3.52×10^{-3}, SF_{Cd}=6.1, SF_{Cr}=4.2, SF_{Ni}=0.91.

The daily exposure dose for adults and children in selected areas are calculated by Equation (2) is shown in Table 6.

Carcinogenic and non-carcinogenic risk values with inhalation by Equations (3), (4), (5) are shown in Tables 7, 8. Because the kinds of heavy metals are different in different cities, non-carcinogenic risk value of individual metal and the total cancer risk value of several metals were calculated. Table 7 shows the *HQ* values for Pb, Zn, and Cu were lower than 1, besides *HI* was also lower than 1. It indicated there was no health risk for Pb, Zn, and Cu in survey areas. Compared the *HQ* values for adults and children, the health risks values of adults were less than children, which may related to the ability of children resisting disease. The health risks values were followed a descending order: Pb>Cu>Zn. From the survey of the city, health risk values for Pb, Cu, and Zn in Kaifeng and Chengdu were significantly higher than other regions, which may related to thriving tourism industry.

Table 8 shows that the carcinogenic risk values of Cd, Cr, and Ni for adults were more than children, which was just the opposite with non-carcinogenic risk. Carcinogenic risk values of Cd, Cr, and Ni in surveied cities were between 10^{-6} and 10^{-4} (cancer risk threshold range) and also within the acceptable level (10^{-4}), indicating that the carcinogenic risk posed by the three metals to children and adult via inhalation is acceptable. Besides, the result of the carcinogenic risk assessment of Cr was based on the assumption that all of the Cr in PM_{10} were in the form of the more toxic hexavalent chromium, to estimate the worst scenario of Cr[25,106]. Hence, the

Table 6. Exposure Dose with Respiration

City	Human	Pb	Zn	Cd	Cu	Cr	Ni
Beijing	Adults	1.86×10^{-5}	5.26×10^{-5}	NC	6.71×10^{-6}	2.30×10^{-6}	9.62×10^{-7}
	Children	1.59×10^{-5}	4.49×10^{-5}	NC	5.73×10^{-6}	4.91×10^{-7}	2.05×10^{-7}
Harbin	Adults	2.96×10^{-5}	5.20×10^{-5}	NC	1.11×10^{-5}	1.26×10^{-5}	NC
	Children	2.52×10^{-5}	4.44×10^{-5}	NC	9.49×10^{-6}	2.69×10^{-6}	NC
Urumqi	Adults	0.64×10^{-5}	NC	6.87×10^{-8}	1.24×10^{-5}	NC	NC
	Children	0.55×10^{-5}	NC	1.47×10^{-8}	1.06×10^{-5}	NC	NC
Kaifeng	Adults	4.80×10^{-5}	6.21×10^{-5}	NC	6.91×10^{-6}	1.48×10^{-6}	9.28×10^{-7}
	Children	4.10×10^{-5}	5.30×10^{-5}	NC	5.90×10^{-6}	3.15×10^{-7}	1.98×10^{-7}
Nanchang	Adults	1.21×10^{-5}	2.43×10^{-5}	3.78×10^{-6}	4.61×10^{-6}	1.37×10^{-7}	3.09×10^{-7}
	Children	1.03×10^{-5}	2.08×10^{-5}	8.06×10^{-7}	3.93×10^{-6}	2.93×10^{-8}	6.60×10^{-8}
Huainan	Adults	1.55×10^{-5}	1.40×10^{-5}	NC	3.91×10^{-6}	4.47×10^{-7}	4.12×10^{-7}
	Children	1.33×10^{-5}	1.20×10^{-5}	NC	3.34×10^{-6}	9.53×10^{-8}	8.80×10^{-8}
Chengdu	Adults	11.7×10^{-5}	19.3×10^{-5}	3.44×10^{-8}	3.73×10^{-5}	8.28×10^{-6}	NC
	Childrn	9.99×10^{-5}	16.5×10^{-5}	0.73×10^{-8}	3.18×10^{-5}	1.77×10^{-6}	NC
Mean	Adults	3.53×10^{-5}	6.64×10^{-5}	1.29×10^{-6}	1.19×10^{-5}	4.21×10^{-6}	6.53×10^{-7}
	Children	3.02×10^{-5}	5.67×10^{-5}	2.76×10^{-7}	1.01×10^{-5}	8.98×10^{-7}	1.39×10^{-7}

Table 7. The Non-carcinogenic Risk Values with Inhalation in Surveyed Cities

City	Human	Pb	Zn	Cu	*HI*
Beijing	Adults	5.28×10^{-3}	0.18×10^{-3}	0.17×10^{-3}	5.63×10^{-3}
	Children	4.52×10^{-3}	0.15×10^{-3}	3.74×10^{-3}	8.41×10^{-3}
Harbin	Adults	8.41×10^{-3}	0.17×10^{-3}	0.28×10^{-3}	8.86×10^{-3}
	Children	7.16×10^{-3}	0.15×10^{-3}	3.70×10^{-3}	11.01×10^{-3}
Urumqi	Adults	1.82×10^{-3}	NC	0.31×10^{-3}	NC
	Children	1.55×10^{-3}	NC	0.27×10^{-3}	NC
Kaifeng	Adults	1.36×10^{-2}	0.21×10^{-3}	0.17×10^{-3}	13.98×10^{-3}
	Children	1.17×10^{-2}	0.18×10^{-3}	4.42×10^{-3}	16.3×10^{-3}
Nanchang	Adults	3.44×10^{-3}	0.08×10^{-3}	0.12×10^{-3}	3.64×10^{-3}
	Children	2.93×10^{-3}	0.07×10^{-3}	1.73×10^{-3}	4.73×10^{-3}
Huainan	Adults	4.40×10^{-3}	0.05×10^{-3}	0.10×10^{-3}	4.55×10^{-3}
	Children	3.78×10^{-3}	0.04×10^{-3}	1.00×10^{-3}	4.82×10^{-3}
Chengdu	Adults	3.32×10^{-2}	0.64×10^{-3}	0.93×10^{-3}	34.77×10^{-3}
	Children	2.84×10^{-2}	0.55×10^{-3}	1.38×10^{-2}	42.75×10^{-3}
Mean	Adults	1.00×10^{-2}	0.22×10^{-3}	0.30×10^{-3}	10.52×10^{-3}
	Children	8.58×10^{-3}	0.19×10^{-3}	4.73×10^{-3}	13.5×10^{-3}

Table 8. The Carcinogenic Risk Values with Inhalation in Surveyed Cities

City	Human	Cd	Cr	Ni
Beijing	Adults	NC	0.97×10^{-5}	0.88×10^{-6}
	Children	NC	2.06×10^{-6}	0.19×10^{-6}
Harbin	Adults	NC	5.29×10^{-5}	NC
	Children	NC	1.13×10^{-5}	NC
Urumqi	Adults	0.42×10^{-6}	NC	NC
	Children	0.09×10^{-6}	NC	NC
Kaifeng	Adults	NC	0.62×10^{-5}	0.84×10^{-6}
	Children	NC	1.32×10^{-5}	0.18×10^{-6}
Nanchang	Adults	2.31×10^{-5}	0.58×10^{-6}	0.28×10^{-6}
	Children	4.91×10^{-6}	0.12×10^{-6}	0.06×10^{-6}
Huainan	Adults	NC	1.88×10^{-6}	0.37×10^{-6}
	Children	NC	0.74×10^{-5}	0.08×10^{-6}
Chengdu	Adults	0.21×10^{-6}	3.48×10^{-5}	NC
	Children	0.04×10^{-6}	0.74×10^{-5}	NC

carcinogenic risk of Cr was overestimated in this study.

Even though carcinogenic and non-carcinogenic risks were also within the acceptable level, we must know the fact that we only account the risk values exposure to metals via ingestion, and if other routes such as dermal contact were considered, the estimated risks might be higher.

CONCLUSIONS

According to the concentrations of heavy metals in roads dust and PM_{10} from China, they are followed a descending orders: Zn>Pb>Cu>Cr>Ni>Cd; the concentrations of heavy metals in PM_{10} from highways is obvious more than cities, which shows that the heavy metals concentrations in PM_{10} around roads are mainly affected traffic. This indicates that the urban road dusts and PM_{10} around roads have been significantly impacted by heavy metals derived from anthropogenic activities.

The results of sources apportionment to heavy metals in road dusts by Correspondence Analysis and Hierarchical Cluster Analysis are the same, and the sources of Cu, Zn, and Pb are similar because of good correlations; the sources of Cr and Ni are classified as a category; Cd alone is a category that is unlike the above two categories. The mean I_{geo} values for Pb, Zn, Cu, and Cd in urban road dust are more than 0, while the mean I_{geo} values for Cr and Ni are lower than 0. It indicates that Cd contamination level belongs to heavily contaminated; Zn, Cu, and Pb are moderately contaminated; Cr and Ni are uncontaminated.

Based on carcinogenic risk values of Ni, Cr, Cd and non-carcinogenic risk values of Cu, Zn, Pb in PM_{10} around roads, carcinogenic and non-carcinogenic risks via ingestion are also within the acceptable level, but if other routes of exposure such as dermal contact were considered, the estimated risks might be higher.

[#]Correspondence should be addressed to WANG Bao Qing, Tel: 13702057415, E-mail: wbqchina@163.com

Biographical note of the first author: CHEN Rong Hui, female, born in 1989, master, majoring in atmospheric particles risk assessment.

Received: June 22, 2014;

Accepted: October 29, 2014

REFERENCES

1. Guo G, Lei L, Chen T, et al. Effect of road traffic on heavy metals in road dusts and roadside soils. Acta Scientiae Circumstantiae, 2008; 28, 1937-45. (In Chinese)
2. Wei B, Yang L. A review of heavy metal contaminations in urban soils, urban road dusts and agricultural soils from China. Microchem J, 2010; 94, 99-107.
3. Christoforidis A, Stamatis N. Heavy metal contamination in street dust and roadside soil along the major national road in Kavala's region, Greece. Geoderma, 2009; 151, 257-63.
4. Hu Z, Wang J, Chen Y, et al. Concentrations and source apportionment of particulate matter in different functional areas of Shanghai, China. Atmospheric Pollution Research, 2014; 5, 138-44. (In Chinese)
5. Valiulis D, Čeburnis D, Šakalys J, et al. Estimation of atmospheric trace metal emissions in Vilnius City, Lithuania, using vertical concentration gradient and road tunnel measurement data. Atmos Environ, 2002; 36, 6001-14.
6. van der Gon HD, Appelman W. Lead emissions from road transport in Europe: a revision of current estimates using various estimation methodologies. Sci Total Environ, 2009; 407, 5367-72.
7. Hu M, Tang Q, Peng J, et al. Study on Characterization and Source Apportionment of Atmospheric Particulate Matter in China. Environment and Sustainable Development, 2011; 36, 15-9. (In Chinese)
8. Gautam P, Blaha U, Appel E. Magnetic susceptibility of dust-loaded leaves as a proxy of traffic-related heavy metal pollution in Kathmandu city, Nepal. Atmos Environ, 2005; 39, 2201-11.
9. Barzyk TM, George BJ, Vette AF, et al. Development of a distance-to-roadway proximity metric to compare near-road pollutant levels to a central site monitor. Atmos Environ, 2009; 43, 787-97.
10. Song S, Wu Y, Jiang J, et al. Characteristics of elements in size-resolved fine particles in a typical road traffic environment in Beijing. Acta Scientiae Circumstantiae, 2012; 32, 66-73. (In Chinese)
11. Bukowiecki N, Lienemann P, Hill M, et al. PM_{10} emission factors for non-exhaust particles generated by road traffic in an urban street canyon and along a freeway in Switzerland. Atmos Environ, 2010; 44, 2330-40.
12. Pan Y, Wang Y, Yang Y, et al. Determination of trace metals in atmospheric dry deposition with a heavy matrix of PUF by inductively coupled plasma mass spectroscopy after microwave digestion. Environmental Science, 2010; 31, 553-9. (In Chinese)
13. Amato F, Nava S, Lucarelli F, et al. A comprehensive assessment of PM emissions from paved roads: real-world emission factors and intense street cleaning trials. Sci Total Environ, 2010; 408, 4309-18.
14. Zehetner F, Rosenfellner U, Mentler A, et al. Distribution of road salt residues, heavy metals and polycyclic aromatic hydrocarbons across a highway-forest interface. Water Air Soil Poll, 2009; 198, 125-32.
15. Saeedi M, Hosseinzadeh M, Jamshidi A, et al. Assessment of heavy metals contamination and leaching characteristics in highway side soils, Iran. Environ Monit Assess, 2009; 151, 231-41.
16. Fujiwara FG, Gómez DR, Dawidowski L, et al. Metals associated with airborne particulate matter in road dust and tree bark collected in a megacity (Buenos Aires, Argentina). Ecol Indic, 2011; 11, 240-7.
17. Samara C, Voutsa D. Size distribution of airborne particulate matter and associated heavy metals in the roadside environment. Chemosphere, 2005; 59, 1197-206.
18. Zhao Y, Zhao C. Concentration and Distribution Analysis of Heavy Metals in Total Suspended Particulates along

Shanghai-Nanjing Expressway. Procedia Environmental Sciences, 2012; 13, 1405-11.
19.Gunawardena J, Egodawatta P, Ayoko GA, et al. Role of traffic in atmospheric accumulation of heavy metals and polycyclic aromatic hydrocarbons. Atmos Environ, 2012; 54, 502-10.
20.Chiang H, Huang Y. Particulate matter emissions from on-road vehicles in a freeway tunnel study. Atmos Environ, 2009; 43, 4014-22.
21.Kuo CY, Wang JY, Chang SH, et al. Study of metal concentrations in the environment near diesel transport routes. Atmos Environ, 2009; 43, 3070-6.
22.Handler M, Puls C, Zbiral J, et al. Size and composition of particulate emissions from motor vehicles in the Kaisermühlen-Tunnel, Vienna. Atmos Environ, 2008; 42, 2173-86.
23.Ning Z, Polidori A, Schauer JJ, et al. Emission factors of PM species based on freeway measurements and comparison with tunnel and dynamometer studies. Atmos Environ, 2008; 42, 3099-114.
24.Marcheselli M, Sala L, Mauri M. Bioaccumulation of PGEs and other traffic-related metals in populations of the small mammal *Apodemus sylvaticus*. Chemosphere, 2010; 80, 1247-54.
25.Hu X, Zhang Y, Ding Z, et al. Bioaccessibility and health risk of arsenic and heavy metals (Cd, Co, Cr, Cu, Ni, Pb, Zn and Mn) in TSP and $PM_{2.5}$ in Nanjing, China. Atmos Environ, 2012; 57, 146-52.
26.Johansson C, Norman M, Burman L. Road traffic emission factors for heavy metals. Atmos Environ, 2009; 43, 4681-8.
27.Shi G, Chen Z, Bi C, et al. A comparative study of health risk of potentially toxic metals in urban and suburban road dust in the most populated city of China. Atmos Environ, 2011; 45, 764-71.
28.Csavina J, Field J, Taylor MP, et al. A review on the importance of metals and metalloids in atmospheric dust and aerosol from mining operations. Sci Total Environ, 2012; 433, 58-73.
29.Chen X, Xia X, Zhao Y, et al. Heavy metal concentrations in roadside soils and correlation with urban traffic in Beijing, China. J Hazard Mater, 2010; 181, 640-6.
30.Hallberg M, Renman G, Lundbom T. Seasonal variations of ten metals in highway runoff and their partition between dissolved and particulate matter. Water Air Soil Poll, 2007; 181, 183-91.
31.Westerlund C, Viklander M. Particles and associated metals in road runoff during snowmelt and rainfall. Sci Total Environ, 2006; 362, 143-56.
32.Winchester JW, Nifong GD. Water pollution in Lake Michigan by trace elements from pollution aerosol fallout. Water Air Soil Poll, 1971; 1, 50-64.
33.Sartor JD, Boyd GB, Agardy FJ. Water pollution aspects of street surface contaminants. Journal Water Pollution Control Federation, 1974, 458-67.
34.Slinn S, Slinn W. Predictions for particle deposition on natural waters. Atmos Environ (1967), 1980; 14, 1013-6.
35.Gallon C, Ranville MA, Conaway CH, et al. Asian industrial lead inputs to the north pacific evidenced by lead concentrations and isotopic compositions in surface waters and aerosols. Environ Sci Technol, 2011; 45, 9874-82.
36.Inoue J, Momose A, Okudaira T, et al. Chemical characteristics of Northeast Asian fly ash particles: Implications for their long-range transportation. Atmos Environ, 2014; 95, 375-82.
37.Wang X, Gao H. Exposure to fine particle mass and number concentrations in urban transportation environments of New York City. TRD, 2011; 16, 384-91.
38.Hu Jh, Ong Lb, Yeo Ch, et al. Trapping, transportation and separation of small particles by an acoustic needle. Sensor Actuat A-PHYS, 2007; 138, 187-93.
39.He Hd, Lu WZ, Xue Y. Prediction of PM_{10} concentrations at urban traffic intersections using semi-empirical box modelling with instantaneous velocity and acceleration. Atmos Environ, 2009; 43, 6336-42.
40.Seto T, Kim S, Otani Y, et al. New particle formation and growth associated with East-Asian long range transportation observed at Fukue Island, Japan in March 2012. Atmos Environ, 2013; 74, 29-36.
41.Ragettli M, Corradi E, Braun-Fahrländer C, et al. Commuter exposure to ultrafine particles in different urban locations, transportation modes and routes. ATmos Environ, 2013; 77, 376-84.
42.Kumar P, Ketzel M, Vardoulakis S, et al. Dynamics and dispersion modelling of nanoparticles from road traffic in the urban atmospheric environment—a review. J Aerosol Sci, 2011; 42, 580-603.
43.Zhu Hj, Pan Q, Zhang Wl, et al. CFD simulations of flow erosion and flow-induced deformation of needle valve: Effects of operation, structure and fluid parameters. Nucl Eng Des , 2014; 273, 396-411.
44.Adeniji-Fashola A, Chen CP. Modeling of confined turbulent fluid-particle flows using Eulerian and Lagrangian schemes. Int J Heat Mass Tran, 1990; 33, 691-701.
45.Reggente M, Peter J, Theunis J, et al. Prediction of ultrafine particle number concentrations in urban environments by means of Gaussian process regression based on measurements of oxides of nitrogen. Environ Modell Softw, 2014; 61, 135-50.
46.Gérardin F, Gentric C, Midoux N. Particle dispersion in the near-wake of an isolated rotating wheel: Experimental and CFD study. J Aerosol Sci, 2014; 76, 56-71.
47.Jorquera H. Air quality at Santiago, Chile: a box modeling approach II. $PM_{2.5}$, coarse and PM_{10} particulate matter fractions. Atmos Environ, 2002; 36, 331-44.
48.Schichtel BA, Rodriguez MA, Barna MG, et al. A semi-empirical, receptor-oriented Lagrangian model for simulating fine particulate carbon at rural sites. Atmos Environ, 2012; 61, 361-70.
49.Rizzo MJ, Scheff PA. Fine particulate source apportionment using data from the USEPA speciation trends network in Chicago, Illinois: Comparison of two source apportionment models. Atmos Environ, 2007; 41, 6276-88.
50.Dong Y, Hays MD, Dean Smith N, et al. Inverting cascade impactor data for size-resolved characterization of fine particulate source emissions. J Aerosol Sci, 2004; 35, 1497-512.
51.Schauer JJ, Rogge WF, Hildemann LM, et al. Source apportionment of airborne particulate matter using organic compounds as tracers. Atmos Environ, 1996; 30, 3837-55.
52.Affum H, Oduro-Afriyie K, Nartey V, et al. Biomonitoring of airborne heavy metals along a major road in Accra, Ghana. Environ Monit Assess, 2008; 137, 15-24.
53.Han Y, Du P, Cao J, et al. Multivariate analysis of heavy metal contamination in urban dusts of Xi'an, Central China. Sci Total Environ, 2006; 355, 176-86.
54.Yan J, Ye Z, Yan Y, et al. Study on Heavy Metals Distribution in Atmospheric Particulate Matter on Both Sides of the Cheng-Ya Expressway. Sichuan environment, 2008; 27, 19-26. (In Chinese)
55.Shao L, Xiao H. Pollution characterization and controlling factors of heavy metals in airborne particulate matter near expressway. Environmental Chemistry, 2012; 31, 323-8. (In Chinese)
56.Wang L. Ditribution Characteristic And Pollution Assessment In Street Dust Along Overhea Road In Shanghai. Shanghai, East China Normal University, 2007. (In Chinese)
57.Slavin W, Slavin W. AAS. Interscience Publishers New York,

1968.
58.Winefordner JD, Elser RC. Atomic fluorescence spectrometry. Anal Chem, 1971; 43, 24-42.
59.Beauchemin D. Inductively coupled plasma mass spectrometry. Anal Chem, 2008; 80, 4455-86.
60.Manning TJ, Grow WR. Inductively coupled plasma-atomic emission spectrometry. Chem Educater, 1997; 2, 1-19.
61.Norrish K, Chappell B. X-ray fluorescence spectrometry. Physical methods in determinative mineralogy, 1977; 201-72.
62.Li C, Lu F, Zhang Y, et al. Spatial distribution characteristics of heavy metals in street dust in Shenyang city. Ecology and Environment, 2008; 17, 560-4. (In Chinese)
63.Zheng N, Liu J, Wang Q, et al. Health risk assessment of heavy metal exposure to street dust in the zinc smelting district, Northeast of China. Sci Total Environ, 2010; 408, 726-33.
64.Wei B, Jiang F, Li X, et al. Spatial distribution and contamination assessment of heavy metals in urban road dusts from Urumqi, NW China. Microchem J, 2009; 93, 147-52.
65.Xiang L, Li Y, Shi J, et al. Investigation of heavy metal and polycyclic aromatic hydrocarbons contamination in street dusts in urban Beijing. Environmental Science, 2010; 31, 159-67. (In Chinese)
66.Wang X, Zhao H, Li X. Characteristics of Heavy Metals in Street Dusts and Urban Runoff in Beijing. Asian Journal of Ecotoxicology, 2010; 5, 426-32. (In Chinese)
67.Chen Q, Wang H, Yang B, et al. Determination and Pollution Assessment of Heavy Metal in Surface Dust from Jinan City. Journal of Jinan University, 2013; 27, 428-32. (In Chinese)
68.Li R, Zhou A, Tong F, et al. Distribution of metals in urban dusts of Hefei and health risk assessment. Environmental Science, 2011; 32, 2661-8. (In Chinese)
69.Han Y, Cao J, Posmentier ES, et al. Particulate-associated potentially harmful elements in urban road dusts in Xi'an, China. Appl Geochem , 2008; 23, 835-45.
70.Zhang Y, Zhang Y, HU X. Assessment of Heavy Metal Contamination and Source Identification of Dust Deposited on Roads Collected from Different Land-Use Zones in Nanjing. Research of Environmental Sciences, 2010; 23, 1376-81. (In Chinese)
71.Fang F, Jiang B, Wang H, et al. Particle size distribution and health risk assessment of heavy metals in surface dust of Wuhu urban area. Geographical Research, 2010; 29, 1193-202.
72.Zhang M, Wang H. Concentrations and chemical forms of potentially toxic metals in road-deposited sediments from different zones of Hangzhou, China. J Environ Sci-China, 2009; 21, 625-31.
73.Shi G, Chen Z, Xu S, et al. Potentially toxic metal contamination of urban soils and roadside dust in Shanghai, China. Environ Pollut, 2008; 156, 251-60.
74.Zhang J. Study on the Heavy Metal Pollution in Urban Street Dust of Shanghai. Shanghai, East China Normal University, 2005. (In Chinese)
75.Lu X, Wang L, Lei K, et al. Contamination assessment of copper, lead, zinc, manganese and nickel in street dust of Baoji, NW China. J Hazard Mater, 2009; 161, 1058-62.
76.Wang J, Zhang H, Zeng X, et al. Distribution and pollution assessment of heavy metals in roadside soil of Guiyang City, China. Research of Environmental Sciences, 2009; 22, 950-5. (In Chinese)
77.Ling T, Shi Z, Wu F, et al. Heavy Metal Pollution and the Ecological Risk Assessment of Urban Street Dust in Kunming. Tropical Geography, 2011; 2, 800. (In Chinese)
78.Duzgoren-Aydin NS, Wong CS, Aydin A, et al. Heavy metal contamination and distribution in the urban environment of Guangzhou, SE China. Environ Geochem Hlth, 2006; 28, 375-91.
79.Li X, Poon Cs, Liu PS. Heavy metal contamination of urban soils and street dusts in Hong Kong. Appl Geochem, 2001; 16, 1361-8.
80.CEPA. Chinese Environmental Protection Administration, Elemental background values of soils in China. Environmental Science Press of China, 1990. (In Chinese)
81.CEPA. Chinese Environmental Protection Administration, Environmental Quality Standard for Soils (GB15618-1995), Beijing, 1995. (In Chinese)
82.Duong TT, Lee BK. Determining contamination level of heavy metals in road dust from busy traffic areas with different characteristics. J Environ Manage, 2011; 92, 554-62.
83.Apeagyei E, Bank MS, Spengler JD. Distribution of heavy metals in road dust along an urban-rural gradient in Massachusetts. Atmos Environ, 2011; 45, 2310-23.
84.Murakami M, Nakajima F, Furumai H. The sorption of heavy metal species by sediments in soakaways receiving urban road runoff. Chemosphere, 2008; 70, 2099-109.
85.Birch G, Scollen A. Heavy metals in road dust, gully pots and parkland soils in a highly urbanised sub-catchment of Port Jackson, Australia. Soil Res, 2003; 41, 1329-42.
86.Chen J, Wang W, Liu H, et al. Pollution Property of Particulates in the Air at the Traffic Crossing in Beijing Part I: Pollution Property of Particulates in the Air and Its Affecting Factors. Research of Environmental Sciences, 2005; 18, 34-8. (In Chinese)
87.Feng Q, Yifang Y, Huifeng Z. Distribution characteristics and speciation of heavy metals in PM10 near urban roads and surrounding areas of Beijing. Research of Environmental Sciences, 2011; 24, 608-14. (In Chinese)
88.Wang K, Yuan C, Liu Y, et al. Concentration and composition analyzing of atmospheric inhalable particles near the road in Harbin. Environmental Protection Science, 2007; 33, 5-8. (In Chinese)
89.Sun L, Zheng C, Wang W, et al. Concentration and enrichment characteristic of heavy metal elements in Urumqi atmospheric PM_{10}. Xinjiang Agricultural Sciences, 2009; 46, 582-8. (In Chinese)
90.Yuan Y. Vertical Distribution of Atmospheric Particles in the Ground Layer in Kaifeng. Kaifeng, Henan University, 2010. (In Chinese)
91.Liang Y. Pollution characteristics and potential hazards of atmospheric particulate in Nanchang City. Nanchang Hangkong University, 2010. (In Chinese)
92.Shen W. Investigation on the Pollution of Airborne In halable Partieulate Matter PM_{10} in Huainan City. Anhui University of Technology, 2007. (In Chinese)
93.Kong X. Reaserch on the Pollution Characteristics and Regional Diffusion Prediction of Atmospheric Heavy Metals in the Central Urban of Chengdu. Chengdu University of Technology, 2010. (In Chinese)
94.Zereini F, Alt F, Messerschmidt J, et al. Concentration and distribution of heavy metals in urban airborne particulate matter in Frankfurt am Main, Germany. Environ Sci Technol, 2005; 39, 2983-9.
95.Birmili W, Allen AG, Bary F, et al. Trace metal concentrations and water solubility in size-fractionated atmospheric particles and influence of road traffic. Environ Sci Technol, 2006; 40, 1144-53.
96.Dongarrà G, Manno E, Varrica D, et al. Mass levels, crustal component and trace elements in PM_{10} in Palermo, Italy. Atmos Environ, 2007; 41, 7977-86.
97.Moreno T, Querol X, Alastuey A, et al. Variations in atmospheric PM trace metal content in Spanish towns:

illustrating the chemical complexity of the inorganic urban aerosol cocktail. Atmos Environ, 2006; 40, 6791-803.

98. Chang W, Chen C. Research of heavy metal pollution by the No.104 national road in Jiangsu Province. Energy Environmental Protection, 2009; 23, 43-6. (In Chinese)

99. Tong Z, Duan H, Ruan X, et al. Spatial numberical model of traffic-source heavy metals in roadside soils. Acta Scientiae Circumstantiae, 2014; 34, 996-1002. (In Chinese)

100. Etyemezian V, Kuhns H, Gillies J, et al. Vehicle-based road dust emission measurement (III): effect of speed, traffic volume, location, and season on PM_{10} road dust emissions in the Treasure Valley, ID. Atmos Environ, 2003; 37, 4583-93.

101. Thorpe A, Harrison RM. Sources and properties of non-exhaust particulate matter from road traffic: a review. Sci Total Environ, 2008; 400, 270-82.

102. Kummer U, Pacyna J, Pacyna E, et al. Assessment of heavy metal releases from the use phase of road transport in Europe. Atmos Environ, 2009; 43, 640-7.

103. Pulles T, Denier van der Gon H, Appelman W, et al. Emission factors for heavy metals from diesel and petrol used in European vehicles. Atmos Environ, 2012; 61, 641-51.

104. Shao L, Xiao Hy, Wu Ds, et al. Review on Research on Traffic-Related Heavy Metals Pollution. Earth and Environment, 2012; 40, 445-59. (In Chinese)

105. Sternbeck J, Sjödin Å, Andréasson K. Metal emissions from road traffic and the influence of resuspension-results from two tunnel studies. Atmos Environ, 2002; 36, 4735-44.

106. Tan J, Duan J. Heavy metals in aerosol in China: pollution, sources, and control strategies. Jounal of Graduate University of Chinese Academy of Sciences, 2013; 30, 145-55. (In Chinese)

107. Alyemeni MN, Almohisen IA. Traffic and industrial activities around Riyadh cause the accumulation of heavy metals in legumes: A case study. Saudi J Biol Sci, 2014; 21, 167-72.

108. Cao F. Study on Distribution of Polycyclic Aromatic Hydrocarbons and Heavy Metal in the Particles of Harbin Main Street. Jilin University, 2012. (In Chinese)

109. Zhao L, Xu Y, Hou H, et al. Source identification and health risk assessment of metals in urban soils around the Tanggu chemical industrial district, Tianjin, China. Sci Total Environ, 2014; 468, 654-62.

110. Liu E, Yan T, Birch G, et al. Pollution and health risk of potentially toxic metals in urban road dust in Nanjing, a mega-city of China. Sci Total Environ, 2014; 476, 522-31.

111. Wang LF, Yang LY, Kong LH, et al. Spatial distribution, source identification and pollution assessment of metal content in the surface sediments of Nansi Lake, China. J Geochem Explor, 2014; 140, 87-95.

112. Yang Z, Lu W, Liu X, et al. Heavy metal identification for near-surface urban dust in Changchun City. Journal of Arid Land Resources and Environment, 2010; 12, 028. (In Chinese)

113. Muller G. Index of geoaccumulation in sediments of the Rhine River. Geojournal, 1969; 2, 108-18.

114. Wang L, Chen Z, Xu S, et al. Distribution and Assessment of Heavy Metals in the Greenbelt Soil along Yanan Overhead Road in Shanghai City. Chinese Journal of Soil Science, 2007; 38, 203-5. (In Chinese)

115. USEPA. Risk assessment guidance for Superfund. Human health evaluation manual, (partA), vol. 1. Washington, DC: Office of emergency and remedial response, 1989.

116. USEPA. Supplemental guidance for developing soil screening levels for Superfund sites. Washington, DC: Soild Waste and Emergency Response, 2002.

117. Ferreira-Baptista L, De Miguel E. Geochemistry and risk assessment of street dust in Luanda, Angola: a tropical urban environment. Atmos Environ, 2005; 39, 4501-12.

118. Huang M, Wang W, Chan CY, et al. Contamination and risk assessment (based on bioaccessibility via ingestion and inhalation) of metal (loid) s in outdoor and indoor particles from urban centers of Guangzhou, China. Sci Total Envron, 2014; 479, 117-24.