# 9.6 CHARACTERIZATION OF PAVED ROAD DUST IN URBAN AREA

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## 1. INTRODUCTION

Many researches have showed the fugitive dust (or geological dust) is a significant or major contributor to ambient air particulate in urban areas, not only by receptor models, but also by the source models and emission inventories. (Chow et al., 1992a, b, 1995, 1999, 2000, 2002; Watson et al., 1994, 2000; Zelenka et al., 1994; Chan et al., 1999; US EPA, 2000, 2003; Samara et al., 2003; Li et al., 2004). And the fugitive dust pollution is severe in lots of cities, especially in the northern cities of China (Zhao et al., 2006; Bi et al., 2007).

The paved road dust is one of the significant types of fugitive dust. It is the loose material on the road surface, and it consists of mud/dirt trackout from unpaved road or construction site, sedimentation of ambient particulate, brake wear, tire wear and some vehicles exhaust. The paved road dust emissions originate from the re-suspension of the loose material by vehicle driving and wind blowing. The loading of the paved road dust is continuously replenished by other sources along with its depletion. Many studies have been carried out aiming at the concentration or speciation of chemical constituents and the amassment of human health. (Miguel et al., 1997; Robertson et al., 2003; Sezgin et al., 2003; Charlesworth et al., 2003; Yeung et al., 2003; Wang et al., 2005; Ferreira-Baptista and Miguel, 2005; Ahmed et al., 2006; Han et al., 2007). In China, few studies on road dust especially on the size distribution and the chemical compositions of $PM_{10}$ and $PM_{2.5}$ (particulate matter with aerodynamic diameters less than 10 and 2.5 μm, respectively) size fractions has been carried out.

Source profiles are necessary for the source apportionment using CMB model that quantifies contributions from different source types to chemically speciated ambient samples. So the collection and analysis methods are crucial for the representativeness of profile of each source type (Hildemann et al., 1991; Chow et al., 1992b, 1995, 2003, 2004; Watson et al., 1994, 2001a, b; Ashbaugh et al., 2003; Ho et al., 2003). During 2000 to 2004, the paved road dust was collected and the $PM_{10}$ profiles were developed in the source apportionment studies of five Chinese cities, Shijiazhuang, Handan, Yinchuan, Zhengzhou and Nanjing. In those studies, the paved road dust was treated as one part of urban resuspended dust and not given a certain contribution to ambient PM, because of the complexity of the sources and the uncertainty and collinearity of the profiles (Zhao et al., 2006; Bi et al., 2007).

In order to obtain the variability of the characteristics both within and between the different types of the paved road dust, the paved road dust in urban area of Tianjin was systematically sampled and analyzed in 2006. The collection and analysis methods of dust samples are given, the characteristics of paved road dust are shown and the source profiles are constructed for Tianjin paved road dust in this paper. In addition, the sampling methods and chemical profiles are compared with that of upper five Chinese cities and some foreign studies. The characterizations of paved road dust are summarized and help to make clear the representativeness of samples from different road types.

## 2. STUDY AREA

Tianjin is located in the North China Plain near the Bohai Sea under continental monsoonal climate (Figure 1a), 11917 square kilometers in all (Figure 1b), and more than 300 square kilometers for central urban area (Figure 1c). The particulate matter has always been the chief pollutant affecting the urban air quality, and the $PM_{10}$ concentrations have never met the National Ambient Air Quality Standard (100μgm$^{-3}$ of annual arithmetic average concentration). According to the Plan for Urban Comprehensive Traffic of Tianjin, the paved road rate in urban area was 6.85% in 2003 and planned to be 20% in 2010. In addition, most of the paved roads are just swept by sweepers using broom at present in Tianjin. The number of civil motor vehicles was 706690 in 2005, and the growth rate increases year by year.

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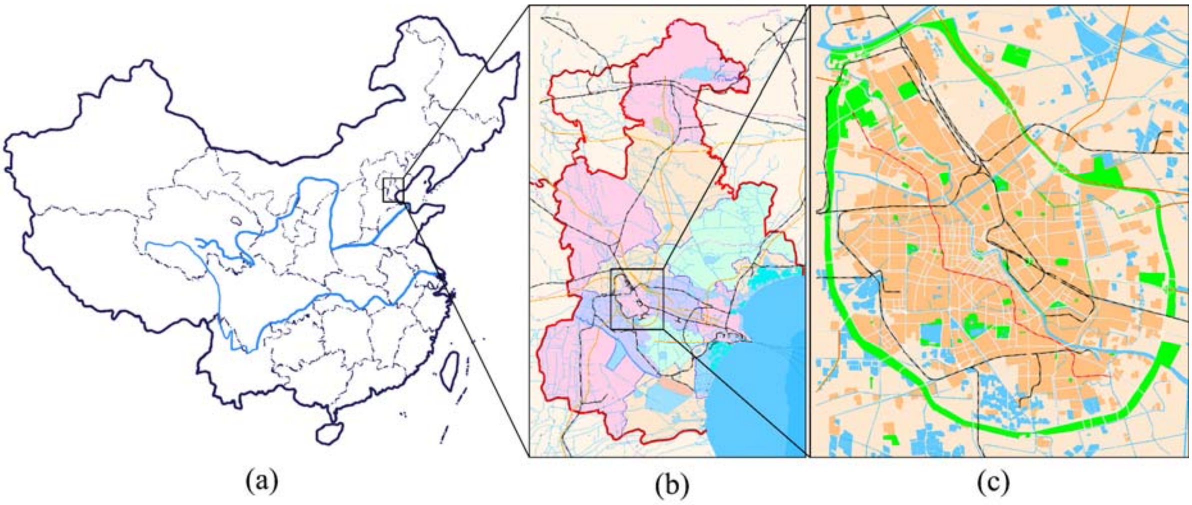


**Figure 1 Sketch map of Tianjin**
(a) China (b) Tianjin (c) Tianjin urban area

The locations of those five Chinese cities (Shijiazhuang, Handan, Yinchuan, Zhengzhou and Nanjing) and the sampling year of the paved road dust for each city are shown in Figure 2. The four eastern cities are under continental monsoonal climate, whereas Yinchuan is under a continental arid climate. The annual arithmetic average concentrations of $PM_{10}$ of these five cities all exceed the National Ambient Air Quality Standard ($100\mu gm^{-3}$) in recent years.


**Figure 2 Locations for cities of paved road dust sampling**
A. Shijiazhuang (2000); B. Handan (2001); C. Yinchuan (2001); D. Zhengzhou (2003); E. Nanjing (2004).

## 3. SAMPLING AND ANALYSIS

### 3.1 *Sampling and treatment*

In China, the urban roads are divided into four levels based on the designed capacity of vehicle flow, which include highway, main road, secondary main road and branch road, according to the Specifications for Urban Roads Design of China. There are two ring highways in urban area of Tianjin, inner ring and middle ring. The inner ring is located in the central commercial and residential area, and the middle ring is almost in the residential area. The urban area is surrounded by an outer ring highway which is located in the suburb and rural area (Figure 3).

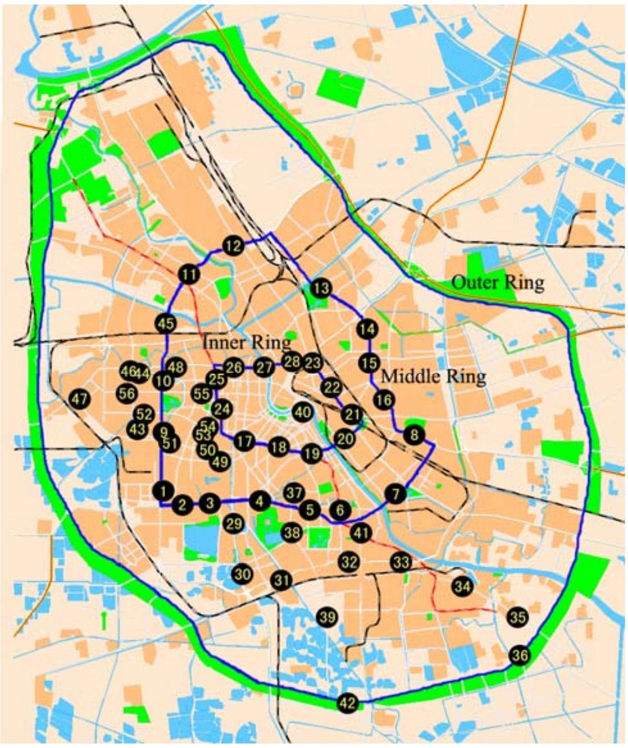


Figure 3 Tianjin paved road dust sampling sites

Three types of road with more vehicles (highway, main road and secondary main road) were chosen for dust collection in Tianjin. The sampling sites are numbered in the sequence of sampling. The locations and serial numbers of sampling sites are shown in Figure 3. Because the vehicles on outer ring were running so fast and the outer ring is not in the urban, the sampling sites were mainly on the inner and middle ring for highway dust collection. The sampling sites categorized by road types are listed in Table 1. The samples from site 36 and 42 were absorbed into the middle ring samples.

Table 1 Road types for sampling sites

| Road type | Sampling site |
|---|---|
| Highway | 1-5, 7-28, 36, 42, 45 |
| Main road | 29-35, 37-39, 41, 44, 46-48, 54-56 |
| Secondary main road | 6, 40, 43,49-53 |

There are lots of windy and sandy days in spring and winter, the majority mass of paved road dust may be the local soil and the sand from outer place. So the samples were collected during non-rain days in August 2006 and the sampling sites were away from the clearly visible mud/dirt trackout.

Three methods for collecting road dust have been used widely. One simple method is by sweeping with the dustpan and brush, and other two are by a small vacuum sweeper trucks or by a battery-powered vacuum cleaner. The first method may cause incomplete collection of fine dust **(Bris et al., 1999)**, but widely used because of convenience and simplicity (see Table 10). The sweeper truck method could not accurately record the mass and area for each sample. So a battery-powered vacuum sampler was used in Tianjin to collect the paved road dust in a filter cylinder. At each sampling site, dust was sampled from the pavement of the road surface not the sidewalk, along a 0.5m wide strip area from edge of cycling way to middle of driveway (Figure 4). The dust on cycling way and driveway was collected separately and the sampling area for each sample was measured.

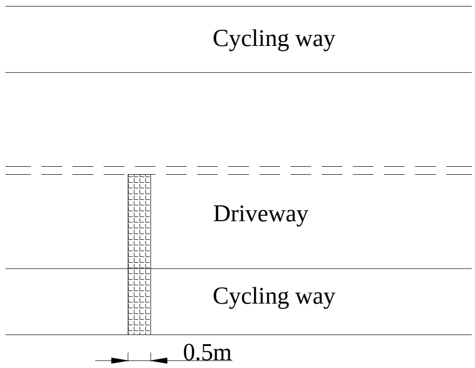


Figure 4 Sketch for road dust sampling

Each dust sample was weighed after dried in a desiccator at room temperature for 48 hours to remove the moisture. The dry dust was sieved through 20, 40, 100, 160 and 200 mesh sieves to get the size distribution of geometric diameter <840μm (840μm for 20 mesh). Then the silt (particles passing the 200 mesh sieve, with geometric diameter <74μm) was divided into two parts, one was separated by a Bahco centrifugal machine for the size distribution of aerodynamic diameters (Godridge et al., 1962) and the other was suspended in a resuspension chamber for $PM_{10}$ and $PM_{2.5}$ for the chemical analysis (Chow et al., 1994). The polypropylene fiber filters and quartz fiber filters were used during dust resuspension. The polypropylene fiber filters collected samples for elemental analysis and quartz fiber filters for total carbon, organic carbon and ions. The filters were weighed both before and after sampling by a sensitive microbalance (Mettler M5). The balance sensitivity was ±0.010mg. The filters were all conserved in the desiccator at room temperature for 48h before weighing.

During 2000 and 2004, the dustpan and brush were used to collect the dust at the crossing of paved road in respective source apportionment study of Shijiazhuang, Handan, Yinchuan, Zhengzhou and Nanjing, and the dust from different parts of road was mixed for each sample. About 8 to 38 samples were collected in these cities for analysis. The $PM_{10}$ parts of dust were get by the Bahco centrifugal machine for Shijiazhuang, Handan, Yinchuan and Zhengzhou, and resuspension sampler for Nanjing. The exact locations, road types and amounts of samples were not recorded in detail, and the $PM_{10}$ profiles shown below are the final form for the paved road dust of five cities.

The samples of other fugitive source types of Tianjin were also collected in source apportionment study in 2001. The average size distributions and the $PM_{10}$ profiles of soil, cement and construction dust were obtained. Some related results will be shown below for comparison.

### 3.2 *Chemical analysis*

In the paved road dust study of Tianjin, the polypropylene fiber filters were analyzed by ICP-AES for 19 elements (Na, Mg, Al, Si, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Cd, Hg and Pb) and the quartz fiber filters were cut into pieces for respective analysis of ions, total carbon and organic carbon.

The polypropylene filter was cut into fragments and put into a conical flask. Then 15mL $HNO_3$ analytical reagent and 5mL $HClO_4$ analytical reagent were added into the flask and heated by an electric stove with a temperature of less than 100℃ for one hour. Then the temperature was raised to 150℃ for another two hours. Finally, the solution was evaporated until there was ~3mL residual in the flask. After cooled, the solution was filtered and decanted into a test tube and diluted to 15mL with ultrapure water. It was finally used for measuring the concentrations of 18 elemental species (Na, Mg, Al, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Cd, Hg and Pb) by ICP analysis (IRIS Intrepid II, Thermo Electron) (Baldwin et al., 1994). Another ~30mL 2% KOH solution was added into the conical flask, which contained the filtered residue. After boiled for 30 minutes, the solution was filtered and decanted into a volumetric flask and diluted to 50mL with ultrapure water for measuring the concentration of silicon.

A clip with the shape of circle (15mm in diameter) from each quartz fiber filter was taken for measurement of TC and OC by an element analyzer (Vario EL, GmbH) (Watson et al., 1991; Chi et al., 1999; Liu et al., 2000; Feng et al., 2007). In the analyzing of TC, the carbon species on the clip was first oxidized into $CO_2$ at a temperature of 980 ℃ for 90s. Then the temperature was reduced to 600 ℃ with the analysis atmosphere of helium gas, and the quantity of TC was determined through the detection of $CO_2$ by a thermal conductivity detector (TCD). The detection procedure of OC fraction was similar to TC analysis with the only difference of an oxidizing temperature of 450℃ instead.

Water-soluble ions were measured by an ion chromatography (DX-120, DIONEX) (Carvalho et al., 1995; Chow and Watson, 1999; Talebi and Abedi, 2005). A clip with 1/4 size of each quartz-fiber filter was cut into fragments and put into a centrifuge tube. Ultrapure water was then added into each tube. These tubes were vibrated in an ultrasonic cleaner (AS3120, AutoScience) at a frequency of 40 kHz for 25 minutes, and then centrifuged at 5000 rpm for 10 minutes. The supernatant solution was decanted into other clean tubes. The residual turbid solution was treated again as described above. Three times of this extraction procedure were needed for each sample so as to make the water-soluble ions of samples extracted adequately. Then the extracts were thoroughly mixed. Finally, 1mL extracted solution of each sample was injected into the ion chromatography for the measurements of $Cl^-$, $NO_3^-$ and $SO_4^{2-}$, and another 1mL extracted solution for $NH_4^+$.

Moreover, blank and duplicate sample analyses were carried out for ~10% of all the samples.

The $PM_{10}$ of paved road dust was analyzed by XRF (3080E2, Rigaku) following the published method (Watson et al., 1999) for the elements abundances in the studies of Shijiazhuang, Handan, Yinchuan and Zhengzhou, and ICP-AES was used in Nanjing.

## 4. RESULTS AND DISCUSSIONS

### 4.1 *Size distributions*

The mass percents of different size ranges of paved road dust <840μm for each road type and other fugitive sources of Tianjin are listed in Table 2. The sieving results show that the dust above 150μm possesses a majority mass fraction on driveway, with the mass percent more than 63%. And the silt contents of road dust are just 13.92% to 20.51% on driveway, much less than cycling way dust, soil and construction dust. The silt contents of road dust on cycling way are quite high, even more than construction dust on inner ring. The vehicle flow is different between road types, decreasing sequently from highway to secondary main road. Similarly, the silt contents also have the relations of highway > main road > sec. main road, both on the roadway and cycling way. It shows the level of silt content has a positive relationship with the vehicle flow and the fine dust on the driveway may have a great contribution to cycling way.

**Table 2 Average size distributions for <840μm component of paved road dust and other fugitive sources by sieving (mass percent for geometric diameter) %**

| Size range | Inner ring | | Middle ring | | Main road | | Sec. main road | | Soil | Construction dust |
|---|---|---|---|---|---|---|---|---|---|---|
| | D* | C | D | C | D | C | D | C | | |
| 840-450μm | 26.46 | 5.14 | 30.22 | 13.43 | 28.70 | 16.26 | 36.92 | 16.32 | 29.65 | 5.62 |
| 450-150μm | 37.29 | 17.34 | 34.78 | 28.89 | 38.56 | 30.88 | 37.60 | 30.19 | 19.70 | 37.60 |
| 150-97μm | 8.84 | 7.88 | 7.56 | 8.40 | 8.50 | 8.19 | 6.09 | 9.58 | 6.15 | 7.30 |
| 97-74μm | 8.18 | 12.97 | 6.94 | 9.87 | 6.75 | 8.67 | 5.46 | 10.53 | 9.22 | 6.73 |
| ~74μm (silt) | 19.23 | 56.67 | 20.51 | 39.41 | 17.49 | 35.99 | 13.92 | 33.38 | 35.28 | 42.75 |

*D-Driveway; C-Cycling way

The silt particles were separated by a Bahco centrifugal machine to see the size distributions further (Table 3). As shown in Table 3, the proportions of particles <6.2μm in the silt of paved road dust are only 0.89% to 2.38%, and 3.19% to 5.37% for particles <13.3μm, both less than that in the soil and construction dust.

**Table 3 Average size distributions for silt particles of paved road dust and other fugitive sources by Bahco centrifugal machine (mass percent for aerodynamic diameter) %**

| Size range | Inner ring | | Middle ring | | Main road | | Sec. main road | | Soil | Construction dust |
|---|---|---|---|---|---|---|---|---|---|---|
| | D | C | D | C | D | C | D | C | | |
| >34.7μm | 89.84 | 89.35 | 84.79 | 88.36 | 87.25 | 84.41 | 86.31 | 83.20 | 89.71 | 61.39 |
| 22.8-34.7μm | 4.83 | 2.99 | 5.70 | 3.48 | 5.31 | 7.13 | 5.37 | 7.35 | | |
| 13.3-22.8μm | 2.14 | 2.99 | 4.49 | 3.00 | 3.17 | 3.45 | 3.75 | 4.08 | 4.50 | 11.71 |
| 6.2-13.3μm | 1.78 | 2.29 | 3.48 | 3.17 | 3.38 | 3.15 | 3.54 | 3.21 | 2.81 | 16.74 |
| ~6.2μm | 1.41 | 2.38 | 1.54 | 2.00 | 0.89 | 1.86 | 1.03 | 2.16 | 2.98 | 10.16 |

The dust emissions from paved roads have been found to vary with what is termed the "silt loading" (the mass of silt-size material equal to or less than 74μm in geometric diameter per unit area of the travel surface) present on the road surface. Silt loading is an important parameter for the dust emission estimation from paved road dust (Watson et al., 2000; WRAP, 2004; EPA, 1995). Having mass of collected dust, silt content and sampling area for each site, the silt loading can be calculated (Table 4). The mean value of cycling way silt loading is much higher than the driveway for each road type. It indicates that a great amount of silt materials on driveway are re-suspended by outside disturbs and deposit on the cycling way.

**Table 4 Silt loadings of different road types ($g/m^2$)**

| | Inner ring | | Middle ring | | Main road | | Sec. main road | |
|---|---|---|---|---|---|---|---|---|
| | D | C | D | C | D | C | D | C |
| Mean | 0.77 | 12.00 | 0.53 | 8.22 | 0.65 | 5.95 | 0.29 | 8.47 |
| Min | 0.06 | 1.34 | 0.09 | 1.57 | 0.19 | 2.21 | 0.10 | 3.61 |
| Max | 3.73 | 27.06 | 2.77 | 17.36 | 2.14 | 14.5 | 0.53 | 16.86 |

### 4.2 *Chemical compositions*

#### 4.2.1 *Tianjin paved road dust*

After the resuspension and analysis, the chemical compositions of samples from one road type are averaged and combined together. The $PM_{10}$ and $PM_{2.5}$ profiles of Tianjin paved road dust for different road types are listed in Table 5.

The abundances of chemical species are alike between different road types both for $PM_{10}$ and $PM_{2.5}$, especially the crustal elements (Si, Ca, Al, Fe, Mg, K and Ti) which are abundant and all with small uncertainties. This result indicates the geological materials' contribution to paved road dust is quite stable. The Spearman correlation coefficients between the $PM_{10}$ profiles of road dust in Table 5 are 0.968 to 0.998, and that between the $PM_{2.5}$ profiles are 0.956 to 0.995. But the crustal element contents in all profiles of paved road dust are evidently lower than the soil.

The mass percent of TC, OC and Zn in paved road dust are much higher than the soil. The Zn is contributed mainly by tire wear, combustion of lubrication oil and the use of Zn compounds in rubber production (Fergusson and Kim, 1991), meanwhile the most mass of vehicle exhaust is TC (Watson et al., 1994, 2001a, b; Chow et al., 1995, 2004). It shows a great contribution of vehicle exhaust to the paved road dust. The $NH_4^+$, $Cl^-$ and $SO_4^{2-}$ abundances are also higher in paved road dust, reflecting the contribution from ambient particulate. The $SO_4^{2-}$, TC, OC and Zn are evidently enriched in $PM_{2.5}$ with higher abundances than $PM_{10}$. On the whole, the abundances of TC, Zn and ions have similar characteristics with the ground based vehicle exhaust profiles in other studies (Watson et al., 2001a, b; Chow et al., 2004).

The Enrichment Factors were also calculated to assist the identification of the contribution from other sources besides the earth crust. The silicon was chosen as the reference element for calculating the enrichment factors. Hence, the enrichment factor $EF_i$ is defined as a ratio of the relative abundance of element $i$ in paved road dust to its relative abundance in the soil (exp.1) (Cyrys et al., 2003). The average enrichment factors of some metal elements for paved road dust are listed in Table 6. The results show that Cr, Mn and Pb are also enriched in Tianjin paved road dust. In addition, Cu, Zn, Ni and V are all detected in the paved road dust, different from the soil.

$$EF_i = \frac{(C_i / C_{Si})_{road}}{(C_i / C_{Si})_{soil}} \quad (1)$$

Table 6 Average enrichment factors of some metal elements for Tianjin paved road dust

| | Na | Mg | Al | K | Ca | Ti | Cr | Mn | Fe | Co | Pb |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $PM_{10}$ | 1.52 | 0.68 | 1.98 | 0.48 | 0.69 | 0.32 | 15.74 | 3.99 | 1.00 | 0.90 | 3.12 |
| $PM_{2.5}$ | 1.35 | 0.51 | 1.93 | 0.49 | 0.76 | 0.47 | 18.40 | 3.08 | 1.04 | 0.65 | 7.23 |

#### 4.2.2 *Other Chinese cities*

The $PM_{10}$ profiles of the paved road dust and the soil for Shijiazhuang, Handan, Yinchuan, Zhengzhou and Nanjing are in Table 7. Different from Tianjin paved road dust, the abundances of crustal elements (Si, Ca, Al, Fe, Mg, K and Ti) in paved road dust are basically on the same level with that in the soil for these five cities. The Spearman correlation coefficient between the profiles of paved road dust and the soil (SCC) for each city is calculated (Table 8). The SCC are all >0.930 for Shijiazhuang, Handan, Yinchuan, Zhengzhou and Nanjing, indicating that the sampled paved road dust is mainly from the soil, whereas the SCC for $PM_{10}$ profiles of Tianjin in Table 5 is only 0.809.

The different characterizations of paved road dust between Tianjin and other five cities can be attributed to the differences of the sampling methods, namely the battery-powered vacuum sampling for Tianjin and the sweeping for other cities. The vacuum sampling method can completely collect the fine dust on the rough surface. Yet the sites with visibly covered dust are always chosen for the sweeping collection to get sufficient amount for analysis, usually more soil in the surface. The $PM_{10}$ profiles of swept paved road dust and soil were also reported in some studies (Vega et al., 2001; Watson et al., 2001a; Ho et al., 2003), with the SCC all >0.930. We can conclude that the content of crustal elements in the sampled paved road dust are closely related to the sampling methods, thus the vacuum sampler can be regarded as a better sampling method for paved road dust.

The mass percent of TC, OC and Zn in paved road dust are higher than the soil. The enrichment factors of metal elements for five cities shows that only Zn in Handan, Shijiazhuang and Yinchuan is evidently enriched (Table 9).

Table 5a Profiles of road dust for highway, Tianjin (weight percent by mass)

| | Inner ring | | | | Middle ring | | | |
|---|---|---|---|---|---|---|---|---|
| | Driveway | | Cycling way | | Driveway | | Cycling way | |
| | $PM_{10}$ | $PM_{2.5}$ | $PM_{10}$ | $PM_{2.5}$ | $PM_{10}$ | $PM_{2.5}$ | $PM_{10}$ | $PM_{2.5}$ |
| Na | 1.1128±0.6743 | 0.9867±0.1121 | 0.7196±0.0839 | 0.7011±0.2675 | 0.8569±0.1179 | 0.4377±0.1123 | 0.6083±0.0420 | 0.8160±0.1888 |
| Mg | 0.1990±0.0564 | 0.3859±0.1221 | 0.4342±0.0426 | 0.2834±0.0000 | 0.5246±0.0332 | 0.1387±0.0742 | 0.2985±0.0469 | 0.5246±0.1279 |
| Al | 4.3294±1.1121 | 5.5996±0.8654 | 6.8169±1.0853 | 6.0468±0.2283 | 5.8616±0.6745 | 6.4782±1.0289 | 5.7610±1.2762 | 7.0286±0.6063 |
| Si | 6.8807±0.9854 | 6.8433±0.4553 | 6.3338±0.2578 | 7.1214±0.0760 | 6.8573±0.0589 | 6.8479±0.2345 | 7.2172±0.0397 | 6.7101±0.7701 |
| K | 0.8551±0.0834 | 0.4483±0.0325 | 0.5520±0.1468 | 0.4358±0.0646 | 0.5894±0.0093 | 0.9962±0.2108 | 0.3985±0.0352 | 0.3279±0.0059 |
| Ca | 1.4937±0.0213 | 2.1941±0.0003 | 2.0155±0.1314 | 2.0869±0.0000 | 1.8940±0.0203 | 1.5438±0.0431 | 1.3329±0.0152 | 1.8261±0.3083 |
| Ti | 0.0839±0.0123 | 0.1319±0.0312 | 0.0989±0.0297 | 0.1289±0.0042 | 0.0501±0.0116 | 0.1319±0.0231 | 0.0650±0.0098 | 0.0606±0.0246 |
| V | 0.0012±0.0003 | 0.0013±0.0001 | 0.0012±0.0000 | 0.0012±0.0001 | 0.0014±0.0002 | 0.0014±0.0002 | 0.0013±0.0000 | 0.0014±0.0003 |
| Cr | 0.0117±0.0034 | 0.0231±0.0055 | 0.1391±0.0248 | 0.0262±0.0054 | 0.0457±0.0321 | 0.0750±0.0211 | 0.0550±0.0683 | 0.0794±0.0660 |
| Mn | 0.0221±0.0048 | 0.0284±0.0032 | 0.0727±0.0134 | 0.0231±0.0121 | 0.0790±0.0121 | 0.0259±0.0113 | 0.0632±0.0179 | 0.0885±0.0089 |
| Fe | 0.8323±0.1275 | 0.9162±0.3211 | 0.9687±0.1533 | 1.1016±0.0247 | 0.9267±0.1245 | 0.7624±0.0983 | 1.0666±0.0841 | 0.9442±0.1682 |
| Co | 0.0012±0.0005 | 0.0022±0.0009 | 0.0012±0.0000 | 0.0035±0.0020 | 0.0055±0.0112 | 0.0017±0.0006 | 0.0014±0.0019 | 0.0000±0.0000 |
| Ni | 0.0035±0.0043 | 0.0017±0.0011 | 0.0048±0.0041 | 0.0089±0.0037 | 0.0196±0.0102 | 0.0043±0.0012 | 0.0159±0.0195 | 0.0134±0.0189 |
| Cu | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0069±0.0098 | 0.0149±0.0122 | 0.0000±0.0001 | 0.0430±0.0609 | 0.0315±0.0446 |
| Zn | 0.0757±0.0189 | 0.1145±0.0332 | 0.1112±0.0369 | 0.1622±0.0762 | 0.0702±0.0201 | 0.1058±0.0341 | 0.1031±0.0236 | 0.1367±0.0244 |
| As | 0.0013±0.0004 | 0.0034±0.0006 | 0.0026±0.0005 | 0.0028±0.0004 | 0.0027±0.0003 | 0.0041±0.0012 | 0.0023±0.0011 | 0.0024±0.0001 |
| Cd | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 |
| Hg | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 |
| Pb | 0.0162±0.0044 | 0.0201±0.0043 | 0.0102±0.0111 | 0.0316±0.0228 | 0.0063±0.0012 | 0.0388±0.0121 | 0.0108±0.0035 | 0.0102±0.0095 |
| TC | 20.5272±2.5640 | 32.6610±1.3245 | 20.6987±8.7227 | 31.4566±6.1746 | 19.0156±3.2213 | 28.0746±2.8974 | 16.5575±2.7482 | 30.2921±1.3989 |
| OC | 12.5612±1.7853 | 21.7698±2.0123 | 9.9949±3.1651 | 17.3222±1.3397 | 12.2214±1.0389 | 16.7846±3.0011 | 10.9133±0.3625 | 19.7350±1.1651 |
| $NH_4^+$ | 0.0636±0.0050 | 0.1655±0.0374 | 0.0630±0.0173 | 0.2279±0.0518 | 0.0423±0.0035 | 0.1121±0.0241 | 0.0445±0.0039 | 0.1273±0.0146 |
| $Cl^-$ | 0.1993±0.0467 | 0.1508±0.0380 | 0.2458±0.1163 | 0.2493±0.1533 | 0.1748±0.0245 | 0.3560±0.0502 | 0.1616±0.0208 | 0.1890±0.0441 |
| $NO_3^-$ | 0.0000±0.0000 | 0.0001±0.0000 | 0.0001±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0001±0.0000 | 0.0000±0.0000 |
| $SO_4^{2-}$ | 1.0693±0.1345 | 0.9041±0.0688 | 1.0069±0.1034 | 0.9613±0.0760 | 1.1936±0.1531 | 1.8691±0.0386 | 0.8223±0.1015 | 1.1586±0.0269 |

Table 5b Profiles of road dust for main road and sec. main road, Tianjin (weight percent by mass) *

| | Main road | | | | Secondary main road | | | | Urban soil (2001) |
|---|---|---|---|---|---|---|---|---|---|
| | Driveway | | Cycling way | | Driveway | | Cycling way | | |
| | $PM_{10}$ | $PM_{2.5}$ | $PM_{10}$ | $PM_{2.5}$ | $PM_{10}$ | $PM_{2.5}$ | $PM_{10}$ | $PM_{2.5}$ | $PM_{10}$ |
| Na | 0.8309±0.1123 | 0.7715±0.0986 | 0.8012±0.0231 | 0.9199±0.1132 | 0.7864±0.1156 | 0.5668±0.0221 | 1.0238±0.2260 | 0.8086±0.2218 | 1.850±0.610 |
| Mg | 0.4101±0.2091 | 0.2774±0.0655 | 0.5126±0.0341 | 0.3196±0.1210 | 0.4704±0.0564 | 0.2443±0.0675 | 0.4583±0.0451 | 0.3679±0.0664 | 2.050±0.500 |
| Al | 6.4146±0.0443 | 5.4620±1.2896 | 6.0071±0.0341 | 4.6945±0.6541 | 6.2559±0.0543 | 6.5796±0.8962 | 6.2029±0.0084 | 5.2344±0.0432 | 10.100±2.940 |
| Si | 6.4740±0.9982 | 6.7591±0.2145 | 6.8573±0.0123 | 6.5254±0.0321 | 6.8106±0.3217 | 6.8918±0.6612 | 6.7217±0.5673 | 6.9461±0.0213 | 22.590±3.040 |
| K | 0.4151±0.0986 | 0.4815±0.0675 | 0.3985±0.1067 | 0.6060±0.3212 | 0.4317±0.3896 | 0.3853±0.0452 | 0.5977±0.1145 | 0.6724±0.0896 | 3.680±0.880 |
| Ca | 1.6581±0.0563 | 1.9511±0.0874 | 1.7653±0.2140 | 1.9154±0.2121 | 1.9297±0.1267 | 2.0994±0.1455 | 1.9226±0.3417 | 2.1656±0.2165 | 8.540±3.840 |
| Ti | 0.0659±0.0123 | 0.0839±0.0215 | 0.0719±0.0021 | 0.1319±0.0213 | 0.0779±0.0112 | 0.1298±0.0187 | 0.0719±0.0547 | 0.0600±0.0100 | 0.760±0.260 |
| V | 0.0011±0.0009 | 0.0013±0.0002 | 0.0014±0.0006 | 0.0013±0.0001 | 0.0014±0.0001 | 0.0015±0.0001 | 0.0015±0.0005 | 0.0013±0.0004 | 0.000±0.000 |
| Cr | 0.0757±0.0078 | 0.0129±0.0065 | 0.0227±0.0078 | 0.1175±0.0634 | 0.0125±0.0224 | 0.0053±0.0221 | 0.0064±0.0021 | 0.1018±0.0764 | 0.010±0.000 |
| Mn | 0.0822±0.0134 | 0.0822±0.0156 | 0.0822±0.0221 | 0.0695±0.0032 | 0.0822±0.0342 | 0.0511±0.0021 | 0.0885±0.0212 | 0.0758±0.0132 | 0.060±0.020 |
| Fe | 0.8183±0.3215 | 0.9372±0.2136 | 0.7973±0.1254 | 0.8743±0.2341 | 0.7973±0.0765 | 0.7981±0.1163 | 0.8813±0.0884 | 1.0981±0.0665 | 2.960±0.170 |
| Co | 0.0012±0.0009 | 0.0025±0.0011 | 0.0030±0.0012 | 0.0013±0.0011 | 0.0052±0.0036 | 0.0036±0.0021 | 0.0029±0.0012 | 0.0011±0.0021 | 0.010±0.000 |
| Ni | 0.0037±0.0045 | 0.0026±0.0008 | 0.0061±0.0023 | 0.0035±0.0012 | 0.0319±0.0123 | 0.0118±0.0134 | 0.0154±0.0035 | 0.0087±0.0065 | 0.000±0.000 |
| Cu | 0.0000±0.0002 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0001 | 0.0000±0.0000 | 0.000±0.000 |
| Zn | 0.0998±0.0678 | 0.1495±0.0098 | 0.1129±0.0078 | 0.1423±0.0034 | 0.1109±0.0433 | 0.1670±0.0654 | 0.1543±0.0322 | 0.2466±0.0775 | 0.000±0.000 |
| As | 0.0007±0.0004 | 0.0007±0.0004 | 0.0022±0.0022 | 0.0056±0.0009 | 0.0034±0.0011 | 0.0051±0.0033 | 0.0019±0.0008 | 0.0014±0.0003 | — |
| Cd | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | — |
| Hg | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | — |
| Pb | 0.0096±0.0032 | 0.0215±0.0121 | 0.0101±0.0045 | 0.0276±0.0045 | 0.0086±0.0009 | 0.0183±0.0032 | 0.0030±0.0010 | 0.0070±0.0042 | 0.010±0.000 |
| TC | 13.4191±1.2210 | 29.3069±2.9850 | 15.7404±3.2411 | 26.5020±2.6974 | 17.2215±2.6640 | 36.3031±3.8875 | 18.4473±1.6542 | 36.7169±3.2210 | 4.920±1.440 |
| OC | 7.9854±2.9911 | 21.6642±1.2620 | 8.5042±2.6780 | 14.9354±3.4464 | 8.8038±0.8850 | 23.7039±2.6654 | 9.8138±0.6789 | 19.9085±2.8864 | 3.130±1.440 |
| $NH_4^+$ | 0.0356±0.0047 | 0.1059±0.0232 | 0.0350±0.0075 | 0.1137±0.0475 | 0.0797±0.0048 | 0.2169±0.0235 | 0.0180±0.0052 | 0.1038±0.0125 | 0.010±0.000 |
| $Cl^-$ | 0.2521±0.0976 | 0.4191±0.0380 | 0.2183±0.0435 | 0.2219±0.0535 | 0.4055±0.0760 | 0.3617±0.0460 | 0.2922±0.0575 | 0.2193±0.0463 | 0.010±0.000 |
| $NO_3^-$ | 0.0001±0.0000 | 0.0001±0.0001 | 0.0000±0.0000 | 0.0000±0.0001 | 0.0001±0.0000 | 0.0000±0.0000 | 0.0000±0.0000 | 0.0001±0.0000 | 0.000±0.000 |
| $SO_4^{2-}$ | 0.7608±0.0967 | 0.8894±0.1444 | 1.0744±0.2110 | 1.0180±0.0832 | 1.2379±0.0952 | 1.1642±0.1834 | 1.0324±0.1652 | 1.1414±0.1334 | 0.750±0.240 |

*The species not analyzed are marked with "—".

Table 7 $PM_{10}$ Profiles of paved road dust and soil for Handan, Shijiazhuang, Yinchuan, Zhengzhou and Nanjing (weight percent by mass)*

| | Handan | | Shijiazhuang | | Yinchuang | | Zhengzhou | | Nanjing | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Paved road | Soil | Paved road | Soil | Paved road | Soil | Paved road | Soil | Paved road | Soil |
| Na | 0.260±0.040 | 0.430±0.190 | 1.106±0.102 | 0.754±0.042 | 1.170±0.372 | 0.891±0.224 | 1.546±0.544 | 1.975±0.473 | 1.789±0.608 | 1.506±0.371 |
| Mg | 1.900±0.010 | 1.640±0.120 | 0.999±0.064 | 1.732±0.096 | 2.219±0.363 | 2.045±0.577 | 1.087±0.346 | 0.952±0.152 | 1.914±0.682 | 0.706±0.185 |
| Al | 7.340±0.210 | 6.840±0.120 | 5.437±0.157 | 7.845±0.260 | 5.726±1.059 | 5.697±0.450 | 6.901±0.585 | 8.024±1.270 | 7.550±0.997 | 9.988±0.542 |
| Si | 20.590±0.660 | 25.080±0.600 | 24.277±1.382 | 24.914±1.165 | 18.543±8.702 | 24.433±7.055 | 27.373±2.835 | 29.872±1.498 | 24.390±1.909 | 27.364±0.637 |
| P | 0.110±0.000 | 0.090±0.010 | 0.105±0.011 | 0.097±0.024 | 0.116±0.008 | 0.096±0.009 | — | — | — | — |
| K | 1.820±0.040 | 2.390±0.160 | 1.453±0.071 | 2.098±0.081 | 1.904±0.085 | 1.952±0.419 | 1.879±0.297 | 2.070±0.549 | 1.430±0.470 | 1.306±0.473 |
| Ca | 11.960±0.540 | 7.030±1.010 | 5.741±0.343 | 4.906±1.950 | 7.404±1.723 | 9.607±5.133 | 9.059±3.780 | 4.198±0.712 | 11.410±3.480 | 5.914±0.423 |
| Ti | 0.290±0.010 | 0.440±0.010 | 0.347±0.015 | 0.439±0.036 | 0.283±0.041 | 0.357±0.177 | 0.142±0.050 | 0.244±0.091 | 0.314±0.068 | 0.475±0.051 |
| V | 0.010±0.000 | 0.010±0.000 | 0.004±0.001 | 0.011±0.003 | 0.008±0.000 | 0.011±0.003 | 0.003±0.001 | 0.003±0.001 | 0.003±0.001 | 0.005±0.001 |
| Cr | 0.010±0.000 | 0.010±0.000 | 0.004±0.001 | 0.010±0.001 | 0.014±0.010 | 0.010±0.011 | 0.013±0.004 | 0.010±0.006 | 0.024±0.016 | 0.027±0.002 |
| Mn | 0.060±0.000 | 0.070±0.010 | 0.047±0.003 | 0.083±0.009 | 0.056±0.011 | 0.061±0.008 | 0.026±0.008 | 0.033±0.011 | 0.043±0.007 | 0.049±0.008 |
| Fe | 4.500±0.100 | 4.030±0.590 | 3.246±0.546 | 4.298±0.347 | 2.233±0.360 | 3.086±0.344 | 1.954±0.264 | 2.062±0.576 | 2.196±0.383 | 2.855±0.231 |
| Co | 0.000±0.000 | 0.000±0.000 | 0.001±0.000 | 0.002±0.000 | 0.002±0.000 | 0.002±0.000 | 0.002±0.001 | 0.003±0.001 | 0.004±0.002 | 0.003±0.002 |
| Ni | 0.000±0.000 | 0.000±0.000 | 0.004±0.002 | 0.005±0.002 | 0.004±0.005 | 0.004±0.000 | 0.004±0.001 | 0.005±0.002 | 0.003±0.002 | 0.008±0.003 |
| Cu | 0.010±0.000 | 0.000±0.000 | 0.005±0.001 | 0.005±0.001 | 0.000±0.000 | 0.000±0.000 | 0.017±0.017 | 0.029±0.066 | 0.028±0.022 | 0.021±0.002 |
| Zn | 0.040±0.000 | 0.010±0.010 | 0.108±0.231 | 0.013±0.002 | 0.041±0.047 | 0.006±0.011 | 0.035±0.020 | 0.024±0.041 | 0.024±0.026 | 0.010±0.002 |
| As | — | — | — | — | — | — | — | — | 0.001±0.000 | 0.001±0.000 |
| Br | 0.000±0.000 | 0.000±0.000 | 0.000±0.000 | 0.001±0.000 | 0.001±0.000 | 0.000±0.000 | — | — | — | — |
| Cd | — | — | — | — | — | — | — | — | 0.000±0.000 | 0.000±0.000 |
| Ba | 0.050±0.000 | 0.060±0.000 | 0.070±0.004 | 0.064±0.005 | 0.050±0.007 | 0.042±0.006 | — | — | — | — |
| Hg | — | — | — | — | — | — | — | — | 0.000±0.000 | 0.000±0.000 |
| Pb | 0.020±0.020 | 0.000±0.240 | 0.010±0.005 | 0.005±0.002 | 0.006±0.001 | 0.010±0.002 | 0.003±0.002 | 0.003±0.002 | 0.003±0.003 | 0.003±0.001 |
| TC | 10.190±1.770 | 4.160±0.550 | 8.406±0.775 | 2.485±1.047 | 5.291±0.733 | 2.013±0.020 | 3.872±0.963 | 1.985±0.593 | 4.705±1.306 | 1.348±0.429 |
| OC | 6.900±1.690 | 2.410±0.580 | 7.161±0.589 | 1.854±1.080 | — | — | 3.860±0.899 | 1.092±0.313 | 2.498±0.748 | 0.791±0.221 |
| $NH_4^+$ | 0.010±0.010 | 0.010±0.010 | — | — | 0.001±0.005 | 0.000±0.000 | 0.001±0.001 | 0.001±0.002 | — | — |
| $Cl^-$ | 0.010±0.010 | 0.020±0.010 | 0.658±0.181 | 0.062±0.031 | 0.251±0.179 | 0.094±0.019 | 0.034±0.012 | 0.006±0.008 | 0.085±0.067 | 0.032±0.045 |
| $NO_3^-$ | 0.000±0.000 | 0.050±0.030 | 0.105±0.036 | 0.125±0.087 | 0.000±0.000 | 0.000±0.000 | 0.005±0.002 | 0.005±0.009 | 0.000±0.000 | 0.000±0.000 |
| $SO_4^{2-}$ | 0.210±0.160 | 0.260±0.110 | 3.622±2.452 | 0.731±0.481 | 0.963±0.431 | 1.135±0.322 | 0.284±0.121 | 0.055±0.077 | 0.101±0.114 | 0.065±0.106 |

*The species not analyzed are marked with "—".

Table 10 The mean concentrations of some heavy metals in $PM_{10}$ and $PM_{2.5}$ paved road dust of several cities (weight percent by mass)

| Reference | (a) | (b) | (c) | (d) | (e) | | (f) | (g) | | (h) | (i) | | (j) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| City | Pasadena | Fresno | Los Angeles | San Jose, Fourth Str. | Mexico | | Craig and Steamboat Springs | Mexicali Imperial | | Fresno | Hong Kong | | San Antonio and Laredo | |
| Collection method | (B) | (A) or (C) | (C) | Not clear | (A) | | (A) | (C) | | (C) | (A) | | (A) | |
| Diameter | $PM_2$ | $PM_{10}$ | $PM_{2.5}$ | $PM_{10}$ | $PM_{10}$ | $PM_{2.5}$ | $PM_{2.5}$ | $PM_{10}$ | | $PM_{10}$ | $PM_{10}$ | $PM_{2.5}$ | $PM_{10}$ | $PM_{2.5}$ |
| Ti | 0.56 | 0.4990 | 0.305 | 0.418 | 0.32 | 0.32 | 0.57058 | 0.360 | 0.363 | 0.3600 | 0.2379 | 0.2139 | 0.2564 | 0.3082 |
| V | 0.027 | 0.0311 | 0.0279 | 0.015 | — | — | 0.01831 | 0.014 | 0.014 | 0.0019 | 0.0020 | 0.0009 | 0.0053 | 0.0065 |
| Cr | 0.017 | 0.0299 | 0.0484 | 0.013 | 0.007 | 0.01 | 0.01276 | 0.007 | 0.009 | 0.0009 | 0.0327 | 0.0265 | 0.0088 | 0.0098 |
| Mn | 0.12 | 0.1056 | 0.0776 | 0.090 | 0.058 | 0.068 | 0.09895 | 0.064 | 0.061 | 0.0752 | 0.1016 | 0.1096 | 0.0399 | 0.0443 |
| Fe | 6.23 | 5.4057 | 5.21 | 5.797 | 3.5 | 4.0 | 6.03 | 3.604 | 3.627 | 4.4880 | 5.0867 | 6.1638 | 2.7493 | 3.3420 |
| Co | — | 0.0059 | — | 0.000 | 0.00 | 0.00 | 0.00100 | 0.000 | 0.000 | 0.0000 | 0.0107 | 0.0238 | 0.0000 | 0.0000 |
| Ni | 0.012 | 0.0111 | 0.0292 | 0.017 | 0.003 | 0.003 | 0.00378 | 0.002 | 0.007 | 0.0026 | 0.0078 | 0.0042 | 0.0045 | 0.0039 |
| Cu | 0.056 | 0.0200 | 0.0526 | 0.015 | 0.014 | 0.015 | 0.00564 | 0.010 | 0.007 | 0.0252 | 0.0600 | 0.0695 | 0.0219 | 0.0284 |
| Zn | 0.15 | 0.1723 | 0.428 | 0.131 | 0.069 | 0.087 | 0.04953 | 0.049 | 0.063 | 0.1119 | 0.5149 | 0.5923 | 0.1429 | 0.1680 |
| As | 0.002 | 0.0014 | 0.0098 | 0.000 | 0.000 | 0.000 | 0.00057 | 0.002 | 0.000 | 0.0021 | 0.0004 | 0.0015 | 0.0005 | 0.0013 |
| Cd | — | 0.0015 | 0.000 | — | — | — | 0.00476 | 0.000 | 0.001 | 0.0000 | 0.0024 | 0.0141 | 0.0005 | 0.0007 |
| Ba | 0.076 | 0.0640 | 0.000 | — | 0.06 | 0.1 | 0.16307 | 0.072 | 0.113 | 0.1627 | 0.1000 | 0.1508 | 0.1237 | 0.1703 |
| Hg | — | 0.0015 | 0.000 | — | — | — | 0.00004 | 0.001 | 0.002 | 0.0006 | 0.0007 | 0.0009 | 0.0002 | 0.0004 |
| Pb | 0.11 | 0.2647 | 0.209 | 0.088 | 0.035 | 0.038 | 0.01820 | 0.018 | 0.020 | 0.0161 | 0.1061 | 0.1209 | 0.0391 | 0.0396 |

(a) Hildemann et al., 1991; (b) Chow et al., 1992b; (c) Watson et al., 1994; (d) Chow et al., 1995; (e) Vega et al., 2001; (f) Watson et al., 2001a; (g) Watson et al., 2001b; (h) Chow et al., 2003; (i) Ho et al., 2003; (j) Chow et al., 2004.
(A) by sweeping with dustpan and brush (B) by small vacuum sweeper truck (C) by battery-powered vacuuming.

Table 8 The Spearman correlation coefficients between PM10 profiles of paved road dust and soil

| City | Handan | Shijiazhuang | Yinchuan | Zhengzhou | Nanjing | Tianjin |
|---|---|---|---|---|---|---|
| SCC | 0.935 | 0.930 | 0.985 | 0.968 | 0.972 | 0.809 |

Table 9 Enrichment factors of metal elements for the paved road dust in five cities

| | Na | Mg | Al | K | Ca | Ti | V | Cr | Mn | Fe | Co | Ni | Cu | Zn | Ba | Pb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Handan | 0.74 | 1.41 | 1.31 | 0.93 | 2.07 | 0.80 | 1.22 | 1.22 | 1.04 | 1.36 | — | — | — | 4.87 | 1.02 | — |
| Shijiazhuang | 1.50 | 0.59 | 0.71 | 0.71 | 1.20 | 0.81 | 0.36 | 0.39 | 0.59 | 0.78 | 0.64 | 0.76 | 1.03 | 8.34 | 1.11 | 2.18 |
| Yinchuan | 1.73 | 1.43 | 1.32 | 1.28 | 1.02 | 1.05 | 1.02 | 1.88 | 1.19 | 0.95 | 1.32 | 1.39 | — | 8.53 | 1.56 | 0.81 |
| Zhengzhou | 0.85 | 1.25 | 0.94 | 0.99 | 2.35 | 0.64 | 1.09 | 1.42 | 0.86 | 1.03 | 0.73 | 0.87 | 0.64 | 1.59 | — | 1.09 |
| Nanjing | 1.33 | 3.04 | 0.85 | 1.23 | 2.16 | 0.74 | 0.70 | 1.03 | 0.99 | 0.86 | 1.37 | 0.41 | 1.46 | 2.78 | — | 1.19 |

#### 4.2.3 *Heavy metals*

The heavy metals can cause great harm to the human health. The mean concentrations of related heavy metals in paved road dust from other studies are sorted out (Table 10). Since the collection and analysis methods are various, we can only make a simple comparison to see the concentration levels of heavy metals in our studies.

The mass percent of Cr in Tianjin is 0.0799% for $PM_{10}$ and 0.0611% for $PM_{2.5}$ on average, much higher than 0.0009% to 0.0327% for $PM_{10}$ and 0.0098% to 0.0484% for $PM_{2.5}$ in other cities. The higher percent of Cr may come from the contamination of some major industries in Tianjin such as paper making, dyeing, metal processing, machinery and instrument making.

The abundances of Cu, Zn and Pb in paved road dust of six China cities are lower than most of the foreign cities, and As, Mn, Co, Ni, Ba are basically on the average level. Hg and Cd are not detected in Tianjin and Nanjing.

Except As in the paved road dust of Tianjin, the concentrations of Cr, Cd and Pb in $PM_{10}$ or $PM_{2.5}$ of paved road dust for six China cities are all lower than the trigger concentrations for parks, playing fields, and open space (Table 11) (ICRCL, 1983).

Table 11 Cr, As, Cd and Pb concentrations which may pose hazards to health (%)

| Contaminant | Planned use | Trigger concentration |
|---|---|---|
| Cr | Domestic gardens, allotments | 0.0600 |
| | Parks, playing fields, open space | 0.1000 |
| As | Domestic gardens, allotments | 0.0010 |
| | Parks, playing fields, open space | 0.0040 |
| Cd | Domestic gardens, allotments | 0.0003 |
| | Parks, playing fields, open space | 0.0015 |
| Pb | Domestic gardens, allotments | 0.0500 |
| | Parks, playing fields, open space | 0.2000 |

## 5 CONCLUSIONS

The silt contents and silt loadings of Tianjin paved road dust on driveways are much less than cycling way for each road type. It indicates that a great amomt of silt materials on driveway are re-suspended by vehicle disturbs and deposit on the cycling way. The silt contents decrease sequently from highway to secondary main road, showing the level of silt content has a positive relationship with the vehicle flow. The proportions of particles <6.2μm and <13.3μm in paved road dust are both less than soil and construction dust.

The chemical compositions of Tianjin paved road dust for highway, main road and secondary main road are similar to each other, not many disparities are found between or within profiles of different road types. The crustal elements content are evidently lower than soil in Tianjin paved road dust, whereas basically on the same level with soil for other five China cities. It shows that the sweeping method may collect more soil, and the vacuuming method is conducive to representativeness of paved road dust collection.

The mass percent of TC, OC and Zn in paved road dust are all higher than the soil in the six Chinese cities, especially in Tianjin. The Mn, Pb and Cr are also enriched in Tianjin paved road dust. The $NH_4^+$, $Cl^-$ and $SO_4^{2-}$ abundances are also higher in most profiles of paved road dust. It shows that a great part of the paved road dust is from vehicle exhaust, tire wear, and ambient particulate. The vehicle exhaust and tire wear are concentrated in $PM_{2.5}$ size fraction due to the enrichment of TC, OC and Zn in $PM_{2.5}$.

Compared with foreign cities, the mass percent of Cr in Tianjin paved road dust is at a high level, and the abundances of Cu, Zn and Pb of the six China cities are lower. The concentrations of Cr, Cd and Pb in paved road dust of six China cities are all lower than the trigger concentrations.

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