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Chemical characteristics of road dust $PM_{2.5}$ fraction in oasis cities at the margin of Tarim Basin

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ABSTRACT

In order to understand the compositions characteristics of particulate matter with aerodynamic diameter less than 2.5 μm ($PM_{2.5}$) fraction in road dust ($RD_{2.5}$) of oasis cities on the edge of Tarim Basin, 30 road dust (RD) samples were collected in Kashi, Cele, and Yutian in the spring, 2018, and $RD_{2.5}$ was collected using the resuspension approach. Eight water-soluble ions, 39 trace elements and 8 fractions of carbon-containing species in $PM_{2.5}$ were analyzed. Ca^{2+} and Ca were the most abundant ions and elements in $RD_{2.5}$ (7.1% and 9.5%). Cl^- in $RD_{2.5}$ was affected not only by attributed to saline-alkali soils in oasis cities of the Tarim Basin and dust from Taklimakan Desert but also by human activities. Moreover, the organic carbon/elemental carbon (OC/EC) ratio indicated that carbon components in $RD_{2.5}$ in Cele town mainly come from fossil fuel combustion, while those in Yutian and Kashi mainly come from biomass combustion. It is noteworthy that high Ca in $RD_{2.5}$ was seriously affected by anthropogenic emissions, and high Na and K contents in $RD_{2.5}$ could be derived from soil and desert dust. It was estimated that Cd, Tl, Sn and Cr were emitted from anthropogenic emissions using the enrichment factor. The coefficients of divergence (COD) result indicated that the influence of local emission on road dust emission is greater than that of long-distance transmission. This study is the first time to comprehensively analyze the chemical characteristics of road dust in oasis cities, and the results provides the sources of road dust at the margin of Tarim Basin.

Introduction

In recent years, atmospheric particulate matter (PM) has become the primary pollutant affecting urban air quality in China (Qiao et al., 2016; Feng et al., 2016, 2018; Tan et al., 2017). The Tarim Basin is located in the west of China. In previous studies, the air pollution in Kashi and Hotian oasis cities on the edge of Tarim Basin, were the most serious, which particulate matter with aerodynamic diameter less than 2.5 μm ($PM_{2.5}$) concentrations were 159 and 105 μg/m^3, respectively (Yu et al., 2019). Compared with most areas of China, such as Beijing-Tianjin-Heibei region ($PM_{2.5}$ was 60 μg/m^3) (China Ecological Environmental State Bulletin, 2018), Urumqi (73 μg/m^3) (Yin et al., 2019) and Lanzhou (53 μg/m^3) (Filonchyk and Yan,

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2018), the $PM_{2.5}$ concentration was higher, but similar to oasis cities abroad, such as Jeddah city (the $PM_{2.5}$ annually concentration was 126 μg/m^3 in 2012) and Makkah (the $PM_{2.5}$ concentrations in four seasons were 113, 88, 68 and 68 μg/m^3 respectively) (Alghamdi et al., 2015; Nayebare et al., 2018). While, PM comes from a number of sources, dust as one of the main sources of PM. It is well known that dust particles produced in the process of soil dust, road construction and building construction have a significant impact on PM in urban air (Zhang et al., 2017; Sun et al., 2019), especially in arid and semiarid areas (Shen et al., 2016; Tao et al., 2017). Nayebare et al. (2018) found that soil dust and industrial mixed dust were the main sources of $PM_{2.5}$, accounting for about 53.6% in Mecca Holy City. Alghamdi et al. (2015) found that the main source of ambient air particulate matter in Jeddah is the suspended soil particles. In the desert area of northern Chile, $PM_{2.5}$ and particulate matter with aerodynamic diameter less than 10 μm (PM_{10}) mainly came from industrial and suspended sand dust, and the average contribution of suspended sand dust to PM_{10} was 50 μg/m^3, and to $PM_{2.5}$ was 9.3 μg/m^3 (Jorquera et al., 2013). In Pinal, Arizona, oasis city in USA, the concentration of PM_{10} and $PM_{2.5}$ exceeded the US National Environmental Air Quality Standards, with 9 and 6 sources of coarse and fine particulates, 46% and 29% of which were fugitive dust, respectively (Clements et al., 2017).

Road dust is a key source of ambient PM. Based on the empirical method in the AP-42 document of the US Environmental Protection Agency, it is assumed that the average weight of a vehicle is 2 tons and the average sediment load on paved roads is 100 g/m^2, the average weight of resuspension PM_{10} emission was estimated to be 30 g/km (USEPA, 2003a, 2003b). Guttikunda. (2008) reported that each new car travels 30 km a day, 6 days a week, and 280 kg of PM_{10} will be resuspended each year. Chen et al. (2012) found that the average road dust load in Beijing was 3.82 g/m^2, of which the maximum load of 24.22 g/m^2 appeared in the urban-rural continuum of Hutongs in winter, and the dust load of high-grade road was lower than that of low-grade road. At present, the physical and chemical characteristics of road dust, emission inventory, emission characteristics and human health risks are the focus of attention of scientists (Zhang et al., 2010; Kong et al., 2011; Cao et al., 2012; Sun et al., 2019). In addition, the suspension of road dust is also affected by unique geographic characteristics and distinctive climate conditions (Ning et al., 1996). Cao et al. (2012) found that it was more conducive to fugitive dust emission in dry winter. Landis et al. (2017) used the resuspension system to analyzed the chemical compositions of $PM_{2.5}$ in anthropogenic dust and natural dust in Asabaska Oil Sand Region (AOSR), Alberta, Canada. It was found that Si was the most abundant substance in all samples, and that Al, Si, K, Ca, Fe and their oxides accounted for 25%-40% and 45%-82% of the particulate matter (PM) fraction, respectively. Sun et al. (2019) selected 21 cities fugitive dust from seven typical regions of China, and found that Ca, Si, Al and Fe were the abundant elements in the urban fugitive dust, and OC (80%) was the main carbon content in urban fugitive dust. Kong et al. (2011) used the elements ratio to calculate for source identification in fugitive dust at Fushun, and it was found that the fugitive dust in Fushun was relative to coal and metallurgy. In addition, they suggested that elemental ratios may vary widely even for the same source type with different processing courses. Chen et al. (2012) found that the elemental abundance of road dust PM_{10} fraction (RD_{10}) and road dust $PM_{2.5}$ fraction ($RD_{2.5}$) in Beijing was 16.17% and 18.50%, respectively. The average abundance of OC and EC in RD_{10} and $RD_{2.5}$ were 11.52%, 2.01% and 12.50% and 2.06%, respectively. Road dust in Beijing mainly comes from soil dust, building dust, coal-fired dust, automobile exhaust and atmospheric particulate matter deposition. However, the research on the regional scale of road dust is more concentrated in the North and South of China (Cao et al., 2012; Shen et al., 2016; Sun et al., 2019), and the study of road dust in arid areas of Western China is more concentrated in Xi'an, Lanzhou, Urumqi and other populous developed areas (Tian et al., 2017; Cao et al., 2007), but less in the marginal oasis area of the Tarim Basin. In addition, the environmental climate and urban development of oasis cities at the margin of Tarim Basin are quite different from those of northern and southern cities (Yu et al., 2019), and the physical and chemical properties of road dust also have some differences (Zhang et al., 2014).

In order to obtain the chemical characteristics of road dust in the oasis of the Tarim Basin, a comprehensive field study is needed, which is also the motivation of this study. In this study, three cities distributed in the southern and southwestern margins of the Tarim Basin were selected, and $RD_{2.5}$ was collected by resuspension chamber system. The main chemical components such as water-soluble ions and elements compositions were analyzed. In part, the source profile of urban dust in this area is established, and the geographic variability and similarity of dust characteristics in this area are determined. The knowledge gained in this study is expected to promote the further systematic study of dust emission and provide scientific basis for the formulation of emission control policies.

1. Materials and methods

1.1. *Sampling method*

In March to May 2018, three oasis cities on the edge of Tarim Basin (Kashi, Cele and Yutian) were selected in this study. We collected 30 road dust samples on the main roads, sub-main roads and branches in three cities (Fig. 1). Each road dust sample was collected with soft brushes and stainless steel shovels, and placed in a cool and dry place for air drying, and then screened with 200 mesh sieves in order to remove stones, branches and other debris from road dust. Moreover, the sifted road dust samples were put into the resuspension chamber, and the samples were collected by a small flow $PM_{2.5}$ sampler with 8.5 L/min. A total of 60 samples were collected on teflon filters (T filter) (Wateman, USA) and quartz filters (Q filter) (Pallflex membrane filters, USA) in this study. In addition, the Q filters were pre-combusted in a muffle furnace at 450°C for 4 hr to remove the contaminants on the filters prior to sampling. For PM mass determination, the filters were weighed in a constant temperature and humidity box with a temperature of 20 ± 0.1°C and a relative humidity of 50% ± 1% before and after the samples were collected. The filters were weighed with a Comde-Derenda AWS-1 automatic weighing system (±1 μg sensitivity; Comde-Derenda, Germany), and the deviations between the repeated weightings were less than 3 μg. Furthermore, the blank filters were concurrently collected in four sampling periods for the purpose of eliminating errors. After weighing, the filters were kept in filter boxes and stored in the refrigerator at -20°C until the chemical analysis.

1.2. *Chemical analysis*

In this study, we mainly analyzed 8 water-soluble ions (WSI), 39 trace elements and 8 carbon components. Q filters were used to analyze the WSI and the carbon elements, while T filters were mainly used to analyze the trace elements.

1.2.1. *Water-soluble ions*

Quarter of each Q filter sample was cut into the centrifuge tube, and 10 mL ultra-pure water (18.2 mΩ·cm) was added into

Fig. 1 – Location of sampling sites. A: Kashi; B: Cele; C: Yutian.

the centrifuge tube with the liquid transfer gun, and then the centrifuge tube was vibrated 30 min in an ultrasonic ice-water bath. After ultrasonic vibration, put it in a centrifugal machine to centrifuge for 2 min. The combined extracts were filtered through a polytetrafluoroethylene (PTFE) syringe filter (pore size, 0.22 μm), and stored in a low-density polyethylene bottle until analysis. In this study, Dionex ICS-2100 and Dionex ICS-1100 (Thermo Fisher Scientific, USA) were used to analyze four anions (Cl^-, NO_3^- and SO_4^{2-}) and five cations (Na^+, K^+, NH_4^+, Ca^{2+} and Mg^{2+}) in PM. In addition, the water-soluble ions detection limits were 0.005 (Cl^-), 0.0125 (NO_3^-), 0.0125 (SO_4^{2-}), 0.0072 (Na^+), 0.0006 (NH_4^+), 0.0017 (K^+), 0.0355 (Mg^{2+}) and 0.03 (Ca^{2+}) mg/L, respectively.

1.2.2. *Elements analysis*

Half of each T filter carrying PM was placed in a Teflon dissolution vessel for acid treatment. Each sample was heated and refluxed with 5 mL extract (pH = 5.4) and 1 mL HF at 220°C for 2.5 hr. The dissolution solution was diluted to 10 mL with 5 mL HCl (pH = 5.4) solution. Using 7500a model inductively coupled plasma-mass spectrometer (ICP-MS) (7500a, Agilent Technology Co., Ltd, USA) to analyze the aliquot. Li, Be, Na, P, K, Sc, As, Rb, Y, Mo, Cd, Sn, Sb, Cs, La, V, Cr, Mn, Co, Ni, Cu, Zn, Ce, Sm, W, Tl, Pb, Bi, Th and U were measured. Another half of each T filter was placed in a nickel crucible for alkali treatment. The sample was treated with 300°C in muffle furnace, and kept at the constant temperature for 40 min, and then gradually rised to 550°C. The filter after ashing was humidified with absolute ethanol, and added 0.2 g solid sodium hydroxide. The mixture melted at 500°C for 40 min in muffle furnace. The molten sample was transferred to a volumetric flask containing 2 mL HCl, and diluted to 10 mL with ultrapure water. Seven elements (Zr, Al, Sr, Mg, Ti, Ca, Fe, Ba and Si) were determined by inductively coupled plasma-optical emission spectroscopy (ICP-OES) (Vista-MPX, Agilent, USA).

1.2.3. *Carbon components analysis*

Using one-four Q filter to detect the elemental carbon (EC) and organic carbon (OC) by organic carbon/elemental carbon analyzer (DRI Model 2001A, Atmoslytic, USA). The analytical method was thermal optic reflection, which following the Interagency Monitoring of Protected Visual Environments (IMPROVE) protocol. Each sample was heated to produce four OC fractions: OC1, OC2, OC3 and OC4 at temperatures of 120, 250, 450 and 550°C in a non-oxidizing He atmosphere; three EC fractions: EC1, EC2 and EC3 at 550, 700 and 800°C in an oxidizing atmosphere of 2% O_2 / 98% He and optically detected pyrolyzed carbon (OPC). OC is defined as OC1 + OC2 + OC3 + OC4 + OPC and EC is calculated by EC1 + EC2 + EC3 - OPC.

1.3. *Quality assurance (QA) and quality control (QC)*

During sample analysis and sampling, blank experiments were performed in order to avoid the error caused by the background value of the filter. In addition, parallel experiments were performed in each sample to ensure that the error was within the range of control. And standard solution and blank test were carried out and the correlation coefficients of standard samples were more than 0.999. The relative standard deviations between real values of standard materials and analyzing results were in the range of 2%-15% and the detection limits ranged from 0.00001 to 0.0005 μg/L for trace elements. For carbonaceous species, one in every ten samples was detected for twice and the precision was less than 1%. Standard concentrations of CH_4/CO_2 mixed gases were used for calibration of the analyzer in each day before and after sample analysis.

2. Results and discussion

2.1. *Water-soluble ions*

Table 1 shows the water- soluble ions (WSI) average mass fractions in $RD_{2.5}$ from the three oasis cities on the edge of Tarim Basin. For these three cities, Cl^-, SO_4^{2-}, Na^+ and Ca^{2+} were the predominant WSI, which accounted for 86.3%, 89.0% and 90% of the total WSI in Cele, Yutian and Kashi. Ca^{2+} was the highest WSI, accounting for 56% of the total WSI, and the highest was observed in Yutian (61%), while the lowest in Cele (51%) (Fig. 2). In these three cities, the emission of cement and aggregate increased due to road and building construction, which led to the increase of Ca^{2+} content. In addition, the deposition of sand and dust after dust weather (including floating dust, blowing sand, sand storm) also resulted in the increase of Ca^{2+} in $RD_{2.5}$. The Ca^{2+} to the total Ca ratio was nearly 1 (0.7) in $RD_{2.5}$ at these three cities, which indicated that Ca in most $RD_{2.5}$ samples exists in the form of ions. The variation of SO_4^{2-}, NO_3^-, Cl^- and Mg^{2+} in three cities is similar, with the maximum concentration in Cele and the minimum concentration in Kashi. SO_4^{2-} concentration accounted for a higher proportion in these oasis cities road dust, the average proportion was 3.82% of the $RD_{2.5}$, which was higher than that in

Table 1 – Average mass fractions and total mass fractions of WSI in $RD_{2.5}$ (%).

	Cele	Yutian	Kashi	Average
Cl^-	0.61±0.22	0.59±0.09	0.42±0.1	0.53±0.17
NO_3^-	1.69±0.77	1.3±0.26	0.74±0.22	1.22±0.64
SO_4^{2-}	4.56±1.33	3.73±0.71	3.19±1.04	3.82±1.21
Na^+	0.58±0.32	0.74±0.17	0.79±0.37	0.7±0.32
NH_4^+	0.05±0.1	0.08±0.07	0.02±0.03	0.05±0.07
K^+	0.33±0.11	0.31±0.07	0.35±0.23	0.33±0.16
Mg^{2+}	0.29±0.11	0.24±0.06	0.19±0.05	0.24±0.09
Ca^{2+}	6.17±0.52	7.92±2.77	7.31±1.69	7.06±1.86
Total	14.29±2.26	14.9±3.01	13.02±3.09	13.95±2.82

$RD_{2.5}$: particulate matter with aerodynamic diameter less than 2.5 μm ($PM_{2.5}$) fraction in road dust; WSI: water-soluble ions.

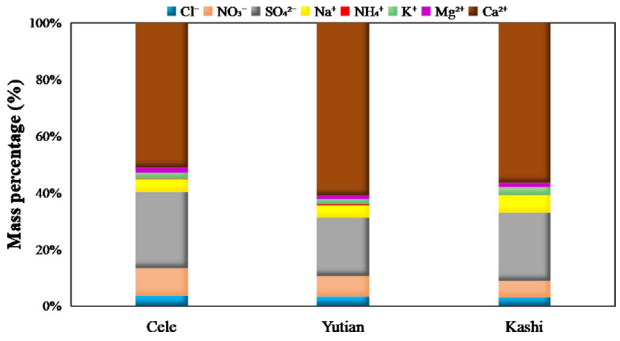

Fig. 2 – Proportion of water-soluble ions in $RD_{2.5}$.

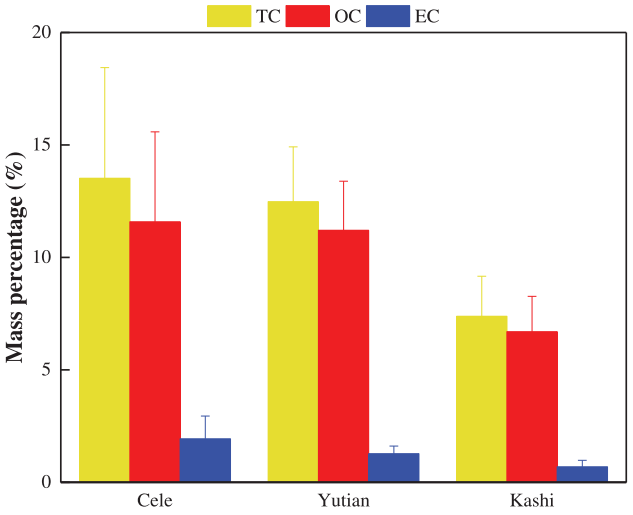

Fig. 3 – Proportion of carbon components in $RD_{2.5}$. TC: total carbon; OC: organic carbon; EC: elemental carbon.

other Chinese cities. While, in most areas of China, SO_4^{2-} was caused by coal-fired heating, but in Tarim Basin, SO_4^{2-} was a stable component in the dust of the Taklamakan Desert (Zhou et al., 2018). Therefore, sand dust from Taklamakan Desert was one of the reasons for the high concentration of sulfate in road dust from oasis urban. The average Cl^- proportion were 3.6%, 3.3% and 3.2% of the $RD_{2.5}$ in Cele, Yutian and Kashi, respective. Moreover, $RD_{2.5}$ in these three oasis cities shows unusual features, there was a significant correlation between Cl^- and SO_4^{2-} ($p < 0.05$), and the abundance of Cl^- was slightly higher than that in other cities in China. According to Zhou et al. (2018), the Taklimakan Desert has paleo-oceanic characteristics, we assumed that there was sea salt Cl^- in $RD_{2.5}$, and used the Excess-Cl^- = $[Cl^-]$ - 1.17$[Na^+]$ (where 1.17 is the typical Cl^-/Na^+ equivalent ratio of average seawater, $[Cl^-]$ and $[Na^+]$ are concentrations of Cl^- and Na^+, respectively (Chester, 1990)) to calculated whether all Cl^- came from sea salt. The result showed that the value of Excess-Cl^- was greater than 0 in three cities, which suggested Cl^- in $RD_{2.5}$ was affected not only by attributed to saline-alkali soils in oasis cities of the Tarim Basin and dust from Taklimakan Desert but also by human activities. Additionally, there was a significant correlation between Cl^- and Na^+ in $RD_{2.5}$ at three cities ($p < 0.05$), indicating that the source of Cl^- and Na^+ was similar. The ratios of Mg^{2+} and Na^+ were 0.38, 0.33 and 0.27 in three cities respectively, which were close to the ratio of Mg^{2+} and Na^+ in seawater (0.23), and there was a significant correlation between Mg^{2+} and Ca^{2+} in these cities ($p < 0.01$), indicating that the Taklimakan Desert has paleo-oceanic characteristics, and sand dust from Taklimakan Desert was one of the sources of road dust. Arimoto et al. (1996) considered that the ratio of NO_3^-/SO_4^{2-} could be used as an index to measure the relative importance of fixed and mobile sources to aerosol particles. In this study, the ratio of NO_3^-/SO_4^{2-} was 0.37, 0.35 and 0.24 in Cele, Yutian and Kashi, respectively. Compared with that in North West China (0.25), the results in this study was similar with it, but it lower than that in Beijing (0.52) (Wang et al., 2005; Shen et al., 2016). The results showed that road dust mainly comes from stationary emission sources.

In order to determine the acidity and alkalinity of $RD_{2.5}$, we used the ion balance calculations formula to analyze it. Detailed formulas for ion equilibrium calculations are described mainly with reference to our previous studies (Feng et al., 2017). The calculated ratios of all measured ionic species in the three cities ranged from 0.13 to 0.63, and there was a significant correlation between anions and cations ($r^2 = 0.65$, $p < 0.001$). Additionally, we found that the slope of regression line deviated from the ratio line of 1:1 in Appendix A Fig. S1, which suggested that almost all $RD_{2.5}$ were alkaline.

2.2. *Carbonaceous fractions characteristics*

Fig. 3 displays the percentage of carbon in $RD_{2.5}$ in three cities. Compared with WSI, TC accounted for a lower proportion of $RD_{2.5}$, ranging from 7.3% to 15.0%. The highest and lowest TC were found in Cele and Kashi, respectively. For these three cities, the concentration of OC was much higher than that of EC in $RD_{2.5}$. Meanwhile, the variation trend of OC and EC in these cities was similar. Compared with other cities, the average proportion of OC and EC in road dust at these oasis cities were lower than that in Beijing and Hongkong, but equal to Shijiazhuang's leve (Ho et al., 2003; Feng et al., 2003). Additionally, the OC/TC was 86%, 90% and 91% in Cele, Yutian and Kashi, respectively. This result was close to that in Beijing and Hongkong (Chen et al., 2012). Higher concentrations of OC and EC in $RD_{2.5}$ are mainly affected by vehicle emissions, including brake and tire wear, oil droplets and engine incomplete combustion (Chen et al., 2012). Secondly, various combustion sources also contribute to the generation of OC and EC. While, in oasis cities on the edge of Tarim Basin, burning sources, including coal combustion and biomass combustion were the main sources of OC and EC in $PM_{2.5}$. In previous studies, the correlation between OC and EC can be used to determine whether the sources of the two carbon components are the same (Feng et al., 2016, 2018). In this study, there was a significant correlation between OC and EC in $RD_{2.5}$ in three cities,

and the p value was lower than 0.001 in Cele and lower than 0.05 in Yutian and Kashi. The results suggested that OC and EC originated from the same source (He et al., 2011). In previous studies, the source of carbon components in $PM_{2.5}$ could be determined by OC/EC ratio. The researchers hypothesized that EC originates directly from anthropogenic emission, while OC may be emitted directly from sources as primary particles, but can also be formed from low vapor pressure products through atmospheric chemical reactions (Gray et al., 1986; Turpin and Huntzicker, 1991; Chow et al., 1996). Watson et al. (2002) reported that the ratios of OC/EC range from 0.3 to 7.6 for fossil fuel combustion, 0.7-2.4 for vehicle emission and 4.1-14.5 for biomass burning. In this study, the OC/EC ratios in $RD_{2.5}$ in Cele, Yutian and Kashi were 6.8, 9.2 and 11.4, respectively. The results indicated that the carbon components in $RD_{2.5}$ of Cele mainly come from fossil fuel combustion, while those in Yutian and Kashgar mainly come from biomass combustion.

2.3. Elements

Pan et al. (2015) reported that the trace elements could be divided into two groups: one is crustal elements (Si, Al, Ca, Fe, Mg, K and Na), which could be mainly attributed to high loading of crustal dust; the other is anthropogenic pollution elements (Zn, As, Pb, V, Ti, Cr, Mn, Ni, Sr, Cu, Li, Cd and Co), which are primarily originated from fossil fuel combustion, industrial metallurgical process and vehicle emission and other anthropogenic activities. In this study, the crustal elements accounted for 22.9%-26.0% of $RD_{2.5}$ in three cities. While, the anthropogenic pollution elements only just accounted for 0.65%-0.74% of $RD_{2.5}$ in three cities. Fig. 4 displays the proportion of trace elements in $RD_{2.5}$ in three cities. Ca was the most abundant elements in crustal elements in three cities, which accounted for 8.6%-11.2% of $RD_{2.5}$. In some studies, Ca was considered to be a tracer element of construction dust (Chow et al., 1992; Yatkin and Bayram, 2008). Higher Ca concentration in road dust was due to more construction activities in these three cities, and construction cement dust produced in the construction process leads to higher Ca content in $RD_{2.5}$. Si and Al as the important crustal elements in sand dust, the contents of Si (4.6%, 3.9%, 2.9% in Cele, Yutian and Kashi) and Al (5.3%, 5.5%, 6.3% in Cele, Yutian and Kashi) in $RD_{2.5}$ in three cities were also abundant. This was mainly due to the sandy weather in three cities in spring and the serious wind erosion of soil, which results in the high content of Si and Al in $RD_{2.5}$.

In many studies, the ratios of mineral dust elements can be considered as a marker for tracing dust sources in different desert areas (Zhang et al., 1996; Alfaro et al., 2003; Arimoto et al., 2004). Since the single element cannot be used to determine its source in desert areas, the values of Na/Al, K/Al, Si/Al, Ca/Al and Mg/Al have been used as tracers in previous studies (Zhang et al., 2014). The ratios of these elements and the results of previous studies were listed in Appendix A Table S1. In this study, the average ratio of Si/Al in $RD_{2.5}$ for three cities was 0.67, and the highest Si/Al was found in Cele, but it was lower than that in other cities and regions, such as Fushun, Hong Kong and North China Plain, Northeast China, Chinese Loess Plateau, and it also lower than crustal dust. The average ratio of Ca/Al in $RD_{2.5}$ for three cities was 1.73, the highest Ca/Al was in Yutian. For Ca/Al value, it was much higher than that for upper continental crust, and Ca/Al in Yutian was similar with that in Chinese Loess Plateau, Eastern China, North China Plain and Northeast China. It is noteworthy that the values of Ca/Al in three cities were higher than those in Asian dust, while in previous studies, the ratio of Ca to Al in Asian dust was mainly derived from natural aeolian processes in desert areas, which was much lower than that in urban dust samples (Arimoto et al., 2004; Xu et al., 2012; Shen et al., 2016; Sun et al., 2019). This result indicated that road dust was seriously affected by anthropogenic emissions. Therefore, the value of Ca/Al can be used to determine whether urban dust comes from local emission or long-distance transmission. Moreover, the ratios of K/Al and Na/Al in $RD_{2.5}$ for three cities were 0.39 and 0.16, respectively. The values were similar with that in Northwestern desert, which implied that high Na and K contents in road dust in these three cities could be derived from soil and desert dust, such as Taklimakan Desert and Xinjiang Gobi.

2.4. Difference and sources of chemical components

Enrichment factor (EF) is usually used to calculate the source of inorganic elements in order to distinguish whether it was a natural source or anthropogenic source. In this study, we selected Al as the reference element, because Al has a significant correlation with other elements. The formula is as follows:

$$EF_X = \frac{\left(\frac{X}{Al}\right)_{samples}}{\left(\frac{X}{Al}\right)_{crust}} \quad (1)$$

where EF_X represents the enrichment factor value of element X in road dust; $(\frac{X}{Al})_{samples}$ represents the ratio of X/Al in the samples, and $(\frac{X}{Al})_{crust}$ represents the ratio of X/Al in the local continental crust elements, and the reference concentrations of crustal were selected from Wei et al. (1990). When the EF was less than 1, indicating the rock and soil are the important sources, while the values higher than 10 indicate the anthropogenic emissions are the main source (Hsu et al., 2010; Pan et al., 2013; Feng et al., 2018). Fig. 5 shows the EFs values of elements in $RD_{2.5}$. In this study, the average EF for the elements in the range of 0.27-44.6. The EFs of Cd, Tl, Sn and Cr were higher than 10, which indicated that they were identified to be of anthropogenic emission. While, the EFs of Mg, K, Mn, Co, Th, Y, Ba, Ce, Sm, Sc, La, Na, Fe and Ti were lower than 1, which suggested that there originated from crustal sources. In addition, there were some elements, such as Zn, Sb, Bi, Pb, Cu, As, Ni, Mo, W, Li, Cs, U, Ca, Be, Zr, Sr, V and Rb, whose EFs ranged from 1 to 10, which indicated that these elements came from a mix of anthropogenic and natural sources of pollution.

In this study, we used coefficient of divergence (COD) to analyze the difference of $RD_{2.5}$ in three cities. COD is calculated as follows (Wongphatarakul et al., 1998; Feng et al., 2007; Han et al., 2010):

$$COD_{jk} = \sqrt{\frac{1}{p}\sum_{i=1}^{p}\left(\frac{x_{ij}-x_{ik}}{x_{ij}+x_{ik}}\right)^2} \quad (2)$$

where x_{ij} represents the average concentration of chemical component i at j sampling site; j and k denote the sampling site j and k; p denotes the number of chemical components. Han et al. (2010) suggested that the value of COD is lower than 0.2, the chemical composition of the two sampling points is similar; on the contrary, when the value of COD approached unity, the chemical composition of the two sampling points is different. For these three cities, the COD value between Cele and Kashi was 0.47, between Yutian and Kashi was 0.38, but between Cele and Yutian was only 0.17. The results showed that the chemical compositions of road dust in the same area was more similar in Yutian and Cele (Hotan Prefecture), which could be aggregated for similarity analysis and source identification. However, the large COD variations between Kashi and the other two cities suggested that road dust in Kashi and the other two cities was affected by very different factors and has

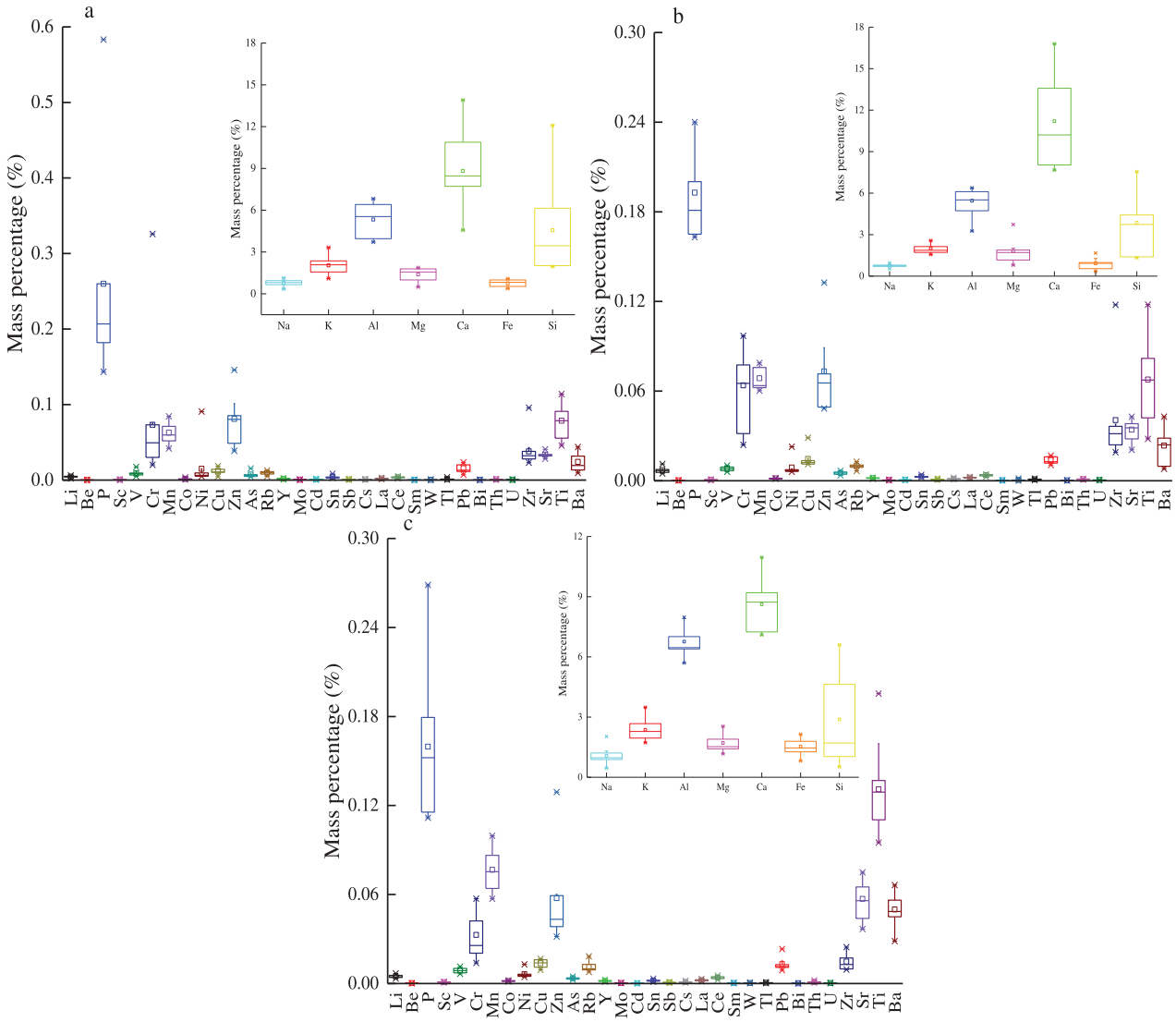

Fig. 4 – Proportion of trace elements in $RD_{2.5}$ in (a) Cele, (b) Yutian and (c) Kashi. Insets: proportion of crustal elements in $RD_{2.5}$ in (a) Cele, (b) Yutian and (c) Kashi.

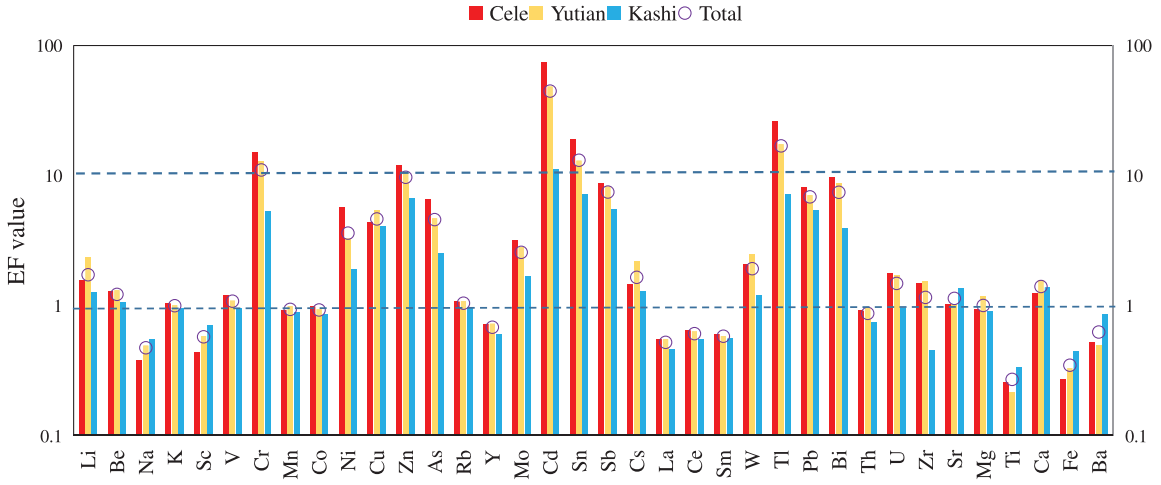

Fig. 5 – Enrichment factors (EF) for trace elements.

different chemical compositions, and reflecting that the influence of local road dust sources on urban road dust was greater than that of long-distance transportation.

3. Conclusions

In order to understand the physical and chemical characteristics and distribution characteristics of $RD_{2.5}$ in oasis cities on the edge of Tarim Basin, road dust in three oasis cities on the edge of Tarim Basin was collected, and 8 water-soluble ions, 39 trace elements and 8 carbon components in $PM_{2.5}$ were analyzed. The source of elements was determined by enrichment factor method and ratio method. In this study, Ca^{2+} was the highest WSI, accounting for 56% of the total WSI, and the highest was observed in Yutian (61%), while the lowest in Cele (51%). The average Cl^- proportion were 3.6%, 3.3% and 3.2% of the $RD_{2.5}$ in Cele, Yutian and Kashi, respective. Moreover, Cl^- in $RD_{2.5}$ was affected not only by attributed to saline-alkali soils in oasis cities of the Tarim Basin and dust from Taklimakan Desert but also by human activities. In addition, the water-soluble ions characteristics of $RD_{2.5}$ indicated that the Taklimakan Desert was one of the main sources of road dust in Oasis cities, and the $RD_{2.5}$ were alkaline. For these three cities, the concentration of OC was much higher than that of EC in $RD_{2.5}$. Additionally, OC and EC originated from the same source, which indicated that combustion source was the main source of OC and EC in $RD_{2.5}$, and the OC/EC ratios in $RD_{2.5}$ indicated that the carbon components in $RD_{2.5}$ of Cele mainly come from fossil fuel combustion, while those in Yutian and Kashgar mainly come from biomass combustion. Ca was the most abundant elements in crustal elements in three cities, which accounted for 8.6%-11.2% of $RD_{2.5}$. It is noteworthy that high Ca in road dust was seriously affected by anthropogenic emissions, and high Na and K contents in road dust in these three cities could be derived from soil and desert dust, such as Taklimakan Desert and Xinjiang Gobi. In addition, higher EFs of Cd, Tl, Sn and Cr indicated that they were identified to be of anthropogenic emission. COD result indicated that the influence of local emission on urban road dust emission is greater than that of long-distance transmission. The research results of this study provides the sources of urban road dust in the marginal oasis of the Tarim Basin, and establishes the corresponding chemical composition data set, which is of great value for the source analysis of local ambient air particulate matters, and also provide scientific basis for formulating emission control policies.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.jes.2020.03.030.

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