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Hospital indoor PM10/PM2.5 and associated trace elements in Guangzhou, China

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Abstract

PM10 and PM2.5 samples were collected in the indoor environments of four hospitals and their adjacent outdoor environments in Guangzhou, China during the summertime. The concentrations of 18 target elements in particles were also quantified. The results showed that indoor PM2.5 levels with an average of 99 μg m^{-3} were significantly higher than outdoor PM2.5 standard of 65 μg m^{-3} recommended by USEPA [United States Environmental Protection Agency. Office of Air and Radiation, Office of Air Quality Planning and Standards, Fact Sheet. EPA's Revised Particulate Matter Standards, 17, July 1997] and PM2.5 constituted a large fraction of indoor respirable particles (PM10) by an average of 78% in four hospitals. High correlation between PM2.5 and PM10 (R^2 of 0.87 for indoors and 0.90 for outdoors) suggested that PM2.5 and PM10 came from similar particulate emission sources. The indoor particulate levels were correlated with the corresponding outdoors (R^2 of 0.78 for PM2.5 and 0.67 for PM10), demonstrating that outdoor infiltration could lead to direct transportation into indoors. In addition to outdoor infiltration, human activities and ventilation types could also influence indoor particulate levels in four hospitals. Total target elements accounted for 3.18–5.56% of PM2.5 and 4.38–9.20% of PM10 by mass, respectively. Na, Al, Ca, Fe, Mg, Mn and Ti were found in the coarse particles, while K, V, Cr, Ni, Cu, Zn, Cd, Sn, Pb, As and Se existed more in the fine particles. The average indoor concentrations of total elements were lower than those measured outdoors, suggesting that indoor elements originated mainly from outdoor emission sources. Enrichment factors (EF) for trace element were calculated to show that elements of anthropogenic origins (Zn, Pb, As, Se, V, Ni, Cu and Cd) were highly enriched with respect to crustal composition (Al, Fe, Ca, Ti and Mn). Factor analysis was used to identify possible pollution source-types, namely street dust, road traffic and combustion processes.

Keywords: Hospital; PM10 and PM2.5; Trace elements; Guangzhou

1. Introduction

Respirable particulates (RP) with aerodynamic diameter smaller than 10 μm (PM10) has received considerable attention in recent years as it is easily inhaled and deposited within the respiratory system (Pope, 1991; Choudhury et al., 1997; Carlton et al., 1999). RP is divided into a coarse fraction (>2.5 μm in diameter) and a fine fraction (<2.5 μm in diameter) (Clayton et al., 1993). The coarse fraction is found to consist mainly of organic material, silicates and larger soot aggregates (Heidi, 2000). The fine fraction typically contains a mixture of particles resulting from different kinds of combustion processes (e.g., exhaust particles) and secondary particulates generated by chemical reactions in the atmosphere (acid condensates, sulfates and

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nitrates) (Heidi et al., 1997). Additionally, PM2.5 is found to contain high concentrations of mutagens (Ando et al., 1996). For example, 79.0–94.5% of polycyclic aromatic hydrocarbons (PAH) is concentrated in PM2.5 (Sun et al., 1994).

Studies show that RP plays a role in the incidence and severity of respiratory disease (Pope, 1991) and have significant associations with decline in lung function, respiratory and cardio-vascular diseases deaths. Especially, public attention has been focused on fine particulates among the RP in aerosol highlighted for adverse health effect (Schwartz, 1994; Dockery and Pope, 1994; Pope et al., 1995). PM2.5, the fine fraction in RP is significantly correlated with deaths from cardiopulmonary disease and lung cancer (Berico et al., 1997). These finer particles are also the potential allergen carriers, which are probably liable to affect respiratory health, as they are able to penetrate deep into the respiratory tree (Heidi, 2000). Therefore, these fine particles seem to be more harmful to humans than the coarse ones. USEPA revised the primary (health-based) particulate matter standards by adding new annual and 24-h PM2.5 standards at 15 and 65 μg/m^3 for outdoor air, respectively, to more effectively control the aerosol problem (USEPA, 1997). Thus, assessment of PM10 and PM2.5 levels assumes significance from an environmental health perspective.

Even though inorganic components only constitute a small portion by mass of the particulates, however, the existence of some trace elements (TEs) such as As, Cd, Co, Cr, Ni, Pb, and Se are human or animal carcinogens even in trace amount (ATSDR, 2003). The origins of the inorganic components can be either natural or anthropogenic. Even though most of these elements are associated with outdoor emission sources (e.g., coal and oil combustion, incinerators, motor vehicles and metal industries (ATSDR, 2003), they may still contribute significantly to indoor PM2.5 via outdoor-to-indoor transport. Other sources of TEs may include crustal material from road dust, construction activities, tire/brake wear, cement factories, etc. Areas that are strongly affected by these sources are expected to have elevated levels of TEs.

Indoor air quality (IAQ) has become a great concern in the large cities of China in recent years (Tang et al., 2001; Shen et al., 2002; Zhang, 2001; Bai and Chen, 1998), as the China government has recognized the potential health risk and problems related to indoor air pollution that occurs in public buildings. China government is striving to investigate and manage the IAQ of various indoor environments. The indoor RP investigation at public places was carried out in Beijing and A total of 49 public places were selected randomly from five districts in Beijing, representing different type of public places, which included computer rooms, student dormitories, restaurants, classrooms in universities, libraries, supermarkets, copy rooms, laboratory and underground (Liu et al., 2004). It revealed that about 22% of 49 public places investigated with PM10 levels exceeded 150 μg/m^3, and 20% of them with PM2.5 levels exceed 65 μg/m^3. Thus, RP is probably to be the major one of indoor air pollutants at public places.

In this study, hospitals are selected for investigation. Their indoor PM10/PM2.5 and associated trace elements were focused on. This is based on three considerations. Firstly, hospital is regarded as a special and important type of public place in China. The number of people is much higher in hospital every day than in other public places. Therefore, effect of hospital IAQ to people is more significant than other public places. Secondly, epidemiological studies showed hospital-acquired respiratory system infection (HARSI, refer to diseases infected from hospital) is well affinity with hospital indoor aerosol that is the carrier for virus diffusion by adhering to aerosol particles. Thus, assessment of PM10 and PM2.5 levels assumes significance from epidemiology. Finally, there are few studies that focused on the indoor air quality of hospitals in China. Few measurements for particulate matter and their chemical composition in hospitals are available. The sources and loadings of RP are presently poorly known.

Therefore, Our study aims to (1) characterize the indoor RP concentrations and associated TEs in hospitals, (2) investigate the potential indoor and outdoor sources. This is the first comprehensive report on quantifying RP and associated TEs at the same time in hospital environment in Guangzhou, China.

2. Methodology

2.1. Sampling sites and descriptions

This study was conducted in the four hospitals that included rural hospital, urban hospital, children hospital and specialist hospital in Guangzhou, China during the summer period from 2 August 2004 to 10 September 2004. The building age covers from 0.5 to 25 years. All the buildings are occupied by patients all day. These hospitals are all located in the densely populated residential areas or commercial areas in urban districts and adjacent to heavy traffic road near by. Owing to the hot summer periods of sampling, these surveyed hospitals are cooled by window-type air conditioners or central

air conditioners all day. These hospitals in Guangzhou forbid smoking indoors and frequent house-cleanings are done in the daytime. Brief information concerning the monitored places including the potential outdoor particle sources is summarized in Table 1.

2.2. Sample collection

Indoor and outdoor particulate samples were collected by one pair of Airmetrics mini-vol portable samplers with a PM2.5 cyclone and a PM10 cyclone. The pre-separators in PM2.5 and PM10 cyclones are designed to have the correct particle size cut point at an air flow rate of 5 l min^{-1} at ambient conditions and samples are collected on a 47 mm in diameter quartz filter. There is a flowmeter inside each sampler. We always checked and recalibrated the samplers by adjusting the flowmeter before and after sampling to make sure that the air flow rate is at 5 l min^{-1}. 24-h PM10 and PM2.5 collections per day were simultaneously performed at different sites in each hospital for 8 consecutive days. During the sampling period, the inlets of the indoor samplers were located at about 1.1 m above ground level of the sampling sites to simulate location of the breathing zone of the patients. For outdoor sampling, the samplers were located on the roof of the highest building in the hospitals and the sampler inlets were located at 1.5 m above the rooftop level. Indoor and outdoor particulate levels were tested simultaneously at all observed sites to evaluate the relationship between indoor and outdoor particulates.

2.3. Trace elements analysis

The filters of samples were digested with 5 ml concentrated nitric acid (ultra-pure) in closed Teflon bombs at 150 °C for five days. The acid solution with filter was shocked using an ultrasonic system every 24 h. After particles on the filter were completely dissolved in the acid solution, the digestate was filtered and then diluted to less than 2% acidity with ultra-pure Milli-Q water. Calibration of the ICP-MS instrument was performed with standard multi-element solutions (Misa04-06) from 5 to 500 ng ml^{-1} for trace elements. For major elements an additional standard from 1000 to 5000 ng ml^{-1} was used. 50 ng ml^{-1} Re was used as

Table 1
General description of sampling sites in four public hospitals investigated in Guangzhou

Hospital name	Type	Site no.	Location	Area (m^2)/ patient num.	Ventilation types	Potential outdoor source
People hospital of Shijing (SJ)	Polyclinic in suburb residual areas	SJA	Treatment room (indoor)	30/50	Exhaust fan	1. Heavy traffic
		SJB	In-patient department (indoor)	250/50 (10 rooms)	Window type air conditioner	2. Family cooking
		SJO	Roof of seven-floor building (outdoor)	–	–	
People hospital of Liwan (LW)	Polyclinic in urban residual areas	LWA	Out-patient department (indoor)	300/50 (a hall and 7 rooms)	MVAC system	1. Heavy traffic
		LWB	In-patient department (indoor)	200/35 (7 rooms)	Window type air conditioner	2. Family cooking
		LWO	Roof of seven-floor building (outdoor)	–	–	
Phthisic hospital (XK)	Specialist for respiratory diseases in urban commercial areas	XKA	Doctor office (indoor)	20/10	Natural ventilation	1. Moderate traffic
		XKB	In-patient department (indoor)	300/90 (16 rooms)	Window type air conditioner	2. Restaurant cooking
		XKO	Roof of three-floor building (outdoor)	–	–	3.Construction activity
Paediatric hospital (ET)	Specialist for children in urban commercial areas	ETA	Emergency treatment department (indoor)	200/130 (a hall and 8 rooms)	Window type air conditioner	1. Heavy traffic
		ETB	In-patient department (indoor)	400/90 (20 rooms)	Window type air conditioner	2. Restaurant cooking
		ETO	Roof of ten-floor building (outdoor)	–	–	3. Construction activity

internal standard. The diluted solution was analyzed for metal elements by PE Elan 6000/ICP-MS. Four blank filters were also analyzed and the sample results were corrected by the average of blank concentrations. The detection limit of trace elements was 0.1 ng l^{-1}. Only those elements exceeding the detection limit by 10 times were discussed in this study.

3. Results and discussion

3.1. PM2.5 and PM10

3.1.1. Common evaluation

Table 2 summarized the statistics of indoor and outdoor concentrations of PM10 and PM2.5, together with indoor/outdoor (I/O) ratios and PM2.5/PM10 ratios at each site in four hospitals. For all observed sites, the indoor concentrations ranged from 40.94 to 214.91 μg m^{-3} with an average of 99.06 μg m^{-3} for PM2.5 and from 61.67 to 250.00 μg m^{-3} with an average of 128.13 μg m^{-3} for PM10, respectively, while the corresponding outdoor levels varied between 51.72 and 187.13 μg m^{-3} with an average of 97.86 μg m^{-3} for PM2.5, as well as between 74.71 and 264.42 μg m^{-3} with an average of 144.40 μg m^{-3} for PM10, respectively. In general, the average indoor levels of PM10 did not exceed 150 μg m^{-3}, the outdoor PM10 standard recommended by USEPA (1997), but those of PM2.5 were significantly higher than the standard of 65 μg m^{-3}. Regarding different hospital departments, average indoor PM2.5 and PM10 concentrations in the in-patient department were a little higher than those measured in the out-patient department in each hospital (e.g., LWB>LWA, ETB>ETA). But the highest particulate levels were found in treatment room (SJA) and the lowest in doctor office (XKA).

For all observed sites, the PM2.5/PM10 ratios were found to be from 0.57 to 0.99 with an average of 0.78 in indoor air and from 0.54 to 0.79 with an average of 0.68 in outdoor air, respectively. The average indoor ratio of PM2.5/PM10 was higher than outdoors, indicating that fine particles comprised a large fraction in PM10 in the four hospitals. Furthermore, PM10 levels were well correlated with PM2.5 loadings with correlation coefficients (R^2) of 0.87 for indoors and 0.90 for outdoors in these hospitals (Fig. 1a–b). This indicated that PM2.5 and PM10 came from similar particulate emission sources.

The I/O ratios of the observed sites varied from 0.56 to 1.38 with an average of 1.01 for PM2.5 and from 0.45 to 1.21 with an average of 0.89 for PM10. The average I/O ratio of PM2.5 was higher than that of

Table 2
Statistics for PM2.5 and PM10 concentrations at different monitoring sites in four hospitals (μg m^{-3})

Sites	Statistics	Indoors			Outdoors			I/O ratios	
		PM2.5	PM10	PM2.5/PM10	PM2.5	PM10	PM2.5/PM10	PM2.5	PM10
SJA	Min.	52.17	72.46	0.58	51.72	74.71	0.57	0.97	0.95
	Max.	168.12	220.78	0.82	125.00	203.15	0.75	1.38	1.12
	Mean	106.87	143.51	0.74	90.85	138.42	0.66	1.17	1.03
SJB	Min.	48.64	84.05	0.58	51.72	74.71	0.57	0.90	0.96
	Max.	146.72	213.68	0.76	125.00	203.15	0.75	1.24	1.12
	Mean	96.93	141.06	0.68	90.85	138.42	0.66	1.07	1.02
LWA	Min.	67.15	77.33	0.81	62.72	85.87	0.57	1.03	0.68
	Max.	125.37	140.12	0.99	120.00	186.15	0.73	1.21	0.90
	Mean	98.07	111.66	0.88	91.40	142.57	0.65	1.08	0.79
LWB	Min.	62.97	96.99	0.57	62.72	85.87	0.57	1.00	0.86
	Max.	136.30	182.89	0.79	120.00	186.15	0.73	1.16	1.21
	Mean	98.23	142.96	0.69	91.40	142.57	0.65	1.06	1.01
XKA	Min.	54.33	66.08	0.80	69.10	88.40	0.68	0.79	0.71
	Max.	133.05	148.15	0.92	129.55	182.84	0.79	1.08	0.85
	Mean	97.06	111.77	0.86	104.60	144.52	0.73	0.92	0.77
XKB	Min.	64.05	81.51	0.75	69.10	88.40	0.68	0.88	0.90
	Max.	144.07	178.62	0.84	129.55	182.84	0.79	1.19	0.98
	Mean	106.38	135.03	0.79	104.60	144.52	0.73	1.02	0.93
ETA	Min.	40.94	61.67	0.66	65.25	96.45	0.54	0.56	0.45
	Max.	147.66	162.53	0.99	187.13	264.42	0.79	0.90	0.71
	Mean	80.27	93.94	0.84	104.58	152.09	0.68	0.77	0.62
ETB	Min.	49.49	77.49	0.64	65.25	96.45	0.54	0.68	0.57
	Max.	214.91	250.00	0.86	187.13	264.42	0.79	1.17	1.17
	Mean	108.63	145.09	0.73	104.58	152.09	0.68	1.02	0.96

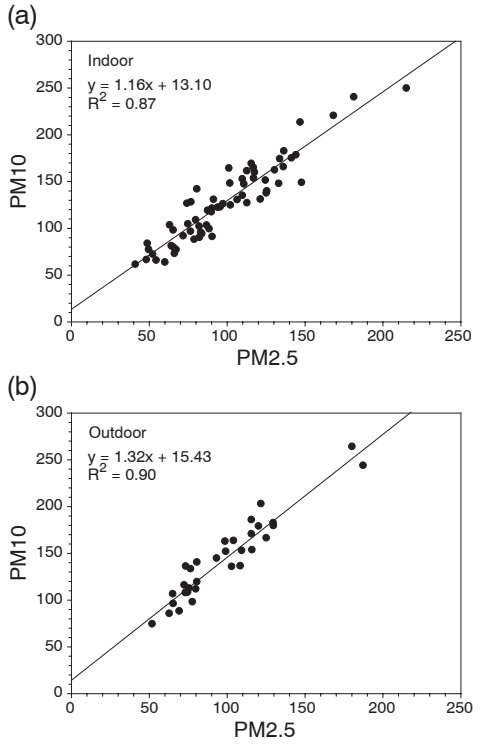

Fig. 1. Relationship between PM10 and PM2.5 concentrations (μg m^{-3}) for indoors and outdoors.

PM10, indicating higher penetration of PM2.5 than PM10 from outdoor to indoor and stronger indoor sources for PM2.5 than PM10 considering the effects of human activities and ventilation types to indoor particulate levels. These impact factors would be discussed in detail in following sections.

3.1.2. Impact of outdoor air conditions

The increased indoor concentrations of PM2.5 and PM10 in the hospitals were probably related to outdoor air condition. The relationship between outdoor and indoor particulates was investigated using linear regression analysis. Fig. 2 showed a scatter diagram for the indoor and outdoor measurements. A proper linear relationship with correlation coefficients (R^2) of 0.67 for PM10 (Fig. 2a) and 0.78 for PM2.5 (Fig. 2b) could be found, which implied that outdoor levels strongly influenced indoor levels. Regarding outdoor factors, firstly, the four hospitals were all situated in close proximity to a heavy-traffic road where a lot of vehicles often caused traffic jams. The effects of traffic condition and motor vehicle exhaust outdoors on the indoor levels of PM2.5 and PM10 in hospitals were very significant. Secondly, construction activities nearby were conducted during sampling. The construction activities significantly increased the ambient suspended particulate matter, which inevitably influenced the indoor air levels of PM2.5 and PM10. Finally, the effect of cooking activities in the restaurants on the indoor air particulate levels in these hospitals nearby was very important. The cooking activities around these hospitals released significant amounts of oily fumes from kitchens to outdoor air. In a word, outdoor particulate infiltration led to direct transportation into indoors of these hospitals.

3.1.3. Effect of ventilation patterns

Outdoor PM10 had a moderate linear relationship (R^2=0.67) with the indoor concentrations (Fig. 2a). However, Pearson paired *t*-test between indoor and outdoor PM10 concentrations (p<0.001) indicated that the indoor PM10 levels were very different to those measured outdoors, and the average PM10 I/O ratios at the different monitored sites were obviously different and varied between 0.62 and 1.03 (Fig. 3a). This suggested that a substantial fraction of PM10 was infected by indoor factors. In our study, ventilation pattern might be an important factor to impact indoor PM10 levels, as it could influence the air exchange between the indoor air and the ambient air (Monn et al., 1995). In China, many hospitals are ventilated with

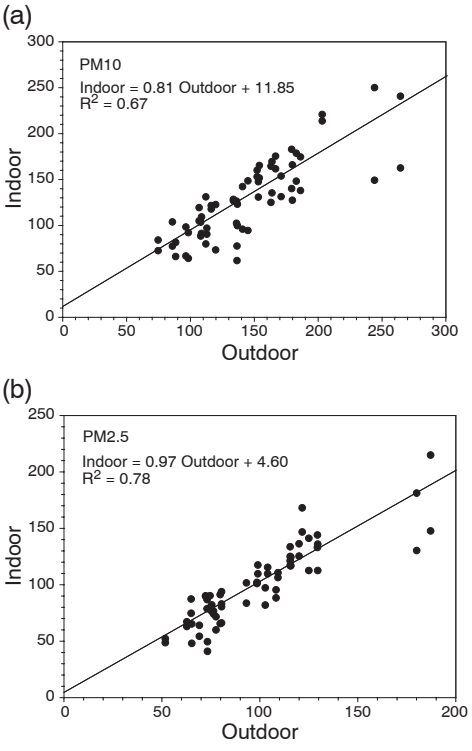

Fig. 2. Relationship between indoor and outdoor for PM10 (a) and PM2.5 (b) concentrations (μg m^{-3}).

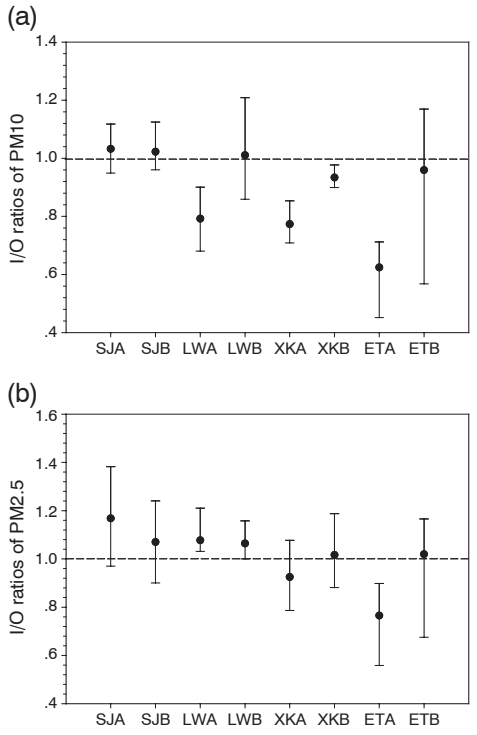

Fig. 3. I/O ratios of PM10 (a) and PM2.5 (b) at each site.

mechanical ventilation air conditioning (MVAC) systems. Some sickrooms are installed with window type air conditioners and exhaust fans for ventilation. Therefore, indoor particulate levels are in affinity with ventilation patterns in hospitals.

To further facilitate our understanding on how the ventilation pattern influenced the indoor PM10 levels in these hospitals, a distinction of I/O ratios was made among ventilation types including ventilation by exhaust fan, natural ventilation by opening windows, ventilation by window type air conditioner and ventilation by MVAC system (Fig. 4). In this study, SJA was classified as ventilation by exhaust fan. XKA was classified as natural ventilation by opening windows. SJB, LWB, XKB and ETB were classified as ventilation by window type air conditioner. LWA and ETA were classified as ventilation by MVAC system. Fig. 4 showed the influence of the ventilation types on I/O ratios of PM10, the coarse particles. The 'exhaust fan' and 'window type air conditioner' cases showed relatively high I/O ratios of PM10 which were higher or close to 1, while 'MVAC system' and 'natural ventilation' cases showed that I/O ratios of PM10 were much lower than 1. This indicated that the filtration process of the MVAC system was most effective to remove coarse particles. MVAC system usually had the equipment of air filters. Particulate matters carried in ambient air were drawn into the hospital buildings and would be filtered through the filtration process of the MVAC systems. Especially, the filters of the MVAC systems could reduce the amounts of coarse particulate matters. Natural ventilation by opening windows resulted in an equilibrium between indoor and outdoor levels, which was also an effective pattern to reduce the amounts of particulate matters. Ventilations by exhaust fan and window type air conditioner were most inefficient to remove particles and even led to particulate accumulation.

3.1.4. Factor of indoor human activities

Pearson paired *t*-test between indoor and outdoor PM2.5 concentrations ($p=0.55$) indicated that the indoor PM2.5 levels were very similar to those measured outdoors. Furthermore, Outdoor PM2.5 also had a good

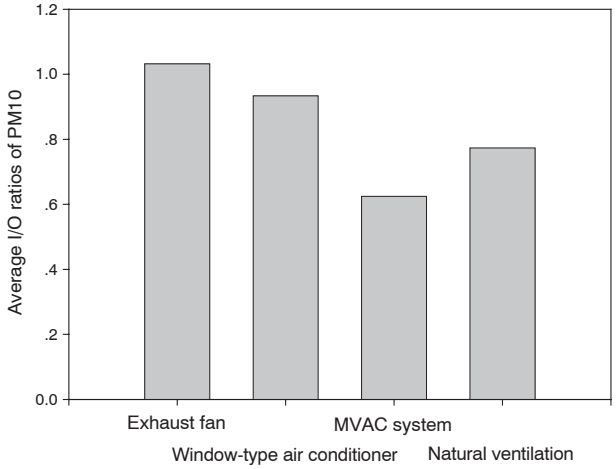

Fig. 4. Comparison of average PM10 I/O ratios for different ventilation types.

linear relationship (R^2=0.78) with the indoor PM2.5 (Fig. 2b). Thereby, there were no significant contributions by indoor emission sources to the overall PM2.5 concentrations in the four hospitals. However, the average PM2.5 I/O ratios at the different monitored sites were obviously different and varied between 0.77 and 1.17 (Fig. 3b). This suggested that the additional indoor factors also contributed to the overall variability in indoor PM2.5 concentrations.

In our study, human activities could act as an important indoor source for particulate generation in hospitals considering that the patient density in the hospital was several times higher than that in other normal public places. Fig. 5 showed the influence of human activities on I/O ratios of PM2.5, the fine particles. A test was conducted to determine if there was significant influence of human activities on indoor PM2.5. It was designed to find if significant differences of indoor particulate concentrations existed between the weekday and weekend in LWA. LWA was an out-patient department in the hospital. It was usually opened from Monday to Friday and closed from Saturday to Sunday. So here, weekend and weekday samples were defined as ones measured from 8 AM Saturday morning to 8 AM Monday morning and from 8 AM Monday morning to 8 AM Saturday morning, respectively. The result indicated that average I/O ratio of weekday samples was significantly higher than that of weekend samples (Fig. 5). This indicated that the indoor particulate level during the weekday was significantly influenced by indoor human activities, leading to resuspension of particles. During the weekday, many people walked in and out of these buildings frequently, which could cause resuspension of particulate matters deposited on floor surfaces, resulting in the elevation of PM2.5 concentrations at the areas. On the contrary, during the weekend, there were little or no activities and favorable deposition losses occurred, leading to a lower I/O ratio of PM2.5.

In addition, Fig. 5 also showed the average I/O ratio of PM2.5 in SJA was highest and much higher than 1, because SJA was a public treatment room with highest occupancy density among all observed sites, which could be regarded as 'activity case.' About 50 patients were receiving treatment at the same time in this 30 m^2 room. The crowded treatment environment easily resulted in poor fresh air movement and distribution. But in XKA, the average I/O ratio of PM2.5 was much less than 1. XKA was a doctor office that could be made a 'reference case,' referring to a situation with little activities owing to an absence of people. In general, not only human activities (e.g. cleaning, walking, working), but even the mere presence of people at room who conducted ordinary activities contributed to resuspension of fine particles, which led to the elevation of indoor PM2.5 levels (Chao and Wong, 2002).

3.2. Trace elements

3.2.1. General levels

Table 3 presented the average concentrations of 18 trace elements at different sites in four hospitals. The total sum of the 18 target elements concentrations (TE) in observed hospitals ranged from 3.40 to 5.50 μg m^{-3} in PM2.5 and from 6.28 to 10.28 in PM10, respectively. Regarding outdoors, TE varied from 5.68 to 9.52 μg m^{-3} in PM2.5 and from 14.47 to 22.99 μg m^{-3} in PM10, respectively. The average TE in four hospitals

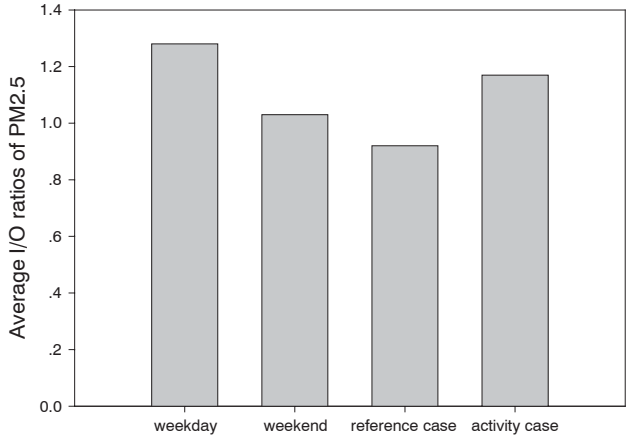

Fig. 5. Comparison of average PM2.5 I/O ratios for different degrees of human activities.

Table 3
Mass concentrations of trace elements (TEs) in PM2.5 and PM10 at different monitoring sites in four hospitals

TEs (μg m^{-3})		Hospital 1			Hospital 2			Hospital 3			Hospital 4		
		Indoor		Outdoor	Indoor		Outdoor	Indoor		Outdoor	Indoor		Outdoor
		SJA	SJB	SJO	LWA	LWB	LWO	XKA	XKB	XKO	ETA	ETB	ETO
Na	PM2.5	0.471	0.434	0.972	0.327	0.408	0.815	0.508	0.485	1.196	0.353	0.330	0.697
	PM10	1.051	1.080	2.834	0.932	0.965	2.973	1.633	1.322	4.013	0.922	0.752	2.369
Mg	PM2.5	0.096	0.106	0.183	0.097	0.102	0.229	0.208	0.173	0.314	0.198	0.284	0.404
	PM10	0.211	0.287	0.615	0.299	0.240	0.739	0.550	0.565	1.054	0.477	0.653	1.135
Al	PM2.5	0.335	0.344	0.941	0.711	0.675	1.521	0.589	0.462	1.708	0.691	0.508	1.608
	PM10	1.149	1.334	4.291	2.257	1.709	5.002	2.319	1.535	8.057	1.776	1.481	6.672
Fe	PM2.5	0.016	0.018	0.030	0.014	0.010	0.035	0.025	0.016	0.042	0.024	0.031	0.066
	PM10	0.035	0.042	0.084	0.033	0.024	0.103	0.071	0.048	0.134	0.062	0.069	0.178
K	PM2.5	0.928	1.023	1.105	1.378	1.679	1.909	1.912	2.016	2.706	0.974	1.398	1.510
	PM10	1.159	1.285	1.390	1.659	2.043	2.351	2.195	2.417	3.378	1.343	1.915	2.111
Ca	PM2.5	0.483	0.579	1.162	0.421	0.378	1.227	0.684	0.759	1.442	0.956	0.877	1.610
	PM10	1.417	1.688	3.507	1.096	1.006	3.637	2.048	1.869	4.292	2.261	1.881	4.679
Ti	PM2.5	0.012	0.015	0.026	0.017	0.012	0.032	0.018	0.014	0.032	0.013	0.020	0.039
	PM10	0.047	0.058	0.110	0.048	0.035	0.124	0.056	0.034	0.137	0.030	0.055	0.120
Mn	PM2.5	0.021	0.016	0.041	0.023	0.018	0.039	0.014	0.016	0.031	0.042	0.030	0.079
	PM10	0.044	0.033	0.094	0.052	0.049	0.121	0.041	0.041	0.095	0.084	0.069	0.221
V	PM2.5	0.046	0.048	0.056	0.048	0.060	0.069	0.060	0.065	0.075	0.059	0.093	0.097
	PM10	0.049	0.060	0.069	0.050	0.061	0.078	0.063	0.071	0.087	0.061	0.101	0.113
Cr	PM2.5	0.035	0.032	0.038	0.034	0.033	0.051	0.050	0.058	0.068	0.047	0.061	0.064
	PM10	0.040	0.038	0.046	0.042	0.040	0.062	0.055	0.066	0.079	0.049	0.063	0.069
Ni	PM2.5	0.023	0.023	0.028	0.023	0.028	0.033	0.025	0.030	0.032	0.024	0.039	0.042
	PM10	0.024	0.028	0.038	0.024	0.030	0.036	0.029	0.035	0.039	0.028	0.047	0.052
Cu	PM2.5	0.038	0.042	0.046	0.072	0.093	0.109	0.062	0.062	0.078	0.036	0.055	0.060
	PM10	0.049	0.052	0.062	0.080	0.103	0.130	0.071	0.077	0.099	0.041	0.068	0.078
Zn	PM2.5	0.585	0.608	0.702	0.430	0.546	0.680	0.632	0.607	0.858	0.775	1.290	1.417
	PM10	0.678	0.769	0.906	0.475	0.640	0.803	0.768	0.761	0.901	0.875	1.572	1.685
Cd	PM2.5	0.008	0.008	0.009	0.009	0.012	0.014	0.009	0.009	0.011	0.006	0.010	0.017
	PM10	0.008	0.009	0.010	0.009	0.013	0.015	0.009	0.009	0.012	0.006	0.010	0.019
Sn	PM2.5	0.017	0.016	0.018	0.017	0.017	0.019	0.022	0.020	0.026	0.014	0.019	0.020
	PM10	0.019	0.018	0.021	0.020	0.020	0.023	0.025	0.023	0.031	0.015	0.021	0.023
Pb	PM2.5	0.233	0.208	0.261	0.231	0.328	0.373	0.258	0.267	0.304	0.199	0.372	0.403
	PM10	0.249	0.239	0.324	0.252	0.337	0.425	0.282	0.280	0.342	0.218	0.382	0.466
As	PM2.5	0.035	0.035	0.041	0.051	0.067	0.081	0.037	0.041	0.046	0.040	0.059	0.064
	PM10	0.037	0.037	0.048	0.053	0.071	0.089	0.040	0.043	0.051	0.042	0.062	0.069
Se	PM2.5	0.015	0.016	0.018	0.023	0.028	0.034	0.022	0.022	0.025	0.014	0.021	0.027
	PM10	0.017	0.017	0.019	0.026	0.029	0.039	0.024	0.023	0.029	0.015	0.021	0.029

account for 3.18–5.56% of PM2.5 and 4.38–9.20% of PM10 by mass, respectively.

The target elements could be grouped into two major groups: earth crust elements or soil tracers and anthropogenic tracers. Earth crust elements comprised of Na, Al, K, Mg, Ca, Fe, Ti and Mn, while V, Cr, Cd, Ni, Cu, Pb, Zn, As, Sn and Se could be considered as partially natural in origin, partially anthropogenic depending on the source region and travel path of the air mass. Metals such as Na, Mg, Al, K, Ca, Zn and Pb have relatively high proportions of the 18 target elements. They accounted for over 90% of TE, while trace metals such as Ti, V, Cr, Ni, Cu, Cd, Sn, As and Se had lower concentrations and account for less 10% of TE. In general, Al, Ca, Zn and Pb were found to be abundant both indoors and outdoors in four hospitals. Al and Ca were the main elements in the Earth's crust and came from wind-blowing soil dust and frictional work from construction sites in ambient environment, while Pb and Zn act as the marker elements for motor vehicle emissions (Huang et al., 1994).

Fig. 6 showed that the average PM2.5/PM10 ratios of earth elements (Al, Ca, Fe, Mg, Mn and Ti) were relatively low which ranged from 0.2 to 0.4 in four hospital. This meant a large proportion of these elements was in PM2.5–10 fraction, the coarse mode. However, the average PM2.5/PM10 ratios of V, Cr, Ni, Cu, Zn, Cd, Sn, Pb, As and Se ranged from 0.7 to 0.9 indicating that they existed more in PM2.5 fraction, the fine particulate mode.

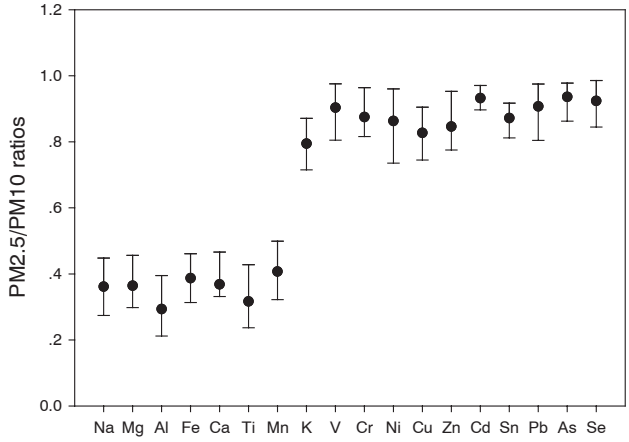

Fig. 6. PM2.5/PM10 ratios of elements.

3.2.2. I/O ratios and outdoor-to-indoor penetration of elements

Table 3 showed that the average indoor concentrations of elements were lower than those measured outdoors by a factor of approximately 0.6 for PM2.5 and 0.5 for PM10, indicating outdoor-to-indoor transportation affected indoor elemental levels. Throughout the study period, there were no special indoor sources for elements to be found. Therefore, we believed that indoor elements originated mainly from outdoor emission sources.

In this study, I/O concentration ratios between the crustal elements (Na, Mg, K, Al, Ca, Fe, Ti, Mn) and anthropogenic elements (V, Cr, Ni, Cu, Zn, Cd, Sn, Pb, As, Se) were compared to observe the degree of penetration of the two groups by emission source. I/O concentration ratios for the crustal elements and anthropogenic elements were shown in Fig. 7. It was clear that on average, anthropogenic elements were more prevalent than crustal elements in terms of I/O ratios. This might be caused by a more favorable infiltration of anthropogenic elements relative to crustal elements considering that there were no special indoor sources for elements to be found during the study period. This led to higher I/O concentration ratios for anthropogenic elements. Furthermore, the average I/O concentration ratios of elements in PM2.5 were little higher than those in PM10, suggesting that elements enriched in the fine mode could penetrate indoors more easily than TEs enriched in the coarse mode.

3.2.3. Enrichment factor analysis

Enrichment factors (EF) can be calculated to show the degree of enrichment of a given element compared to the relative abundance of that element in crustal material and used as a first step in attempting to evaluate the strength of the crustal and non-crustal

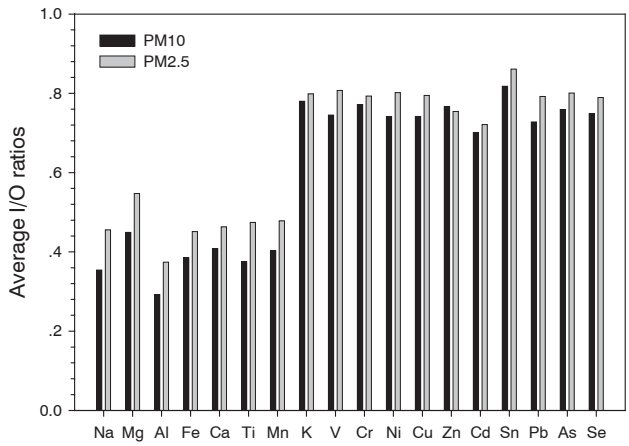

Fig. 7. Average I/O ratios of elements in PM10 and PM2.5.

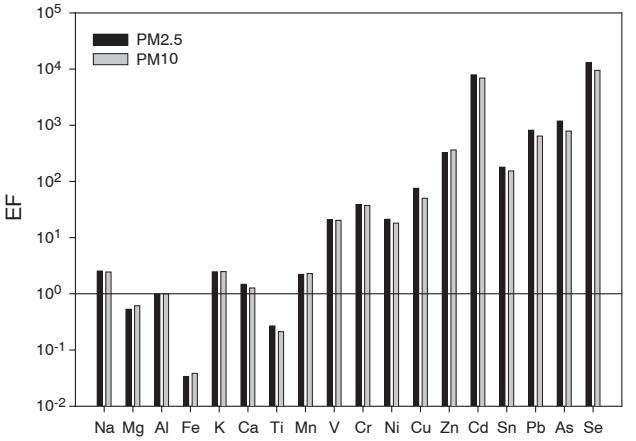

Fig. 8. Enrichment factors of elements in PM10 and PM2.5.

sources (Gao et al., 1992). The enrichment factor EF is defined as $EF=(X/Al)_{air}/(X/Al)_{crust}$ (Duce et al., 1975), where $(X/Al)_{air}$ and $(X/Al)_{crust}$ refer to the ratio of concentration of element X to that of Al in the air and in the average crustal material, respectively. Aluminum is the common reference element for crustal particles in EF calculations based on the crustal chemical composition given by Mason (1966). The enrichment factors were calculated for each element at four hospitals and shown in Fig. 8.

As Fig. 8 shown, Cd and Se exhibited the highest enrichment factors (>10,000). Pb, As, Sn and Zn also showed high enrichment factors (>100). Ni, V, Cr and Cu also appeared to be moderately enriched even if to a lesser extend (10<EF<100). The high enrichment of these elements suggested that the dominant sources for these elements were non-crustal and a variety of pollution emissions contributed to their loading in the ambient air. For example, Cr likely reflects a variety of pollution sources, in particular coal combustion and sewage sludge incineration (Nriagu and Davidson, 1986). Non-crustal V is primarily from the combustion of heavy fuel oil (Rahn and Lowenthal, 1985). High-temperature processes such as metal smelting and fuel combustion are usually the source of non-crustal volatile metals (e.g. Cd, Ni, Cu) in the atmosphere (Nriagu, 1989). Pb and Zn are traditional tracers of vehicle emissions (Janssen et al., 1997). Note that the elements (V, Cr, Ni, Cu, Zn, Cd, Sn, Pb, As, Se) with large enrichment factors (50–10,000) had rather low concentrations. On the contrary, Na, Mg, K, Ca, Ti, Mn, and Fe had rather high concentrations but showed low enrichment factors (<5), thus suggesting negligible contribution of anthropogenic sources and mainly originating from the street dust.

3.2.4. Factor analysis

In a further attempt to assess the sources responsible for the observed pollution levels, factor analysis using principal component method with Varimax rotation was applied to data set of total concentrations. Although there are no well-defined rules on the number of factors to be retained, usually either factors that are meaningful or factors with eigenvalues larger than unity are retained. In this work, total 98.53% of the variance was explained by the four factors that describe groups of chemical species with different sources (Table 4). The commonalties for individual chemical species were over 0.65, which indicated the fact that the four component solutions were quite satisfactory.

Table 4
Factor loadings of TEs data combined from four hospitals

Variance	Factor 1	Factor 2	Factor 3	Factor 4
Al	0.93			
Ca	0.89			
Ti	0.85			
Na	0.85			
Fe	0.84			
Mn	0.82			
Mg	0.76			
V		0.97		
Zn		0.95		
Ni		0.92		
Cr		0.75		
Pb		0.69		
Cu			0.94	
Cd			0.93	
Se			0.92	
As			0.89	
Sn				0.84
K				0.73
% Variance	30.16	25.70	24.87	12.88

Factor 1 explained about 30.16% of the total variance. The high loading for Al, Ca, Ti, Fe, Mn and Mg in this factor indicated a soil dust contribution. This factor had been identified as "soil factor."

Factor 2 with high loading for V, Zn, Ni, Cd and Pb explained about 25.70% of the total variance. It represented the main types of the anthropogenic pollution sources in the region, most likely waste incinerators (Cd, Pb), traffic emission (Pb, Zn), and oil combustion (V, Ni).

Factor 3 explained about 24.87% of the total variance. This factor was strongly loaded by Cu, Cd, Se and As. It was associated with emissions by industrial operation. These sources could contribute significantly to the loadings of the elements in our study region.

Factor 4 was strongly loaded by K and Sn and explains 12.88% of the total variance. This factor represented combustion emissions. Both K and Sn might be related to biomass burning.

However, separating this complex pollution into individual components is difficult. For example, it is not possible to distinguish between the Cu and As originated in the industrial process and that produced directly by the burning of fossil fuels. The actual contribution in a quantitative manner, however, cannot be found by this method. More sophisticated method such as the chemical mass balance approach in source apportionment study is needed.

4. Conclusion

The characteristics of indoor and outdoor RP and associated elemental compositions were evaluated in the four hospitals of Guangzhou, China. It was observed that indoor PM2.5 levels were significantly higher than PM2.5 standard (65 μg m^{-3}) recommended by USEPA (1997) and indoor PM2.5 constituted a large fraction of PM10 with about 78%, indicating fine particulate pollution was much significant in the investigated hospitals. High correlations were found between PM2.5 and PM10, showing that PM2.5 and PM10 came from similar PM emission sources. The indoor particle levels were correlated with the corresponding outdoor levels (R^2 of 0.78 for PM2.5 and 0.67 for PM10), demonstrating that outdoor infiltration could lead to direct transport into indoors. In addition to outdoor infiltration, human activities and ventilation types could influence indoor PM levels. It was found that the average TE in four hospitals account for 3.18–5.56% of PM2.5 and 4.38–9.20% of PM10 by mass, respectively. Na, Al, Ca, Fe, Mg, Mn and Ti were found in the coarse particulate fraction, while V, Cr, Ni, Cu, Zn, Cd, Sn, Pb, As and Se existed more in the fine particulate fraction. The average indoor concentrations of elements were lower than those measured outdoors, suggesting that indoor elements originated mainly from outdoor emission sources. Enrichment factor analysis showed that those species (V, Cr, Ni, Cu, Zn, Cd, Sn, Pb, As and Se) existing in fine mode were highly enriched, while those species existing in the coarse mode (Na, Al, Ca, Fe, Mg, Mn and Ti) had their EF close to 1. The fine mode species were probably from combustion related sources and the coarse mode species were probably from the crust and of soil nature.

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