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RESEARCH ARTICLE

Characterizations of particle-bound trace metals and polycyclic aromatic hydrocarbons (PAHs) within Tibetan tents of south Tibetan Plateau, China

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Abstract
Introduction Exposure to trace metals and polycyclic aromatic hydrocarbons (PAHs) adsorbed on particulates is of a serious health concern. Levels of some trace metals in total suspended particulate and 13 PAHs of fine particulate matter were measured from nomadic tents in the southern Tibetan Plateau in summer 2010.
Results and discussion The indoor air within the tents was seriously polluted, mainly due to yak dung combustion. Average trace metal concentrations were much higher (range of indoor/outdoor ratio 61–291) than those of the outdoor air. Additionally, enrichment factors of most trace metals of indoor air were similar to those of outdoor air, indicating outdoor air quality of the studied area was possibly influenced by pollutants emitted from local tents. Mean concentrations of total PAHs and BaP within tents was 5372.45 and 364.79 ng/m^3, hundred times higher than that of outdoor air of the Tibetan Plateau. Three- and four-ring PAHs were the predominant components. The diagnostic ratio of BaA/(BaA+Chr) was 0.33. Since Tibetan women typically spend longer time within the tents, they were exposed to PAHs (BaP exposure=1.81 μg/m^3) about two times of other family members. Among all the PAHs, Bap contributed the most (82.6%) of the total carcinogenicity. Similarly, the excess lifetime cancer risk for women and other family members were 2.75×10^{-4} and 1.27×10^{-4}, respectively, indicating Tibetan herdsmen, especially women who are in charge of most house chores were at risk for adverse health effects.

Keywords Trace elements · PAHs · Indoor air quality · Health risk · Tibetan tents

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1 Introduction

Indoor air pollution is a serious problem because people spend long time indoors everyday (Delgado-Saborit et al. 2011). Exposure to organic and inorganic toxic chemical compound contents absorbed on airborne particulate matter (PM) is considered as an important factor affecting human health (Spengler and Sexton 1983; Samet et al. 2000; Smith and Mehta 2003; WHO 2005). Within PM, fine particles, such as particulate matter with an aerodynamic diameter ≤2.5 μm ($PM_{2.5}$) is especially of concern (Samet et al. 2000; Zhang and Smith 2007; See and Balasubramanian 2008; Lim et al. 2011). $PM_{2.5}$ not only holds large amount of polycyclic aromatic hydrocarbons (PAHs) and trace metals (Deng et al. 2006), but can also penetrate into deeper parts of the lungs, causing a vast range of severe diseases (Ormstad 2000). Some PAHs are carcinogens according to US Environmental Protection Agency (USEPA) and International Agency for Research on Cancer (1987), and trace metals such as As, Cd, Co, Cr, Ni, and Pb are also classified as carcinogens. Indoor air pollution is serious in developing

countries due to the usage of domestic cooking stoves (Zappoli et al. 1999; Bruce et al. 2000; Smith and Mehta 2003; Zhang and Smith 2007; Hasan et al. 2009). In general, poor ventilation, low efficiency of stoves, and extensive use of biofuels greatly enhance pollutant concentrations of indoor environments (Pandit et al. 2001). At present, large amounts of PAHs and trace metals are emitted annually in China (Xu et al. 2006), and a number of studies on exposure levels to these compounds within indoor air have been performed mainly in well-developed areas (Zhu and Wang 2003; Zhang et al. 2007; Lu et al. 2008; Guo H et al. 2010).

However, few such studies were conducted on the Tibetan Plateau (TP)—one of the cleanest regions in the world (Kang et al. 2007). Currently, millions of Tibetan residents still live in primitive tents and follow traditional nomadic life on the grassland. Although outdoor air of the TP is very clean (Li et al. 2007b), indoor air quality within tents is poor due to the combustion of solid biomass fuels, especially yak dung. For instance, studies on total suspended particle concentration of the Tibetan tents (Kang et al. 2009) and daily average $PM_{2.5}$ concentrations in rural area (Gao et al. 2009) both revealed a high particle concentrations (TSP, 3,157 μg/m^3; $PM_{2.5}$, 134.91 μg/m^3). So far, however, no comprehensive data on trace metals and PAHs are reported at the same time within Tibetan tents, except a pilot research study on three trace metals within tents (Kang et al. 2009) and a PAHs study in a stable house made of stone in a Tibetan rural area (Lu et al. 2006). Although atmospheric PAHs exist in particulate or gaseous phases, particle-bound PAHs are generally considered to be the most hazardous substances to human health because they contain more fractions of higher carcinogenicity (Chang et al. 2006). This study intended to examine particle-bound trace metal concentrations indoor and outdoor of the Tibetan tents, and to compare association between indoor and outdoor air of the TP. Furthermore, association between indoor and outdoor air of the TP were compared by means of trace metal compositions measured in this study and from our previous article (Kang et al. 2009).

Additionally, pollutant levels of our study were also compared to published data and related standards (Zhu and Wang 2003; Lu et al. 2006; See et al. 2006; Gong et al. 2011; USEPA 2004) to describe the characteristics of trace metals and PAHs within the Tibetan tents. The potential health threat based on PAH concentrations and molecular compositions were also evaluated by means of daily PAH intake.

2 Experimental

2.1 Description of sampling sites

This study was conducted in four typical nomadic tents using open stoves in the Nam Co area (30°46.44′ N, 90° 59.31′ E; 4,730 m a.s.l.), southern TP (Fig. 1), in summer 2010. The detailed information of this area and structure of the tents (houses) have been described previously (Li et al. 2007a; Kang et al. 2009). All of the tested families have similar tribal backgrounds, economic status, and living style. All of the selected tents (5×4.5×1.9 m) have similar layout and air ventilation conditions and smoke produced from open stoves disperses into the tents directly before release out of tent from a rectangular hole on top of the tent (Fig. 2). All households in this area burn yak dung exclusively for energy generation. Generally, women get up early to do most of the household chores such as cooking, weaving yak hair, and cleaning the tents. Comparatively, men are in charge of herding and spend relatively longer periods on the grassland and return to the tents only for eating lunch or having a short rest during daytime.

2.2 Sample collection

$PM_{2.5}$ samples were collected in summer 2010 on quartz fiber filters (90 mm in diameter, Whatman Corp.) by a sampler with $PM_{2.5}$ cyclone at flow rate of 100 L/min (TH150-A, Wuhan Tianhong INST Group) for the analysis of metal and PAH concentrations. Total suspended particles (TSPi) samples were collected in summer 2008 on Teflon filters (47 mm in diameter, Millipore Corp.) for the analysis of metal concentrations (Kang et al. 2009). The samplers were placed 1.5 m above the ground and 1 m away from the stove horizontally within the tents. Additionally, TSP samples of outdoor air (TSPo) were also collected on Teflon filters in summer 2006 for measuring metal concentrations at Nam Co Station for Multisphere Observation and Research (NAMOR) about 5 km away from the selected tents (Fig. 1). In general, each $PM_{2.5}$, TSPi and TSPo sample was collected for 1 h, 1 h, and 7–10 days, respectively. Finally, 8, 11, and 13 samples for $PM_{2.5}$, TSPi, and TSPo were collected, respectively. Time distribution of residents' daily activities such as staying within the tents during daytime, going out of tents and sleeping at night were counted. Furthermore, daily variations of $PM_{2.5}$ were measured by a model AM510 SidePak personal aerosol monitor (TSI Company) to achieve $PM_{2.5}$ concentrations of daytime and night within the tents. The participators were women and each tent was monitored for 3 days.

Quartz fiber filters were pre-treated by baking at 550°C for at least 12 h to reduce any residual organic matter on the filters. Both quartz and Teflon filters were weighed by microbalance for both pre- and post-sampling at the Institute of Tibetan Plateau Research, after being equilibrated at stable temperature and humidity environment (20°C, 39 RH) for at least 24 h. All samples were weighed at least three times to get mean concentrations in both pre- and post-weighing. Finally, filters were stored in a refrigerator at 4°C before extraction and chemical analyses. Air volume passed

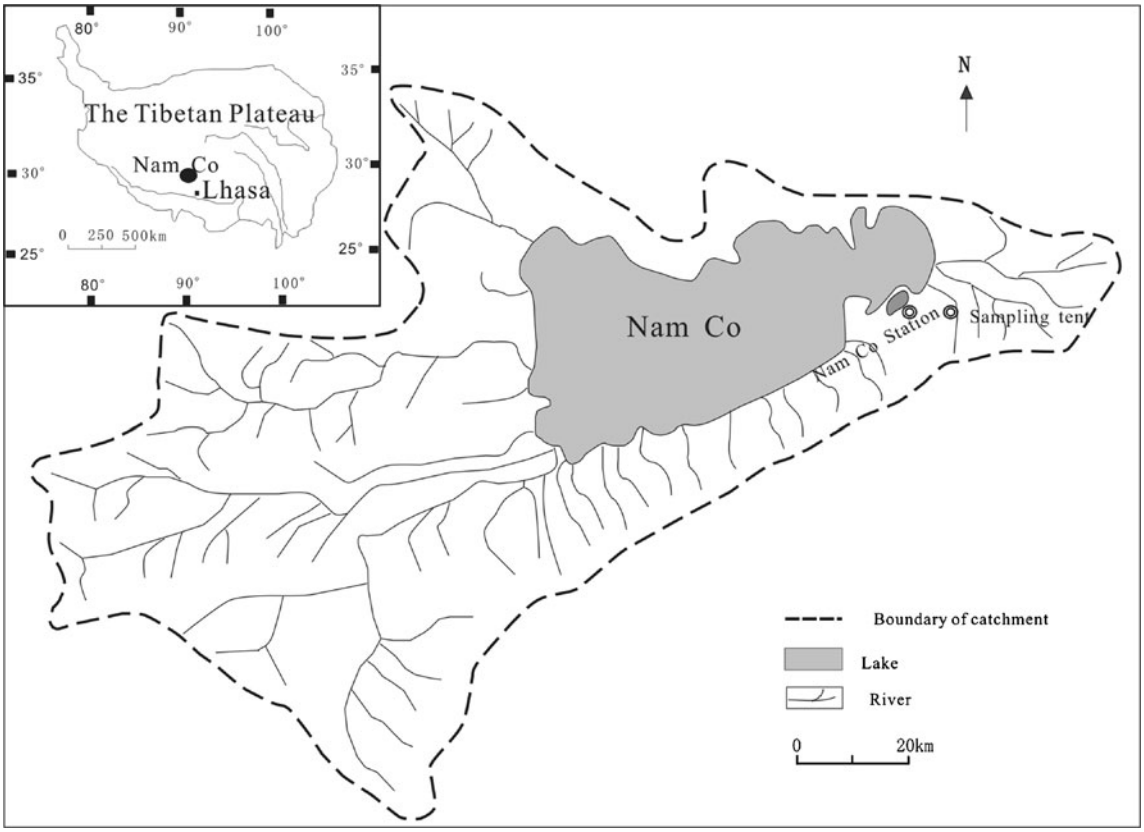

Fig. 1 Location map of sampling site

through each filter was converted into standard condition automatically by sampler according to the synchronous air pressure and temperature of study area. Blanks were also transported to the field but not opened, and taken back to the lab for analysis.

Metal concentrations of collected particles were determined by ICP-MS (X-7 Thermo Elemental) at Key Laboratory of Tibetan Environment Changes and Land Surface Processes, Institute of Tibetan Plateau Research. Filter samples were digested by a high-pressure digestion process in

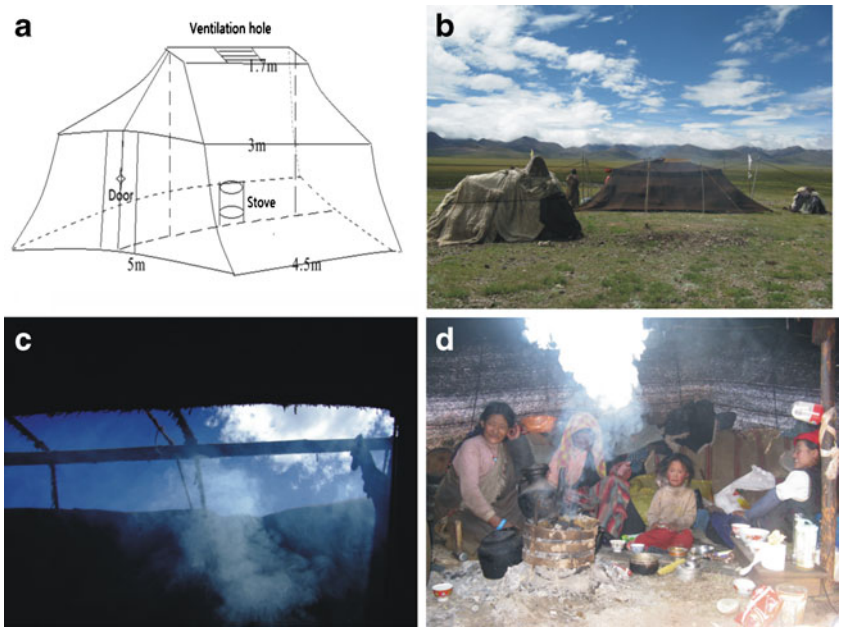

Fig. 2 The general layout of typical tent (**a** and **b**), ventilation hole of the tent (**c**), and a local family using open stove (**d**)

Teflon vessels with a mixture of HNO_3 (BVIII) and HF (BVIII) (Kang et al. 2009). In short, filter samples were initially placed in a Teflon high-pressure digestion vessel with 1.5-mL concentrated HNO_3, 0.5-mL concentrated HF. Subsequently, the vessels were treated in ultrasound bath for 20 min. Then, the samples were digested in an oven at 190°C for 24 h. After cooling, the solutions were dried on a hot plate at 150°C, and HNO_3 was added into the residue and heated at 170°C for 24 h. Finally, Indium and Rhodium were added as internal standards and the digest was diluted up to 10 mL using Milli-Q water. In each digestion batch, a reagent blank was used to check the sample handing processes.

Meanwhile, PAHs were analyzed at same lab by GC–MS following the same procedure described by Gong et al. (2011). The recoveries for surrogates in field samples were 72–113% for pyrene-D10 and 75–96% for perylene-D12. All PAH concentrations were not corrected for the recoveries. The following 13 PAHs were determined: fluorene (Flu), phenanthrene (Phe), anthracene (Ant), fluoranthene (Fla), pyrene (Pyr), benzo[a]anthracene (Baa), chrysene (Chr), benzo[b]fluoranthrene (Bbf), benzo[k]fluoranthrene (Bkf), benzo[a]pyrene (BaP), indeno(1,2,3cd)pyrene (Ind), dibenzo(a,h) anthracene (Dah), benzo(g,h,i)perylene (Bghi). The related parameters of the blank and instruments are shown in Table 1.

2.3 Risk estimation

Since only particle phase were collected and measured in this study, it was proposed that PAH exposure to residents occurred through inhalation. Therefore, the total carcinogenic risk was estimated by adding the excess lifetime cancer risk (ELCR) of each single PAH 1 to n (ELCRi) (United States Department of Energy Guidance for conducting risk assessments and related risk activities for the DOE-ORO environmental management program 1999):

$$\mathrm{Ci} = \frac{T \times Cc,i + Ts \times Csc,i}{T + Ts} \quad (1)$$

$$\mathrm{ELCR} = \sum_{i=1}^{n} (\mathrm{Ci} \times \mathrm{IUR}i) \quad (2)$$

Where Ci is the mean concentration of each PAH inhaled in the whole day (in milligrams per cubic meter); Cc,i and Csc,i are PAH concentrations during daytime and night time within the tents (in milligrams per cubic meter); IURi is inhalation slope factor (per milligrams per cubic meter) (Table 2). According to USEPA, a lifetime risk of one in a thousand or greater is considered serious and is a high priority for attention (USEPA 1992).

3 Results and discussion

3.1 Particle and metal concentrations and their implications

Table 3 presents metal concentrations obtained in this study and other urban areas. Particle and metal ratios between indoor and outdoor air are also shown. Due to high background levels of some metals for quartz fiber filter, only six metals of $PM_{2.5}$ are reported here. Firstly, TSP concentration

Table 1 Parameters of metal and PAH concentrations(parts per billion)of blank samplers, detection limit (parts per billion) of instrument, recovery (%) of standard materials (GSS-8, Chinese national reference material) for trace metals

Element				PAHs		
	Concentration	Detection limit	Recovery		Concentration	Detection limit
Na	4.20	0.811	1.09	Flu	13	0.42
Mg	6.00	0.065	1.56	Phe	655	0.50
Al	46.66	0.114	1.02	Ant	33	0.72
K	3.75	3.509	1.79	Fla	71	0.29
Ca	38.42	2.234	0.99	Pyr	88	1.00
Cr	ND	0.052	2.37	BaA	15	0.75
Co	ND	0.005	2.51	Chr	58	0.65
Ni	ND	0.022	1.00	BbF	11	0.38
Cu	0.28	0.012	2.68	BkF	1	0.90
Zn	3.05	0.052	1.20	BaP	11	0.85
As	0.18	0.090	1.74	Ind	6	1.60
Cd	0.00	2.409	1.50	Dah	3	0.92
Cs	0.01	0.001	1.48	Bghi	12	0.50
Pb	0.05	0.004	1.79			
Bi	ND	0.688	1.14			

Unit for detection limits of Cd and Bi is parts per trillion

Table 2 Toxicity profiles of PAHs

PAHs	IARC groups	TEF_a	IUR_b $(mg/m^3)^{-1}$	MW	Number of rings
Nap	2B	0.001	3.4×10^{-2}	128	2
Acy	NR	0.001	NR	152	3
Ace	NR	0.001	NR	154	3
Flu	3	0.001	NR	165	3
Phe	3	0.001	NR	178	3
Anth	3	0.01	NR	178	3
FLt	3	0.001	NR	202	4
Pyr	3	0.001	NR	202	4
BaA	2A	0.1	8.8×10^{-2}	228	4
Chr	3	0.01	8.8×10^{-4}	228	4
BaF	2B	0.1	8.8×10^{-2}	252	5
BkF	2B	0.1	8.8×10^{-3}	252	5
BaP	2A	1	8.8×10^{-1}	252	5
DBahA	2A	1	8.8×10^{-1}	278	6
Bghi	3	0.01	NR	276	6
Ind	2B	0.1	8.8×10^{-2}	276	6

IARC group of 2A, 2B, and 3 indicate probable human carcinogens, possible human carcinogens, and IARC group not classifiable as to human carcinogenicity, respectively

MW molecular weight, *NR* non-reported

[a](Nisbet and LaGoy 1992)

[b](USDOE 1999)

within tents in this study was approximately 650 times that of outdoor air at study area (Kang et al. 2009). Similarly, $PM_{2.5}$ concentration of this study clearly exceeded the standard (25 μg/m^3) for 24-h mean value proposed by WHO (2005), and about 30 and 60 times the concentrations of samples collected in the urban area of Daejeon, Korea (Lim et al. 2011) and Guangzhou, China (Huang 2007), respectively, indicating both TSP and $PM_{2.5}$ concentrations within the tents were high. Secondly, concentrations of all metals within the tents were also significantly higher than those of outdoor air in the Nam Co area, especially for metals K, Cd, and Bi. K is generally enriched in particles of biomass combustion (Hedberg et al. 2002), Cd is a type of volatile metal and Bi is naturally enriched in the Tibetan top soil (Li et al. 2009). Furthermore, all trace metal concentrations except Zn and Pb within tents were higher than those of

Table 3 Particle concentrations (micrograms per cubic meter), element concentrations (nanograms per cubic meter), and I/O ratio of Nam Co and the comparison with other areas

	Nam Co region							Guangzhou($PM_{2.5}$)		Daejeon(PM2.5)	
	TSP					$PM_{2.5}$					
	Indoor	SD	Outdoor	SD	I/O	Indoor	SD	Indoor	I/O	Indoor	I/O
Particle	3,157	2,149	6.74	4.86	660	1,668	2,350	88.8	0.90	47.6	–
Na	3,591	3,275	22.60	10.00	159	–	–	–	–	265	1.20
Mg	3,242	2,419	19.97	13.03	162	–	–	–	–	105	0.82
Al	16,390	14,084	74.31	53.53	221	–	–	–	–	503	1.03
K	7,317	7,553	28.67	18.56	255	–	–	1,155.4	0.96	523	1.74
Ca	14,496	14,006	74.10	79.07	196	–	–	959	0.90	–	–
Cr	278	256	4.54	4.64	61	–	–	7.7	0.23	12.7	1.21
Co	5.79	3.32	0.07	0.05	86	2.96	2.13	–	–	0.49	2.88
Ni	157	117	1.43	1.41	110	–	0.00	19.7	0.98	–	–
Cu	86.79	104	–	–	–	186.33	114.38	36.4	1.01	9.96	0.93
Zn	374	266	2.22	2.31	169	–	0.00	407.9	0.97	66.6	1.60
As	32.94	19	0.28	0.34	120	20.34	15.43	21.8	0.89	2.65	1.13
Cd	3.45	4.07	0.01	0.01	291	–	0.00	–	–	–	–
Cs	7.39	5.55	0.04	0.06	164	0.34	0.17	–	–	–	–
Pb	72.79	111	0.43	0.42	171	12.44	4.34	185.1	0.96	–	–
Bi	3.49	3.18	0.01	0.02	276	0.31	0.47	–	–	–	–

selected urban areas. High concentrations of Zn and Pb of urban area were mainly contributed by vehicles and refuse incineration (Chueinta et al. 2000; Chao and Wong 2002). Therefore, indoor air within Tibetan tents is seriously polluted by trace metals, and pollutant concentrations within Tibetan tents were high and derived mostly from yak dung combustion. According to living style of Tibetan residents, boiling is the main cooking practice and produces few pollutants (Zhu and Wang 2003). Cooking activities, therefore, contributed a small part to the air pollution within Tibetan tents. In contrast, outdoor air of the TP was very clean with high values of I/O ratios for TSP and most metals, indicating that indoor air quality within the tents was rarely affected by outdoor sources. This is different from that of urban areas (I/O ratios for most metals around 1), where indoor air quality is influenced by both indoor sources (cooking) and outdoor sources (industrial and vehicle emissions) (Huang 2007; Lim et al. 2011) due to serious outdoor air pollution within urban areas.

To study association between indoor and outdoor air in the Nam Co area, we adopted enrichment factors (EF), which helps elucidate the basic aspects of indoor as well as outdoor source processes (Slezakova et al. 2009). Generally, EF is shown as relative concentration ratio [EFx $= (C_X/C_R)$sample$/(C_X/C_R)$ upper continental crust]. Where C_X represents concentration of tested element X; C_R is concentration of a reference element. In this study, Al was selected as reference element. Upper continental crust value is adopted from Taylor and McLennan (1995). EFs of various metals for indoor and outdoor TSP are shown in Fig. 3. Although EF values varied widely in a range of 0.6–198, EF spectrum of indoor air is similar to those of outdoor air, with low EF values around 1 for major metals (Na–Ca) and high EF values >100 for some trace metals (e.g., As and Cd). In addition, most trace metals had similar EF values (e.g., Zn, Cs, Pb, and Bi) between indoor and outdoor air, indicating their potential common source region. Higher EF values of Cr, Ni, and As for outdoor air were possibly induced by other contributions beside indoor air pollution of tents such as vehicles (Huang 2007) of this area or even long-range transported pollutants from south Asia (Cong et al. 2007; Li et al. 2007b). High EF values normally indicate anthropogenic origin, and metals with EF values between 10 and 200 were categorized as "moderately enriched" (Huang 2007). It is clear that TSP within tents is produced mainly from yak dung combustion. Therefore, based on the higher metal concentrations of indoor air relative to those of outdoor air and their similar metal EF values, conclusion can be drawn that particles emitted from local tents possibly contribute to outdoor air of the Nam Co area to some extent in summer. Previous studies of this area also revealed that some anions of precipitation were derived mainly from activities of local residents (Li et al. 2007a).

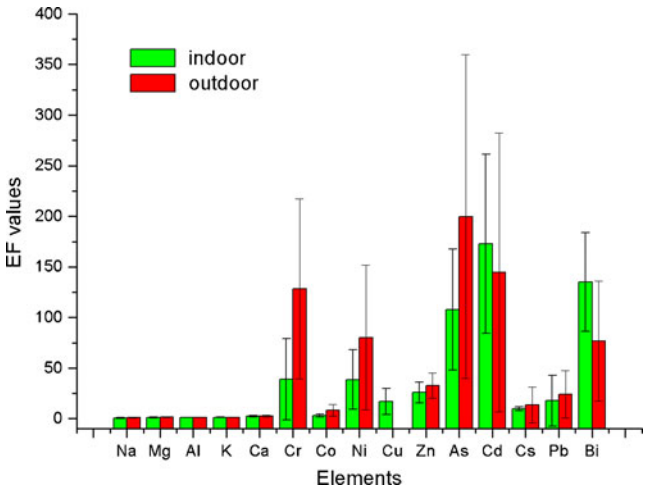

Fig. 3 Enrichment factors of elements in TSP of indoor and outdoor airs

3.2 PAH concentrations within tents

Mean PAH concentrations during daytime are given in Table 4. Total PAH concentrations in this study was about 5,372.45 ng/m^3 (ranging from 2,817.21 to 8,672.91 ng/m^3), which was much higher than those from kitchens of Tibet rural area (Lu et al. 2006). Similarly, our data were much higher than that of outdoor air of the Nam Co area (0.7 ng/m^3) (Xiao et al. 2010). BaP is often used as a marker for total PAH exposure in the environment and is of special concern. BaP concentration in this study was 364.79 ng/m^3 accounting for about 7% of total PAHs. This was a high ratio and a characteristic phenomenon found in this study, in line with PAH compositions of other biomass (e.g., wood and incense) combustion (Raiyani et al. 1993). For each determined PAH, Phe had the highest concentration, followed by Pyr, Flu, and Chr. These four components (three-ring and four-ring), combined together, contributed to more than 70% of the total PAH, because large amounts of particles generated by yak dung combustion enables this component of PAHs to partition to the particle phase (Lima et al. 2005). In contrast, five- to six-ring PAHs with heavy molecular weight were of less importance, which was similar to other researches on biomass combustion (Raiyani et al. 1993; Fine et al. 2001; Schauer et al. 2001). Amount and compositions of PAHs produced by fuel combustion are influenced by various conditions such as amount of oxygen and combustion temperature. Generally, lack of oxygen favors the production of PAHs (Lima et al. 2005).

3.3 Fingerprints for aerosol of tents

PAH compositions vary significantly among different combustion sources. The diagnostic ratios can be served as

Table 4 Levels of PAHs (nanograms per cubic meter) in $PM_{2.5}$ of Nam Co and the comparison with other areas

	This study	Min	Max	A	B	C
Flu	23	5	49	8	5.63	71
Phe	1,229	360	2,360	123	12.23	633.33
Ant	273	105	493	22	3.9	276
Fla	868	540	1,272	–	–	–
Pyr	1,057	672	1,513	48	10.63	626.67
BaA	366	240	589	10	9.3	266.67
Chr	808	467	1,199	76	18.5	230
BbF	28	12	49	–	48.7	–
BkF	157	92	271	–	9.1	5.23
BaP	365	210	558	82	7.5	15.37
Ind	22	8	44	–	43.87	–
Dah	6	3	10	–	–	–
Bghi	171	103	257	–	–	–
Total PAHs	5,372	2,817	8,662	369	169.37	2,124.27
BaA/(BaA+Chr)	0.33	–	–	0.54	–	–

A Kitchens of Tibet rural area, *B* three commercial kitchen stalls in Singapore, *C* kitchens of Hangzhou with no-smoking family

markers or tracers of pollution sources. Ratio of BaA/(BaA+Chr) (Table 4) was clearly different from those of commercial kitchens, suggesting their different source areas and production processes. In general, ratio of BaA/(BaA+Chr) is widely used for distinguishing PAHs between fossil fuel and biomass fuel combustion. Ratio of BaA/(BaA+Chr)>0.35 implies combustion (Yunker et al. 2002). However, according to the above standard, ratio of our samples (BaA/(BaA+Chr)=0.33) was close to the above threshold, implying unique PAH compositions of yak dung combustion. Regardless, our ratio provides a useful database for source region investigations of particle PAHs of the Tibetan Plateau. Notwithstanding, the above comparison is not very strong due to potential influence of both ventilation conditions and the size of the selected rooms.

3.4 Daily intake of PAHs and health risk assessment

The daily intake of PAHs for residents comes from both food and air. PAH levels and compositions in air of Tibetan tents can be used in epidemiological studies to assess the cancer risk for Tibetan residents due to inhalation of PAHs. In addition, this database can be used together with other results of PAHs intake to study total daily intake of PAHs.

Calculated Intake (I) was applied to calculate daily intake of Tibetan residents (Zhu and Wang 2003):

$$I = 20\% \times V \times C \tag{3}$$

Where V is the air volume inhaled (cubic meter) and C is the PAH concentration (micrograms per cubic meter), respectively. Generally, a normal person breathes 1.35 m^3 of air in 1 h. Based on our statistics on daily activities of Tibetan residents, women and other family members spend 7 h sleeping in the tents at night, while 13 and 6 h, respectively, in the tents during daytime. Meanwhile, according to results of personal aerosol monitors, the level of $PM_{2.5}$ at night is about 100 times lower than that of daytime because stove is extinguished at night and most particles are quickly emitted out of the tent. Therefore, the PAH levels within the tents is about 1% of that of daytime. PAHs levels of outside are approximately considered as zero due to very clean outdoor air. Among all the PAHs, BaP exposure of Tibetan women (1.81 μg/m^3) was even two times higher that of cooks in seriously polluted commercial kitchen in Hangzhou, China (0.94 μg/m^3) (Zhu and Wang 2003).

In general, BaP is considered as a marker of the carcinogenic potency of PAHs. To estimate the health risks associated with yak dung combustion, mass concentrations of PAHs were compared to present regulatory standards. The equivalent mass concentrations of BaP (C_{BaPeq}) in Tibetan tents were calculated over a 24-h period according to the following equation:

$$C_{\mathrm{BaPeq}} = \sum_{i=1}^{n} (Ci \times \mathrm{TEF}i) \tag{4}$$

where Ci is the concentration of individual PAHs and TEFi is the toxic equivalency factor of the PAH (Table 2) (Nisbet and LaGoy 1992). By using TEFs, the carcinogenic properties of the individual PAHs can be discussed.

C_{BaPeq} for women and other family members were 339.98 and 157.89 ng/m^3, respectively. Both of these two values are higher than that of Chinese National Environmental Quality Standard (10 ng/m^3) and of WHO Standard (1 ng/m^3). In addition, BaP contributed most (82.6%) to the total carcinogenic potential of the PAH mixture. This is a large contribution compared to previous studies (Evagelopoulos et al. 2008;

Delgado-Saborit et al. 2011) largely due to its high carcinogenic potential (TEF=1) and high concentration. However, this comparison with exposure limits is only a qualitative estimate. A deep understanding of the associated health risks can be achieved by calculating the ELCR according to Eqs. 1 and 2 (See et al. 2006). The ELCRs were estimated to be 2.75×10^{-4} and 1.27×10^{-4} for women and other family members, respectively, which was higher than the acceptable target risk range of 10^{-6} to 10^{-4} for occupational workers set by the USEPA (1992). Therefore, the Tibetan residents, especially women, are exposed to a large amount of fine particles containing carcinogenic PAHs. Furthermore, according to living habits of local residents, little children spend more time within tents than their mother. Accordingly, they are exposed to higher pollutants. Consequently, PAHs are an important contributor to the carcinogenic burden of Tibetan residents. Thus, efficient measures against PAH pollution must be taken for Tibetan people, especially women in charge of house chores and little children spend long time within tents.

4 Conclusions

Emissions of trace metals and 13 PAHs from selected Tibetan tents using open stoves were quantitatively measured. Trace metal concentrations within the tent ranged from 3.45 ng/m^3 (Cd) to 373.82 ng/m^3 (Zn), which were much higher than those of outdoor air of study area. Despite this, the spectrum of EF values between indoor and outdoor air were similar for most trace metals, implying that yak dung combustion was a significant source of trace metals, and outdoor air quality of the study area was affected by indoor air pollutants to some extent. The average concentration of PAHs was 5,372.45 ng/m^3, with three- and four-ring PAHs accounting for 70% of the sum of PAHs. The diagnostic ratios of BaA/(BaA+Chr) was different from the common values of biomass combustion, maybe due to lack of oxygen in the study area and absorption of PAHs to the indoor furnishings within the tent. The exposure to equivalent mass concentrations of BaP for women and other family members were 453.31 and 210.53 ng/m^3, respectively; both were much higher than WHO Standard. BaP contributed over 80% to the carcinogenic potential of total PAHs. Excess lifetime cancer risk analysis indicated that the exposure to PAHs for local residents is a health concern. Therefore, comprehensive epidemiological study is needed to be performed to quantify the yak dung combustion impact on the health of local residents. In summary, despite very clean outdoor air of the Tibetan Plateau, levels of both trace metals and PAHs within the Tibetan tents using open stove are high. Control strategies such as replacing yak dung with new energy, changing life style of the local residents and introducing improved stove are therefore proposed to minimize residents' exposure to pollutants. Among all of them, introducing improved stove with chimney to release the pollution directly out of the tent is highly recommended because it is the easiest way and costs little money.

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