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Concentration, Source, and Health Risk Assessment of Polycyclic Aromatic Hydrocarbons: A Pilot Study in the Xuanwei Lung Cancer Epidemic Area, Yunnan Province, China

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Abstract: Polycyclic aromatic hydrocarbons (PAHs) are toxic and hazardous volatile environmental pollutants that have been studied as possible major causative agents of lung cancer in Xuanwei. In this paper, indoor and outdoor $PM_{2.5}$ samples were collected from two homes at different time periods in Hutou, the lung cancer epidemic area in Xuanwei. The results showed that PAH pollution levels from coal combustion in Xuanwei lung cancer epidemic area were significant. The mass concentrations of total PAHs, major carcinogenic compounds, and benzo[*a*]pyrene-based equivalent concentration (BaP_{eq}) were significantly higher in the coal-using home than in the electricity-using home. For the coal-using home, the PAHs were mainly derived from coal combustion. For the electricity-using home, the PAHs might have been a combination of traffic and coal combustion sources. The human health risk due to inhalation exposure to the PAHs was represented by the incremental lifetime cancer risk (ILCR) of the inhalation exposure. The results showed that the indoor cancer risk for the coal-using home in Xuanwei is higher than that of the electricity-using home and much higher than that of Chinese megacities such as Beijing and Tianjin. Long-term exposure to indoor coal-burning environments containing high levels of PAHs may be one of the main reasons for the high incidence of lung cancer in Xuanwei.

Keywords: coal combustion; Xuanwei; polycyclic aromatic hydrocarbons (PAHs); benzo[*a*]pyrene-based equivalent concentration (BaP_{eq}); lung cancer risk

1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) are organic contaminants produced by the incomplete combustion of carbonaceous materials that occur in the atmosphere [1,2]. PAHs in the air, both gaseous and particle phases, have been found to have direct effects on human health [3,4]. $PM_{2.5}$ refers to particulate matter in the ambient air that has an aerodynamic equivalent diameter of less than or equal to 2.5 μm, which can enter the human lungs [5]. $PM_{2.5}$ is of more concern due to its large specific surface area and strong adsorption capacity [6]. $PM_{2.5}$-bound PAHs can easily enter the respiratory system and cause lung cells to mutate, leading to lung cancer [7,8]. Due to the high toxicity, mutagenicity and carcinogenicity of PAHs, 16 PAHs are regarded as priority pollutants by the United States Environmental Protection Agency (USEPA) [9], in which benzo[*a*]pyrene (BaP), benz[*a*]anthracene (BaA), benzo[*b*]fluoranthene (BbF), benzo[*k*]fluoranthene (BkF), chrysene (Chr), dibenz[*a*,*h*]anthracene (DahA) and indeno [*1,2,3-cd*]pyrene (IcdP) have been classified as probable human carcinogens [10]. BaP has been listed as the control pollutant of the Ambient Air Quality Standards of China (GB 3095–2012). Therefore, the health risk assessment of exposure to PAHs in the environment has become a major concern all over the world.

Xuanwei, located in the northeast of Yunnan Province in China, has one of the highest morbidity and mortality rates due to lung cancer in the world [11]. Especially in Laibin, a lung cancer epidemic area of Xuanwei, the mortality from lung cancer exceeds $160/10^5$ [12]. The main energy source for residents in Xuanwei is the local C1 coal, which is situated stratigraphically at the onset of the End-Permian mass extinction [13–15]. The coal is characterized by medium to high ash yields (average 31.0%), low to medium volatile contents (average 20.0%), low sulfur contents (averaged 0.17%), and mid-range vitrinite reflectance from 1.19% to 1.37% [13]. The combustion of C1 coal releases a large quantity of toxic particles, including PAHs, SiO_2, and heavy metals [16–19]. A number of studies have indicated that long-term exposure to high concentrations of toxic particles in the indoor coal-burning environment may be the main reason for the high incidence of lung cancer in Xuanwei [20–22]. He et al. suggested that the large quantity of PAHs emitted from indoor coal combustion in Xuanwei may be a major risk factor for the high incidence of lung cancer [23]. Tian et al. suggested that the high incidence of lung cancer in Xuanwei may be related to the presence of microcrystalline SiO_2 in the C1 coal [24]. Large et al. suggested that the combined effect of SiO_2 and the volatile fraction in the coals at the uppermost Permian may be the geological cause of the high incidence of lung cancer in Xuanwei [20]. Shao et al. have carried out a toxicological study of respirable particulate matter and have shown that the particles emitted from the indoor coal combustion in the Xuanwei lung cancer epidemic area had a significantly higher oxidative damage capacity than in the control area, and that this oxidative capacity was closely related to the higher concentrations of heavy metals in the particulate matter [25].

Clearly, the high incidence of lung cancer in Xuanwei may be the result of a complex synergistic effect of multiple factors. However, PAHs are recognized as the most significant correlated factor with the mortality of Xuanwei lung cancer among several carcinogenic factors [26]. When compared to other samples, the expression of PAH-DNA adduct in the lung tissue of Xuanwei females were higher than those found in Xuanwei males and non-Xuanwei females [27]. Similarly, the female users of bituminous coal in Xuanwei had significantly higher average urinary mutagenicity levels than those anthracite coal users [28]. At present, studies of PAH pollution in the Xuanwei area are mainly focused on the average pollution levels and exposure risks of PAHs in household air, lacking the quantitative assessment of health effects, especially cancer risk due to PAH exposure [16,29,30]. The incremental lifetime cancer risk (ILCR) proposed by the USEPA is widely used for the quantitative characterization of human health risks. However, there are no studies showing that ILCR levels in lung cancer epidemic areas of Xuanwei at present. Therefore, a comprehensive and systematic characterization of indoor and outdoor pollution levels and health risks of PAHs in different homes of lung cancer epidemic areas in Xuanwei is needed.

In this study, $PM_{2.5}$ samples were collected from two homes in the Xuanwei lung cancer epidemic area (Hutou village of the Laibin town) to characterize the pollution levels, sources, and health risk related to $PM_{2.5}$-bound PAHs. We hoped to gain understanding of the air pollution with potential carcinogens in the area and provide a basis for exploration of the synergistic effects of multiple factors in the future.

2. Materials and Methods

2.1. Sampling

This pilot study was carried out in the Hutou, a village of the Laibin town, which is a high lung cancer mortality area in Xuanwei, Yunnan Province, China (Figure 1). Local farmers mainly use coal as a domestic fuel, while some have changed to use electricity. In order to investigate the impact of different fuel types on local air pollution, a total of 22 samples were collected from two typical homes—coal-using and electricity-using—from

28 February to 6 March 2019. In the coal-using home, indoor $PM_{2.5}$ samples were collected in the kitchen, in which bituminous coal is used in a ventilated fixed stove for cooking, while in the electricity-using home, indoor $PM_{2.5}$ samples were also collected in the kitchen, in which induction stoves are mainly used for cooking. The corresponding outdoor $PM_{2.5}$ samples were also collected in the yards of the sampling homes (10 m from chimney). The stoves were not in use at night.

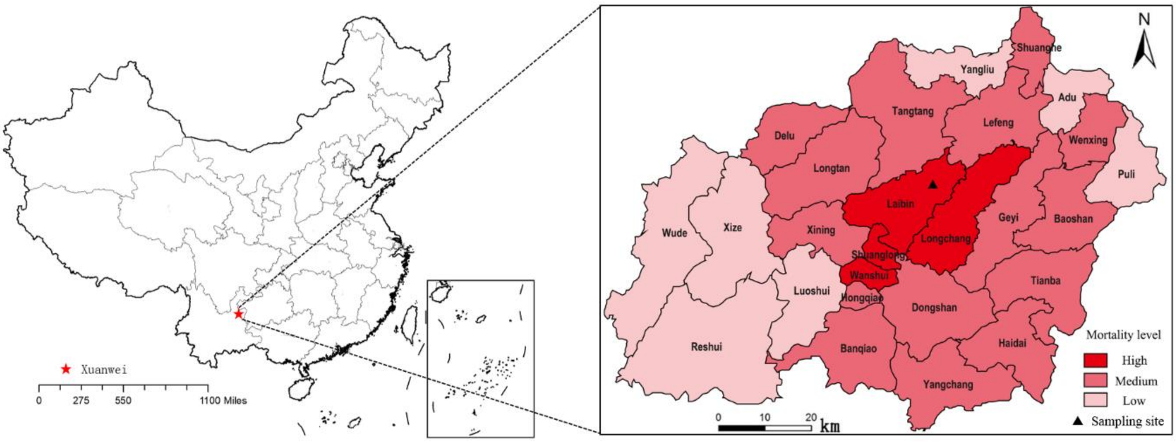

Figure 1. Map of Xuanwei showing the county-specific annual lung cancer mortality rates in 2014–2016. Raw data from Liu et al. [31].

A TSP-PM_{10}-$PM_{2.5}$ sampler (KB-120E, Qingdao, China) and quartz microfiber filters (90 mm, Whatman, China) were used to collect $PM_{2.5}$ at a flow rate of 100 L/min. The sampling points were at the average breathing height (1.5 m above the floor). A pocket weather tracker (Kestrel 5500 Weather LiNK, USA) was used to record meteorological data during sampling. Before sampling, the quartz fiber filters were heated at 450 °C for 4 h and placed in a constant temperature and humidity chamber (Hitachi, Japan; temperature 20 °C ± 5 °C, relative humidity 45% ± 5%). Due to the volatility of PAHs, samples were stored in a refrigerator (Haier, China; temperature −20 °C) after collection. Detailed sample information and the meteorological conditions during the sampling period are shown in Table 1.

Table 1. Sampling information and meteorological conditions during the sampling periods in the two homes of the Hutou village of the Laibin town, Xuanwei city.

Sample Number	Sampling Date	Sampling Site	Indoor/Outdoor	Day/Night	Average Temperature (°C)	Relative Humidity (%)	Average Pressure (kpa)
XW01	2019.02.28	coal-using home	Indoor	Night	17.4	63.2	900.6
XW02	2019.02.28		Outdoor	Night	16.8	67.6	799.9
XW03	2019.03.01		Indoor	Day	14	60.4	801.2
XW04	2019.03.01		Outdoor	Day	11.8	65.9	800.5
XW05	2019.03.02		Indoor	Night	16.9	43.3	799.7
XW06	2019.03.02		Outdoor	Night	6.5	54.2	801.5
XW07	2019.03.03		Indoor	Day	12.4	50.8	802.2
XW08	2019.03.03		Outdoor	Day	5.4	56.1	802.2
XW09	2019.03.03		Indoor	Night	13.3	62.4	798.6
XW10	2019.03.03		Outdoor	Night	20.6	25.5	797.6
XW11	2019.03.04		Indoor	Day	13.5	58	798.5

Table 1. *Cont.*

Sample Number	Sampling Date	Sampling Site	Indoor/ Outdoor	Day/Night	Average Temperature (°C)	Relative Humidity (%)	Average Pressure (kpa)
XW12	2019.03.04	coal-using home	Outdoor	Day	12.3	43.3	797.3
XW13	2019.03.04		Indoor	Night	16.9	57.3	796.2
XW14	2019.03.04		Outdoor	Night	18.4	34.7	795
XW15	2019.03.05	electricity-using home	Indoor	Day	14.9	49.2	799.2
XW16	2019.03.05		Outdoor	Day	16.3	43.1	798.5
XW17	2019.03.05		Indoor	Night	15.6	54.3	802
XW18	2019.03.05		Outdoor	Night	10.6	64.5	800.9
XW19	2019.03.06		Indoor	Day	13.5	55	803.8
XW20	2019.03.06		Outdoor	Day	9.2	81.7	799.4
XW21	2019.03.06		Indoor	Night	12.9	62.6	801.5
XW22	2019.03.06		Outdoor	Night	8.8	80.8	799.5

2.2. Quantification of PAHs

Determination of PAHs was carried out by Zhongkebaice company following the standard of the Ministry of Ecology and Environment of Peoples Republic of China (HJ 646-2013). Briefly, each sample was processed with rapid solvent extraction (Labtech, HPSE) with a mixture of hexane and diethyl ether (V:V = 9:1) for approximately 5 min under 100°C, then washed through a 60% leaching tank, purged with nitrogen for 60 s, and the extraction repeated twice. After that, the extracts were concentrated to 10 mL with a rotary evaporator (Labtech, MultiVap-8) followed by evaporation under purified nitrogen to 1 mL.

PAHs were determined using a gas chromatograph coupled with a mass spectrometer (GC-MS, Shimadzu QP2010 ultra, China) equipped with an DB-5MS capillary column (Agilent, J&W Scientific, 30 m × 0.25 mm × 0.25 µm) in the electron ionization (EI) mode. The carrier gas was high-purity helium at a flow rate of 1 mL/min. The column oven temperature program was started at 70 °C (held for 2 min) and increased by 10 °C/min to 320 °C (held for 5 min). Injector, interface, and ion source temperatures were 280 °C, 250 °C, and 230 °C, respectively. The target compounds were identified based on retention times and standard ions in the selected ion monitoring (SIM) mode. The resulting concentrations were calculated based on the peak area ratios and response factors relative to the corresponding internal standard. The field and procedural blanks were measured and subtracted from the final results of the samples. A replicate was conducted for every 10 actual samples. The method detection limits (MDLs) of PAHs were estimated from a signal-to-noise ratio of 3 and MDLs of target PAHs ranged from 0.01 to 0.08 ng/m^3.

2.3. Cancer Risk Estimates

The USEPA BaP-based equivalent concentration (BaP_{eq}, ng/m^3) was used for the overall toxicity analysis (USEPA, 2010). It is calculated as follows:

$$BaP_{eq} = \sum_{i=1}^{n} C_i \times TEF_i \quad (1)$$

where C_i and TEF_i are the mass concentrations (ng/m^3) and the toxic equivalent factor (*TEF*) of the *i*th species, respectively. The relevant *TEF* values were tabulated in Table 2.

Table 2. Toxic equivalent factors (TEFs) of individual PAHs (USEPA, 2010).

Species	BaP-Based TEF
FLT	0.001
PYR	0.001
BaA	0.1
CHR	0.1
BbF	0.1
BkF	0.1
BaP	1
IcP	0.1
BgP	0.01

The human health risk due to inhalation exposure to the PAHs was represented by the incremental lifetime cancer risk (ILCR) of inhalation exposure [32]. The ILCR was characterized by the following formula:

$$\mathrm{ILCR} = \frac{BaP_{eq} \times IR \times EF \times SF \times CF}{BW \times AT} \tag{2}$$

where IR represents inhalation rate (m^3/h), EF represents exposure frequency (day/year), SF represents the cancer slope factor for BaP inhalation exposure [30], BW represents body weight (kg), AT represents average life span for carcinogens [33], and CF represents conversion factor (mg/ng). Due to the possible uncertainties in BaP_{eq} concentrations, inhalation rates, and body weights, Monte Carlo simulation was conducted to characterize uncertainties in calculation by generating distribution of ILCR with MATLAB 10,000 times. Detailed information on the cancer risk calculation is shown in Table 3.

Table 3. Detailed information on incremental lifetime cancer risk (ILCR) [30,33].

Factor	Unit	Value
IR	m^3/h	0.83
EF	h	153,300
SF	mg/kg.day	3.1
BW	kg	70
AT	day	25,550
CF	-	10^{-6}

2.4. Source Apportionment

The diagnostic ratio method was used to identify the major sources of pollution based on the distinction between different source components [34]. These diagnostic ratios suggest an inter-source similarity, but intra-source variability [35]. In this study, the BaP/BghiP ratios were used to determine the sources of PAHs [36], with the values ranging from 0.3 to 0.44 for traffic sources, 0.9 to 6.6 for coal combustion sources, and values in between indicating a mixture of coal combustion and traffic sources.

3. Results

3.1. Mass Concentrations of $PM_{2.5}$

The indoor and outdoor $PM_{2.5}$ mass concentrations in Xuanwei are shown in Figure 2. The highest $PM_{2.5}$ mass concentration was found in the indoors of the coal-using home during the day at 149 ± 13 $\mu g/m^3$ and the lowest value was found in the outdoors of the coal-using home at night at 58 ± 15 $\mu g/m^3$. The average indoor $PM_{2.5}$ mass concentration in Xuanwei was 98 ± 10 $\mu g/m^3$, which exceeded the secondary standard limit (75 $\mu g/m^3$) of the Ambient Air Quality Standards of China (GB3095-2012).

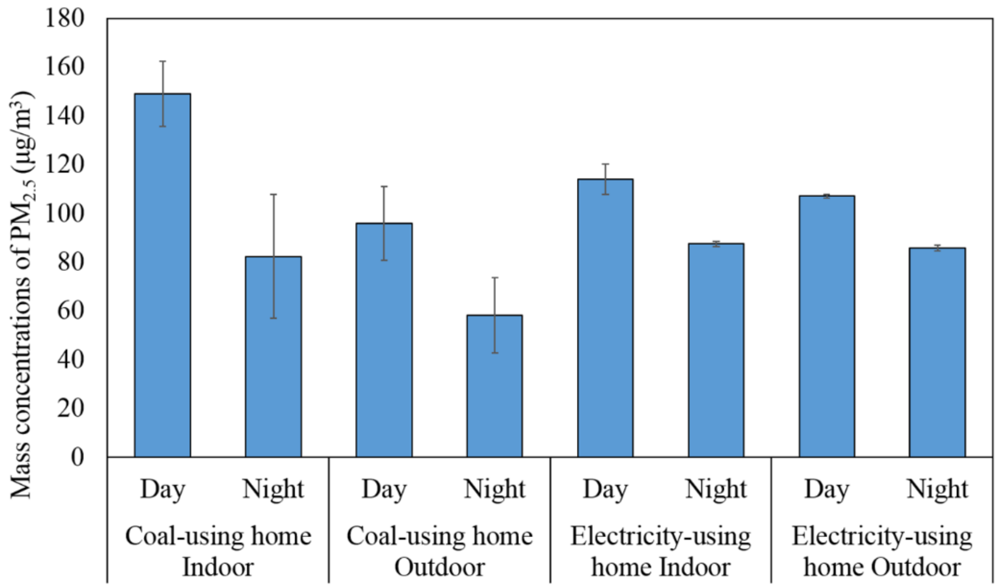

Figure 2. Average mass concentrations and standard deviation of $PM_{2.5}$ collected inside and outside the homes in the Hutou village of the Laibin town, Xuanwei city.

The ratios of indoor and outdoor $PM_{2.5}$ mass concentrations, i.e., I/O ratios, are often used to assess the relationships between indoor air and outdoor air [25]. An I/O ratio higher than 1 indicates that the indoor $PM_{2.5}$ is mainly sourced indoors, while lower than 1 indicates that the indoor $PM_{2.5}$ is mainly sourced outdoors. The I/O ratios for the coal-using home were higher than 1, ranging from 1.1 to 2.1, which indicated that indoor activities were the major source of the indoor particles. However, the I/O ratios for the electricity-using home were very close to 1. In other words, the indoor $PM_{2.5}$ mass concentrations were almost equal to that outdoors, since the electricity-using home has better ventilation and particulate matter cannot be present indoors for long.

There were also differences in $PM_{2.5}$ concentrations between daytime and nighttime. Under the same conditions, $PM_{2.5}$ concentrations were always higher during the daytime than during the nighttime, which is due to the fact that the sampling sites were located inside and outside the kitchens, which are used significantly more frequently during the day. This indicated that human activities (coal burning and kitchen fumes) were the main cause of significantly higher concentrations of $PM_{2.5}$. However, as there were no significant differences in $PM_{2.5}$ mass concentrations between the different homes ($p = 0.683 > 0.05$), it is difficult to determine the main causal factors of indoor $PM_{2.5}$ pollution in Xuanwei by concentrations alone. Therefore, further analysis of the chemical composition of the samples is required.

3.2. Mass Concentrations of PAHs

A total of eight samples were tested for the PAHs classified as priority pollutants by the USEPA using GC-MS, and their mass concentrations in air were calculated. The results are shown in Table 4. A total of 15 PAHs compounds in the Xuanwei $PM_{2.5}$ samples were detected, including naphthalene (NAP), acenaphthylene (ACY), acenaphthene (ACP), fluorene (FLR), phenanthrene (PHE), anthracene (ANT), fluoranthene (FLT), pyrene (PYR), benz[*a*]anthracene (BaA), chrysene (CHR), benzo[*b*]fluoranthene (BbF), benzo[*k*]fluoranthene (BkF), benzo[*a*]pyrene (BaP), indeno[*1,2,3-cd*]pyrene (IcP), and benzo[*g,h,i*]perylene (BgP). However, as two- and three-ring PAHs are mainly present in the gas phase under the sampling conditions, the concentrations of NAP, ACY, ACP, FLR, PHE, and ANT are not discussed in this paper.

Table 4. Average mass concentrations (ng/m^3) of PAHs in the $PM_{2.5}$ samples from homes in the Hutou village of the Xuanwei city.

Species / Samples	XW07	XW08	XW10	XW13	XW15	XW17	XW20	XW22
FLT	71	78	34	30	32	15	27	20
PYR	117	96	43	34	43	20	34	27
BaA	794	392	100	367	106	32	138	73
CHR	140	79	19	63	22	9	29	12
BbF	210	188	51	182	64	38	63	49
BkF	70	63	33	49	34	17	12	10
BaP	142	88	25	87	33	14	32	23
IcP	112	95	24	80	28	16	27	23
BgP	106	84	29	67	38	22	38	29
∑PAHs	1762	1162	356	959	399	185	399	265

The sum of the above PAH compounds was expressed in terms of ∑PAHs. The concentrations of ∑PAHs ranged from 185 to 1762 ng/m^3 with an average of 686 ± 520 ng/m^3. Among them, BaA was the compound with the highest concentration (average concentration of 413 ± 248 ng/m^3 for the coal-using home and 87 ± 39 ng/m^3 for the electricity-using home), followed by BbF and BaP. FLT was the compound with the lowest concentration for the coal-using home, accounting for 53 ± 21 ng/m^3, and CHR was the compound with the lowest concentration for the electricity-using home.

4. Discussion

4.1. Distribution of PAHs

The concentrations of ∑PAHs ranged from 185 to 1762 ng/m^3 with an average of 686 ± 520 ng/m^3. The ∑PAHs concentrations measured in this study were significantly lower than in a previous study [9] in Xuanwei (mean 1716 ng/m^3), which may be caused by the increasing number of households that choose to replace traditional coal cookers with induction cookers and the addition of indoor ventilation facilities in recent years. This proves that improving ventilation and replacing traditional energy sources can indeed be effective in reducing indoor environmental pollution [16]. However, indoor air concentrations of ∑PAHs in Xuanwei are still much higher than in other cities of China, such as Hangzhou (10 ng/m^3) [37], Beijing (20 ng/m^3) [38], and Taipei (238 ng/m^3) [39].

As shown in Figure 3, the PAH concentrations were higher in the coal-using home than in the electricity-using home, which indicates that indoor coal burning is the main source of PAH pollution. In addition, the PAH concentration was higher in the daytime than in the nighttime, which is consistent with the results of Downward et al. [40]. The daytime peak was attributed to coal combustion and oil-smoke emissions during cooking. It can be found that the difference in PAH concentrations between daytime and nighttime in the coal-using home was much greater than that in the electricity-using home, indicating that coal combustion contributes more to indoor PAH pollution than oil-smoke emissions.

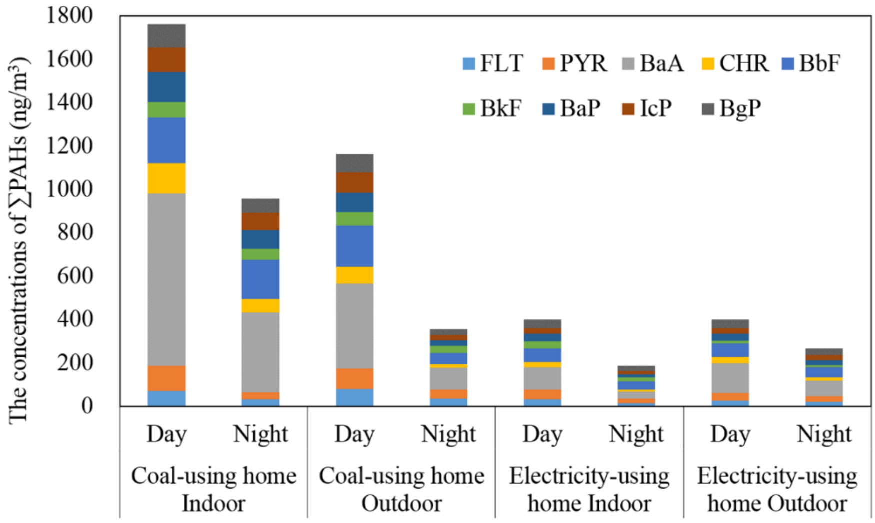

Figure 3. Mass concentration distribution of PAHs in $PM_{2.5}$ samples from the homes in the Hutou village of the Laibin town, Xuanwei city.

4.2. Source Assessment of PAHs

The PAH diagnostic ratios have been used as tracers to distinguish between various source characteristics of PAHs, such as diesel and gasoline exhausts, biomass and wood burning [34]. These diagnostic ratios suggest an inter-source similarity, but intra-source variability [35]. In this study, the BaP/BghiP ratios were used to determine the sources of PAHs [36], with the values ranging from 0.3 to 0.44 for traffic sources, 0.9 to 6.6 for coal combustion sources, and values in between indicating a mixture of coal combustion and traffic sources. As shown in Figure 4, the BaP/BghiP ratios of the coal-using home are almost all above 0.9, indicating that the PAHs are mainly emitted from coal combustion. The BaP/BghiP ratios for the electricity-using home range from 0.44 to 0.9, indicating that the PAHs have been mainly influenced by nearby road traffic sources. It is worth noting that the BaP is less stable in the presence of sunlight, and the BaP/BghiP ratio might be influenced by the length of time in the air. Especially for the samples collected outdoors during the day (i.e., XW08), the actual BaP/BghiP ratio should be slightly higher than that shown in Figure 4.

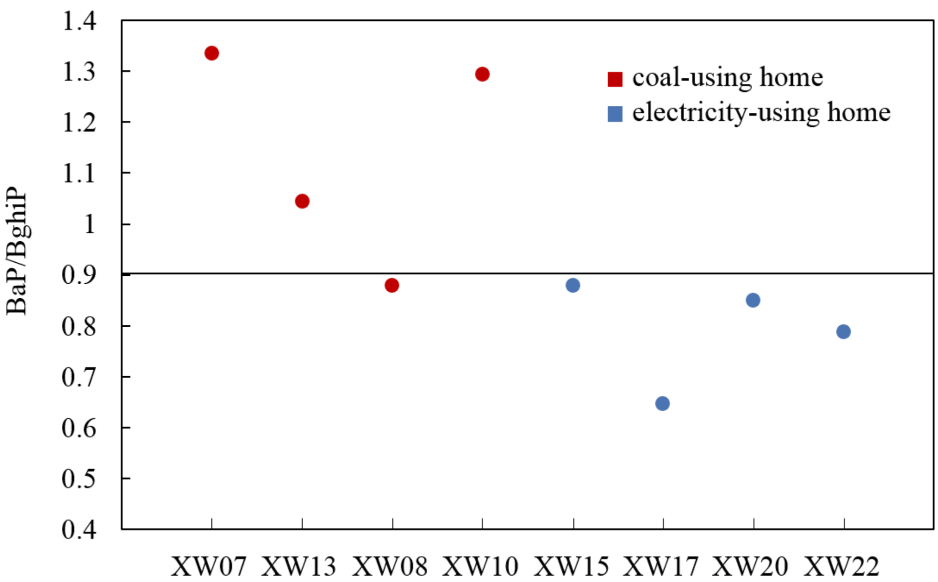

Figure 4. The BaP/BghiP ratios of samples collected from the homes in the Hutou village of the Laibin town, Xuanwei city.

4.3. Distribution of BaP$_{eq}$

Of all PAH compounds, BaP has been extensively studied for its significant and direct carcinogenicity and is commonly found attached to the surface of particles [41–43]. The measured BaP concentrations in this study ranged from 14 to 142 ng/m^3 with an average of 56 ± 45 ng/m^3, which is significantly higher than the standard limit (1 ng/m^3) of the Ambient Air Quality Standard of People's Republic of China (GB3095-2012).

To characterize the lung cancer risk of indoor PAHs in Xuanwei, the BaP was used as a representative carcinogen, and the toxic equivalents of other compounds equivalent to BaP were calculated by formula 1 to obtain the BaP-based equivalent concentration (BaP$_{eq}$) of samples.

As shown in Figure 5, the concentration of BaP$_{eq}$ was higher in the daytime than in the nighttime, higher indoors than outdoors, and higher in the coal-using home than in the electricity-using home. The concentrations of BaP$_{eq}$ ranged from 26 to 276 ng/m^3, with the average of 164 ng/m^3 in the coal-using home and 46 ng/m^3 in the electricity-using home. In comparison to other studies, the BaP$_{eq}$ in Xuanwei was found to be much higher than those in the megacities such as Beijing (43.67 ng/m^3), Shanghai (14.82 ng/m^3), and Guangzhou (9.74 ng/m^3) [44]. In addition, the BaP$_{eq}$ in Xuanwei was about eightfold that in rural northeast China where coal is also the main domestic fuel [45].

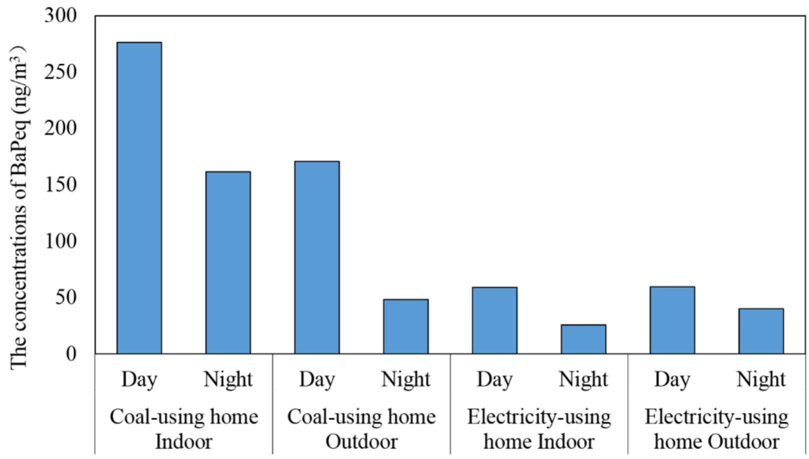

Figure 5. Distribution of BaP$_{eq}$ in the homes in the Hutou village of the Laibin town, Xuanwei city.

4.4. Lung Cancer Risk Assessment

The ILCR was calculated by formula 2 to characterize the human health risk due to inhalation exposure to the PAHs in the high lung cancer incidence area of Xuanwei. The ILCR was 48.21 × 10^{-6} indoors for the coal-using home and 9.33 × 10^{-6} indoors for the electricity-using home. According to the USEPA (2010), one in a million chance of additional human cancer over a 70-year lifetime (ILCR = 1 × 10^{-6}) is the level of risk considered acceptable or inconsequential [46]. It is seen that the ILCR in Xuanwei is much higher than the international standard of 1 × 10^{-6}.

As shown in Table 5, the ILCR of the coal-using home was much higher than the electricity-using home, suggesting that indoor coal burning poses a higher lung cancer risk. The type of coal is an important factor influencing local cancer risk [47]. The ILCR indoors in Xuanwei is about threefold that of Shanxi [48,49]. This result is consistent with Liu (2009), who characterized the PAHs from combustion of different residential coals in north China and demonstrated that indoor exposure to PAHs from bituminous coals was sevenfold that of anthracite coals [50]. Compared to other urban areas, the ILCR of Xuanwei is much higher, for example the megacities like Beijing and Tianjin, where bulk coal burning is banned [51–53]. Overall, the cancer risk in coal-burning areas is much higher than non-coal-burning areas, strongly supporting the view that indoor coal burning is a cause of the high incidence of lung cancer.

Table 5. Estimated incremental lifetime cancer risk (ILCR) in different locations.

Location	Main Fuel	ILCR ($\times 10^{-6}$)	Reference
Xuanwei	Coal	48.21	This study
Xuanwei	Electricity	9.33	This study
Shanxi	Coal	17.00	[48]
Taiyuan	Coal and electricity	15.00	[49]
Beijing	Electricity	1.00	[51]
Tianjin	Electricity	0.02	[52]

5. Perspectives

In this study, the $PM_{2.5}$ samples were collected from two homes in the Xuanwei lung cancer epidemic area to characterize the pollution levels, sources and health risk related to $PM_{2.5}$-bound PAHs. In order to better highlight the impact of coal combustion on indoor PAH pollution, farmers using a single fuel (coal or electricity) were selected for this study. Some households in Xuanwei use both coal and electricity or even biomass as domestic fuels. Therefore, the homes selected for sampling in this study only reflect a typical local living condition, and may not fully represent the pollution situation of the whole region. The exposure risk of PAHs in more households and areas of Xuanwei should be further investigated.

6. Conclusions

1. The average indoor $PM_{2.5}$ mass concentration in Xuanwei was $97.6 \pm 9.8\ \mu g/m^3$, and generally showed a pattern of being higher indoors than outdoors and higher in the daytime than in the nighttime.
2. The concentration of total PAHs in the Xuanwei lung cancer epidemic area was $686 \pm 520\ ng/m^3$, significantly lower than in other cities of China.
3. The concentrations of total PAHs, major carcinogenic compounds, and benzo[a]pyrene-based equivalent concentration (BaPeq) were significantly higher in the coal-using home than in the electricity-using home, indicating that indoor coal combustion may be the main source of PAH pollution in Xuanwei.
4. The ILCR was 48.21×10^{-6} indoors for the coal-using home and 9.33×10^{-6} indoors for the electricity-using home, which is much higher than the international standard of 1×10^{-6}.
5. The indoor cancer risk for the coal-using home is higher than that for the electricity-using home and much higher than that of Chinese megacities such as Beijing and Tianjin. Long-term exposure to indoor coal-burning environments containing high levels of PAHs may be one of the main reasons for the high incidence of lung cancer in Xuanwei.

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