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Characterization and Risk Assessment of Airborne Polycyclic Aromatic Hydrocarbons From Open Burning of Municipal Solid Waste

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In order to reveal the pollution characteristics and risk level of polycyclic aromatic hydrocarbons (PAHs) exposed to air from open burning in China, $PM_{2.5}$ samples were collected from the open burning of different types of municipal solid waste (MSW). The component of MSW differed from plastics, paper, wood and bamboo, and mixed garbage. A flue gas dilution sampling system was employed to simulate open burning testing on MSW samples from different functional urban areas. Emission characteristics and health risk assessments of PAHs in $PM_{2.5}$ were analyzed. The results showed that the 16 PAHs were detected ranged from 16.0 to 10,386.9 ngm^{-3}. The total PAH concentration of wood and bamboo wastes was the highest (24,512.1 ngm^{-3}), while that in plastics was the lowest (4,084.7 ngm^{-3}). Speciation composition of PAHs in $PM_{2.5}$ with high-molecular-weight PAHs was dominant compared to low-molecular-weight PAHs. Health risk assessment showed that the proportion of samples with the lifelong lung carcinogenic risk value greater than 10^{-6} was 68.7% of the totals, most of the PAHs in $PM_{2.5}$ had a certain risk of cancer. The speciation of Bap posed the greatest health risks to adults and children. The carcinogenic sequence of four components of wastes was as follows: wood and bamboo > mixed garbage > paper > plastics and the risk for adults was about 2.26 times higher than for children. Totally, the PAHs speciation of BaP, DBahA, BbF, IcdP, BaA, BkF, and Chr in $PM_{2.5}$ from the open burning of MSW can bring high carcinogenic risk to human health by respiratory exposure, and the risk value of adults is higher than that of children. The findings show the different conclusion with the results of related researches on the environmental effect of waste incineration power plants or incinerators. Therein, it can provide supplementary data to evaluate the impact of open burning of MSW on ambient air quality.

Keywords: municipal solid waste, open burning, polycyclic aromatic hydrocarbons, respiratory exposure, health risk assessment

INTRODUCTION

With the rapid development of urbanization and industrialization, the production of municipal solid waste (MSW) in China has increased sharply. Open burning is another waste treatment method besides landfill and composting. It is a kind of incomplete combustion under the condition of insufficient air or heat, and the whole burning process without any purification facilities and subsequent treatment (Kakareka and Kukharchyk, 2003; Cheng et al., 2020). The complex composition of MSW, including food waste, paper, rubber plastics, e-waste, and medical waste, emits hazardous and toxic species during the open burning process (Park et al., 2013; Peng et al., 2016; Sharma et al., 2019). However, due to the simple and convenient operation and the low cost of clearing and transportation, open burning is quite popular in small and medium-sized cities and fails to be prohibited (Kumari et al., 2019).

Open burning is small-scale and widely distributed, whose burning sites in cities are usually located near densely populated areas, such as residential areas, commercial areas, and areas with heavy traffic (Zhang et al., 2011; Solorzano-Ochoa et al., 2012; Lundin et al., 2013). It is reported that the annual production of MSW in China has reached more than 300 million tons, of which 30 percent is treated by open burning (Wiedinmyer et al., 2014; Wang et al., 2017). And with the increase of MSW production, the frequency of open burning is also increasing. Therefore, the impact of pollutants from open burning on the environment and humans has received urgent attention of society.

Polycyclic aromatic hydrocarbons (PAHs) are the hazardous pollutants produced by the open burning of MSW, which can be emitted from the pyrolysis or incomplete combustion of waste plastics, wood, paper, and other carbon-containing fuels (Mugica-Alvarez et al., 2015; Abdel-Shafy and Mansour, 2016; Kalisa et al., 2018). Additionally, it is reported that the PAHs released from open burning contributes to 61.0% of the total anthropogenic PAHs' emissions (Nagpure et al., 2015). PAHs are a group of semi-volatile hydrocarbons that widely exist and many PAHs are carcinogenic, teratogenic, and mutagenic (Haritash and Kaushik, 2009; Pongpiachan et al., 2015; Wang et al., 2015). PAHs can persist in the environment and accumulate in vascular plants, which can be harmful to human health for their position in the food chain (Zha et al., 2018). Exposure of PAHs can cause temporary hazards such as eye inflammation and respiratory tract irritation (Unwin et al., 2006; Shen et al., 2019), as well as long-term health effects such as lung cancer, liver damage, and cardiopulmonary death (Zhang et al., 2009). In addition, Particulate PAHs (PM-PAHs) is considered to be more harmful to human health because they are carcinogenic, teratogenic, and mutagenic, and they can be inhaled and deposited in the respiratory system (Barakat, 2003; Akhtar et al., 2014; Alessandria et al., 2014). The research found that children were more likely than adults to be exposed to air pollutants (Gautam et al., 2020).

Open burning and PAHs emission have attracted the attention of researchers of the world. Previous studies about waste burning mainly focused on the research of waste incinerator and waste incineration plant, while the research of open burning was lacked (Meng et al., 2018; Deng et al., 2020). Deng et al. (2020) sampled the air and soil collected near an urban solid waste incinerator in Shanghai, measured the concentration level of PCDD/Fs in the air and soil, and assessed the carcinogenic and non-carcinogenic risks. Meng et al. (2018) used AERMOD model to simulate the spatial distribution of pollutants released from waste incineration plants, and conducted risk assessment on respiratory exposure of pollutants such as Pb, Hg, Cd and dioxins. Compared with waste incinerator and waste incineration plant, open burning belongs to the state of open and low temperature incomplete combustion, the two have a big difference, so the study of waste incinerator and waste incineration plant can not reflect the real state of open burning. Secondly, studies on PAHs produced by open burning mostly focused on fly ash or bottom ash, and were limited to the distribution and content of pollutants. There is a lack of studies on PAHs in $PM_{2.5}$ produced by open burning of MSW and few studies on health risks caused by open burning (Peng et al., 2016; Kumari et al., 2019). Chen et al. (2013) studied the production and distribution of PAHs during open burning and incineration of medical waste. The results show that the content of PAHs in the fly ash of the incinerator is much higher than that of the bottom ash. In addition, health risks of different types of MSW have not been comprehensively studied, so this study can provide a supplement for the shortcomings of previous studies.

The PAHs produced by open burning of MSW can cause serious harm to human body. It is necessary to analyze the emission characteristics of PAHs from MSW open burning in China, and the toxic equivalent quantity (TEQ) model and the incremental lifetime cancer risk (ILCR) model are utilized to assess the toxicity and health risks of PAHs. It can provide basic data and theoretical basis for disposal plan and PAHs emission control by open burning.

MATERIALS AND METHODS

Collection and Pretreatment of MSW Samples

In this study, we selected waste paper, used plastics, waste wood and bamboo, and mixed garbage as the samples. Random sampling was carried out in the trash bins in the residential areas, commercial areas, office areas, and road cleaning areas of the city, collected once every 7 days, 4 times in total. The samples collected were dried four times and mix them naturally, then the quarter method was used to reduce the four types of garbage into samples that weighed 1 kg and were stored in a sealed container for the next incineration operation.

Small-scale open burning simulation experiments were conducted outdoors on four types of garbage samples with 12 groups, and each group of experiments was conducted with three parallel tests. The flue gas dilution sampling system was used to collect samples: After the sample was ignited, the flue gas entered the dilution channel under the action of the blower and the exhaust fan, and was connected to the $PM_{2.5}$ cutter (MiniVol TAS, AirMetrics, USA) at the end of the dilution channel. The flow rate of the dilution channel was 6 L/min. The portable particulate matter sampler sampling $PM_{2.5}$ in the flue gas was equipped with a quartz fiber filter membrane (Tissue quartz™ Filter 7,203, PALL, USA) at a time. The filter membranes were placed in the muffle furnace before sampling and were heated at 800°C for 4 h to remove carbon components, then they were weighed for use after being cooled in the refrigerator for 24 h. After the burning process, the filter membrane in the particulate matter sampler was removed, placed in a membrane box, sealed, and stored in the refrigerator.

Analysis of PAHs

According to *the national environmental protection industry standard (HJ646-2013)*, a $PM_{2.5}$ sampling filter membrane containing PAHs was cut and placed into a Soxhlet extractor, and then 60 ml diethyl ether/n-hexane (V:V = 1:9) was added to it. The extract was refluxed at a rate of more than 4 times/h for 16 h, then was removed and added to anhydrous sodium sulfate. This mixture was allowed to stand for 30 min. Approximately 30 ml of the extract was concentrated to 1 ml through K-D and filtered through an organic filter into a sample bottle. Finally, the gas chromatography-mass spectrometer (GC-MS, 7890A-5975C, Agilent Technologies, USA) was used for detection. A total of 16 PAHs were determined in $PM_{2.5}$ from the open burning of MSW: naphthalene, acenaphthylene, acenaphthene, fluorine, benzo [g, h, i] perylene, indeno [1, 2, 3-cd]pyrene, dibenz [a, h]anthracene, benzo [b]fluoranthene, phenanthrene, anthracene, fluoranthene, benz [a]anthracene, chrysene, pyrene, benzo [a]pyrene, and benzo [k]fluoranthene.

Quality Assurance and Quality Control

Before sampling with quartz fiber filter paper, the filter paper was placed in the oven for 12 h to remove moisture and impurities on the filter paper, and was weighed three times before sampling to ensure constant weight. After sampling, the filter membrane was wrapped with tin foil and stored in the refrigerator to avoid contamination of the sample. When testing samples, each sample is tested three times to reduce error. The details can be seen in our previous study (Cheng et al., 2020).

Human Health Assessment of PAHs

The Equivalent Toxicity Concentration

PAHs have attracted much attention due to their potential toxicity. Benzo [a]pyrene (BaP) was the most representative, and was used to evaluate the cancer risk of PAHs. In this study, we used the toxic equivalent quantity (TEQ) model to evaluate the potential risk of PAHs. The product of a single PAH concentration and its toxic equivalence factor (TEF) was called the equivalent toxicity concentration. In general, humans are exposed to a mixture of multiple PAHs at the same time. The total toxicity of the sample was expressed by the sum of the TEQs of the individual PAH compounds, and the formula was as follows (Sulong et al., 2019).

$$TEQs = \sum TEQ = \sum (C_i \times TEF_i) \tag{1}$$

where TEQs represents the total toxicity equivalency concentration of PAHs ($\mu g \cdot m^{-3}$); TEQ represents the toxicity equivalency concentration of individual PAH compounds ($\mu g \cdot m^{-3}$); C_i represents the concentration of PAH compound i ($\mu g \cdot m^{-3}$); and TEF_i represents the corresponding individual equivalency factor for PAH compound i and can be seen in **Table 1** (Nisbet and LaGoy, 1992).

TABLE 1 | TEF of 16 types of PAHs.

PAHs	Abbreviation	Rings	TEF
Naphthalene	Nap	2	0.001
acenaphthylene	Acy	3	0.001
acenaphthene	Ace	3	0.001
fluorene	Flu	3	0.001
benzo [g,h,i]perylene	BghiP	6	0.001
indeno [1,2,3-cd]pyrene	IcdP	6	0.01
dibenz [a,h]anthracene	DahA	5	1
benzo [b]fluoranthene	BbF	5	0.1
phenanthrene	Phe	3	0.01
anthracene	Ant	3	0.001
fluoranthene	Fla	4	0.001
benz [a]anthracene	BaA	4	0.1
chrysene	Chr	4	0.1
pyrene	Pyr	4	0.001
benzo [a]pyrene	BaP	5	1
benzo [k]fluoranthene	BkF	5	0.1

Incremental Lifetime Cancer Risk of PAHs

The ILCR model can estimate the degree of harm to human health caused by pollutants entering the human body in different ways. Respiratory inhalation, dermal absorption, and hand-to-mouth ingestion (oral ingestion) are the three pathways of human exposure (Bai et al., 2019; Roy et al., 2019). Inhalation is considered as the primary exposure path in previous studies (Chen et al., 2017; Gao et al., 2019; Zhang et al., 2020). Therefore, respiratory inhalation was deemed to be the exposure pathway of PAHs in $PM_{2.5}$ from the open burning of MSW in this study. The differences between children and adults on the respiratory rate and the biochemical response to toxic substances were considered.

The lifetime average daily dose (LADD) of PAHs in the smoke inhaled by the residents in the sampling environment (open burning sites of MSW) was calculated based on the inhalation rate, average lifetime, exposure frequency, and other parameters. Based on the LADD of PAHs, the ILCR of humans during exposure was quantified to assess the risk of cancer from long-term exposure to open burning. **Eq. 2** and **Eq. 3** are used to calculate the parameter of LADD and ILCR.

$$LADD = C \times IR \times ED \times EF / BW \times ALT \tag{2}$$

$$ILCR = LADD \times CSF \tag{3}$$

where C represents the toxic equivalent concentration of the individual PAHs (ngm^{-3}); IR represents the inhalation rate ($m^3 \cdot d^{-1}$); EF is the frequency of annual exposure ($dyear^{-1}$); ED represents the exposure duration (year); BW represents the body weight (kg); ALT is the averaging lifetime for carcinogens

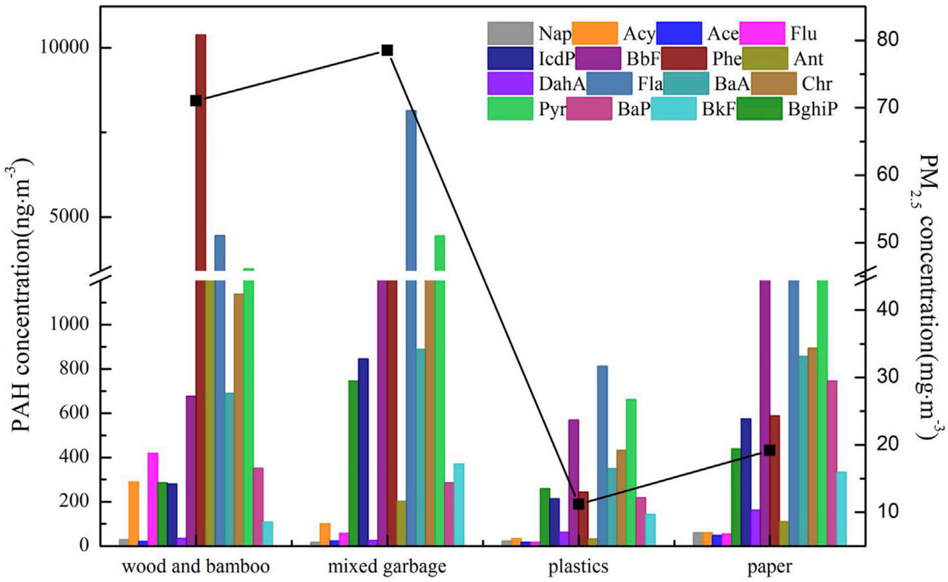

FIGURE 1 | The distribution characteristics of in $PM_{2.5}$ and PAHs concentrations from open burning of MSW.

(day); and *CSF* represents the cancer slope factor (per $mgkg^{-1}{\cdot}day^{-1}$).

RESULTS AND DISCUSSION

The Emission Feature of PAHs in $PM_{2.5}$ From Open Burning of MSW

The average concentrations of $PM_{2.5}$ generated by open burning of plastics, paper, wood and bamboo, and mixed wastes were 11.2 mgm^{-3}, 19.2 mgm^{-3}, 71.0 mgm^{-3} and 78.5 mgm^{-3}, respectively. $PM_{2.5}$ concentrations above 300 $\mu g\,m^{-3}$ in the Chinese atmosphere were defined to be serious pollution, and the concentration of PAHs produced by open burning can reached at 37–261 times of it. A large amount of garbage burning in the open inevitably leads to the increase of $PM_{2.5}$ concentration in the air, which further leads to the decrease of air visibility and increase of haze weather. The high concentration of fine particles also provided sufficient carriers for PAHs generated during the burning process, allowing more PAHs to be absorbed in $PM_{2.5}$ and subsequently enter the ambient air.

The variation of PAH contamination in $PM_{2.5}$ produced by the open burning of four kinds of MSW was shown in **Figure 1**. All 16 priority PAHs of the United States Environmental Protection Agency (US EPA) were detected in the waste samples during the open-burning. The concentration of 16 individual PAH compounds in plastics, paper, wood and bamboo, and mixed garbage was in the ranges of 16.0–812.6 ngm^{-3}, 47.2–1,624.34 ngm^{-3}, 20.3–10,386.9 ngm^{-3}, and 16.2–8,146.8 ngm^{-3}, respectively. The highest ΣPAHs mean concentration happened in wood and bamboo wastes with an average value of 1,532.0 $ng\,m^{-3}$, and followed by mixed garbage (1,399.6 ngm^{-3}), paper (582.8 ngm^{-3}), and plastics (255.3 ngm^{-3}). Phe from the open burning of wood and bamboo was the highest concentration of the individual PAH compounds, which was 42.4% of the total concentration of PAHs produced by wood and bamboo. The concentration of PAHs in wood and bamboo wastes fluctuated greatly, and Ace was the lowest PAHs in wood and bamboo wastes, which was only 20.3 ngm^{-3}. The concentration trend of 16 PAHs produced by the open burning of paper wastes was as follows: Fla > Pyr > BaA > Chr > BbF > BaP > Phe > IcdP > BghiP > BkF > DahA > Ant > Nap = Acy > Flu > Ace. Fla was the highest concentration of PAHs produced by mixed garbage, which can reach 8,146.8 ngm^{-3}. The concentrations of PAHs during the open burning of plastic wastes were significantly lower than those of the other three types of MSW. The variation trend of PAHs concentration in plastic garbage was basically similar with that in paper garbage, but the concentration of PAHs produced by plastic garbage was less than twice that of paper garbage. The reason for this was that plastic garbage contains high-density plastics such as beverage bottles, and it was difficult to achieve full combustion due to insufficient oxygen in the burning process, resulting in the presence of corresponding pollutants in the combustion bottom ash. Totally, the concentrations of PAHs produced by the four types of wastes varied greatly, while the variation trends were generally similar.

Studies have shown that the average concentration of PAHs in atmospheric particulates in Chinese cities was 3.3–910.0 ngm^{-3}, and the annual average concentration was 74.0 ngm^{-3}. The concentration of PAHs produced by the open burning of urban household garbage far exceeded the concentration of PAHs in urban air. It was difficult to ignore the contribution of open burning of MSW to the atmospheric environment. It is well known that PAHs bound by fine particulate matter can only be removed by atmospheric dry and wet precipitation and rainfall after they enter the atmospheric environment. Therefore, it is necessary to control the occurrence of open burning at the source. Although open burning has been banned in China, many cities still have the phenomenon of "knowing the law and breaking the

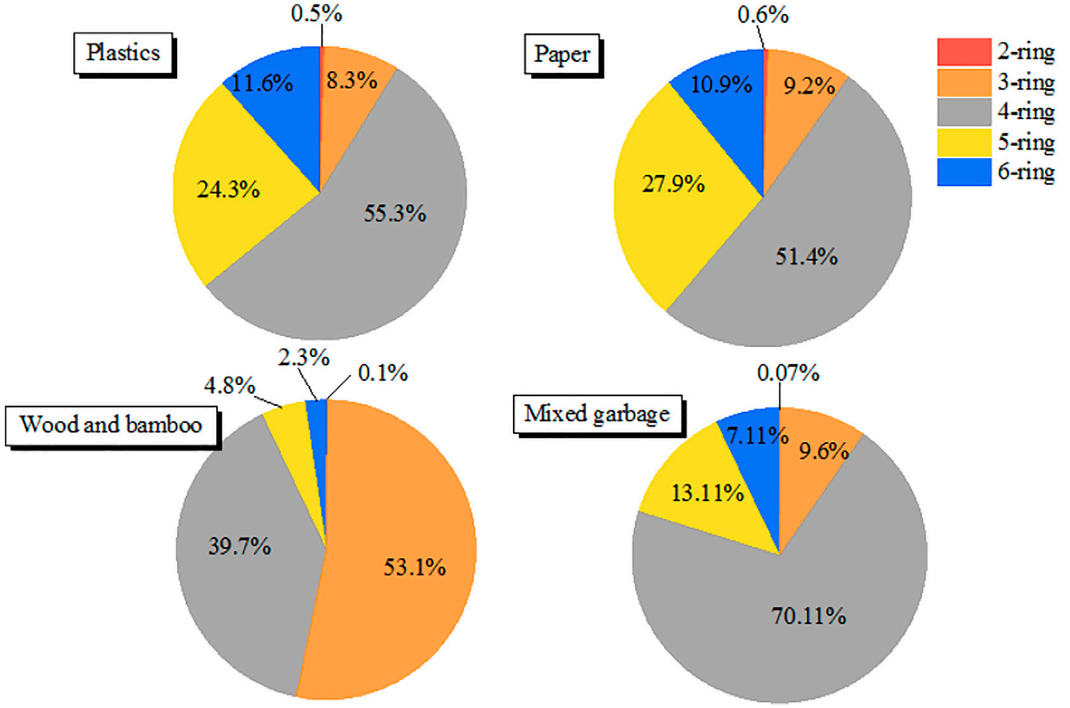

FIGURE 2 | The ring PAHs at different components of waste during open burning.

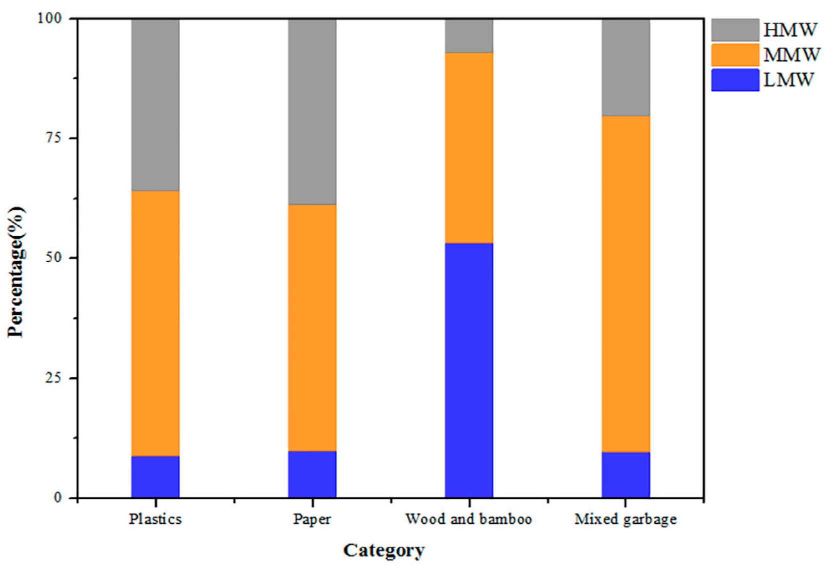

FIGURE 3 | The ratio of LMW, HMW, MMW of PAHs in different waste components during open burning.

law", which requires the state and local authorities to strengthen the control of it.

Speciation Composition of PAHs in $PM_{2.5}$

According to the number of aromatic rings and molecular weight, the 16 PAHs could be classified into three types: low-molecular-weight PAHs (LMW-PAHs, 2,3-ring), median-molecular-weight PAHs (MMW-PAHs, four rings), and high-molecular-weight PAHs (HMW-PAHs, ≥5 rings). **Figure 2** shows the distribution characteristics of PAHs according to their number of rings. For plastics, the order of PAHs with different rings based on their proportion was: four rings (55.3%) > 5 rings (24.3%) > 6

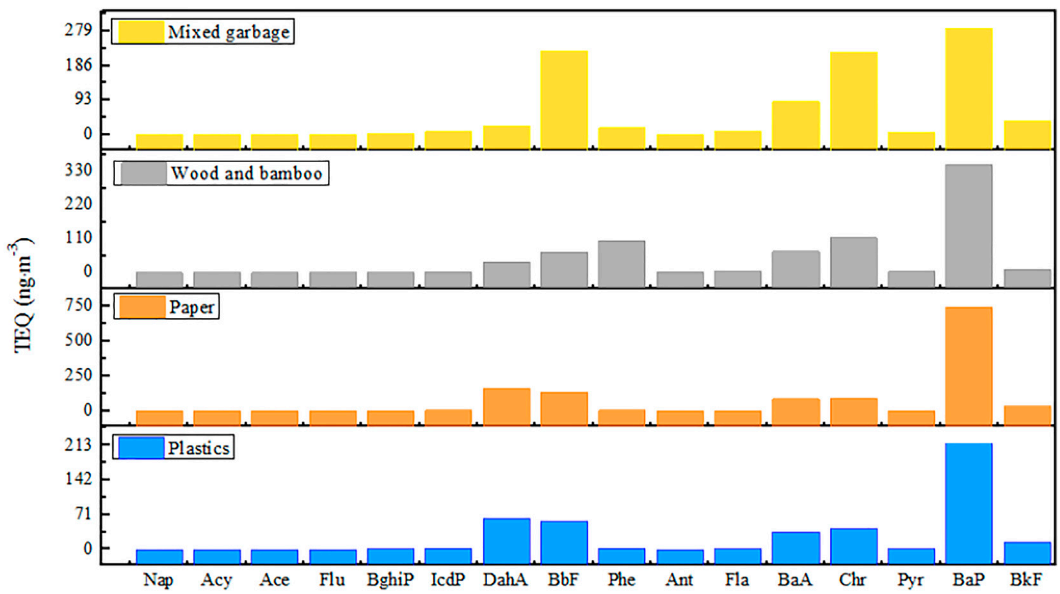

FIGURE 4 | The distribution characteristics of TEQ of PAHs.

rings (11.6%) > 3 rings (8.3%) > 2 rings (0.52%). Paper was similar to plastics in terms of the number of rings with the four rings accounting for the largest proportion (51.4%) and five rings accounting for 27.9%, while the proportion of PAHs with other ring numbers was lower than that in plastics. The proportions of PAHs with rings in mixed garbage and plastics were slightly different. Among the mixed garbage, the 4-ring was dominant, and its proportion reached 70.1%. The proportion of PAHs with three rings was higher than that with six rings, and the proportion of PAHs with two rings was only 0.07%. For wood and bamboo, 3-ring PAHs accounted for the most (53.1%), followed by the 4-ring (39.7%), 5-ring (4.8%), 6-ring (2.3%), and 2-ring (0.12%) PAHs.

The composition of different molecular weights in the four categories of MSW can be seen in **Figure 3**. The ratios of LMW, MMW, and HMW were respectively 1.0:6.2:4.1 for plastics, 1:5.2: 3.9 for paper, 7.5:5.6:1.0 for wood and bamboo, and 1.0:7.3:2.1 for mixed garbage. MMW-PAHs were predominantly presented in plastics, papers, and mixed garbage, whereas wood and bamboo mainly contained LMW-PAHs. Generally, HMW-PAHs were dominant compared to LMW-PAHs during the open burning of MSW, which was similar to the phenomenon that the flue gas released from MSW incineration power plant were mainly MMW-PAHs and HMW-PAHs with low proportion of LMW-PAHs (Wang et al., 2006). The reason for this phenomenon was that PAHs with two to three aromatic rings were mainly in the gas phase, while PAHs with more than four rings were mainly adsorbed by solid particles. The open burning of MSW is a mode of incomplete combustion under the condition of insufficient air. Therefore, most of the polycyclic aromatic hydrocarbons produced by open burning are high polycyclic aromatic hydrocarbons. Compared with other components of MSW, the burning of wood and bamboo is more complete, which can cause the higher proportion of LMW-PAHs.

Health Risk Assessment of PAHs Emission From Open Burning of MSW

In previous studies, BaP was widely used as the carcinogenicity indicator to evaluate cancer risk, because it was regarded as Group 1 carcinogenic agent by the International Agency for Research on Cancer (IARC). On that basis, TEFs have been established by taking BaP as a toxic benchmark to calculate the TEQs of PAHs. The order of TEQs of the PAHs produced by the four types of MSW was: paper > mixed garbage > wood and bamboo > plastics. The TEQs of paper reached up to 1,266.8 ngm^{-3}, and those of mixed garbage, wood and bamboo, and plastics were 924.3, 763.8, and 437.4 ngm^{-3}, respectively.

The TEQ calculated from the TEF for the 16 types of PAHs in the $PM_{2.5}$ from the open burning of four types of MSW can be seen in **Figure 4**. Among the four types of wastes, the average TEQ value of PAHs was 27.3 ngm^{-3} for plastics, 79.2 ngm^{-3} for paper, 47.7 ngm^{-3} for wood and bamboo, and 57.8 ngm^{-3} for mixed garbage. For plastics, the TEQ trend of the 16 PAHs was as follows: BaP > DBahA > BbFA > Chr > BaA > BkF > Phe > IcdP > Fla > Pyr > BghiP > Acy > Ant > Nap > Ace = Flu. Among them, BaP as the main contributor, its equivalent toxicity reached 218.1 ngm^{-3}, and the contribution rate reached 49.9%. The TEQ trend of PAHs from the burning of paper was the same as that of plastics, but the value was about 3 times that of plastics. From 0.02 to 351.2 $ng\,m^{-3}$ was the range of TEQ of wood and bamboo. It was worth noting that 4-ring and 5-ring PAHs were the main contributors to the toxicity of wood and bamboo, and their contribution rates were 25.0% and 60.7%, respectively. Chr and BbF in mixed wastes were much

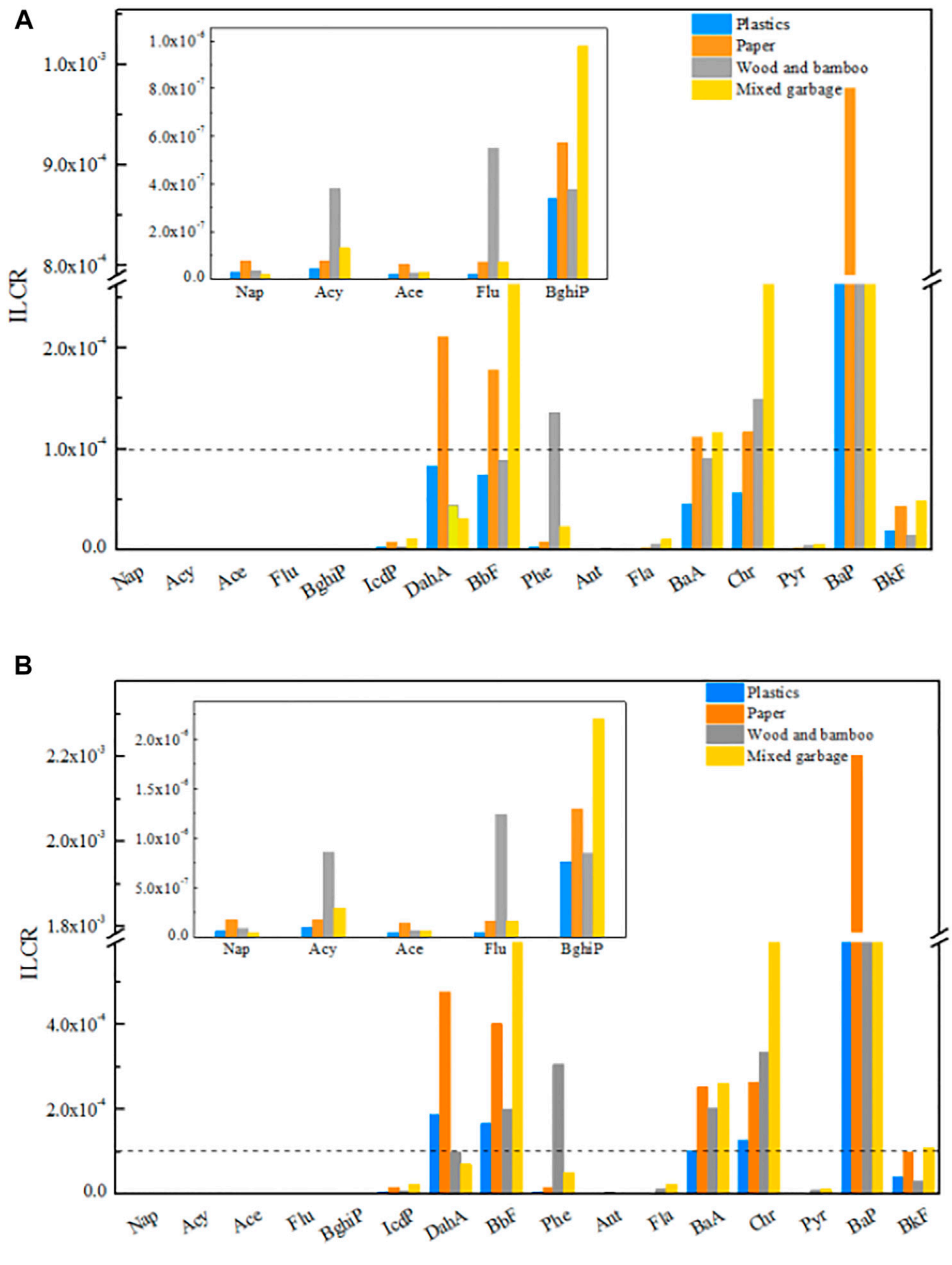

FIGURE 5 | Health risks of individual PAHs: **(A)** Children; **(B)** Adult.

higher than the other three components, and the sum of the two accounted for 48.5% of the TEQs. The component of MSW had an obvious impact on the toxicity of PAHs generated by the open burning of MSW. The TEQ of the three PAHs (Bap, BbF, Chr) accounted for a relatively high percentage of total TEQs in the four samples, which were 47.2%, 14.3%, and 13.8%, respectively.

Assessment of Lifelong Lung Carcinogenic Risk (ILCR)

The health risks of PAHs in $PM_{2.5}$ from open burning to adults and children were shown in **Figure 5**. In general, the less than or equal to 10^{-6} ILCR value indicated that there was no cancer risk or it could be negligible. And the ILCR between 10^{-6} and 10^{-4} means a certain potential carcinogenic risk in humans, but the value was still in the acceptable range for humans. If the ILCR was larger than 10^{-4}, it indicated a serious threat to human health. The carcinogenic risks of $\sum_{16}$PAHs from the open burning of plastics, paper, wood and bamboo, and mixed wastes for adults by inhalation exposure were 1.3×10^{-3}, 3.7×10^{-3}, 2.3×10^{-3} and 2.7×10^{-3}, respectively, all of which were 2.3 times higher than those for Children (5.7×10^{-4}, 1.7×10^{-3}, 1.0×10^{-3}, 1.2×10^{-3}). In this study, the ILCR values of PAHs were between 10^{-8} and 10^{-3}. The proportion of samples with the ILCR value greater than 10^{-6} was 68.7% of the total, while the parts with the ILCR value greater than 10^{-4} accounted for 25.8%. The result showed most PAHs in $PM_{2.5}$ generated by the open burning of MSW had a definite carcinogenic risk. Moreover, adults were more likely to develop cancer through respiratory exposure than children.

The ILCR values of 16 PAHs from the open burning of paper wastes for the respiratory exposure of children varied from 2.1×10^{-8}–9.8×10^{-4}, with Bap has the highest risk. The rank order of ILCR values of 16 individual PAHs from plastic burning was Bap > DahA > BbF > Chr > BaA > BkF > Phe > IcdP > Fla > Pyr > BghiP > Acy > Ant > Nap > Flu > Ace. BaP, DahA, BbF, Chr, and BaA from plastics had obvious carcinogenic risks to adults, and only Bap had obvious carcinogenic risks to children. BaP, DahA, BbF, Chr, and BaA were also PAHs with obvious carcinogenic risks produced by paper. Different from plastics, their risks to adults and children were greater than 10^{-4}. The ILCR value of BaP in wood and bamboo for adults was as high as 1.0×10^{-3}, which was higher than 10^{-4} and obviously unsafe for humans. In addition, Phe was also a kind of PAH produced by wood and bamboo with obvious carcinogenic risk. Bap > BbF > Chr > BaA > BkF > DahA > Phe > IcdP > Fla > Pyr > BghiP > Ant > Acy > Flu > Ace > Nap was the sort of PAHs produced by mixed wastes according to ILCR value. The health risk values of the first 11 PAHs have exceeded the human health threshold (10^{-6}). Overall, the five types of PAHs (Bap, BbF, Chr, BaA, BkF) from the open burning of plastics, paper, wood and bamboo, or mixed MSW had certain cancer risks in humans. Comparatively, current researches mainly focused on the emission and environmental effect of waste incineration power plants or incinerators, and the research results showed that the carcinogenic and non-carcinogenic risks of environmental exposure to pollutants were at an acceptable level for the surrounding residents (Meng et al., 2018; Deng et al., 2020). However, the findings of our study show an opposite conclusion, which can provide data and scientific basis for clarifying the impact of open burning of MSW on ambient air quality and evaluating its potential health risks. This study only considered the health risks of exposure pathway of direct respiratory intake, while the routes of skin contact and oral intake were not included tentatively. By integrating the comprehensive exposure pathways, the risk assessment results will be more accurate.

CONCLUSION

In summary, our study illustrated emission characteristics and corresponding health risk assessment of PAHs in $PM_{2.5}$ from the open burning of MSW in China. We observed an obvious variation of the content of PAHs in $PM_{2.5}$ from the open burning of different types of MSW. The total concentration of 16 PAHs produced by the open burning of mixed wastes was higher than that of wood and bamboo, followed by paper and plastics. The ring number distribution of PAHs also varied with different garbage components. According to the health risk model, partial PAHs generated from the open burning of MSW were carcinogenic to the surrounding residents with respiratory exposure. And the carcinogenic risk of PAHs through respiratory exposure for the adult group was higher than those for the children group. The prevention and control actions are highlighted to be conducted to reduce and even eliminate the open burning of MSW. Furthermore, more investigations focusing on the pollutants in the diverse environmental medium like soil and water around the places with frequent open burning of MSW are called for in the future, so as to help manage the public health risks in response to regional air pollution.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

KC: Data curation, Writing-Original draft preparation. JL: Conceptualization, Methodology. YW: Data curation, Investigation. WJ: Software, Validation. YC: Writing-Reviewing and Editing.

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