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Understanding exposure risks of women and children to PAHs in biomass using households of Brahmaputra valley

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ABSTRACT

Introduction: Biomass burning is a principal contributor of Polycyclic Aromatic Hydrocarbons (PAHs) in the air. A vast majority of rural households in South Asia are still using crude biomass fuel in kitchens causing poor air quality. This pushes the children and women population to severe exposure risk. In this work, 14 PAHs out of 16 priority PAHs of the United States Environmental Protection Agency (USEPA)-bound to Biomass Fuel Smoke Particles (BFSPs) produced during burning various crude biomass fuels in rural kitchens had been characterized.

Materials and methods: Representative rural households were taken for this study. Two sets of samples were collected during dry and wet periods using filter paper by a passive collection method and analyzed by High Performance Liquid Chromatography (HPLC).

Results: PAHs with even number of rings (2-ring and 4-ring PAHs) dominated the Biomass Fuel Smoke Particles (BFSPs). PAH contents in BFSPs of the wet period were higher than the dry period samples. Different PAH ratios differed from reported studies on ambient atmosphere particulates and test environment. Higher Incremental Lifetime Cancer Risk (ILCR) values were found during the wet period compared to the dry period in most BFSPs. The risk via ingestion and dermal contact was about 10^4 to 10^5 magnitudes higher than the inhalation risk.

Conclusion: The study reported seasonal variation of PAHs from biomass fuels and associated health risks to the exposed population. The higher levels of PAHs and the associated health risks may pose significant risks to the exposed women and children.

Introduction

Biomass burning of various forms is one of the critical issues linked to the air quality [1-5]. The smoke released from domestic solid fuel burning reduces indoor air quality, increase inflammatory reaction, and oxidative stress [6], and also contribute to different

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acute and chronic health problems, including cardiovascular disease, respiratory infections, lung disease, reduced childbirth, etc., which has been documented well [7-8]. Biomass burning releases a vast spectrum of pollutants, and researchers endorsed the household cooking process as being the most significant donor to the carcinogenic activity of indoor air [9]. Combustion of poor-quality fuels like biomass of various types and improper burning conditions provided by inefficient cooking stoves produce various small soot harmful pollutants of which particles can enter deep into the lungs [10].

The Polycyclic Aromatic Hydrocarbons (PAHs), known for their carcinogenic effects on humans [11], make major constituents of biomass smoke. Besides carcinogenic, many of them are genotoxic, mutagenic and teratogenic [12-13]. A significant amount of outdoor PAHs come from biomass burning [14]. Researchers established that biomass burning in the residential/commercial sector (60.5%), biomass burning in an open field (13.6%), and burning of petroleum-based fuel motorized vehicles (12.8%) contribute significantly to the total global emission of PAHs (504 Gg/year) [15]. An earlier study reported that biomass burning had contributed to over 90 and 60% of total PAH emissions from two countries, India and China, respectively [16]. More so, in developing countries like China, Indonesia and India, indoor emissions from biomass burning contribute more than 50% of atmospheric PAHs [15]. One of the significant factors regarding exposure to PAHs is cooking [17]. An increase of PAHs by 74 and 77% for Particulate Matter less than 2.5 and 10 μm ($PM_{2.5}$ and PM_{10}) individually during the cooking period over non-cooking periods in kitchens using biomass fuel was reported [18]. There are several simulated studies on the emission of PAHs from different classes of biomass fuel burning from India and elsewhere [19-23]. There are studies from China in simulated test kitchens on the PAHs emission from various kinds of fuel used by the rural population of China [24-25]. Very high exposure of PAHs and Particulate Matter (PM) was reported in poorly ventilated houses [18].

There are numerous studies on PAHs concentration and related health risks in different indoor, outdoor as well as simulated environments throughout the world [9, 17, 26-32]. Different factors influence PAHs concentration and the associated health risk. Levels of PAHs depend on the prevailing meteorological conditions [14, 33]. A study found that carcinogenic potency and excess cancer risk of PAHs were higher during winter than the summer [32]. Ventilation and the occupancy rate of an indoor environment are closely associated with PAHs level [30]. It is noticeable that the health risk may vary in different areas of an indoor environment [26].

The majority of South Asia's rural population is still using dirty biomass fuel in poorly ventilated kitchens equipped with rudimentary mud cookstoves [34]. India is among such countries where people mainly depend on unprocessed solid biomass fuel in poorly ventilated conditions which increases the hazard risk of the low-income strata of the society [29, 35]. Especially women are directly exposed to biomass smoke. The openness of the kitchen plays a significant role in the potential health impact of rural women from biomass smoke exposure [35]. Despite government initiatives, the conditions of kitchen air have not changed due to non-affordability of better-quality wood and stove and the well-ventilated house of the rural poor. Otherwise, it is known that the proper functioning of burning stoves, well ventilation of kitchens, and alternative cleaner fuels could make the condition less vulnerable and hazardous [36].

One study had reported the elements, ions, and carbon present in the Biomass Fuel Smoke Particles (BFSPs) collected from biomass burning in rural kitchens of mid Brahmaputra Valley, which are different from the

characteristics of ambient particulate matter [34]. In a similar study, characterization of elements, ions, carbon, and PAHs in particulate deposits and ashes in households of Nepal was conducted and compared these compositions with particulates of outdoor deposits [37]. Significant differences were reported in PM (PM_1, $PM_{2.5}$, PM_{10}) concentrations among biomass using different community households of mid Brahmaputra valley [35]. The concentrations of PM were much higher in biomass using households than the Liquid Petroleum Gas (LPG) users. The present study was taken to characterize the PAHs in BFSPs emitted from crude biomass fuel burning of various types in actual burning conditions in traditional rural kitchens. Health risk assessment posed by the PAHs contents in the particulates has been calculated and presented.

Materials and methods

Sampling site

The study was performed in the Sonitpur district of Northeast India. Four representative villages– Na-pam, Amola Pam, Rupkuria and Bhaluk Jharani were chosen surrounding Tezpur University campus, geographically located at 26°37′ N; 92°50′ E (Fig. 1). The participating households were chosen based on a pilot survey. The households selected for the present study had similar characteristics like women were the main cook, cooking at least two meals a day and absence of smoking members. The village population from different cultural lineages inhabit these villages. Sonitpur district has a population of over 1.7 million, with 89% rural population according to the 2011 Census, government of India.

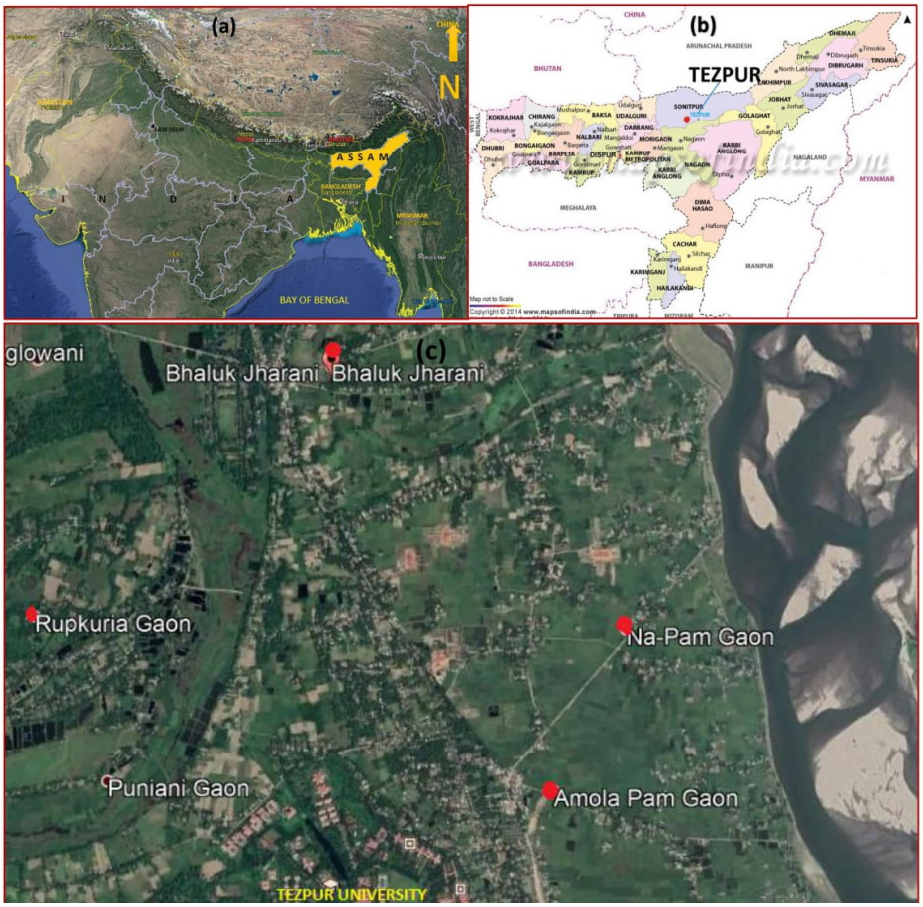

Fig. 1. Map of the study area. a) India showing Assam in yellow color; b) Assam showing Tezpur in the northern bank of Brahmaputra river, c) 4 sampling villages (here, Gaon stands for village in local language, Assamese)

Sampling of biomass fuel smoke particles (BFSPs)

A pilot survey was conducted to select representative households using different biomass fuels for cooking. Twenty families from 4 villages (5 houses/village) were approached to participate in the study, and 14 of 20 households agreed and allowed sampling in their respective kitchens. Two characteristic seasons; dry (from December 2010 to February 2011) and wet (from June to September 2011), were taken for the study, and consequently, collections of BFSP samples were done during these periods. Whatman glass fiber filters (exposed area of 133 in^2) in a wooden frame were secured to the roof above the cooking place to collect the smoke particles. Twenty-eight samples (2 from each participating kitchen) were taken for the present study. Deposited samples were collected in an aluminium foil using a stainless-steel spatula and then stored at 4°C until further sample preparation.

The BFSPs produced from burning various biomass fuels have been abbreviated after the respective biomass fuel, namely, cow dung fuel stick by CD, Mixed Biomass Fuel by MBF, Cow Dung and Mixed Biomass Fuel by CDMBF, Sugarcane Bagasse by SCB. The dry and wet periods samples were represented by letters D and W, respectively, after the specific abbreviations.

Analyses of PAHs

The PAHs were extracted from an aliquot of BFSPs by ultrasonication in dichloromethane (at 20 kHz for 20 min.). This extract was subsequently filtered and reduced to 0.5-1 mL using a rotary evaporator (Hahnshin Scientific Co.) and cleaned up in a Silica gel column (USEPA method 3630C). Elute was reduced to 0.5-1 mL, and the solvent was exchanged with acetonitrile, the volume adjusted to 2 mL, and kept at 4 ºC till further chromatographic analysis [38].

The estimation of PAHs was performed in an HPLC system of waters, USA. The HPLC system has a PAH C18 column (symmetry C^{18}, 4.6 x 250 mm, waters) and a UV detector for separating the species with good resolution and intelligent detection. A reverse-phase protocol with a gradient of acetonitrile vs ultrapure water was adopted to separate the target PAHs in the HPLC column. Further identifications of the target PAHs were achieved by matching their retention times with a chromatogram of a standard PAH mixture (EPA method 610 Polynuclear Aromatic Hydrocarbon 16 solutions in acetonitrile, procured from Supelco, USA). Fourteen PAHs were quantitatively measured. The measured PAHs are Naphthalene (NAP), Acenaphthylene (ACY), Acenaphthene (ACE), Fluorene (FLU), Phenanthrene (PHE), Anthracene (ANT), Fluoranthene (FLA), Pyrene (PYR), Benzo[a] anthracene (BaA), Chrysene (CHR), Benzo[b] fluoranthene (BbF), Benzo[k]fluoranthene (BkF), Benzo[a]pyrene (BaP), and Dibenzo[a,h] anthracene (DBA) (Table 1).

Quality assurance/quality control

The glassware was prewashed in chromic acid, followed by repeated rinsing with acetone and drying in an oven. Amber color glass vials (Sigma-Aldrich) were used to store the extracts until analyzed to minimize PAHs loss. All the reagents used during preparation and analysis of samples were of HPLC grade procured from Merck. For the measure of accuracy, internal standards were spiked into the samples and blanks before extraction of PAHs. The internal standard mixture has naphthalene-d_8, acenaphthene-d_{10}, phenanthrene-d_{10} and chrysene-d_{12} (Supelco, Bellefonte, USA) and an average recovery of 68±27% (naphthalene-d_8), 67±1% (phenanthrene-d_{10}) and 101±16% (chrysene-d_{12}) were observed. Replicate analyses of samples were performed for some samples, and the uncertainty of measurement was within ±10%. Volatilization loss of low molecular weight PAHs could not be prevented during sampling. However, samples were taken good care of after collection to minimize the loss.

Table 1. Levels of PAHs (µg/g BFSP) in different BFSPs (ND: not detected)

PAHs	CD	MBF	CDMBF	SCB
NAP	93.95±146	50.32±45	117.21±157	20.76±20
ACY	32.81±37	43.99±32	23.83±20	28.17±40
ACE	1.45±1	1.70±3	ND	ND
FLU	6.93±5	7.96±5	6.52±5	5.37±7
PHE	50.39±73	72.82±93	127.50±177	40.53±48
ANT	86.26±85	38.87±36	86.79±94	31.95±44
FLA	240.17±106	113.86±86	190.23±175	162.45±180
PYR	93.74±47	27.64±23	50.74±56	44.47±28
BaA	123.45±86	155.27±110	84.08±54	75.46±94
CHR	91.70±27	44.41±46	128.68±24	65.00±87
BbF	15.28±13	19.45±13	14.41±16	23.90±9
BkF	4.95±3	3.61±5	30.08±7	10.56±15
BaP	2.55±1	2.58±3	9.07±3	5.38±2
DBA	8.35±3	2.55±2	20.26±11	13.77±3
$\sum_{14}$PAHs	851.98±632	585.02±501	889.40±799	527.78±578

Results and discussion

Concentration profile of PAHs

Table 1 presents average concentrations of 14 PAHs. Fluoranthene, BaA, PHE, and CHR were the major contributing PAHs in all BFSPs. Fluoranthene was found to be maximum in CD, CDMBF and SCB, and BaA in MBF. In a similar study, CHR dominance in indoor particulates of biomass using kitchens was reported [37]. Previous studies have also reported the dominance of lower molecular weight PAHs from biomass burning particulates [21, 24]. The dominance of FLA, PYR, and BaA from different biofuel burning was reported in a chamber study [21]. PHE, FLA, FLU, and PYR were the principal PAHs in the particulate phase emitted from burning crop

residue [24]. The dominance of PHE, ACY, FLA, and PYR was reported from the combustion of different solid fuels in rural cooking stoves in China [25]. A predominance of ANT, FLA, PYR, BaA, and CHR from biomass fuel burning (fuelwood, dung cake and crop residue) from a laboratory experiment was reported [20]. FLA, PYR, BaA, CHR, BbF, and BaP were the major constituents of PAHs emitted from all kinds of biomass fuels in another laboratory experiment from India [39].

International Agency for Research on Cancer (IARC) had included BaP in the list of carcinogenic PAHs to humans [40]. Exposure to PAHs, particularly BaP, can cause immune suppression in humans and animals [39]. As per biomass burning and BaP is concerned, 1 mg of BaP is emitted from every kilogram of wood burnt [41]. We recorded a maximum average BaP concentration in CDMBF (9.07±3 µg/g BFSP) followed by the concentrations in SCB, MBF and CD (5.38±2, 2.58±3 and 2.55±1 µg/g BFSP, respectively).

The maximum average ∑PAH14 concentration was recorded in CDMBF (889.40±799 µg/g BFSP) followed by the concentrations in CD, MBF, and SCB (851.98±632,585.02±500 and 527.78±578 µg/g BFSP, respectively). The difference in concentrations of PAHs in the cases of CDMBF and CD was not much. However, concentrations of PAHs in MBF were much lower than in CD. So, much of the contribution of PAHs in CDMBF could be from cow dung fuel sticks burning in the kitchens. Previous researchers [20] also reported maximum PAHs from cow dung followed by fuelwood and crop residue due to smoldering phase burning in a simulated biomass burning condition, which would enhance pyrolysis resulting in more formation of PAHs [42]. A higher emission of PAHs for dung cake and briquette fuel than wood burning in a simulated biomass burning condition was reported [21]. Similarly, maximum PAHs emissions from dung cake followed by firewood, coal, LPG, and kerosene was reported in a study [29].

The concentrations of PAHs were compared with data reported from biomass burning in simulated cooking environments to see the concentration differences (Table 2). Compared with ambient atmospheric $PM_{2.5}$ bound PAHs during biomass burning period [43], concentrations of PAHs of the present study were much on the higher side except BaP. Most biomass burning vis-à-vis PAHs emission experiments provide emission factors against respective biomass. Remarkably, Particle Emission Factors in the actual cooking condition are over three times greater than laboratory simulated experiments [44].

Periodic variations and ring-number wise distribution of PAHs

Fig. 2 presents the concentrations of PAHs in respective BFSPs during two different periods of the year. Baring SCB, concentrations of PAHs in different BFSPs were found to be maximum in the wet period (Fig. 2a). This would mean that the wet period BFSPs could be incrementally formed from incomplete combustion of biomass fuel, which are moisture laden and undergo smoldering, thus enhancing the ease of PAHs formation during combustion [45, 46]. More toxic particle generation under incomplete combustion compared to complete combustion was found [5].

Interestingly, PAHs with the even number of rings were comparatively greater in abundance than odd number ring PAHs. The dominance of 4-ring PAHs followed by 2-ring, 3-ring and 5-ring PAHs were observed (Fig. 2). More concentrations of high molecular weight PAHs (4-6 rings) than the low molecular weight PAHs (2-3 rings) during the wheat-residue and paddy-residue burning period in the Indo-Gangetic Plain of India was reported [47]. In a chamber experiment, higher emissions of 4-6 ring PAHs (BbF, BkA, BaA, FLA, CHR, BaP and DBA) from dung cake burning and 3-4 ring PAHs (PHE, ANT, PYR, FLA and BaA) from the combustion of crop residue and fuelwood was reported [20]. The 6-ring PAHs were not analyzed in this study, yet would this be an interesting aspect to understand the greater ease of formation of even ring PAHs in the biomass combustion process.

Table 2. Concentration of PAHs in particulate from various combustion sources reported by other researchers elsewhere

PAHs	Paddy residue [43]	Wheat residue [43]	Dung cake [43]	Fuelwood [20]	Crop residue [20]
NAP	1.5	28.3	0.48	2.33	1.57
ACY	0.4	3.5	0.27	1.78	0.61
ACE	0.4	0	0.83	0.96	1.29
FLU	0.4	0	0.08	1.36	0.52
PHE	1.5	49.5	2.66	3.6	6.9
ANT	0.4	14.1	5	4.65	5.28
FLA	4.1	81.3	4.38	8.92	8.1
PYR	4.9	84.8	3.84	10.92	6.14
BaA	5.6	21.2	5.32	9.28	5.08
CHR	-	-	7.78	2.78	2.36
BbF	-	-	8.92	2.47	1.74
BkF	-	-	8.34	2.02	Nd
BaP	19.4	102.5	3.42	2.3	1.68
DBA	4.1	17.7	3.96	Nd	Nd
∑PAHs	-	-	55.28	53.37	41.27

[43]: (values converted to µg/g $PM_{2.5,}$ ambient measurement during biomass burning period)
[20]: (µg/g fuel emission factors, test environment)

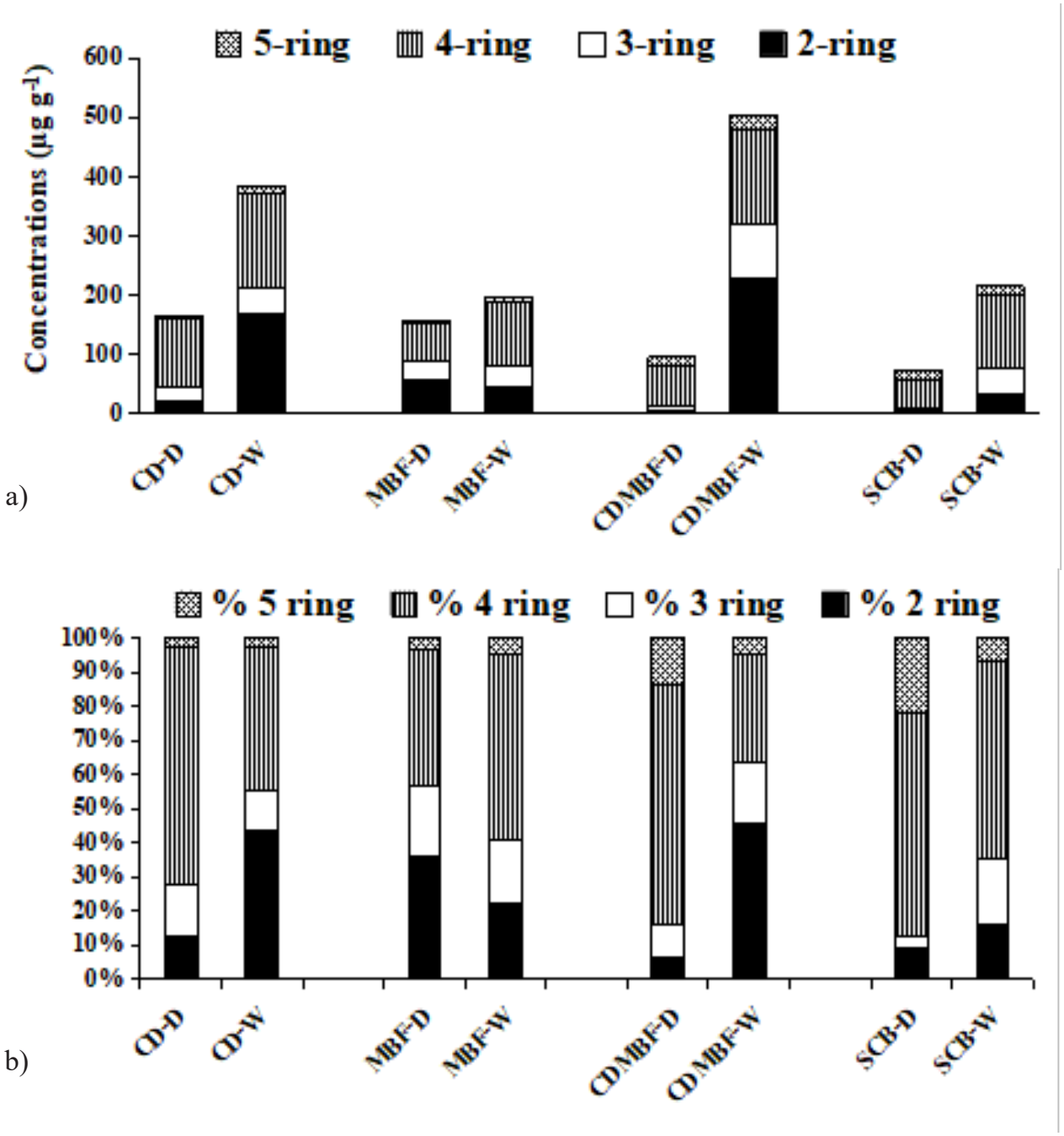

Fig. 2. a) Ring wise distribution of PAHs in different BFSPs; b) Percent contribution by different ringed PAHs (Column height (100%) is representative of ∑14PAHs)

Isomeric ratios vis-a-vis particulates of biomass burning origin

Isomeric ratios of PAHs are frequently used to understand the sources of PAHs. The ratios of indicator PAHs, together with other reported studies, are given in Table 3. All diagnostic ratios of the present study were slightly higher than the reported values of ambient and/or test environment particulates. Yet, BaA/(BaA+CHR) ratios were found to be comparable with other studies, except one study [48]. This difference could be due to the disparity in burning conditions as the present study was conducted in an actual burning environment in rural kitchens [24]. Also, photodegradation of PAHs over the sampling

period may affect the PAHs- specific ratios from field study [49].

From the above discussion, it may be summarized that biomass types, moisture content of biomass and burning conditions influence PAHs emission from biomass fuel burning, making it difficult to come up with standard ratios complementing biomass fuel burning.

Health risk assessment

To appraise the cancer risk of PAHs, parameters like BaP equivalent concentration and toxic equivalent factor (TEF) were used frequently [27, 30, 50-53]. There is no literature of risk assessment of PAHs of particles collected from biomass burning during cooking. In the present study, TEF was used to see the cancer risk from PAHs exposure. The particles emitted from biomass fuel burning in the kitchens can be remain suspended in the atmosphere for few days or can be settled down in a short period of time. Thereafter, these settled particles can be ingested or enter our body by dermal contact, just like soil particles or street dust. BaP has a very high carcinogenic effect for which it is used as the reference compound in the TEF approach, and the potency factors are assigned, i.e. TEF values relative to BaP for other PAH compounds [53]. TEF values were taken from a study [54]. BaP–equivalent is calculated using Eq. 1 [55].

$$BaP_{eq} = \Sigma (C_i \times TEF_i) \quad (1)$$

In Eq. 1, PAH concentration is denoted by Ci. TEF_i is the TEF value of that PAH relative to BaP. The obtained BaP_{eq} was used to calculate the daily intake of PAHs by three exposure pathways (i.e. ingestion, inhalation, and dermal contact) of particulates emitted from biomass burning in kitchens using Eq. 2, 3, and 4 [56, 57].

$$ILCR_{ingestion} = \frac{(BaP_{eq} \times (CSF_{ing} \times \sqrt[3]{(\frac{BW}{70})}) \times \text{Ing R} \times \text{EF} \times \text{ED})}{(\text{BW} \times \text{AT} \times 10^6)} \quad (2)$$

$$ILCR_{inhalation} = \frac{BaP_{eq} \times (CSF_{inh} \times \sqrt[3]{(\frac{BW}{70})}) \times \text{Inh R} \times \text{EF} \times \text{ED})}{(\text{BW} \times \text{AT} \times \text{PEF})} \quad (3)$$

$$ILCR_{dermal} = \frac{(BaP_{eq} \times (CSF_{der} \times \sqrt[3]{(\frac{BW}{70})}) \times \text{AF} \times \text{SA} \times \text{ABSd} \times \text{EF} \times \text{ED})}{(\text{BW} \times \text{AT} \times 10^6)} \quad (4)$$

The unit of different intake is mg/kg. day. Details of the parameters used are provided in Table 4. Multiplication of intake with cancer slope factor (CSF) of B[a]P gives Incremental Lifetime Cancer Risk (ILCR). CSF is the upper bound of the probability of a response per unit intake of a chemical over a lifetime [56]. The unit of CSF is mg/kg. day, and its value through ingestion, inhalation, and dermal contact are 7.3, 3.85, and 25, respectively [56].

ILCR value 10^{-6} is usually considered as negligible. Significant concern is there when ILCR exceeds 10^{-4}. It is potentially carcinogenic to humans when ILCR values ranged between 10^{-6} and 10^{-4} [56]. ILCR value 10^{-6} is comparable with normal human activities like diagnostic X-rays and fishing [61].

ILCR values were calculated for women and children as they are the most vulnerable population of the society to household air pollution, especially in developing countries (Table 5). They spend most of the time indoors, and women are the main cook of a household. The total ILCR values for different BFSPs in dry and wet periods ranged from 10^{-4} to 10^{-3}. This indicates a significant risk from exposure to BFSPs. The risk via inhalation was between 10^{-9} to 10^{-8}. These values were 10^4 to 10^5 magnitudes lower than the ingestion risk and dermal contact risk. The ILCR values were not significantly different for children and women. ILCR values were greater during the wet period than the dry period in most of the BFSPs. The inhalation risk associated with PAH of combustion aerosols produced from different household fuels was studied [29]. They found that the hazard associated with non-solid fuels is lower than solid biomass combustion. The 50th percentile of risk was 9.11×10^{-5} for dung cake, 6.25×10^{-5} for firewood, 2.99×10^{-5} for coal, 1.14×10^{-5} for kerosene and 3.84×10^{-6} for LPG stove, respectively.

Table 3. Diagnostic ratios of PAHs in BFSPs

	ANT/(ANT+PHE)	FLA/PYR	FLA/(FLA+PYR)	BbF/(BbF+BkF)	BaA/(BaA+CHR)	References
CD	0.63±0.38	2.66±0.94	0.71±0.06	0.75±.25	0.51±0.29	
MBF	0.42±0.24	5.62±5.05	0.78±0.14	0.84±0.17	0.68±0.25	Present study
CDMBF	0.63±0.36	4.64±1.63	0.81±0.05	0.27±0.21	0.38±0.20	
SCB	0.29±0.23	2.96±2.18	0.70±0.16	0.73±0.38	0.52±0.64	
Paddy residue/ambient	0.15±0.03	0.84±0.04	0.46±0.01	-	-	[43]
Wheat residue/ambient	0.10±0.05	0.97±0.13	0.49±0.03	-	-	[43]
Crop residue/stove	0.12±0.01	-	0.53±0.03	0.55 ± 0.03	0.48 ± 0.02	[24]
Crop residue/open fire	0.17-0.25	-	0.34-0.53	0.35-0.80	0.39-0.50	[24]
Wood /stove	0.10-0.30	-	0.43-0.74	0.35-0.51	0.39-0.56	[24]
Rice straw/stove	-	-	0.51	-	0.46	[58]
Wood burning/stove	-	-	0.43	-	0.21	[48]
Biomass	0.18±0.04	-	0.47±0.05	0.77±0.05	0.51±0.08	[59]
Biomass	0.16±0.01	-	0.46±0.02	0.74±0.02	0.46±0.03	[60]
Yak dung cooking	0.20±0.03	-	0.50±0.05	0.80±0.15	0.61±0.07	[28]
Sheep dung cooking	0.21±0.04	-	0.67±0.09	0.73±0.05	0.57±0.04	[28]

Table 4. Parameters used in health risk assessment

Parameters	Abbreviations used	Values for adults	Values for children	References
Ingestion Rate (mg/day)	IngR	100	200	[56]
Inhalation rate (m^3/day)	InhR	20	10	[62]
Exposure frequency (days/year)	EF	365	365	[56]
Exposure duration (year)	ED	24	6	[63]
Conversion Factor (kg/mg)	CF	10^{-6}	10^{-6}	[56]
Body weight (kg)	BW	60	18	[64]
Averaging time (days) [70 years x 365 days/year]	AT	25550	25550	[56]
Particulate Emission Factor (m^3/kg)	PEF	1.36×10^9	1.36×10^9	[63]
Skin adherence factor (mg/cm^2)	AF	0.07	0.2	[63]
Exposed skin area (cm^2)	SA	5700	2800	[63]
Dermal adsorption fraction	ABSd	0.13	0.13	[63]

Table 5. ILCR values for women and children in dry and wet period BFSPs

ILCR values	CD		MBF		CDMBF		SCB	
	Women	Children	Women	Children	Women	Children	Women	Children
Dry period								
ILCR ing	1.71E-04	1.82E-04	9.85E-05	1.05E-04	3.45E-04	3.67E-04	2.88E-04	3.06E-04
ILCR inh	1.33E-08	3.53E-09	7.64E-09	2.03E-09	2.68E-08	7.11E-09	2.23E-08	5.94E-09
ILCR derm	3.04E-04	2.27E-04	1.75E-04	1.31E-04	6.13E-04	4.57E-04	5.12E-04	3.82E-04
ILCR total	4.75E-04	4.09E-04	2.74E-04	2.35E-04	9.58E-04	8.24E-04	8.00E-04	6.88E-04
Wet period								
ILCR ing	3.40E-04	3.61E-04	1.93E-04	2.06E-04	7.09E-04	7.53E-04	4.36E-04	4.64E-04
ILCR inh	2.63E-08	7.00E-09	1.50E-08	3.99E-09	5.50E-08	1.46E-08	3.38E-08	8.99E-09
ILCR derm	6.04E-04	4.50E-04	3.44E-04	2.56E-04	1.26E-03	9.39E-04	7.75E-04	5.78E-04
ILCR total	9.43E-04	8.11E-04	5.37E-04	4.62E-04	1.97E-03	1.69E-03	1.21E-03	1.04E-03

Many researchers had applied the risk assessment study based on the TEF and CSF approach to see the risk associated with PAHs exposure to soil and street dust. The ILCR values of the present study were much higher than such studies [51-53]. This indicates a very high risk of cancer to the people living in biomass fuels using households, and this risk is many folds high than the PAHs exposure from soil and street dust.

Conclusion

The PAHs were found to be maximum in BFSPs emitted from CD and CDMBF. There has been a periodic bias in the concentrations of PAHs – a greater abundance of PAHs in wet period samples. FLA, PHE, BaA, and CHR were the major PAHs in all BFSPs. Two and 4-ring PAHs were predominant compared to 3 and 5- ring PAHs, which at the moment we consider as incidental. Differences in ratios of PAHs were observed between different BFSPs types of the present study. Health risk assessment study revealed a very high risk of cancer to the people living in biomass fuels using households. ILCR values were greater during the wet period than the dry period in most of the BFSPs. In the future, a comparative study of particle characterization vis-à-vis PAHs between traditional stoves and improved cookstoves may provide fascinating results to formulate recommendations.

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Competing interests

There is no competing interest.

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Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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