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Emission of black carbon from rural households kitchens and assessment of lifetime excess cancer risk in villages of North India

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A R T I C L E I N F O

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A B S T R A C T

The use of biomass solid fuels (BSFs) for cooking, contribute significantly to the household air pollution (HAP) in developing countries. Emissions resulting from a variety of BSFs (cow dung cakes, wood, and agriculture residues) contain a significant amount of air pollutants, which are now recognized for their role in climatic change and adverse human health impacts. In the current study, daily variations in black carbon (BC) or Short-Lived Climate Forcer concentrations were studied from rural household kitchens using portable aethalometer. The hourly average concentration of BC ranges from 5.4 μg·m^{-3} to 34.9 μg·m^{-3} for various types of household kitchens. The peak levels of BC were found to be significantly higher, when compared to World Health Organization $PM_{2.5}$ limits for ambient air and hence pose a threat to the health of the vulnerable population, i.e., women, children, older adults and those who have health problems. The study also highlights the variation of BC concentration in different kitchen type. The average BC concentration in indoor, outdoor and semi-open kitchen was observed to be 14.54, 14.28 and 24.69 μg·m^{-3}, respectively. The excess lifetime carcinogenic risk for cooking 4 h/day in these kitchens in the North Indian villages was estimated to be 1.25×10^{-7}, 1.22×10^{-7}, and 2.12×10^{-7} respectively. Age-specific excess cancer deaths due to BC exposure were measured highest in children below four years of age in Chandigarh, India. Hence, there is a need to shift the BSF users to clean fuel alternatives to reduce the exposure to HAP. This can be achieved by generating local/regional evidences of BSFs associated health risks to support policy interventions. Further, more research is required to improve the air quality in indoor micro-environments and specifically in kitchens.

Novelty: The first study reporting the near real-time measurements of BC from different types of rural households kitchens of north India. Diurnal pattern of BC concentration was also studied including the effect of chimney, ventilation and kitchen size on observed BC concentration. This study also estimates lifetime excess cancer risk due to BC exposure in rural households in India. The recent 'Global Burden of Disease' report identifies household air pollutants as a major cause of disease and disability in Asia. The study will help to plan suitable policies and intervention to reduce household air pollution in the region.

1. Introduction

Unprocessed biomass solid fuels (BSFs) are commonly used for domestic cooking in developing countries, where an average housewife spends the majority of her working hours on cooking as an occupation. BSF uses could release up to 50 times more air pollutants than cooking gas and it has been reported that BSF smoke contains significant amounts of several noxious pollutants namely carbon monoxide (CO), suspended particulate matter (SPM), hydrocarbons (HCs) and oxides of nitrogen (NOx) (Traynor et al., 1987; Guofeng et al., 2012). Further, BSF smoke also includes several toxic organic compounds such as polycyclic aromatic hydrocarbons (PAHs), which are known for their carcinogenic properties (Torres-Duque et al., 2008).

Along with other emissions from burning of biomass in cooking, black carbon (BC) emissions are of major concern. BC is defined as the "black" optically absorbing component of carbonaceous aerosol particles in the atmosphere. It is formed by incomplete combustion of fossil fuels, biomass burning, and other carbon-containing fuels and due to both anthropogenic and natural activities. BC scatters and absorbs light strongly, impairs visibility, modifies cloud formation and properties, and it plays an important role in influencing global as well as regional climate. These effects are enforced by the several day's long residence time of soot in the atmosphere, which enables it to be transported over long distances. It was estimated that BC emission is the second strongest contribution to current global warming, after carbon dioxide emissions (Ramanathan and Carmichael, 2008).

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Apart from global warming, epidemiological studies have shown an association of cardiopulmonary diseases with exposure to BC which could be associated with its small dimension, structure, and the ability to adsorb a large number of different species (WHO, 2012). It was observed that cooking with BSFs was one of the major sources of ambient BC and $PM_{2.5}$ over the Indo-Gangetic Plains region (Rehman et al., 2011; Choudhary et al., 2018; Rajeev et al., 2018; Sorathia et al., 2018). Hence, occupational health risks associated with traditional cooking practices are of major concern in developing countries (Fullerton et al., 2008; Akintan et al., 2018; Ravindra and Smith, 2018). The vulnerable groups are women, small kids playing around, older adults and people suffering from diseases; who are most likely to be affected by indoor air pollution caused by biomass cooking. The indoor air pollution threatened the millennium development goal (MDG), MDG-4 and MDG-5 which ensured to reduce under-five child mortality by two-thirds between 1990 and 2015 and reduce maternal mortality by three quarters between 1990 and 2015 respectively (United Nations, 2009; Bryce et al., 2013).

Many studies have reported alterations in lung function, chronic cough and phlegm in women exposed to biomass smoke (Balakrishnan et al., 2011). Exposure to biomass smoke can also result in adverse pregnancy outcomes apart from respiratory and non-respiratory effects (Balakrishnan et al., 2018). In another study, it was highlighted that more than half of women cooking with traditional cooking stoves experience health problems (Singh et al., 2014). Studies have also shown that PAH containing substances pose a risk of cancer to humans (Boström et al., 2002; Rehfuess et al., 2006; Ravindra et al., 2008a; Lui et al., 2017). Due to lack of data and lower concentration of ambient PAH, the cancer estimates of PAH are uncertain. Benzo[*a*]pyrene (BaP) is used as an indicator of carcinogenic PAH and its derivatives (He et al., 1991; Agudelo-Castañeda et al., 2017; Shahsavani et al., 2017).

According to the World Health Organization the illness due to household air pollution (HAP) could attribute to annually 4.3 million premature deaths annually on a global scale (WHO, 2012). This is also confirmed by the recent Global Burden of Disease (GBD) study, which identifies HAP as a second major cause of mortality in India. Hence, policy action is required to curb the uses of SBF at the national and regional levels (Lim et al., 2012; Cohen et al., 2017). The focus of these policies should be on major sources of air pollution including BC or soot particles.

It has been reported that soot particle absorb and adsorb several toxic compounds such as PAHs (Bencs et al., 2008; Lawrence et al., 2016). Similarly, Ravindra et al. (2001, 2006, 2008b) and Sarigiannis et al. (2015) also reported that PAHs are mainly adsorbed by the fine particulate matter and significantly contribute to its genotoxicity. On the other hand, it was recommended by EPA to convert carcinogenicity of PAHs to an equivalent concentration of BaP (USEPA, 1993) Hence, increasing HAP (including BC) emissions from rural areas may significantly affect the health of the rural population. It was also suggested that BC could be considered as an additional indicator of adverse health impact (Pandey and Tyagi, 2012; Clark et al., 2013). Hence, there is a need to study the co-exposure to BC to minimize the health impacts of HAP (Clark et al., 2013).

The current study focuses on the measurement of BC concentrations in various types of rural household kitchens, which uses BSFs for cooking. The variation in BC concentrations between cooking and non-cooking hours, and with a change in kitchen type was also determined. Further, the study also estimates the lifetime excess cancer risk including uncertainty analysis. This can provide the needed impetus to plan suitable regional policies and interventions to reduce the burden of disease and disabilities, mainly in Asian and African countries.

2. Experimental

2.1. Study area

The study was conducted in Dubahali and Khera villages of Fatehgarh Sahib District, Punjab, India during 20th January to 3rd April 2014 which constitutes winter, pre-summer and summer season in India (GOI, 2010). These villages are located far away from the main highway, traffic and industry and hence, were not under any direct influence of external air pollutants source. BC was monitored in 17 randomly selected houses, where traditional stoves or chullas are used for cooking. In some cases, the houses which used both traditional stoves and Liquefied Petroleum Gas (LPG) for cooking were also monitored. For the comparison of household and outdoor BC concentration, ambient air samples were also collected.

2.2. Type of kitchens and sampling locations

Randomly selected houses had different types of kitchen depending upon the economic condition of the household. In the study area following types of kitchens were observed: a) separately indoor built kitchen with chimney; b) indoor built kitchen but instrument in living area; c) indoor built kitchen with ventilation; d) separately outside built kitchen with chimney; e) semi-open type kitchen with chimney; f) semi-open kitchen; g) open cooking; h) cooking in open rooftop; i) LPG kitchen adjacent to outside separately built stove kitchen; j) veranda or porch; k) kitchen in Living Area; and h) ambient air measurements of BC.

The sampling duration in various houses ranged from the minimum of 21 h to the maximum of 102 h depending upon the socio-economic conditions of the household. Other factors like power source and safety of instrument were taken into consideration. The dimensions and the ventilation sources of the various kitchens were measured. The instrument was always placed at the cooking height of 0.9 m and a distance of 1.2 m from the stove. The stoves in households were made up of mud and bricks, and some stoves had chimney over them. In some kitchens, the gas stoves were also there along with a traditional stove. The fuels mainly used in cooking were cow dung cakes, wood, and agriculture residues.

2.3. Instrumentation and sampling

The sampling was done with the portable Aethalometer (Model AE42, Magee Scientific Company, Berkeley, California) which reports quantitative Black Carbon mass by measuring the light attenuation through aerosol deposited on a quartz fiber filter. AE42 has automatically advancing quartz fiber filter tape. The sample was collected on reinforced quartz fiber tape, and it advances 1 cm automatically when loading threshold is reached, and loading corrections were conducted as detailed in Singh et al. (2018). The change in attenuation of light per unit time is correlated with the BC concentration deposited on the filter according to the following formula (Hansen et al., 1984; Virkkula et al., 2005)

$$BC\ (\mu g \cdot m^{-3}) = \frac{1}{\alpha_{abs}} \frac{A}{Q} \frac{\Delta ATN}{\Delta t}$$

where, α_{abs} is the mass-specific cross-section of BC, which depends on aerosol type and age (Liousse et al., 1993; Petzold and Niessner, 1995) and ranges from (5–20) $m^2 \cdot gm^{-1}$, A is the filter sampling area, and Q is the volumetric air flow. It assumes that BC is the only light absorbing component and that the attenuation is linearly proportional to the BC particles loading; therefore, the BC concentration is calculated from the rate of change of attenuation. But, Aethalometer measurement of light absorbing carbon has several filters related artifacts such as “multiple scattering” and “shadowing effect”. The former results in overestimation of BC loading due to increase in optical path of light in the filter matrix, when the filter is less loaded, whereas the latter results in underestimation of BC, when the filter is heavily loaded and accumulated particles absorb a portion of scattered light as reported by LaRosa et al. (2002), Weingartner et al. (2003), Arnott et al. (2005) and Kirchstetter and Novakov (2007).

Thus for calculating black carbon reported data, the correction was done using the methodology discussed in Virkkula et al. (2007), Park et al. (2010), Drinovec et al. (2015) and Magee Scientific - Model AE42 - Portable Aethalometer Manual. The instrument has a resolution of 0.001 μg·m^{-3} and detection limit (1 h) < 0.005 μg·m^{-3}. The correction was done on the basis of the following equation:

$$\mathbf{BC}\ (\text{reported}) = \mathbf{BC}\ (\text{zero loading}) \times \{1 - \mathbf{k}\cdot\mathbf{ATN}\}$$

where **BC** (zero loading) is defined as the real ambient BC value, which should be achieved in the absence of any loading effect, **k** (0.0015 at 880 nm optical wavelength) is known as loading compensation parameter, **ATN** is attenuation.

The instrument was also equipped with the inbuilt internal battery providing for mobile operation. The instrument was placed on a stool and sampling was done at the cooking height of the person and the distance of 1.2 m away from the traditional cooking stoves (Sidhu et al., 2017). The data was sampled for different durations considering many factors such as cooking pattern, electricity, and socio-economic conditions of the house residents.

2.4. Methodology for cancer risk assessment

The kitchens were divided as indoor, outdoor and semi-open types for carcinogenic risk assessment. Total BC concentration was considered equivalent to benzo[*a*]pyrene (BaP), since potency factor of other PAHs such as chrysene, fluorine were unavailable. Hence reference dose of BaP was considered for the calculation of cancer risk. Scientific Committee on Consumer Safety (SCCS, 2015) reports that 97% BC contains elemental carbon and < 1% of BC consists of extractable organic material having significant amount of carcinogenic PAH. Thus, total BC was considered equivalent to BaP for cancer risk calculation as a worst-case scenario (SCCS, 2015). The EPA (USEPA, 1986) recommended standard values for daily intake of air and body weight were taken into consideration for cancer risk estimation (Li, 2018).

The cancer risk assessment for BC was carried out for average 4 h of cooking in each kitchen type. Two different cancer risk assessments were made, i.e., standard (i.e., 70 years age having 70 kg of body weight for an adult) and for age-specific cancer calculation, taking different age groups. The upper limit of each age group was considered as the number of exposure years, and respective average body weights of those age groups were taken from CDC (2000) and Marwaha et al. (2011). The average body weight of an adult was taken as 70 kg, and the amount of air breathed daily as 20 m^3/day while a lifetime exposure of 70 years was taken. The overall reference dose (RfD) for BaP was taken as 3×10^{-4} mg/kg/d (USEPA, 2017). Absorption of 60% is taken for inhalation route (Liao and Chiang, 2016). For age-specific cancer deaths of Punjab, data of Sangrur, SAS Nagar, and Mansa district were taken for calculation purpose (CBCPS, 2014).

The age specific death rate (ASDR) of cancer for Chandigarh was calculated and further standardized for an age-group wise population of Punjab. The CDR and standardized deaths rates based on the population of India (2011) for different states were also assessed based on the data collected from cancer registry (Census of India, 2011; CBCPS, 2014; ICMR, 2014; PBCRM, 2017; PBCRS, 2017; PBCRSND, 2017). A detailed conceptual framework developed for the cancer risk assessment is depicted in Fig. 1.

$$\text{Risk} = \text{CDI} \times \text{Potency factor}$$

$$\text{CDI} = \text{Total Dose (mg)/Body weight (kg)} \times \text{Lifetime (days)}$$

$$\text{TD} = \text{Contaminant concentration} \times \text{Intake rate} \times \text{Exposure duration} \times \text{Absorption Fraction}$$

where CDI is 'chronic daily intake' and TD represents 'total dose.'

2.5. Uncertainty analysis

As shown in Section 2.4 risk calculation comprises independent variables, dependent variables, and relationships between these quantities. Exposure to BC may vary within some range and may introduce uncertainty regarding them. Hence, it is important to quantify uncertainty for better estimation of risk including uncertainty analysis.

As the current study include limited BC measurements, the parametric test could not be applied, and the bootstrapping method was used for the original measure of dispersion before the uncertainty analysis. Bootstrapping was used to randomly simulate measured BC concentration over 1000 times to estimate the median, lower limit (LL) and upper limit (UL) for open kitchen types, indoor kitchen, a semi-open kitchen and taking all 17 kitchens together using R software vs 3.4.1 for windows. Bias and standard error were also obtained for median of the data. Further, a sensitivity analysis was undertaken to assess the effect of uncertainties in the BC measurements.

3. Results

The hourly averages of the concentration of BC with standard deviation (SD) were calculated for different types of sampling locations during the study period. Based on the daily time-activity pattern, it was observed that female cook spent on an average 6 h in the kitchen in Fatehgarh Sahib, Punjab. Except for three households, no other household cooked meal during noon, i.e., from 11:00 am to 3:00 pm. It was observed that women cook generally close the windows and door during cooking due to cold mornings and evenings during winter season. Hourly average, maximum and minimum concentrations of BC observed in different households are depicted in Table 1. The variation in BC concentration based on the micro-environmental setting of kitchen and type of ventilation are shown in Fig. 2 and also discussed below in detail.

3.1. Separately built an indoor kitchen with chimney

The hourly average BC concentration of 13.30 ± 5.27 μg·m^{-3} was recorded in an indoor separately built kitchen having a chimney (D1) with a maximum hourly average concentration of 27.26 μg·m^{-3}, recorded during the evening cooking hours between 9:00 pm to 10:00 pm and the minimum concentration of 6.71 μg·m^{-3} during 5:00 am. to 6:00 am. The maximum concentration was 29.65 μg·m^{-3} for the time interval of 5 min which was during the evening cooking hours. Another household having similar kitchen type (D2) had the hourly average BC concentration higher than the first household (30.41 ± 26.55 μg·m^{-3}), whereas the maximum hourly average BC concentration of 114.59 μg·m^{-3} during evening cooking hours 6:00 pm to 7:00 pm, which is more than four times of the first household (D1). Minimum BC concentration of 8.06 μg·m^{-3} was recorded just before the evening cooking between 5:00 pm to 6:00 pm.

Further BC level shows the peak of 190.68 μg·m^{-3} for the time interval of 5 min during cooking hours. In the third household kitchen (K5), the recorded hourly average BC concentration was 21.86 ± 26.55 μg·m^{-3}. Similar to D2, the highest hourly average BC level of 105.39 μg·m^{-3} was noticed during the evening cooking hours, i.e. between 7:00 pm to 8:00 pm and the minimum concentration of 2.40 μg·m^{-3} was observed between 2:00 pm to 3:00 pm. The highest level of BC concentration (180.03 μg·m^{-3}) was noticed during morning

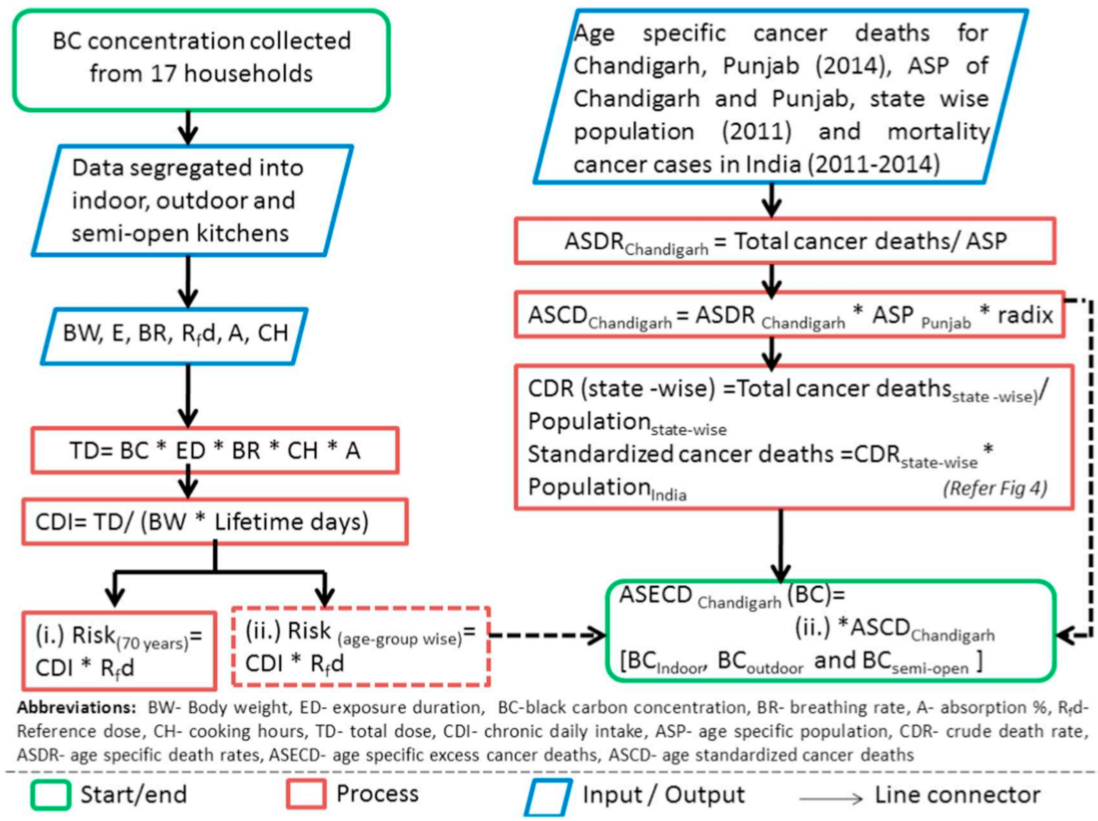

Fig. 1. Conceptual framework used for the lifetime carcinogenic risk estimation.

cooking for the time interval of 5 min. Very high maximum BC concentrations (hourly and overall) were observed in D2 and K5 kitchens as compared to D1 Kitchen. This can be attributed to smaller dimensions of kitchen room and lack of ventilation, which result in a buildup of BC concentration. This shows that the proper ventilation and room size significantly reduce the level of BC exposure.

3.2. Indoor built kitchen with ventilation

This category includes the indoor kitchen with exhaust fan and windows (K7; Table 1). One of the kitchens also had the LPG gas stove in it, but they also used biomass for cooking. In this type of kitchen, hourly average BC concentration was 10.70 ± 11.81 $\mu g{\cdot}m^{-3}$ having the highest peak of BC levels (79.83 $\mu g{\cdot}m^{-3}$) during morning cooking hours between 10:00 am to 11:00 am, whereas lowest levels of BC (1.32 $\mu g{\cdot}m^{-3}$) was recorded during early morning hours, i.e., between 3:00 am to 4:00 am. For the time interval of 5 min, the highest observed level of BC was 119.87 $\mu g{\cdot}m^{-3}$, during morning cooking hours. Another household with similar kitchen type (K6; Table 1), had an hourly average BC level of 13.81 ± 20.37 $\mu g{\cdot}m^{-3}$, having the highest peak of 96.55 $\mu g{\cdot}m^{-3}$ during the noon cooking hours between 12:00 pm to 1:00 pm and lowest BC level of 1.78 $\mu g{\cdot}m^{-3}$ from 4:00 pm to 5:00 pm.

Highest recorded BC level of 185.14 $\mu g{\cdot}m^{-3}$ was observed during noon cooking hours for the time interval of 5 min. The BC concentrations observed in both kitchens were found lower than the separately build indoor kitchen without ventilation. This confirm that proper ventilation in household kitchens significantly reduce the BC concentration.

3.3. Separately outside built kitchen with chimney

In this case, BC sampling was done in a separately build outside kitchen (D3; Table 1), and hourly average BC concentration of 31.58 ± 29.07 $\mu g{\cdot}m^{-3}$ was observed. The levels of BC in the kitchen are similar to that observed in indoor build kitchen with chimney. The hourly average peak of BC (134.36 $\mu g{\cdot}m^{-3}$) was observed during the morning cooking hours (5:00 am to 6:00 am) whereas, minimum levels of BC (11.60 $\mu g{\cdot}m^{-3}$) was noticed between 3:00 pm to 4:00 pm. For the time interval of 5 min, the maximum observed BC concentration was 491.71 $\mu g{\cdot}m^{-3}$during morning cooking hours. The maximum BC concentrations (hourly and overall) were higher than that observed in separately build an indoor kitchen with a chimney which may be due to smaller dimensions of the kitchen.

3.4. Semi-open type kitchen with chimney

In this type of semi-open kitchen (K1; Table 1), the observed hourly average BC concentration was 19.28 ± 6.80 $\mu g{\cdot}m^{-3}$. The maximum and minimum hourly average BC concentration were found to be 33.33 $\mu g{\cdot}m^{-3}$ during the late night between 1:00 am to 2:00 am, and 7.41 $\mu g{\cdot}m^{-3}$ between 2:00 pm to 3:00 pm. During the evening cooking hours, the recorded BC concentration reached up to 168.82 $\mu g{\cdot}m^{-3}$ for the time interval of 5 min. In another similar semi-open type kitchen attached outside to house (K2; Table 1), hourly average BC concentration of 15.18 ± 7.6 $\mu g{\cdot}m^{-3}$ was noticed. The maximum and the minimum hourly average BC concentration were 35.9 $\mu g{\cdot}m^{-3}$ and 3.14 $\mu g{\cdot}m^{-3}$, which were observed during morning cooking hours (5:00 am to 6:00 am), and noon (1:00 pm to 2:00 pm). During the morning cooking hours, the observed BC levels reached up to 70.69 $\mu g{\cdot}m^{-3}$ for the time interval of 5 min.

3.5. Semi-open kitchen

In the semi-open kitchen with no chimney (D4; Table 1), the hourly average BC concentration was found to be 34.90 ± 51.09 $\mu g{\cdot}m^{-3}$. The maximum hourly average BC level (332.20 $\mu g{\cdot}m^{-3}$) was noticed during the evening cooking hours (4:00 pm to 5:00 pm), whereas the lowest level (6.89 $\mu g{\cdot}m^{-3}$) were found between 3:00 am to 4:00 am. During

Table 1
Variation in BC concentration in various type of kitchen in Fatehgarh Sahib, Punjab, India.

Location	Kitchen type	Kitchen dimensions (1 ft = 0.30 m)	Sampling duration in hours	BCmin $\mu g{\cdot}m^{-3}$	BCmax $\mu g{\cdot}m^{-3}$	BC concentration hourly average ± SD $\mu g{\cdot}m^{-3}$
D1	Indoor separately built kitchen with chimney	15 × 10 × 12 ft. with a door of 3 × 7 ft. and a window of 3 × 3 ft. Stove distance from sampling probe - 5 ft	27	6.71	27.26	13.30 ± 5.27
D2	Indoor separately built kitchen with chimney	8 × 10 × 11 ft. and with a door of 3 × 7 ft. and two small ventilators of 1 × 1 ft. at the height of 10 ft. in two different walls of which one was facing towards the living room.	21	8.06	114.59	30.41 ± 26.55
D3	Outside separately built with chimney	6 × 10 × 8 ft. and a door of 3 × 7 ft., two windows of 1 × 1.5 ft. at the height of 6 ft. Stove distance from sampling probe - 2 ft	38	11.60	134.36	31.58 ± 29.07
D4	Semi-open kitchen	10 × 7 × 8 ft. enclosed from two sides with a roof while the other two sides were fully open	53	6.89	332.20	34.90 ± 51.09
D5	Semi-open kitchen	14 × 12× 10 ft. enclosed from two sides with a roof while the other two sides were fully open	102	1.63	156.70	29.41 ± 30.70
D6	Indoor build but instrument in the living area	The living area of 15 × 12 × 10 ft. has two doors of dimension 3 × 7 ft., two windows of 1 × 1 ft., Stove distance from sampling probe - 4 ft	55	6.05	33.39	14.41 ± 7.29
K1	Semi-open with the chimney	12 × 10 × 10 ft. enclosed from two sides with a roof while the other two sides were constructed up to the height of 4 ft. with one side had the entrance size of 4 ft.	67	7.41	33.33	19.28 ± 6.80
K2	Semi-open with the chimney	12 × 10 × 8 ft. and was enclosed from two sides with a roof while the other two sides were constructed up to the height of 3 ft. with one side had the entrance size of 4 ft., Stove distance from sampling probe - 4 ft	100	3.14	35.92	15.18 ± 7.60
K3	In open living area (veranda)	Porch enclosed from three sides with a roof while the fourth open side was 15 ft. length, 10 ft. in width and 11 ft. in height. There were three emission sources near by the instrument, an exhaust fan of LPG kitchen at the distance of 12 ft. and at the height of 10 ft., an indoor stove kitchen at the distance of 15 ft. and an open kitchen stove at the distance of 20 ft.	91	0.96	38.48	9.49 ± 6.84
K4	In LPG kitchen adjacent to stove kitchen	10 × 10 × 11 ft. with an exhaust fan at the height 10 ft. and a window of 2 × 4 ft. and a door of 5 × 7 ft., stove distance from sampling probe - 4 ft	51	0.95	35.44	6.40 ± 5.78
K5	Separately build an indoor kitchen with chimney	10 × 5 × 10 ft. and a door of 3 × 7 ft. and having a window of 2 × 1 ft	31	2.40	105.39	21.86 ± 26.55
K6	Indoor build kitchen with ventilation	12 × 12 × 10 ft. and a door of 3 × 7 ft., a window of 2.5 × 4 ft. at the height of 3 ft. and a ventilation fan at the height of 9 ft.	22	1.78	96.55	13.81 ± 20.37
K7	Indoor build kitchen with ventilation	10 × 12 × 10 ft. and a door of 3 × 7 ft., a window of 2 × 2 ft. at the height of 5 ft. and a ventilation fan at the height of 9 ft	75	1.32	79.83	10.70 ± 11.81
K8	Open cooking	In the courtyard	45	1.81	50.83	10.52 ± 13.04
K9	Ambient air readings of village	At the height of 24 ft. On rooftop. The house was located 400 m away from the local village road, and there were no obstructions of other houses nearby at that height.	71	0.94	25.21	6.10 ± 3.98
K10	Cooking in living room	–	3	3.6	7.4	5.4 ± 1.9
K11	Cooking in open rooftop	In open rooftop at the height of 13 ft. from the ground	28	1.50	13.95	5.53 ± 3.25

D - Dubahali village; K - Khera village.

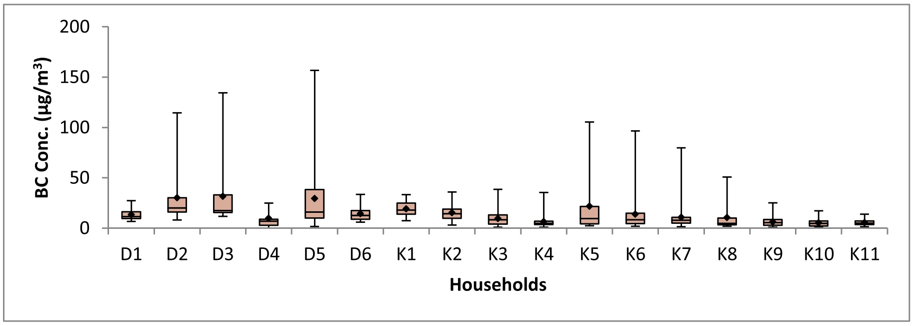

Fig. 2. Box-whisker plots showing BC concentrations in different types of kitchen in Fatehgarh Sahib, Punjab, India. (Note: Boxes indicate the 25–75 percentile range with the horizontal line inside at median and black dots as the mean value, maximum whisker length is 1.5 times the interquartile range), (D - Dubahali village; K - Khera village; 5 minute data averaged to hourly concentrations).

the evening cooking hours, the recorded BC concentration reaches up to 1195.74 μg·m^{-3} for the time interval of 5 min. Another household having a semi-open kitchen with no chimney (D5; Table 1) had an hourly average BC concentration of 29.41 ± 30.70 μg·m^{-3}. Highest hourly average level of BC (156.70 μg·m^{-3}) was observed during evening cooking hours (4:00 pm to 5:00 pm), whereas minimum BC concentration of 1.63 μg·m^{-3} was noticed during early morning hours (3:00 am to 4:00 am). During the morning cooking hours, the recorded BC concentration reached up to 428.63 μg·m^{-3} for the time interval of 5 min. Relatively, very high concentrations of BC was observed in this type of kitchen due to the absence of chimney and lower height of the roof.

3.6. Open cooking (courtyard and rooftop)

Here, the cooking activities were carried out by using an open biomass chulla (stove) in the courtyard (K8; Table 1). The hourly average BC concentration of 10.52 ± 13.04 μg·m^{-3} was observed in this type of open kitchen. Further, the observed maximum and minimum hourly average BC concentrations were 50.83 μg·m^{-3} (9:00 am to 10:00 am) and 1.81 μg·m^{-3} (between 2:00 pm to 3:00 pm) respectively. The maximum BC concentration for 5 min was 155.88 μg·m^{-3} during morning cooking hours. In another household, the instrument was placed at rooftop of a house, which has two rooms on the same roof at the distance of 2.44 m from the stove (K11, Table 1). The hourly average BC level in this type of kitchen was 5.5 ± 3.25 μg·m^{-3}. Further, highest hourly average BC concentration of 13.95 μg·m^{-3} was observed during the night cooking hours (7:00 pm to 8:00 pm), whereas the lowest level of BC (1.50 μg·m^{-3}) was noticed between 2:00 pm to 3:00 pm. The highest BC concentration for the time interval of 5 min was observed to be 27.36 μg·m^{-3}. However, the hourly average in courtyard and rooftop were found to be comparable, but cooking in courtyard kitchen shows higher peak BC concentration in contrast to open rooftop. This shows that the movement of air in the open rooftop kitchen could dilute the BC concentrations.

3.7. LPG kitchen adjacent to outside separately build stove kitchen

The instrument was placed in the LPG kitchen (K4) on the same shelf in which LPG stove was placed having hourly average BC concentration of 6.40 ± 5.78 μg·m^{-3}. The maximum hourly average level of BC (35.44 μg·m^{-3}) was observed during the morning cooking hours, i.e., between 5:00 am to 6:00 am, whereas minimum BC concentration (0.95 μg·m^{-3}) was noticed during noon. BC concentration for the time interval of 5 min reached up to 101.64 μg·m^{-3} during the morning cooking hours.

3.8. Indoor build kitchen but an instrument in the living area

The BC concentration was observed in the living area of household adjacent to an indoor stove kitchen (D6) having hourly average BC concentration of 14.41 ± 7.29 μg·m^{-3}. The maximum hourly average BC concentration (33.39 μg·m^{-3}) was observed between 5:00 am to 6:00 am, whereas minimum BC concentration (6.05 μg·m^{-3}) was noticed during evening hours (5:00pm to 6:00 pm). For the time interval of 5 min, BC concentration reaches up to 101.71 μg·m^{-3} during the morning cooking hours.

3.9. Veranda or porch

The BC concentration was also observed in one porch (K3). There were three emission sources nearby the aethalometer, i.e., exhaust fan of LPG kitchen at the distance of 3.6 m and 3 m height, an indoor LPG kitchen at the distance of 4.5 m and an open biomass stove at the distance of 6 m. The hourly average BC concentration at this site was 9.49 ± 6.84 μg·m^{-3} having maximum hourly average BC level of 38.48 μg·m^{-3} during the morning cooking hours (7:00 am to 8:00 am). Further, the lowest level of BC (0.96 μg·m^{-3}) were recorded during the early morning hours (3:00 am to 4:00 am). However, during the morning cooking hours, the observed BC levels reach up to 82.80 μg·m^{-3} for the time interval of 5 min.

3.10. Kitchen in living area

The BC concentration was also observed in the living area of a household having dimension 3.6 × 3 × 3 m. There was a biomass stove in (kitchen) inside the same room (K10). However, due to the poor economic condition of the study participants, there was no source of electricity. During the non-cooking hours, BC concentration average for 2 h was 4.5 μg·m^{-3} for data collected at a time interval of 5 min. During the physical examination of the living room cum kitchen, it was observed that the walls and the roof of the room were fully covered with blackish particulate matter (soot) emitted from biomass cooking stove.

3.11. Black carbon concentration in rural ambient air

The aethalometer was also placed on the rooftop of a house in Khera village (K9) at the height of 7.3 m. The house was located 400 m away from the local village road, and there were no obstructions of other houses nearby at this height. The hourly average BC concentration of 6.10 ± 3.98 μg·m^{-3} was observed in ambient air of rural area. The maximum hourly average level of BC (25.21 μg·m^{-3}) was recorded between 7:00 am to 8:00 am, and the minimum BC concentration (0.94 μg·m^{-3}) was noticed during 5:00 pm to 6:00 pm. Highest BC concentration for the time interval of 5 min reaches up to 78.60 μg·m^{-3} and found to be associated with the cooking hours in the village.

3.12. Excess lifetime cancer risk from BC exposure

The lifetime risk from cancer due to exposure to BC for different cooking periods and different concentrations have been shown in Fig. 3. The age specific excess cancer deaths (ASECD) were estimated considering an average of daily 4 h of cooking for different age groups of Chandigarh, India. The lifetime risk from exposure to indoor kitchens

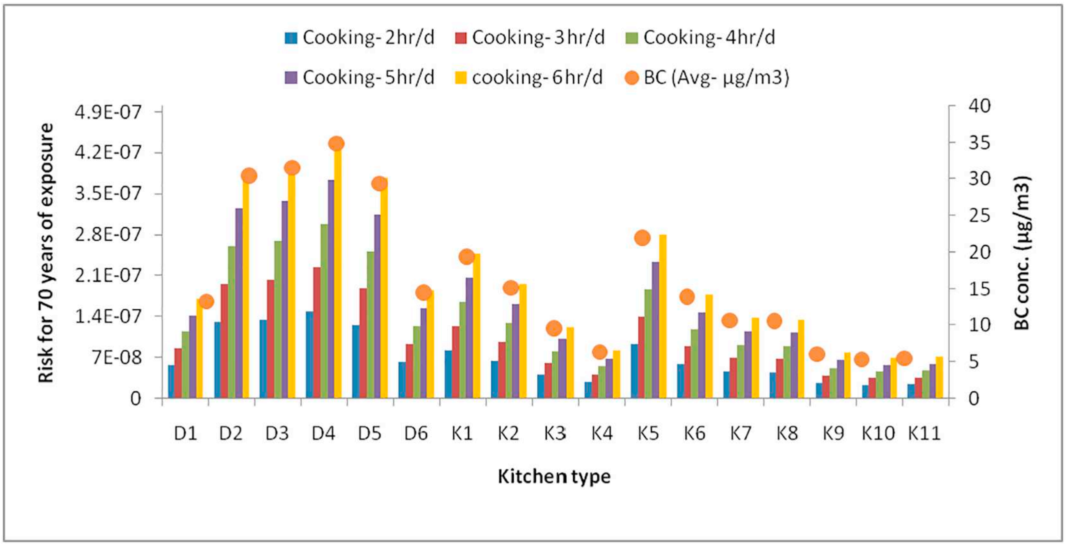

Fig. 3. Excess carcinogenic risk from lifetime exposure to BC concentrations due to different cooking periods.

BC concentration of 14.54 µg·m^{-3} is 1.25 × 10^{-7}, outdoor kitchens BC concentration of 14.28 µg·m^{-3} is 1.22 × 10^{-7}, and semi-open kitchens BC concentration of 24.69 µg·m^{-3} is 2.12 × 10^{-7} (Table 2 and Supplementary Table S1). ASECD from exposure to BC was found to be maximum for age group 0–4 and minimum for above 65 years of age for all type of kitchens. The maximum and minimum ASECD for outdoor kitchens were found to be 0.048 and 0.002 respectively. Similarly, ASECD from exposure to BC in indoor kitchens was 0.049 and 0.002 respectively. The ASECD from exposure to BC in semi-open kitchens were 0.083 and 0.003 respectively.

The age-standardized cancer deaths (ASCD) for Chandigarh using population-based cancer registry was found to be lowest for 0–4 years of age group at 0.90 per 100,000 and highest for 75+ age group at 89.64 per 100,00 for the population as shown in Table 3 (CBCPS, 2014). The average BC concentration for 17 households was observed to be 16.36 µg.m^{-3}, and the lifetime ASECD was found to be 1.79 × 10^{-3} from BC for the age group 70–74 and 55.08 × 10^{-3} for the age group 0-4 (Table 3). This shows that age-specific excess cancer deaths due to BC exposure are highest in children. The lifetime carcinogenic risk and ASECD in semi-open kitchens were found to be highest followed by indoor and outdoor kitchens. The standardized cancer deaths for different states of India using ICMR study (ICMR, 2014) is shown in Fig. 4. Ferlay et al. (2010) reported 12.7 million new cancer cases and 7.6 million cancer deaths worldwide in 2008. In a study based on a cancer survey in India, 195,300 cancer deaths were reported among women in 2010 (Dikshit et al., 2012).

Estimation of carcinogenic risk is related to uncertainties in the BC concentration. That might have implications for exposure as the location and number of people exposed to a predicted pollution level are sensitive to the uncertainties associated with this prediction. To reduce the uncertainty in the risk assessment model univariate sensitivity analysis was conducted.

The bootstrapping of BC measurements and values of the uncertainty analysis of risk assessment are shown in Table 4. The uncertainty in the measured BC concentration is related to lifetime carcinogenic risk and ranges from 1.21 × 10^{-7} to 5.54 × 10^{-8} for all kitchen. It can be seen from Table 4 uncertainty attributed to the carcinogenic risk increases as BC concentration increases, which may be due to the increase in the carcinogenic fraction of BC (Ravindra et al., 2008a). Further, the range of carcinogenic risk remains stable for overall and all kitchen type except for the outdoor kitchen. This may be attributed to the wider range of BC concentration for outdoor kitchens.

Table 2
Total dose, chronic daily intake and lifetime carcinogenic risk in different kitchen types.

Kitchen types	Location	BC (concentration µg·m^{-3})	Total dose (TD), mg	CDI = (TD / wt ∗ lifetime) (mg/kg/d)	Risk from cooking - 4 h/day
Semi-open	D4	34.90	1783.39	0.000997	2.99E−07
	D5	29.41	1502.85	0.00084	2.52E−07
	K1	19.28	985.21	0.000551	1.65E−07
	K2	15.18	775.70	0.000434	1.30E−07
	Average	24.69	1261.79	0.000706	2.12E−07
Outdoor	D3	31.58	1613.74	0.000902	2.71E−07
	K3	9.49	484.94	0.000271	8.13E−08
	K8	10.52	537.57	0.000301	9.02E−08
	K11	5.53	282.58	0.000158	4.74E−08
	Average	14.28	729.71	0.000408	1.22E−07
Indoor	D1	13.30	679.63	0.00038	1.14E−07
	D2	30.41	1553.95	0.000869	2.61E−07
	D6	14.41	736.35	0.000412	1.24E−07
	K4	6.40	327.04	0.000183	5.49E−08
	K5	21.86	1117.05	0.000625	1.87E−07
	K6	13.81	705.69	0.000395	1.18E−07
	K7	10.70	546.77	0.000306	9.17E−08
	K10	5.40	275.94	0.000154	4.63E−08
	Average	14.54	742.80	0.000415	1.25E−07

Table 3
Total dose, Chronic daily intake, Excess lifetime carcinogenic risk and Age-specific excess BC Cancer deaths from exposure to BC in Chandigarh

Age Group	Average body weight, kg	Age-specific cancer deaths in Chandigarh[a]	ASP Chandigarh	Age-specific cancer mortality rate Chandigarh (per 10^3)	ASCD in Chandigarh[b] (per 10^5)	Total dose (TD), mg	CDI = (TD/ wt x lifetime) (mg/kg/d)	Carcinogenic risk from BC	Age-specific excess BC Cancer Deaths / mortality rate Chandigarh (ASECD)		Proportion of excess cancer deaths due to exposure to BC in Chandigarh
									Deaths (x 10^{-3})	Mortality Rate (per 10^3)	
						All types of kitchen taken together into consideration for BC_{avg} concentration (16.36 $\mu g.m^{-3}$)					
0-4	15	1	84165	0.0119	0.905276	47.77	0.002181	6.54E-07	55.08	0.000654	0.055078
5-9	25	2	92851	0.0215	1.821555	107.49	0.001309	3.93E-07	36.46	0.000393	0.018229
10-14	40	2	95117	0.0210	1.939892	167.20	0.000818	2.45E-07	23.34	0.000245	0.011671
15-19	50	2	109847	0.0182	1.832094	226.91	0.000654	1.96E-07	21.57	0.000196	0.010783
20-24	60	4	130300	0.0307	3.044026	286.63	0.000545	1.64E-07	21.32	0.000164	0.005329
25-29	60	4	118904	0.0336	2.960012	346.34	0.000545	1.64E-07	19.45	0.000164	0.004863
30-34	60	8	98366	0.0813	7.018634	406.06	0.000545	1.64E-07	16.09	0.000164	0.002012
35-39	70	10	90071	0.1110	7.886405	465.77	0.000467	1.40E-07	12.63	0.00014	0.001263
40-44	70	19	74773	0.2541	16.22946	525.48	0.000467	1.40E-07	10.49	0.00014	0.000552
45-49	70	17	66050	0.2574	14.59412	585.20	0.000467	1.40E-07	9.26	0.00014	0.000545
50-54	70	47	52465	0.8958	40.13287	644.91	0.000467	1.40E-07	7.36	0.00014	0.000157
55-59	70	46	40894	1.1249	38.42572	704.63	0.000467	1.40E-07	5.73	0.00014	0.000125
60-64	70	43	30805	1.3959	49.67954	764.34	0.000467	1.40E-07	4.32	0.00014	0.000100
65-69	70	34	17901	1.8993	48.80894	824.05	0.000467	1.40E-07	2.51	0.00014	0.000074
70-74	70	56	12775	4.3836	80.38179	883.77	0.000467	1.40E-07	1.79	0.00014	0.000032
75+	70	63	15966	3.9459	89.64568	895.71	0.000467	1.40E-07	2.24	0.00014	0.000036

[a] Data from population-based cancer registry of Chandigarh (CBCPS, 2014).
[b] Age- standardized death rate for Chandigarh using Panjab state population as standard.

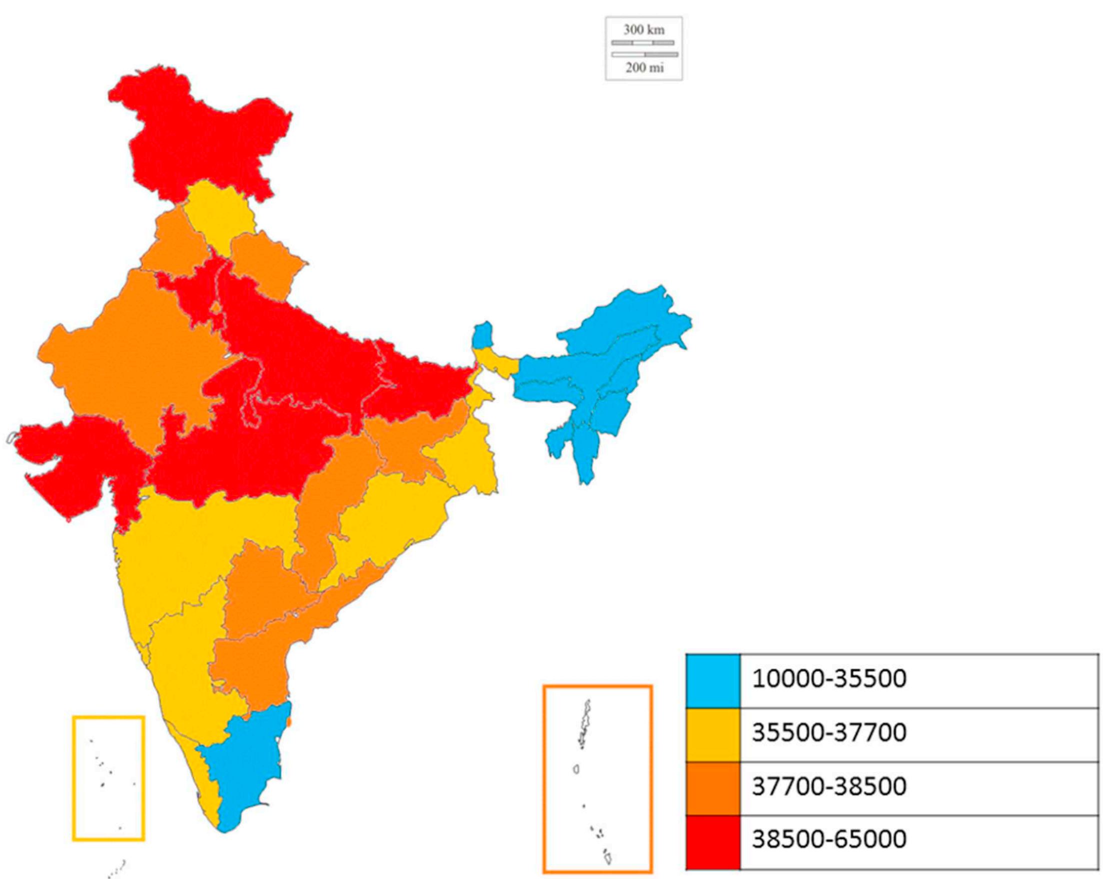

Fig. 4. Standardized cancer deaths for different states of India using 2011 population and base data from ICMR (2014).

Table 4
Results of bootstrapping and uncertainty values of risk assessment.

Kitchen type	Statistic	Bootstrapped BC value ($\mu g \cdot m^{-3}$)	Bias	Standard error	Risk
All kitchen types	Median	14.11	0.436	2.93	1.21×10^{-7}
	Lower limit	6.36			5.45×10^{-8}
	Upper limit	17.70			1.52×10^{-7}
Semi-open	Median	24.34	0.438	5.57	2.09×10^{-7}
	Lower limit	13.79			1.18×10^{-7}
	Upper limit	33.51			2.87×10^{-7}
Outdoor	Median	10.0	2.68	6.48	8.58×10^{-8}
	Lower limit	−11.57			-9.9×10^{-8}
	Upper limit	14.48			1.24×10^{-7}
Indoor	Median	13.56	−0.205	3.02	1.16×10^{-7}
	Lower limit	5.25			0.45×10^{-7}
	Upper limit	19.05			1.63×10^{-7}

4. Discussion

In the present study, the hourly average concentration of BC ranges from 5.4 ± 1.9 $\mu g \cdot m^{-3}$ to 34.90 ± 51.09 $\mu g \cdot m^{-3}$ for different types of household kitchens. In kitchens without a chimney and lacking proper ventilation, 5 min average BC concentration was over 1100 $\mu g \cdot m^{-3}$. The hourly average peak levels of BC were found to be significantly higher than the ambient limit of $PM_{2.5}$, i.e. 25 $\mu g \cdot m^{-3}$ for 24-hour mean. BC is one of the most toxic fractions of $PM_{2.5}$, and there are no standards for BC, and thus it was compared with the $PM_{2.5}$ standards (Janssen et al., 2011). Overall, semi-open kitchen shows the highest hourly average and maximum BC concentrations due to the lower height of the kitchen compared to indoor kitchens. Further, open rooftop cooking and LPG cooking were found having the lowest BC concentration in all types of kitchens. Maximum hourly average BC concentration was noticed during the evening cooking hours in most of the kitchens studied.

Several studies have reported the BC concentration levels from cooking emissions in rural and urban locations, which are summarized in Table 5. It was reported that BC concentration varies from 3 to 1070 $\mu g \cdot m^{-3}$ in the rural village of Uttar Pradesh and daily average concentration varied between 6 and 20 $\mu g \cdot m^{-3}$ in an urban location in Kanpur, Uttar Pradesh (Tripathi et al., 2005). In a controlled cooking test Kar et al. (2012) found BC concentration as 127 $\mu g \cdot m^{-3}$ in the breathing zone. Van Vliet et al. (2013) measured BC levels at a rural location in Central Ghana and reported mean BC concentration of 14.5 $\mu g \cdot m^{-3}$ in the kitchen area (Van Vliet et al., 2013).

HAP is the major cause of premature deaths accounting for 3.5–4.0 million deaths per year. According to the findings of Gordon et al. (2014) exposure to HAP results in chronic obstructive pulmonary disease and bronchial asthma in women. Advanced cookstoves have been used in some studies as an intervention to reduce HAP exposure to women. Balakrishnan et al. (2015) studied the HAP exposure patterns in pregnant women using forced draft advanced combustion cookstove and found modest improvements in daily average exposure to $PM_{2.5}$. However, a decline in usage over time has been found in interventions of clean cookstove with traditional, which stabilized after 200 days (Pillarisetti et al., 2014). Recently, Government of India has launched several schemes (PAHAL- to pay for subsidized fuel into people's bank account, Give-it-Up- which focus on voluntarily giving the subsidy on LPG fuel by wealthy people, PMUY (Pradhan Mantri Ujjwala Yojana) - to provide free LPG connections to below poverty line families) to address the issue of SBFs. Till October 2018, over 50 million household received the benefits of PMUY.

It is expected that these schemes could help to reduce the health risks associated with the uses of SBF in India (Chowdhury et al., 2018; Ravindra and Smith, 2018) but the effectiveness of these measures and benefits of PMUY clean cooking fuel programmes need to be evaluated. Further, to plan an effective intervention, there is a need to improve

Table 5
Reported BC concentrations at various outdoor and household locations.

Place	Location/duration	BC ($\mu g \cdot m^{-3}$)	Author
Surya village, Uttar Pradesh, India	Rural/Nov, 2009	Morning cooking Evening cooking Indoor 54 ± 73 (~3–1970) 62 ± 61 (~3–1070) Outdoor 24 ± 39 (~3–390) 26 ± 18 (~3–180)	Rehman et al., 2011
IIT Kanpur, India	Urban and industrial/December 2004	Ambient daily average 6–20	Tripathi et al., 2005
Indo-Gangetic Plains, Surya village, Uttar Pradesh, India	Rural, May–June 2010 Controlled cooking test	Mud stove Concentration in breathing zone 127.55 ± 03.51C.I. (95%) Concentration in Plume zone 335.22 ± 46.41C.I. (95%)	Kar et al., 2012
Kintampo North and South districts of the BrongAhafo Region, Ghana	Rural/July and December 2007	Kitchen area 14.5 (12.0, 16.9) mean C.I. (95%) Kitchen area Enclosed 13.8 [7.2, 20.5] mean C.I. (95%) Semi-enclosed 15.6 [10.6, 20.6] mean C.I. (95%) Outdoor 13.7 [10.2, 17.2] mean C.I. (95%)	Van Vliet et al., 2013
Agartala, Tripura	Rural, continental, winter, 2010–2012	17.8 ± 9.2	Guha et al., 2015
Huxian county in Shaanxi Province, China	Rural/winter November 11 to December 12, 2007, and from June 7–June 29, 2008.	Living room 16.5 Roof top 18.1	Zhu et al., 2010
Uttar Pradesh India	Rural, April 24 to May 30, 2013	26.2 ± 11.5	Patange et al., 2015
Yunnan Province, China	Rural, December 2008–August 2009	5.2 (geometric mean), summer-4 (range: 2–14) winter-6 (range: 2–44)	Baumgartner et al., 2014

monitoring and exposure assessment. The burning of crop residue in agricultural fields may also add to BC exposure in rural households (Ravindra et al., 2019). Clark et al. (2013) also highlight that there is a need to study the co-exposure to BC to minimize the health impacts of HAP. Hence, the finding of the current study may provide aid to plan regional policies and effective measure to reduce the burden of HAP associated disease and to minimize the regional and global climatic impact.

Highest BC concentrations up to 1195 $\mu g \cdot m^{-3}$ were observed in the semi-open kitchen without a chimney; whereas similar kitchen with chimney showed maximum concentration levels of 168.82 $\mu g \cdot m^{-3}$. This shows that having a chimney in the kitchen can greatly reduce the maximum concentration levels as also highlighted by Ravindra and Smith (2018) and De la Sota et al. (2018). Indoor and outdoor separately build kitchens with chimney showed little difference in hourly average BC concentrations. Open rooftop cooking resulted in low BC concentration levels of 5.4 $\mu g \cdot m^{-3}$ in term of hourly average concentration. Kitchens with ventilation such as large windows and bigger room size showed a significant reduction in hourly average and maximum BC concentration levels. LPG cooking also resulted in very less BC concentration levels both in terms of hourly average (6 $\mu g \cdot m^{-3}$) and maximum concentration (35 $\mu g \cdot m^{-3}$).

The risk from a lifetime exposure of BC due to different periods of cooking has been shown in this study (Fig. 3). The lifetime carcinogenic risk from BC ranged between 1.22×10^{-7}–2.12×10^{-7} for 4 h/day of cooking. As the cooking hours increased the lifetime risk also increased, while it was found to be maximum for kitchen D4 which is a semi-open kitchen. The cancer risk for 2 h of cooking per day over a lifetime of exposure was 150 among 1 billion people while for 6 h it was 447. The lowest risk was observed for kitchen K10 which is a living room in the Khera village. The cancer risk for 2 h of cooking per day over a lifetime of exposure was 23 among 1 billion people while for 6 h it was 69.

Cacuci et al. (2003) highlight that uncertainty analysis help to assess the effects of parameter uncertainties on the uncertainties in calculated risk from the model. Sensitivity analysis indicates how much of the overall uncertainty in the model predictions are associated with the individual uncertainty in BC measurement and it shows that bootstrapped BC levels have lower and upper limits of 6.36 $\mu g \cdot m^{-3}$ and 17.70 $\mu g \cdot m^{-3}$ respectively and the risk of lifetime carcinogenic risk increases as the levels of BC increases. This may be due to the increase in the carcinogenic fraction of BC as highlighted by Ravindra et al. (2008a) and Agudelo-Castañeda et al. (2017). Hence, the finding of the current study urges to plan effective BC mitigation measure not only to reduce the burden of HAP associated disease but also to minimize the regional and global climatic impact.

5. Conclusion

BC concentration was evaluated at 17 rural kitchens of Punjab in 2014. The average BC concentration in indoor, outdoor and semi-open kitchen was observed to be 14.54, 14.28 and 24.69 $\mu g \cdot m^{-3}$, respectively. Highest BC concentrations up to 1195 $\mu g \cdot m^{-3}$ were observed in semi-open kitchen without a chimney; whereas similar kitchen with chimney showed maximum concentration levels of 168.82 $\mu g \cdot m^{-3}$. It was also observed that as the cooking hours increased the excess lifetime, carcinogenic risk also increase significantly. The average cooking time of 4 h/day was used in current study for BC exposure risk estimation. The average BC concentration for 17 households was observed to be 16.36 $\mu g \cdot m^{-3}$. The lifetime carcinogenic risk for cooking 4 h/day in these kitchens was 1.25×10^{-7}, 1.22×10^{-7}, and 2.12×10^{-7} respectively considering total BC as carcinogenic and having potency factor equivalent to BaP. The ASECD due to BC exposure were estimated highest in the children (55.08×10^{-3}) below four years of age. Hence, there is a need to address the issue of BSFs through suitable policies and interventions to reduce the burden of morbidities and mortalities.

Limitations of the study

The current study aims to identify excess lifetime cancer risk cause due to BC concentrations emitted from solid biomass fuels used for cooking in rural areas. All of BC concentrations were assumed to be BaP which may not be the case. BC consists of complex mixtures of organic compounds (other than PAHs) and an inorganic fraction. Apart from that, the projection of cancer cases was calculated based on national registry data (population-based cancer registry). However, there may be underreporting in such datasets. Even the population data has been extrapolated and projected since the last census data of 2011 was only available. Due to the unavailability of data for calculation different types of cancer and sites could not be identified, which could have been of higher relevance in the current study. Some cancers may be caused by synergistic effects of diet, lifestyle habits and other unknown causes thus it needed to be investigated further whether BC is responsible for a certain cancer type. For the outdoor kitchen type, the sample size was small having wider range of results in the negative lower limit after bootstrapping, which holds no significance for theoretical risk calculation.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2018.11.008.

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Competing finance interest

The author declares no actual or potential competing financial interests.

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