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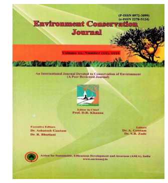

Status of particulate matter in the indoor air of residential units of Sunderbani area of Rajouri district (J&K), India

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ABSTRACT

Air pollution is currently the greatest environmental threat to human health and one of the fastest growing issues on the global health agenda. The extremely fine particulate matter (aerodynamic diameter < 2.5 microns) is of greatest concern because the particles can penetrate deep into human lungs and enter the bloodstream. The elderly, asthmatics and immune-deficient population are the most vulnerable with the increasing levels of particulate matter. The present study was conducted to assess the concentration of size-segregated Indoor Particulate Matter ($PM_{2.5}$, $PM_{1.0}$, $PM_{0.50}$, $PM_{0.25}$) in Sunderbani, Rajouri, J&K. The average values of $PM_{2.5}$, $PM_{1.0}$, $PM_{0.50}$, and $PM_{0.25}$ were reported as 110.36µg/m^3, 180.50µg/m^3, 276.99µg/m^3 and 445.93µg/m^3 respectively in the sampled households of the study area. The average value of $PM_{2.5}$ in the study area was found to be above the permissible limits of 60µg/m^3 given by central pollution control board (CPCB). This was the first study on concentration of size-segregated particulate matter in the indoor environment of study area and the data obtained from the study will serve as baseline data for future studies in the area.

Introduction

Air pollution is one of the greatest threats among the various other type of pollution. Indoor air pollution is more harmful than outdoor air pollution as most of the people spend their maximum time in indoor environment such as schools, offices, malls etc. (Karakas *et al.,* 2013; Gautam *et al.,* 2018; Ruhela *et al.,* 2022a & b). Indoor air pollution refers to the deterioration of indoor quality of air which is caused by the presence of various toxic chemicals and materials in the indoor environment. Indoor air pollution from sources like solid fuels was responsible for 3.5 million deaths and 4.5 percent of global daily-adjusted life year (DALY) in 2010, as well as 16 percent of particulate matter pollution. Though household air pollution from solid fuels has decreased in Southeast Asia, it still ranks third among risk factors in the Global Burden of Disease report. Combustion, construction materials, and bioaerosols are the main causes of indoor air pollution (Bhutiani *et al.,* 2021; Ruhela *et al.,* 2022b). Although radon, heavy metals, volatile organic matter, pesticides, asbestos and tobacco smoke are regarded as the major indoor contaminants in developed countries, biomass fuel combustion products are the most polluting in developing countries. These indoor air pollutants may be categorised as organic, inorganic, biological, or radioactive in general (Tran *et al.,* 2020). In India, 49 percent of the 0.2 billion people who use firewood, 28.6% liquefied petroleum gas, 8.9% cow dung cakes, 2.9 percent kerosene, 1.5 percent coal, lignite, or charcoal, 0.4 percent biogas, 0.1 percent electricity, and 0.5 percent some other means for cooking. The incomplete combustion of biomass fuels releases some products such as suspended particulate matter (SPM), carbon monoxide (CO), polyaromatic hydrocarbons (PAHs), formaldehyde (HCHO), etc., all of which are harmful to human health. Sulfur, arsenic, and fluorine oxides are generated during

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the combustion of coal (Kankaria *et al.,* 2014).According to World Health Organization (WHO), 3.8 million people die each year as a result of exposure to indoor air pollution. Gases, chemicals, and other pollutants that come from various sources contribute to household air pollution. Fine particles, which can penetrate deep into the lungs, infiltrate the bloodstream, and migrate to the organs, are an excellent indicator of health risks (Viana *et al.,* 2013). Particulate matter concentrations can surpass the levels recommended by WHO by a factor of 100 in various poorly ventilated places. It has been found that concentrations of indoor PM were reported to be higher during domestic activities (Jones *et al.,* 2000). There is currently a lack of data on the pollutant load by different sizes of particulate matter ($PM_{2.5-1.0}$ and $PM_{1.0-0.5}$) (Masih *et al.,* 2019). In the present study, attempt has been made to assess the status of Indoor Particulate Matter ($PM_{2.5,}$ $PM_{1.0,}$ $PM_{0.50,}$ $PM_{0.25}$) in the households of Sunderbani area, Rajouri (J&K).

Material and Methods

Study area and Sampling sites description:

The study area, Sunderbani, is a town and a notified area in Rajouri district in Jammu and Kashmir (UT) in the coordinates of $33^{0}4'$ north, $74^{0}49'$ east at an altitude of 633 metres (2077 feet) above sea level. The study was carried out during February, 2020 to December, 2020. The study area was divided into two zones viz. residential zone and commercial zone. Each zone was further divided into following sites on the basis of type of cooking fuel and ventilation in the kitchen. The study area is shown in figure 1 and table 1.

Table 1: Showing the description of sampling sites.

Category	Site Code	Description
Residential Sites	**RLE**	Households with LPG as type of cooking fuel and exhaust in the kitchen
	RLWE	Households with LPG as type of cooking fuel and without exhaust in the kitchen
	RLIE	Households with LPG-Induction as type of cooking fuel and exhaust in the kitchen
	RLIWE	Households with LPG & Induction as type of cooking fuel and without exhaust in the kitchen
	RLIM	Households with LPG & Induction as type of cooking fuel and modular kitchen
	RTC	Households with traditional cooking stove (mud stove/chullah) and wood as type of cooking fuel
Commercial Sites	**CLE**	Households with LPG as type of cooking fuel and exhaust in the kitchen
	CLWE	Households with LPG as type of cooking fuel and without exhaust in the kitchen
	CLIE	Households with LPG-Induction as type of cooking fuel and exhaust in the kitchen
	CLIWE	Households with LPG & Induction as type of cooking fuel and without exhaust in the kitchen
	CLIM	Households with LPG & Induction as type of cooking fuel and modular kitchen
	CTC	Households with traditional cooking stove (mud stove/chullah) and wood as type of cooking fuel

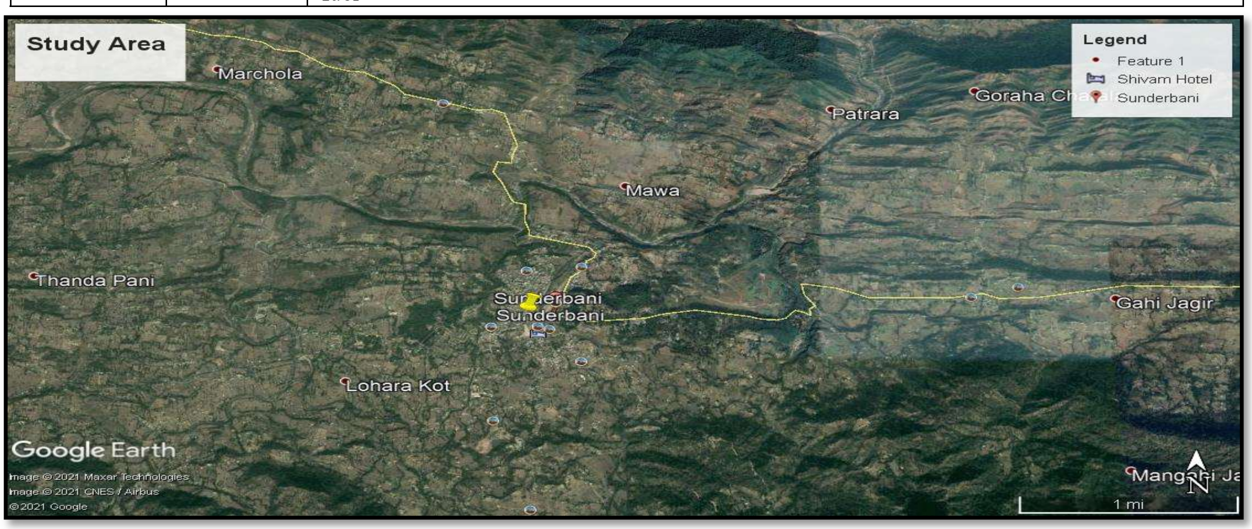

Figure 1: Satellite image showing the study area

Sampling of indoor air and data collection:
At each site sampling of indoor air was done thrice (once each in Kitchen, bedroom, and drawing room on three consecutive days) by CPCB Gravimetric method given by CPCB (2014) using Leland Legacy Sample Pump (at selected air flow rate of 9 L/min) in combination with a five-stage Sioutas Personal Cascade Impactor provided with particle size cut points of 2.5 µm, 1 µm, 0.5 µm and 0.25 µm on Zefluor™ supported PTFE filter paper of pore size 0.5 µm (micrometre) and 25 mm diameter for 24 h. All the filter papers before and after sampling were weighed thrice using Mettler Toledo micro balance with sensitivity of 0.01 mg. The concentration of PM ($PM_{2.5}$, $PM_{1.0}$, $PM_{0.50}$, $PM_{0.25}$)
$PM_{0.25}$) was calculated by the formula:

$$\textit{Conc. of PM}\ (\mu g/m^3) = (W_2 - W_1) \times \frac{10^6}{\textit{Volume of air}}$$

where,
W_1 - initial weight of filter paper (mg).
W_2 - final weight of filter paper (mg).

Results and Discussion

The results are tabulated in table 2, 3, 4, 5, 6 and 7 and figure 2, 3 and 4. The critical analysis of data at Residential area revealed that values of $PM_{2.5}$ were highest in RTC followed by RLWE and least in RLIM whereas the values of $PM_{1.0}$, $PM_{0.50}$ and $PM_{0.25}$ were found highest in RTC followed by RLIM and least by RLIE households (Figure 4). Highest values of indoor particulate matter were reported in households with traditional chullah (TC) which supports the finding that indoor $PM_{2.5}$ concentration were higher for Traditional Cooking Stoves (TCS) and lower for Improved Cooking Stove (ICS) reported by Parajuli *et al.* (2016). The critical analysis of data at Commercial area revealed that values of $PM_{2.5}$ were highest in CTC followed by CLWE and least in CLIM whereas the values of $PM_{1.0}$ were highest in CTC followed by CLE and least by CLIM, $PM_{0.50}$ were highest in CTC followed by CLIE and least by CLE and $PM_{0.25}$ were found highest in CTC followed by CLWE and least by CLIE households (figure 4).
These results support the findings of Nishu and Rampal (2019) that in comparison to residences even without exhaust, Chulha-using households showed higher levels of indoor $PM_{2.5}$ at all the study sites. Further, the analysis of the data of particulate matter in the households with traditional chullah revealed that kitchens of residential area exhibited insignificantly ($p>0.05$) higher values of $PM_{2.5}$, $PM_{1.0}$, $PM_{0.50}$ and $PM_{0.25}$ as compared with that of commercial area.
The overall comparison of particulate matter in the non-wood burning fuel households with exhaust and households without exhaust at residential and commercial areas revealed that households without exhaust exhibited higher values of particulate matter as compared with that of households with exhaust and even households with modular kitchen exhibited lowest values of particulate matter which validates the claim of Parajuli *et al*. (2016) that in order to enhance the indoor air quality of rural homes, greater attention should be paid to ventilation and chimney location. It was also reported that UFP concentrations during cooking were highest when kitchen exhaust fan was turned off and gas stove was utilised at a higher temperature by Zhang *et al*. (2010). The analysis of particulate matter in the households with LPG as cooking fuel and exhaust at study area revealed indoor $PM_{2.5}$, $PM_{1.0}$, and $PM_{0.25}$ exhibited highest values in the Kitchen followed by Drawing room and lowest in the Bedroom whereas indoor $PM_{0.50}$ exhibited the trend Kitchen followed by Bedroom and lowest in the Drawing room (Table 2). Households with LPG as cooking fuel and without exhaust exhibited highest values of indoor $PM_{2.5}$, $PM_{1.0}$, $PM_{0.50}$ and $PM_{0.25}$ in the Kitchen and lowest in the Bedroom (Table 3).
Households with LPG-induction as cooking fuel and exhaust exhibited highest values of indoor $PM_{2.5}$ and $PM_{0.50}$ in the Kitchen followed by Drawing room and lowest in the Bedroom whereas $PM_{0.25}$ exhibited the trend Kitchen followed by Bedroom and lowest in the Drawing room and $PM_{1.0}$ exhibited the trend Drawing room followed by Kitchen and lowest in the Drawing room in the overall study area (Table 4). Households with LPG-induction as cooking fuel and without exhaust in the study area exhibited highest values of indoor $PM_{2.5}$ and $PM_{0.50}$ in the Kitchen followed by Drawing room and lowest in the Bedroom whereas $PM_{1.0}$ and $PM_{0.25}$ exhibited the trend Kitchen followed by Bedroom and lowest in the Drawing room (Table 5).

Table 2: Indoor PM (2.5, 1.0, 0.50, 0.25) concentrations in household with LPG and Exhaust in overall Study area

PM Size	PM Average (μg/m³)			
	Kitchen	Bedroom	Drawing room	Study Area
$PM_{2.5}$	41.66	18.51	20.82	26.99±12.75
$PM_{1.0}$	28.93	12.72	17.35	19.66±8.34
$PM_{0.50}$	17.35	15.04	5.78	12.72±6.12
$PM_{0.25}$	41.66	15.04	19.67	25.45±14.22

Table 3: Indoor PM (2.5, 1.0, 0.50, 0.25) concentrations in household with LPG and Without Exhaust in overall Study area

PM Size	PM Average (μg/m³)		
	Kitchen	Bedroom	Study Area
$PM_{2.5}$	56.71	26.62	41.66±21.27
$PM_{1.0}$	20.83	16.20	18.51±3.27
$PM_{0.50}$	15.02	10.41	12.71±3.25
$PM_{0.25}$	38.19	24.30	31.24±9.82

Table 4: Indoor PM (2.5, 1.0, 0.50, 0.25) concentrations in household with LPG-Induction and Exhaust in overall Study area

PM Size	PM Average (μg/m³)			
	Kitchen	Bedroom	Drawing room	Study Area
$PM_{2.5}$	32.40	26.61	31.24	30.08±3.06
$PM_{1.0}$	17.35	15.04	19.67	17.35±2.31
$PM_{0.50}$	19.67	12.72	16.20	16.19±3.47
$PM_{0.25}$	30.08	11.57	10.41	17.35±11.03

Table 5: Indoor PM (2.5, 1.0, 0.50, 0.25) concentrations in household with LPG-Induction and Without Exhaust in overall Study area

PM Size	PM Average (μg/m³)			
	Kitchen	Bedroom	Drawing room	Study Area
$PM_{2.5}$	47.45	20.82	26.61	31.62±14.00
$PM_{1.0}$	28.93	12.72	11.57	17.74±9.70
$PM_{0.50}$	27.77	10.41	16.19	18.12±8.84
$PM_{0.25}$	34.71	23.14	20.83	26.22±7.43

Table 6: Indoor PM (2.5, 1.0, 0.50, 0.25) concentrations in household with LPG-Induction and Modular Kitchen in overall Study area

PM Size	PM Average (μg/m³)			
	Kitchen	Bedroom	Drawing room	Study Area
$PM_{2.5}$	16.20	25.45	19.67	20.44±4.67
$PM_{1.0}$	11.57	17.35	27.77	18.89±8.21
$PM_{0.50}$	11.56	16.20	35.87	21.21±12.90
$PM_{0.25}$	20.82	18.51	52.08	30.47±18.75

Table 7: Indoor PM (2.5, 1.0, 0.50, 0.25) concentrations in household with Traditional Chullah in overall Study area

PM Size	PM (μg/m³)
	Kitchen Average (Study Area)
$PM_{2.5}$	190.58
$PM_{1.0}$	342.58
$PM_{0.50}$	537.80
$PM_{0.25}$	865.73

Figure 2: Filter papers showing accumulation of different types of PM (2.5-0.25) in the Household with Traditional Chullah at the Residential area

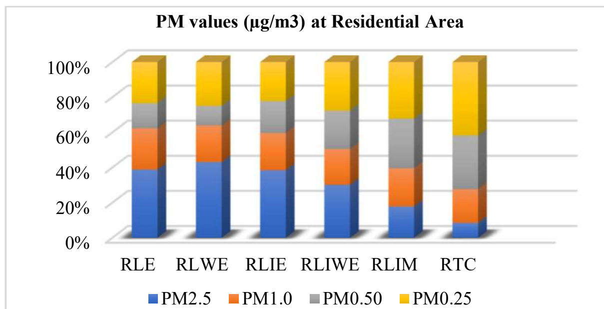

Figure 3: PM concentrations (μg/m³) at Residential area with different fuel and ventilation conditions

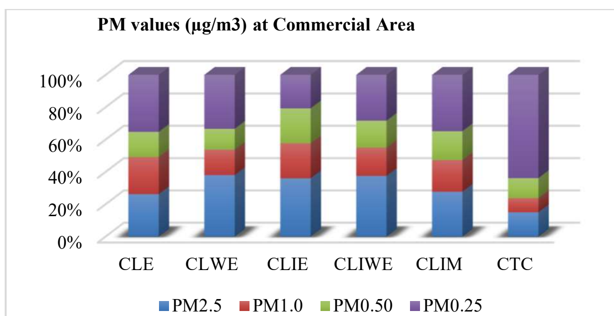

Figure 4: PM concentrations (μg/m³) at Commercial area with different fuel and ventilation conditions

Households with LPG-induction as cooking fuel and without exhaust in the study area exhibited highest values of indoor $PM_{2.5}$ and $PM_{0.50}$ in the Kitchen followed by Drawing room and lowest in the Bedroom whereas $PM_{1.0}$ and $PM_{0.25}$ exhibited the trend Kitchen followed by Bedroom and lowest in the Drawing room (Table 5). Households with LPG-induction as cooking fuel and Modular Kitchen revealed $PM_{1.0}$ and $PM_{0.50}$ exhibited the trend Drawing room followed by Bedroom and lowest in the Kitchen whereas $PM_{2.5}$ exhibited the trend Bedroom followed by Drawing room and lowest in the Kitchen and $PM_{0.25}$ exhibited the trend Drawing room followed by Kitchen and lowest in the Bedroom in the overall study area (Table 6). Rampal and Chib (2013) while studying indoor suspended particulate matter (SPM) levels in kitchens of households using various cooking methods noticed that SPM levels were higher than the levels prescribed by CPCB (200 $\mu g/m^3$) in all households. They also found that fuelwood using kitchens had the highest SPM (1435.54 ± 849.47$\mu g/m^3$), followed by kitchens using kerosene oil (710.06 ± 180.37$\mu g/m^3$), kitchens using LPG (376.79 ±140.98$\mu g/m^3$) and kitchens using electric heater (262.08 ± 95.90$\mu g/m^3$) as their mode of cooking. Households with Traditional chullah in the overall study area on the basis of compilation of data showed the average value of $PM_{2.5}$ as 190.58$\mu g/m^3$, $PM_{1.0}$ as 342.58$\mu g/m^3$, $PM_{0.50}$ as 537.80$\mu g/m^3$, $PM_{0.25}$ as 865.73$\mu g/m^3$. The value of average indoor $PM_{2.5}$ was found to be 3.1 times above the CPCB prescribed 24 hrs. limit of 60 $\mu g/m^3$ in the study area (Table-7 and Figure-4). This observation was supported in one study which reported that wood users were subjected to much more particle pollution (1200 $\mu g/m^3$) than charcoal users (540$\mu g/m^3$) or modern fuel users like LPG and electricity (200-380 $\mu g/m^3$) during the cooking process in Mozambique conducted by Ellegard (1996). Vicente *et al*. (2020) also observed that the levels of PM_{10} were about 12 times higher during the usage of wood burning devices in uninhabited rural households.

Generally, kitchens in the households of study area exhibited higher values of all types of particulate matter, PM $_{(2.5,\ 1.0,\ 0.50,\ 0.25)}$ except in the household with LPG-Induction and Modular Kitchen when compared with the average values recorded in the bedrooms and drawing rooms. This was due to the higher fuel emissions and less space in the kitchen as indoor air pollutants accumulate more quickly in the enclosed spaces rather than in the open spaces.

The average values of $PM_{2.5}$, $PM_{1.0}$, $PM_{0.50}$ and $PM_{0.25}$ in the Wood fuel burning Households were observed to be significantly ($p<0.05$) higher than the average values of $PM_{2.5}$, $PM_{1.0}$, $PM_{0.50}$ and, $PM_{0.25}$ in the non-wood fuel burning households of the study area. This observation find supports from the findings of Mukkannawar *et al.* (2014) who also observed higher particulate matter concentrations in homes using chullah as compared to kerosene stove and LPG stove respectively. And the values obtained were found to be 81.8% and 97% times more than NAAQS values of $PM_{2.5}$ and PM_{10} respectively thereby concluding that people residing in households using traditional chullah and kerosene stove were exposed to greater risk of disastrous respiratory health impacts. Kurmi *et al.* (2014) also reported both men and women who were exposed to biomass smoke had greater respiratory issues than those who were exposed to

cleaner fuel found in a study in Nepal.

Conclusion

The average values of $PM_{2.5}$, $PM_{1.0}$, $PM_{0.50}$ and $PM_{0.25}$ in all types of wood and non-wood fuel burning households of the study area were observed to be 110.36$\mu g/m^3$, 180.50$\mu g/m^3$, 276.9$\mu g/m^3$ and 445.93$\mu g/m^3$ respectively. The value of average indoor $PM_{2.5}$ was observed to be 1.8 times above the CPCB prescribed 24 hrs. limit of 60 $\mu g/m^3$ in the study area. The average values of $PM_{2.5}$, $PM_{1.0}$, $PM_{0.50}$ and, $PM_{0.25}$ in the wood fuel burning households were observed to be significantly ($p<0.05$) higher than the average values of $PM_{2.5}$, $PM_{1.0}$, $PM_{0.50}$ and, $PM_{0.25}$ in the non-wood fuel burning households of the study area. The information gathered in the current study will serve as a baseline for further research to identify the presence of toxic metals and ions, their sources that contribute to ambient air and have an impact on the environment and human health. Moreover, study of more size segregated particulate matter in indoor and outdoor environment is expected that will enable the researchers to effectively address the effects of these on health in the future.

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Conflict of interest

The authors declare that they have no conflict of interest.

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