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Assessment of seasonal variations in the fine particulate matter of indoor air in sub urban area of Jammu District (J&K), India

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ABSTRACT

Indoor aerosol $PM_{2.5}$ is more harmful due to its penetration deep into lungs most ofpeoplespendingmore than 90% of their time indoor. The present study is the first timeinvestigation to evaluate the indoor aerosols ($PM_{2.5}$) in the households located in residential, commercial and industrial sub urban areas Jammu District (J&K) during different seasons of the two year study period (2017-2019). The indoor $PM_{2.5}$ was observed to exhibit deceasing trend i.e. more in summer> winter >rainy season. In non-wood fuel burning households exhibited annual average indoor $PM_{2.5}$ values below the values prescribed by CPCB and wood fuel burning households exhibited values above the values prescribed by CPCB. Moreover the indoor aerosols ($PM_{2.5}$) was observed be to almost four times higher in wood fuel burning households as compared with that of non-wood fuel burning households.

Introduction

Environmental and health conditions prevailing in the country are determined by air quality of a country (Singh, 2016; Ruhela *et al.*, 2022a; Ahamad *et al.*, 2022). Major proportion of the world's population resides in sub-urban and rural areas and consuming fuels like kerosene oil, wood and cow dung cakes to fulfil their energy demands (Ampitan and Oleyerind, 2015). Due to lack of complete premixing of the fuel and air during burning inside the cooking and heating stoves solid fuels are difficult to burn therefore liquid and gaseous fuels are preferred in which complete premixing of the fuel and air during burning take place easily (Smith, 2000; Mac Kinnon *et al.,* 2019; Ruhela *et al.*, 2022b). A lot of work and financial budget has been spent to control the major outdoor air pollutants but indoor pollution has received attention only recently. Indoor air pollution has been considered as being among the top five environmental risks to the public health by the U. S. Environment Protection Agency (EPA) as people spend long period indoors at home and at workplace (Morowska, 1999). One of the major environmental issues that need to be addressed in megacities was reported to be cooking fume pollution (Lin *et al.*, 2014) which not only causes indoor air pollution, but significantly contributes fine particulate matter ($PM_{2.5}$) in the ambient atmosphere (Zheng *et al.*, 2002; Robinson *et al.*, 2006; Abdullahi *et al.*, 2013).Diameter between 0.002µ to 100 µ of any solid or liquid droplet is called particulate matter (PM) which can be PM_{10} with an aerodynamic diameter ≤10µm or $PM_{2.5}$ with an aerodynamic diameter ≤ 2.5µm or ultrafine particles with an aerodynamic diameter of ≤0.1µm). $PM_{2.5}$ and ultrafine particles are considered most harmful because of their tendency to penetrate deeply into the lungs. Cooking operations emit $PM_{2.5}$ which poses great danger to several major organ systems like emissions industrial, power, mobile, residential, agricultural sources (Abbey *et al.*, 1995, Romieu *et al.*, 1996 and Lighty *et al.*, 2000; Bhutiani *et al.*, 2021).Various carcinogenic components like PAHs remain attached to black carbon of PM, (IARC, 2010a and b). Particulate matter has been estimated to attribute approximately 3% of cardiopulmonary and 5% of lung cancer deaths globally (Cohen *et al.*, 2004). Recent study has indicated that annual$PM_{2.5}$ was responsible for 3.1 million deaths and around 3.1% of global disability-adjusted life years (Lim, 2012). Potential risks to human health from cooking fumes were observed to be higher due their emission at a relatively lower height thereby signifying the importance of control of cooking fume pollution. In present study attempt has been made to evaluate the

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indoor aerosols ($PM_{2.5}$) in the households located in residential, commercial and industrial sub urban areas Jammu District (J&K) during different seasons of the two year study period (2017-2019).

Material and Methods

Study area and Sampling sites

The study area, District Jammu of J&K, lies between $32^0\ 15^/$ and $37^0\ 17^/$ north latitude to $72^0\ 35^/$ and $80^0 20^/$ East longitude at the foothills of Himalayan region. The specific study area (Sub urban area) was divided into three zones i.e. 1) Residential zone (R), 2) Commercial zone (C) and 3) Industrial zone (I). Each zone was further demarcated into seven sites based on the type of fuel used for cooking and ventilation conditions of kitchen for the sampling of indoor air. The description of the sampling sites has been tabulated in Table 1.

Table 1: The sampling sites of the study area

Zones	Codes of the site	Cooking fuel and kitchen conditions	Specific Location
Residential	SURLE	LPG and exhaust in the kitchen	Khour
	SURLWE	LPG and without exhaust in the kitchen	Narayana
	SURLM	LPG and modular kitchen	Parwah, Marh
	SURLHE	LPG-Heater(Induction) and exhaust in kitchen	HalkaMarh
	SURLHWE	LPG-Heater(Induction) and without exhaust in kitchen	PatyaliChak
	SURLHM	LPG-Heater(Induction) and modular kitchen	Gajansoo
	SURC	Traditional Cooking Stove (Chullah)	Karloop
Commercial	SUCLE	LPG and exhaust in the kitchen	Gajansoo
	SUCLWE	LPG and without exhaust in the kitchen	GhouManhasan
	SUCLM	LPG and modular kitchen	Sari
	SUCLHE	LPG-Heater(Induction) and exhaust in kitchen	Padrore
	SUCLHWE	LPG-Heater(Induction) and without exhaust in kitchen	Deichak
	SUCLHM	LPG-Heater(Induction) and modular kitchen	Pounichak
	SUCC	Traditional Cooking Stove (Chullah)	Sarora
Industrial	SUILE	LPG and exhaust in the kitchen	Bawe Talab
	SUILWE	LPG and without exhaust in the kitchen	Patta
	SUILM	LPG and modular kitchen	Marjali
	SUILHE	LPG-Heater(Induction) and exhaust in kitchen	Shamachak
	SUILHWE	LPG-Heater(Induction) and without exhaust in kitchen	SukaPakhian
	SUILHM	LPG-Heater(Induction) and modular kitchen	Deharan
	SUIC	Traditional Cooking Stove (Chullah)	Bawe Talab

Indoor air sampling and collection of data

The sampling of indoor $PM_{2.5}$ was done thrice (once each in Kitchen, drawing room and bed room of two room accommodation and thrice in same one-room accommodation on three consecutive days) during the summer season (March-June), rainy season (July-October) and winter season (November-February) using Sioutas Personal Cascade Impactor with Leland Legacy Sampling Pump on Zefluor™ supported with PTFE filter paper of 0.5 micron pore size and 25 mm diameter for 24 hours at 9 lpm. Central Pollution Control Board (2014) prescribed the Gravimetric method was used. The filter paper was weighed usingMettler Toledo Microbalance Model MS105DU with a sensitivity of 0.01 mg. The determination ofthe $PM_{2.5}$ was made by the formula:

Conc. of $PM_{2.5}$ ($\mu g/m^3$) = $(W_1-W_0) \times 10^6$ / Volume of air

Where,
$W_1$and W_0 is Final and Initial weights of filter paper in mg.

All data was subjected to One-way ANOVA and Post Hoc Test using IBM SPSS Statistics Version 22 analysis after calculating average values with standard deviation.

Results and Discussion

The results of all the sites are given in table 2 to 5. The sites (i.e. SURLE, SURLWE, SURLM, SURLHE, SURLHWE and SURLHM) in in

Table 2: Seasonal variations in indoor $PM_{2.5}$ levels in residential zone sites of study area

SITE	$PM_{2.5}$ µg/m^3 during			
	Summer season	Rainy season	Winter season	Significance value (p) (One-way ANOVA)
SURLE	38.50±14.30 (25.45-58.10)	19.12±2.87 (14.12-21.29)	21.87±4.18 (16.66-27.77)	0.31
SURLWE	43.63±20.11 (26.89-70.60)	19.09±3.73 (16.20-25.23)	27.46±6.50 (21.06-36.57)	0.33
SURLM	34.14±13.58 (20.67-51.38)	15.96±2.11 (13.88-19.44)	18.81±2.49 (15.70-22.68)	0.34
SURLHE	40.99±16.21 (27.77-62.69)	19.74±6.08 (15.04-29.86)	31.32±6.76 (24.53-41.20)	0.32
SURLHWE	46.44±20.08 (30.09-72.68)	24.18±4.67 (19.21-31.48)	36.87±6.19 (30.09-45.83)	0.31
SURLHM	37.70±13.77 (24.65-56.48)	18.38±3.23 (14.00-22.45)	20.71±3.81 (16.20-26.38)	0.36
SURC	140.5±23.70 (141.57-183.92)	115.05±20.60 (119.56-149.87)	127.5±16.80 (133.44-164.53	0.39

Table 3: Seasonal variations in indoor $PM_{2.5}$ levels in Commercial zone sites of study area

SITE	PM2.5µg/m3 during			
	Summer season	Rainy season	Winter season	Significance value (p) (One-way ANOVA)
SUCLE	41.19±15.78 (28.89-62.26)	35.23±7.49 (28.24-45.60)	37.84±9.35 (30.09-50.92)	0.35
SUCLWE	48.11±21.44 (31.77-76.15)	36.83±7.64 (30.32-47.91)	40.31±10.48 (31.48-54.62)	0.31
SUCLM	35.59±8.58 (27.77-47.68)	28.97±4.94 (23.61-36.11)	32.17±5.57 (26.38-40.74)	0.29
SUCLHE	55.97±27.41 (34.72-92.12)	37.76±7.50 (31.48-48.37)	42.24±12.17 (32.87-59.25)	0.41
SUCLHWE	59.81±31.11 (37.74-100.23)	40.23±8.84 (32.40-52.08)	44.97±13.48 (34.25-63.88)	0.33
SUCLHM	41.12±15.24 (29.72-62.50)	32.78±7.18 (26.38-42.82)	35.37±7.19 (28.24-45.60)	0.36
SUCC	174.12±16.96 (147.29-181.21	144.93±20.80 (111.39-174.56	158.35±14.81 (141.20-181.21)	0.35

residential zone, sites (i.e. SUCLE, SUCLWE, SUCLM, SUCLHE, SUCLHWE and SUCLHM) Commercial zone and the sites (i.e. SUILE, SUILWE, SUILM, SUILHE, SUILHWE and SUILHM) in industrial zone were observed to be exhibit insignificant variations ($p>0.05$) in Indoor $PM_{2.5}$ except households at sites SURLM , SUCLM and SUILM with Modular kitchen exhibited significantly ($p<0.05$) lowest values of indoor $PM_{2.5}$ as compared with other types of households with non wood fuel burning practice.. Patel *et al.* (2017) while assessing spatio-temporal indoor particulate matter in households in Raipur, India also observed that PM concentrations in kitchen and adjoining rooms was effected with ventilation. Among the Residential Zone sites (i.e. SURLE, SURLWE, SURLM, SURLHE, SURLHWE and SURLHM), SURLHWE exhibited the highest value of 46.44µg/m^3 during summer season and SURLM exhibited the lowest value of 15.96µg/m^3 during rainy season. Among Sub-urban Commercial Zone sites (i.e. SUCLE, SUCLWE, SUCLM, SUCLHE, SUCLHWE and SUCLHM), SUCLHWE exhibited the highest value of 59.81µg/m^3 during summer season and SUCLM exhibited the lowest value of 28.97 µg/m^3 during rainy season and among Sub-urban Industrial Zone sites (i.e. SUILE, SUILWE, SUILM, SUILHE, SUILHWE and SUILHM), SUILHWE exhibited the highest value of 62.63µg/m^3 during summer season and SUILM exhibited the lowest value of 31.2µg/m^3 during winter season.

The critical analysis of indoor PM $_{2.5}$ of kitchens , drawing rooms and bedrooms in the sub urban households during study period (2017 -2019) revealed that all the kitchens, drawing rooms and bedrooms exhibited significantly ($p<0.05$) higher values during summer season followed by winter season and lower values during rainy seasons.The non-wood fuel burning households during summer seasons exhibited significantly ($p<0.05$) higher values of indoor PM followed winter season and lower values during rainy seasons during the two year study period .The present observation was contrary to that of Shukla and Sharma (2008) who observed the lowest concentration of PM_{10} during monsoon period and higher variability in summers in Kanpur because of higher wind speed in summers but present observation find support from the work of Kamath and Lokeshappa, (2014) who observed concentration of pollutants were more in summer in comparison to the pre monsoon and post monsoon seasons in Bangalore and that of Cheng and Wang-Li (2019) who reported $PM_{2.5}$

Table 4: Seasonal variations in indoor $PM_{2.5}$ levels in Industrial zone sites of study area

SITE	$PM_{2.5}$ µg/m^3 during			
	Summer season	**Rainy season**	**Winter season**	**Significance value (p) (One-way ANOVA)**
SUILE	47.89±20.10 (34.08-75.23)	36.87±8.38 (29.62-48.37)	38.11±10.61 (29.62-52.54)	0.32
SUILWE	56.38±26.53 (36.79-91.43)	38.77±9.04 (30.32-51.38)	41.12±12.82 (30.32-58.33)	0.36
SUILM	39.00±12.19 (29.56-56.71)	31.28±7.20 (24.53-41.43)	31.20±7.33 (24.53-41.43)	0.35
SUILHE	59.09±29.17 (37.03-98.37)	44.94±9.84 (36.80-58.33)	45.48±11.01 (36.80-60.87)	0.42
SUILHWE	62.63±30.86 (39.72-103.24)	48.95±12.68 (38.65-66.66)	48.71±12.39 (38.65-65.50)	0.39
SUILHM	42.89±15.18 (30.08-63.88)	34.56±6.71 (28.93-43.51)	36.33±8.78 (28.93-48.37)	0.35
SUIC	178.12±16.96 (149.29-181.21	164.12±16.96 (147.29-180.21	161.11±18.61 (121.54-159.96	0.39

Table 5: Year wise seasonal variations of Indoor PM $_{2.5}$ (µg/m3) levels in Study area

One-way ANOVA (zone and season wise) variations Significant ($p<0.05$)

Average Indoor aerosols (PM $_{2.5}$) level in Study area with wood and non wood burning for cooking during two year study period was calculated to be 93.71±59.98µg/m^3.

Site	Summer (Non-Wood fuel)	Summer (Wood fuel)	Rainy (Non-Wood fuel)	Rainy (Wood fuel)	Winter (Non-Wood fuel)	Winter (Wood fuel)	Two Year Study Period (Non-Wood fuel)	Two Year Study Period (Wood fuel)	Average Two Year Study Period
Residential	40.23±4.40 (20.67-72.68)	140.7 ±1.20 (141.57-183.92)	19.41±2.68 (13.88-31.48)	115.475±5.77 (119.56-149.87)	26.17±7.00 (15.70- 45.83)	127.49±8.41 (133.44-164.53	28.60±10.62 (13.88-72.68)	127.89± 12.62 (119.56-183.92)	78.24± 55.37 (13.88-83.92)
Commercial	46.96±9.42 (27.7100.23)	175.06±8.69 (147.29-181.21)	35.3±3.97 (23.61-52.08)	144.24±4.30 (111.39-174.56)	38.81±4.66 (26.38- 63.88)	158.76± 7.21 (141.20-181.21	40.35±5.98 (23.61-100.2)	159.35±15.41 (111.39-181.21)	99.85±66.01 (23.61-81.21)
Industrial	51.31±9.47 (29.56- 103.2)	179.24±6.61 (149.29-181.21)	39.22±6.60 (24.53- 66.66)	146.115±5.31 (147.29-180.21	40.15±6.34 (31.20- 65.50)	162.24±3.23 (121.54-159.96	43.56±6.72 (24.53-103.2)	162.53±16.56 (121.54- 181.21)	103.04± 66.13 (24.53-81.21)
Average	46.16 ± 5.58 (20.6- 103.2	165.00 ± 21.13 (141.5-183.92	31.31 ±10.49 (13.8-66.66)	135.27± 17.17 (111.39- 180.21)	35.04 ± 7.71 (15.70- 65.50	149.49 ± 19.13 (121.5-181.21)	37.50 ±7.87 (13.88-103.2)	149.92± 19.14 (111.39- 183.92)	93.71 ± 59.98 (13.88-83.92)

concentrations higher in summer and lower in winter in North Carolina.The study also revealed that Kitchen exhibited significantly ($p<0.05$) higher values of indoor $PM_{2.5}$ followed by Bedrooms and lower values at drawing room.The higher values of indoor PM $_{2.5}$ during summer seasons followed winter season and lower values during rainy seasons in all the wood fuel burning households were observed to be insignificant ($p>0.05$). The higher values of indoor PM $_{2.5}$ at industrial sites as compared with that of commercial sites followed by residential sites during all the seasons of two year study period were also observed to be insignificant ($p>0.05$).

All the households with non wood fuel burning for cooking exhibited average annual indoor PM $_{2.5}$ of 37.50±7.87 μg/m^3 which was observed to be below the annual limit of 40 μg/m^3 as prescribed by CPCB .whereas all types of households with wood fuel burning for cooking at study area exhibited annual indoor PM $_{2.5}$ of 149.92±19.14 μg/m^{3}which was observed to be above the annual limit of 40 μg/m^3 as prescribed by CPCB observation find solution by Chafe *et al.,* (2014) who suggested only by improving household cooking conditions ambient air quality would be improved. The present observation also support work of the Ojo *et al.,* (2015) who observed the mean indoor PM$_{2.5}$ using wood fuel to be 4584μg/m^3, 1657 μg/m^3, and 2414 μg/m^3 for the traditional, alternative mud brick stove and Envirofit G-series in Nepal respectively.

Statistical analysis revealed exhibited significantly ($p<0.05$) higher values (149.92±19.14 μg/m^3) of indoor PM $_{2.5}$ in households with wood fuel burning for cookingas compared with that (37.50±7.87μg/m^3) of households with non wood fuel burning for cooking at study area. Zhou *et al.* (2011) observed particulate matter due to cooking practices lowest in high socio-economic status households and highest in low socio-economic status households Moschandreas *et al.* (1980) observed higher indoor levels of respirable particulates, carbon-monoxide and organics due to wood burning in the households. This observation find support from the work of (Shrestha and Shrestha, 2005) who observed average PM$_{10}$ levels three times higher in households using biomass fuels than those using cleaner fuels like LPG, Kerosene and biogas. Jiang and Bell (2008) also reported three times higher PM$_{10}$ levels in rural kitchens as compared with that of urban kitchens and also that more than six times higher PM$_{10}$ levels at the time of cooking than at time of non-cooking for rural kitchens.

Conclusion

Indoor PM$_{2.5}$ average values in wood fuel burning households of study area exhibited value (149.92±19.14 μg/m^3) almost four times higher than the value (37.50±7.87 μg/m^3) of non wood fuel burning households. Fuel wood burning added more PM$_{2.5}$ indoor pollutant. Year wise and Site Wise variations (except at Household with modular kitchen) exhibited insignificant ($p>0.05$) values as analysed by One way ANOVA and Post Hoc Test during Statistical Analysis of data by IBM SPSS Statistics Version22. Season wise variations exhibited significant ($p<0.05$) values as analysed by One way ANOVA and Post Hoc Test during Statistical Analysis of data by IBM SPSS Statistics Version 22.

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Conflict of interest

The authors declare that they have no conflict of interest.

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