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Daily Personal Exposure of Women Cooks to Respirable Particulate Matters during Cooking with Solid Bio-Fuels in a Rural Community of West Bengal, India

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ABSTRACT

About 60% of the Indian population are still relying on the traditional bio-fuels comprising of firewood, cow dung cake, crop residue etc. More than 85% of the rural households use these unprocessed bio-fuels for cooking purposes. Biomass fuel burning in daily cooking with traditional inefficient earthen stoves, in an un-vented kitchen, usually emits very high levels of smoke containing a complex mixture of a wide array of potentially hazardous pollutants, especially, particulate matters of varying size range. Size smaller than the PM_{10} particles, can penetrate further deep into the gas exchange region of the lungs and are termed as the respirable particulate matter with 50% cut point at 4 µm. Respirable particulate exposure assessment is particularly important in case of health hazard explanation because it can enter into the deepest of the lungs. Personal exposures to respirable particulate matters were assessed during cooking hours in the varied opened kitchens, considering the seasonal change and the meal preparation as covariates. Maximum variability for the particulate exposures was observed in the kitchens with openness range of 15–60%. Greater particulate exposures were found in the least opened kitchens. Two-way ANCOVA showed significant impact of seasonal change on the differential opened kitchens for personal exposure to respirable particulate matters. Tukey post hoc test reveals significant mean differences of respirable particulates in all pair-wise seasonal combinations and in all the pair-wise openness type combinations except for the < 15% and 15–30% opened kitchens. Winter season came out to be one of the significant predictor for the personal exposure prediction model. Across all the seasons and kitchen openness, average exposure concentration of the respirable particulate matters was 1445 µg m^{-3}.

Keywords: Bio-fuels; Personal exposure; Respirable particulate matters; Rural kitchen; Woman cook.

INTRODUCTION

Indoor air pollution from bio-fuel combustion is now well recognized as one of the major threats to the human health (Fullerton *et al.*, 2008; Torres-Duque *et al.*, 2008). Census of India, 2011 reported that more than 60% of the Indian population is dependent on the traditional bio-fuels comprising fire wood, cow dung cake, crop residue etc. More than 85% of the rural households use these unprocessed bio-fuels for cooking purposes. Easy availability of the agricultural waste, crop residue and dung from domestic cattle, virtually at no cost led the rural population use these for cooking (Parikh *et al.*, 2001; Massey *et al.*, 2013). Researchers found that smaller the particulate matter, larger the effects on health (Schwartz and Neas, 2000; Long *et al.*, 2001; Dominici *et al.*, 2006; Kelly and Fussell, 2012). Smaller particulates with more toxic loadings (reactive oxygen species) on its increased surface area pose more hazards for their enhanced potential to enter deep into the lungs and reacting there with delicate gas exchange surface (Pope III *et al.*, 2002; Risom *et al.*, 2005; Monteiller *et al.*, 2007).

Biomass fuel burning in daily cooking with traditional inefficient earthen stoves in an un-vented kitchen usually emits very high levels of smoke containing a complex mixture of a wide range of potentially hazardous pollutants which includes particulates, gases (carbon monoxide, oxides of nitrogen and sulphur) and vapors (polycyclic aromatic hydrocarbons, volatile organic compounds) (Ezzati *et al.*, 2004; Smith *et al.*, 2004; Zhang and Smith, 2007). Particulate matters emitted from the biomass fuel combustion have shown to vary in a wide range of size fractions predominated with the smaller scaled aerodynamic diameters (Hays *et al.*, 2002; Begum *et al.*, 2009). PM_{10} particulates generally enter in to the lower thoracic region of the respiratory tract of the lungs (Maynard and Aitkenm, 2007; Brown *et al.*, 2013). According to National Institute for Occupational Safety and Health (NIOSH, 1984), particles smaller than PM_{10} can penetrate further deep into the lungs and are termed as respirable particulate matter with 50% cut point at 4 µm. Studies noted that for the particulate exposure and dose

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assessment, it is more scientific to study on health based particulate matters (inhalable, thoracic and respirable) rather than the conventional physical cut point based particulate matters (PM_{10}, $PM_{2.5}$) (Miguel *et al.*, 2005; Sivulka *et al.*, 2007; Lehnert *et al.*, 2012; Brown *et al.*, 2013). Respirable particulate exposure assessment is particularly important in case of health hazard explanation because it can enter into the deepest of the lung, at the non-ciliated gas exchange regions (Brown *et al.*, 2013).

Personal sampling is generally considered to mimic the real exposure to a human subject out of the different forms of samplings (Lange, 2003; Brouwer *et al.*, 2004; Cherrie, 2004). Personal sampling generally shows more exposure concentration rather than the area sampling (Janssen *et al.*, 2000). Unplanned structures of kitchens in rural areas vary across a wide range of structures and sizes.

In context of indoor air pollution from cooking, PM exposure is considered to be determined by the factors like fuel type, ventilation quality, food and cooking habits, time activity patterns etc. (Rohra and Taneja, 2016). Choice of primary cooking fuel in households subsequently depends on socio-economic factors like family income and education. Food and cooking habits in different regional communities vary considerably in the country like India but for a localized community, the pattern remains almost same. Time activity pattern for women in rural kitchen depends on the food and cooking habits.

Openness in the kitchen is one of the primary criteria for quick dispersion and dilution of the pollutants during cooking (Gao *et al.*, 2009). Earlier, very few studies have been conducted in rural Indian context for health based respirable particulate (50% cut point at 4 µm) sampling from biomass fuel combustion and the studies were conducted in the southern part of the India where exposure to the respirable particulate matters were assessed as 24 hours' time weighted averages (TWA) (Balakrishnan *et al.*, 2002, 2004). The present study is novel in the sense that it has been conducted in an intensive agricultural based rural community on the eastern part of India, whose primary sources of the cooking fuels come from agriculture and domestic cattle. Also, the respirable particulate matters were sampled throughout the entire cooking episode of a day comprising the lunch and dinner preparation time. Further, for accurately exploring the exposure variation to respirable particulate matters in rural kitchen; different seasons, openness of kitchen, and the amount of food prepared for a specific day were assessed.

METHODS

Study Location

For the present study, a field survey was conducted across 5 blocks of the agriculture economy based Burdwan district, West Bengal, India. Four villages from each block were randomly selected and included in the survey to know the homogeneity of the cooking-related information. Fifty households from each village and thus, 200 households from each block together comprised of total 1000 households. The study area experiences tropical savannah type climate. Although, the people of the region experience six seasons yearly, three seasons (summer, rainy and winter) are felt most acutely.

Field Survey

In rural households, cooking space is made in an unplanned manner and always manages to get a small space, sometimes in the 'verandah' for cooking. Here, in this article, the word 'kitchen' is used to indicate all the cooking spaces used for cooking in the rural households. Preliminary extensive household survey was carried out with the questionnaire including questions about primary cooking fuels, annual cooking fuel use pattern etc. Households which use biomass fuels predominated with the cattle dung cake for regular cooking with traditional earthen stoves without any artificial ventilation, were included in the study. Further detailed information was collected about family member composition, spatial feature of the households, cooking area-living area distance, kitchen architecture, kitchen ventilation etc. As openness also varies widely from kitchen to kitchen, here standardized criteria was made for percentage of openness of the rural kitchen to see its influence on the respirable particulate exposure concentration. Ventilation of the kitchen was accounted as the percentage of the openness which is the percentage of the open area from the total wall area comprising the four sides inside the kitchen, leaving the floor and the roof. The study purpose and procedure were explained to each of the households and written consent was taken from the heads of the households before any personal information collection.

Household Selection

Based on the survey, household data were assessed for the openness of the kitchens and were classified into six openness groups, i.e., < 15%, 15–30%, 30–45%, 45–60%, 60–75%, and > 75%. Then 10 households for each of the six groups were selected for particulate sampling. Households were carefully selected so that they could represent along the entire range of each of the openness groups.

Study Sample

At least one particulate sample for each of the three seasons, viz. summer, rainy and winter which comprises three samples for each of the households were collected. Thus, for six groups, 60 households and 3 samples for each of the households, totaling 180 samples for respirable particulate samples were collected.

As majority of the households generally prefer to use the mixed solid bio-fuels, which also varies on day-to-day basis rather than a specific one, and although the cattle dung cake is used always as a basic fuel for cooking, no categorization is made for fuel types. Agricultural wastes and crop residues are generally used for cooking along with dung cake in traditional earthen cook stove. Studied households have kitchen space at least with a shade or roof which is made up of straw, asbestos sheet, tin etc. Most of the kitchen fencing is made up of mud and bamboo. Kitchen is generally used as multipurpose space, i.e., for storing cooking fuels, agriculture produce etc. None of the kitchens were equipped with any artificial ventilation system or chimney at the time of sampling. Inside the kitchen, the woman cook sits on a wooden piece locally called '*piri*', which is hardly 10 cm high from the floor and the distance generally maintained at the time of cooking is within 60 cm from the cooking stove. Cooking utensils used for cooking are more or less similar across the rural households; a hollow pot with lid locally called '*hundi*' is generally used for rice preparation and a hollow pot locally called '*kadai*' is generally used for frying. No modern cooking utensils were found in use for regular household cooking. Though the majority of the households have cooking space separated from the living area but it is not too far from the cooking space as most of the households have cooking space within 5 meter distance from the living area. Standard adult equivalent fraction of the family members whose meals were prepared, comprising the lunch and the dinner, was noted down as meal prepared for the day of each sampling (Table 1).

Instrumental Setup

Sampling strategy was adopted according to the NIOSH method 0600 for respirable particulates which also conforms to ISO 7708 standard. Sampling was done by drawing air through a 37 mm aluminum cyclone equipped with a three-piece filter cassette housing 37-mm PVC filter, specified for 50% cut-point of 4 µm for respirable particulates. The cut-point specific flow rate (2.5 L min^{-1}) according to ACGIH/ ISO/CEN convention was maintained by a constant flow, battery operated personal sampling pump (PCXR8, SKC, USA). The cyclone was clipped to the blouse on shoulder to keep it within the breathing zone of the cook. The sampling pump was mounted by the waist belt at the abdomen of the cook. A tygon® tube of ¼ inch ID was connected to the filter cassette holder to the sampling pump. Sampling train was calibrated before each sampling for the specific cut-point flow of the pump as per the supplier guidelines using electronic calibrator. All the instrumental setup was supplied by the SKC Inc. (Eighty Four, PA, USA). Precaution was taken in sampler installation to avoid any inconvenience for normal kitchen activities by the women cook. Care was being taken by the women cook so that the aluminum cyclone remain in vertical position and its front faced inlet opening is not obstructed by clothes throughout the sampling.

Sampling

Sampling was done in two phases, i.e. in daytime, at the time of lunch preparation and in the evening at the time of dinner preparation. After day time sampling, sampler pump was paused by pressing the 'HOLD' button and was kept carefully with the sampling train at a normal room temperature until the sampling process was resumed in the evening in the same manner as it was in the daytime sampling event. Before each day sampling during cooking, minimum one hour and maximum two hours, sampling was carried out in the indoor kitchen to know the background concentration of the particulates. After each sampling, the filter cassette was detached from the cyclone, sealed with the supplied plug, kept temporarily at room temperature, if needed, and was carried to the laboratory carefully for gravimetric analysis. Before any gravimetric measurement, filters were equilibrated under control condition at least for 24 hours. Pre- and post-weight of the filters were measured by an electronic semi-microbalance (Uni Bloc AUW220D, Shimadzu, Japan) calibrated according to the manufacturer instruction. Each filter was measured at least for three times and each time for approximately 5 minutes to get the best stable and accurate reading. The room having the weighing balance was maintained at 20 ± 3°C temperature and 50 ± 5% relative humidity conditions.

At the beginning of the study, 10 samples were collected from the least opened kitchens (< 15% category) to know the average net particulate load on the filters, assuming that the said kitchens would show maximum net particulate load. The results showed that the particulate load was well below the 2 mg limit recommended by the NIOSH method 0600. 10% field blanks of all the samples were simultaneously taken when the samplings were carried out. Blank corrected increase of particulate mass was taken for the final air concentration calculation.

Table 1. Standard adult equivalent fractions of family members as per different age and sex.

Gender	Age (years)	Fraction of standard adult
Child	0–14	0.5
Female	> 14	0.8
Male	15–59	1
Male	> 59	0.8

(Joseph, 1990).

Data Analysis

Data analyses were carried out in Microsoft excel 2007 and SPSS software (ver.20, SPSS, Inc., Chicago IL, USA). Descriptive statistics (mean, standard mean error, geometric mean) were used to express the respirable particulate matter concentration. Boxplot with whiskers were used to represent the distribution of the data. Clustered bar diagram represented the comparison of the respirable particulate matters in differentially opened kitchens in different seasons. Bivariate Pearson correlation analysis was conducted to know the interrelationships among the scale variables. Univariate general linear model based two-way ANCOVA method was applied to explore the interaction between the independent variables (openness and season) for the variance in the respirable particulate pollution (dependent variable) in the kitchen. Subsequent post-hoc test revealed the intra variable mean difference of the independent variables. Multiple linear regression (MLR) analysis was applied to know the model which could predict the exposure of respirable particulates (dependent variable) in rural kitchen based on the independent variables (meal prepared for the day, openness of the kitchen and season). All the comparisons were made upon the log transformed data.

RESULTS

Boxplot with whiskers showing the distribution of the data for respirable particulate matters during cooking time are presented in Fig. 1. Maximum data variability for respirable particulate matters was found in kitchens with 15–60% openness. Respirable particulate concentrations across the openness of the kitchen and seasons are presented in Table 2 and in bar diagram chart Fig. 2. Significant positive correlation was found between exposure concentration of respirable particulates and meal preparation of the day (r = 0.429, p = 0.000), whereas, significant negative correlation was found between the openness of the kitchen and respirable particulate exposure concentration (r = –0.923, p = 0.000). Maximum particulate pollution load was found in the kitchen with least ventilation (< 15% openness) and minimum with the highest ventilation (> 75% openness). Two way ANCOVA analysis reveals that there was a significant interaction effect [F (10,161) =2.01, p = 0.035] of independent variables, i.e., openness and season on the exposure concentration of the respirable particulate matters in rural kitchen after controlling for the effect of covariate, meal preparation (Table 3). Openness [F (5,161) = 276.34, p = 0.000] and season [F (2,161) = 16.25, p = 0.000] individually also have significant effects on the particulate exposure concentration. Subsequent post hoc test reveals significant mean differences in all pair-wise seasonal combinations and in all the pair-wise openness type combinations except for the < 15% and 15–30% openness combination. Multiple linear regression analysis revealed insignificant contribution of the independent variables, meal preparation and summer season in explaining the variation of respirable particulate exposure concentration. Final model was run only on the significant independent variables i.e., openness and winter season which explained about 86% of the variation of the respirable particulate matter exposure concentration in rural kitchen (Table 4).

DISCUSSION

From the study it was found that openness and season both are significant influential factors in the exposure concentration of respirable particulate matters during cooking in the rural kitchen. Whereas, openness alone plays a major role in explaining about 90% particle exposure variability, seasons could explain only about 17% particulate exposure variability across the studied rural kitchens during cooking time. Interacting with each other, openness and season explained about 11% of the particulate exposure variability. It can be said that under seasonal influence, kitchen openness acted significant differentially for the dispersion of the particulate pollutants emitted from the burning of the biomass fuels. Pair-wise comparison for seasonal effect showed that winter-monsoon combination significantly differed most, while least significant difference was found in summer-monsoon combination. Bar diagram chart showed no specific seasonal impact pattern on the respirable particulate exposure concentration, especially in the two least opened kitchens (< 15% and 15–30%). Subsequently with the growing

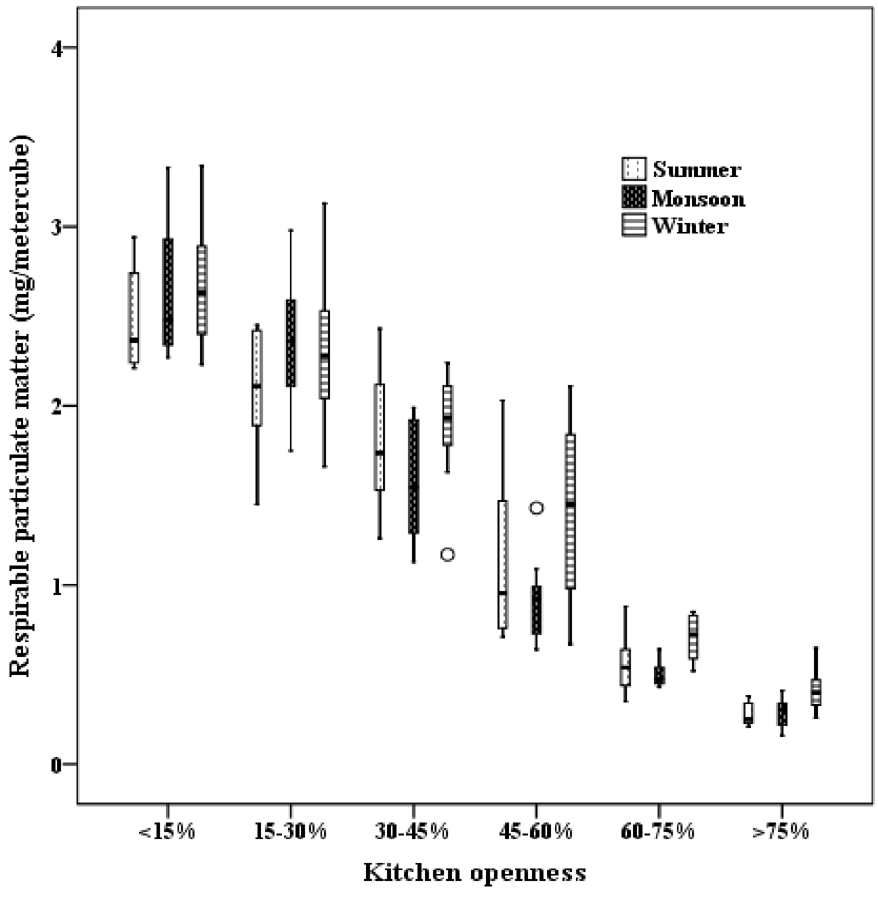

Fig. 1. Box with Whiskers showing distribution (data spread) of respirable particulate matters.

Table 2. Descriptive statistics on the respirable particulate matters.

Season	Openness group	Mean (mg m^{-3})	SEM[a]	GM[b]
Summer	< 15%	2.476	0.087	2.46
	15–30%	2.071	0.102	2.046
	30–45%	1.778	0.120	1.741
	45–60%	1.143	0.145	1.068
	60–75%	0.555	0.047	0.537
	> 75%	0.272	0.020	0.265
Monsoon	< 15%	2.640	0.119	2.624
	15–30%	2.321	0.119	2.291
	30–45%	1.569	0.095	1.542
	45–60%	0.920	0.072	0.896
	60–75%	0.500	0.021	0.496
	> 75%	0.289	0.024	0.279
Winter	< 15%	2.690	0.117	2.667
	15–30%	2.338	0.157	2.292
	30–45%	1.887	0.100	1.858
	45–60%	1.430	0.160	1.342
	60–75%	0.709	0.041	0.697
	> 75%	0.418	0.038	0.403

[a] SEM = Standard error of mean. [b] GM = Geometric mean.

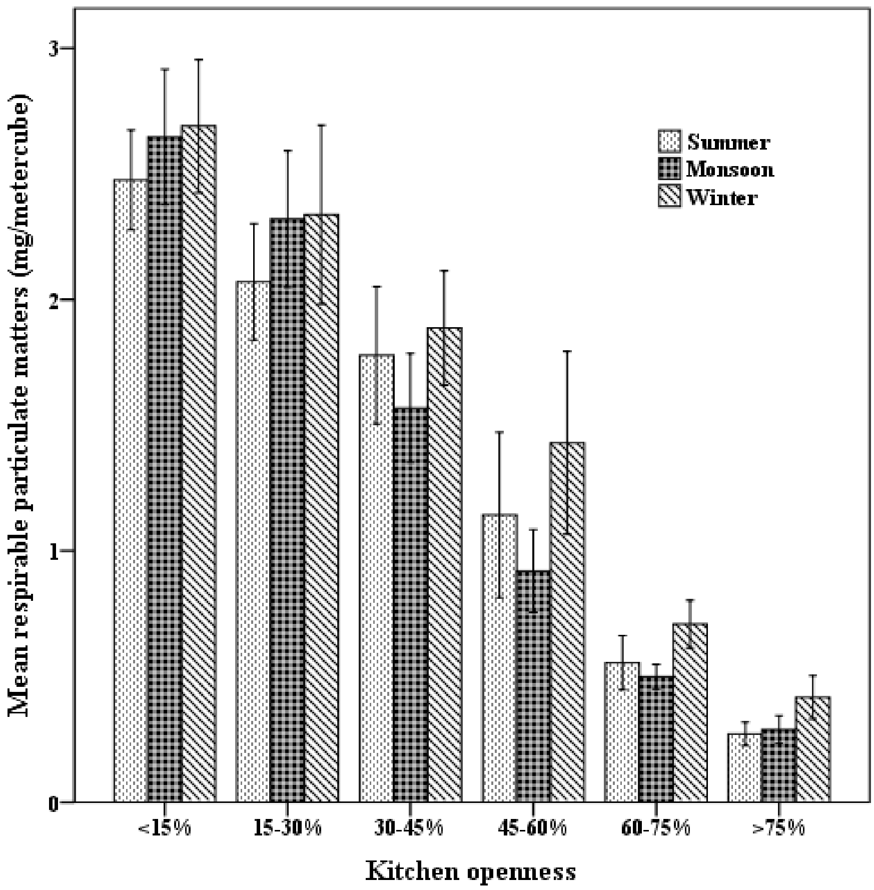

Fig. 2. Openness wise seasonal exposure concentration of respirable particulates.

openness of the kitchens, seasonal interaction may have showed a typical pattern of particulate exposure concentration, whereas, in winter, pollution load was maximum, in monsoon it was minimum. Multiple linear regression (MLR) analysis showed that meal preparation and summer season was not the significant predictors of the respirable particular matter exposure in the rural kitchen. The outcome MLR model, based on the significant predictors, i.e., openness and winter

Table 3. Tests of between-subjects effects of ANCOVA analysis.

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	19.989[a]	18	1.111	110.214	0.000	0.925
Intercept	0.008	1	0.008	0.760	0.385	0.005
Meal preparation	0.002	1	0.002	0.194	0.661	0.001
Season	0.328	2	0.164	16.255	0.000	0.168
Openness	13.922	5	2.784	276.344	0.000	0.896
Season * Openness	0.203	10	0.020	2.018	0.035	0.111
Error	1.622	161	0.010			
Total	21.985	180				
Corrected Total	21.612	179				

[a] R Squared = .925 (Adjusted R Squared = .917).

Table 4. Showing multiple linear regression (MLR) model parameters.

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
(Constant)	2.913	0.055		52.763	0.000	2.804	3.022
Openness	–0.033	0.001	–0.923	–33.256	0.000	–0.035	–0.031
Winter	0.200	0.052	0.106	3.815	0.000	0.097	0.304

Dependent Variable: Respirable particulate matter concentration (mg m^{-3}).

season has been given below:

$$\text{Respirable particulate matter (mg m}^{-3}) = 2.913 - 0.033 \text{ (Openness in \%)} + 0.2 \text{ (Season)} \quad (1)$$

where, Season = 1 for winter and 0 for monsoon.

The prediction equation (Adjusted R^2 = 0.89) is based on the un-standardized coefficients, which states that for one percent openness increase, respirable particulate pollution exposure decreases by 33 µg m^{-3}, controlling for winter effect.

The study provides insight about the cooking time respirable particulate matters exposure concentration to the women cook. Average daily cooking time comprising of all the households was found to be 224 minute. From the survey, it was found that highest number of households (about 39%) fall under the 30–45% openness group, followed by 23%, 18% and 9% households for 45–60%, 15–30% and 60–75% openness group respectively, while least number of households fall under the two extreme openness categories (7% and 4% respectively for < 15% and >7 5% openness group). Samples collected during non-cooking periods, specifically before the cooking sampling, showed that the background respirable particulate matter varied around 10–30 µg m^{-3}. Overall, across the seasons and openness of the kitchens, exposure concentration of the respirable particulate matter was found to be 1445 µg m^{-3}.

Exposure to particulate matter depends on the fuel type, stove type, housing architecture and ventilation (Gao *et al.* 2009). Among the solid fuels generally used in rural households, dung cakes have shown potential to emit more hazardous particulate pollution in typical rural kitchen setting (Sussan *et al.*, 2014). Rural household earthen stoves are simple and inefficient where incomplete combustion of the solid fuels can generate mass fraction of un-burnt particles to more than 90% of the total particle mass (Nussbaumer, 2001; Ancelet *et al.*, 2013). Because of the close proximity, pollutants from the kitchen from biomass combustion can easily enter the living space, thus neither in cooking time nor the woman cook alone, are the only perceptive group of the pollutants (Balakrishnan *et al.*, 2002). Temperature inversion which is generally found in winter may influence in severe pollution exposure, entrapping the pollutants in the kitchen. The study is the first of its kind, exploring exposure assessment of respirable particulate matters in real cooking situation under the influence of openness of the kitchens across the seasons. Because of the regional differences of food habits, cooking stoves, kitchen architecture, food preparation and fuel use, community wise exposure to particulates also varies. From our practical experience, it has been seen that socially higher-caste households always try to keep women's cooking activities out of sight from outsiders. For that, openness of the kitchen decreases in these families, letting the woman cook to spend at least 3 hours per day in the smoke chamber of the kitchen. On the other side, poor and socially backward people don't care much about kitchen, and keep kitchen space maximum open, having only the shade upon the head. In winter, they prefer to cook under open sky. Some poor households with very small family members were found sometimes to even skip their night time cooking. Thus, socio-cultural behavior in cooking of the community may be an indirect predictor of pollution exposure from the rural kitchen.

CONCLUSIONS

Information on kitchen openness wise respirable particulates exposure data on women in rural household in third world countries in general, and India in particular, is lacking. The personal exposure to respirable particulate matters emitted from unprocessed biomass fuel with dung cake combustion in ill-vented rural kitchens under the influence of covariates, viz., openness, seasonality, and meal quantity was assessed. Seasonal as well as openness influence to the particulate exposure in kitchen, controlling for meal preparation were found to be significant. Seasonal impact was less effective in explaining the particulate exposure variation in the least opened kitchens. Even the interaction between the seasonal change and openness was a significant factor to explain the particulate exposure variability. Among the seasons, winter came out to be a significant predictor for kitchen level particulate exposure. Because winter season is a significant predictor for kitchen level particulate exposure, this information can be used to educate the women cook to adopt pollution avoidance behavior like use of nose mask, doing accessory cooking activities (vegetable cutting, spice paste making) outside of the kitchen. Above all, it is the socio-economic-cultural status of the community on which covariates for pollution exposure in the rural kitchen depends. Thus, the community specific present study on agriculture based population is very unique to explain the personal respirable particulate exposure in rural kitchen during cooking period. The study will also help in formulating policy for better indoor air quality in rural households.

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CONFLICT OF INTEREST

No conflict of interest related to the present research study is there between the authors.

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