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# Impact of indoor air pollution exposure from traditional stoves on lung functions in adult women of a rural Indian district

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ABSTRACT

**Introduction:** Biomass Fuels (BMF) used for daily cooking in developing countries inside home is the highest exposures to air pollutants. Inhalation of these pollutants causes harmful health effects. This study aims to assess the health effects with the indoor air pollutants generated BMF.

**Materials and methods:** A cross-sectional study, conducted in a rural village of India. 450 households were divided into two groups based on the cooking fuel, the BMF group and the Liquefied Petroleum Gas (LPG) clean fuel group. Socioeconomic and respiratory symptoms information was obtained using a standard questionnaire. Indoor air concentration for $PM_{10}$ and $PM_{2.5}$ was measured during cooking hours. Pulmonary Function Tests (PFTs) were conducted for the women inhabitants using spirometer.

**Results:** Respiratory symptoms like chest pain, breathlessness, eye irritation, and blackout found to be significantly higher in biomass users ($P<0.05$). Moreover, an increasing trend in the prevalence of symptoms/ morbid conditions observed with an increase in exposure.

**Conclusion:** Findings of the study confirms that the traditional use of biomass fuels exposes all family members daily to air pollution levels that well exceed available health guidelines for indoor air quality and highlights the critical gender and age dimensions of the Household Air Pollution (HAP) problem. Women exposed to BMF smoke suffer more from health problems and are at higher risk of respiratory illnesses than other fuel users.

## Introduction

Household Air Pollution (HAP) is caused mainly by the residential burning of solid fuels for cooking and, to some extent, heating, the major types of which are wood, dung, agricultural residues, coal, and charcoal [1-3]. The sources of HAP vary considerably among developing and developed nations. Environmental Tobacco Smoke, volatile organic compounds from furnishings, and radon from the soil are significant important sources in developed countries [2]. The Indoor air quality in household environments of developing countries like India is the most critical issue and the exposure to pollutants released during the combustion

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of solid fuels. India faces the dual challenge of exposures from both ambient and household air pollution [4]. Existing evidence suggests that India, with a population of 1·38 billion people living across states at different levels of economic, social, and health development, has one of the highest air pollution levels in the world which has significant risk factor for disease burden [4]. It has been stated by the World Health Organization (WHO) that a pollutant released indoors is 1000 times more likely to reach the lung than that released outdoors. There is a serious impact of air pollutants on human health as they are taken by blood and circulated in the body [5]. According to WHO, indoor smoke from solid fuels is one of the top ten risk factors for the global burden of disease, accounting for 3.8 million premature deaths each year [6]. Fine particles less than 2.5 µm in diameter ($PM_{2.5}$) lodge deeply into the lungs posing the most significant health risks because of their small size.

In India, approximately 86.7% of rural households and 26.3% of urban households rely on solid biomass fuels for their cooking needs [7]. BMF emit substantial amounts of toxic pollutants when used in simple cooking stoves. This includes respirable particles, carbon monoxide, oxides of nitrogen and sulfur, benzene, formaldehyde, 1,3-butadiene, and polyaromatic compounds, such as benzo (α)pyrene [8-13]. Household Air Pollution (HAP) arising from the combustion of BMF for cooking is a significant contributor to four of the top five causes of mortality and morbidity in India. HAP is also a substantial contributor to outdoor air pollution [14, 15].

Clean cooking fuels are a highly cost-effective health intervention and household's energy-behavior also indicates the economic development of a country [16]. In Pradhan Mantri Ujjwala Yojana (PMUY), the government provided connections to a total of 50 million poor households (from 2016 to 2018) [17].

There is limited data available about the health effects of the use of BMF and clean fuels in a rural area, as LPG penetration in the district has increased with the launch of PMUY. Earlier studies have demonstrated high $PM_{2.5}$ and $PM_{10}$ levels in the household using BMFs, but they have not evaluated the association between the indoor PM concentration and the lung function of those exposed to it. So the present study was done to evaluate the BMFs impact on health and its associated risk factors, among women residing in a rural area of Nagpur, Maharashtra, India, in the wake of availability of clean fuel.

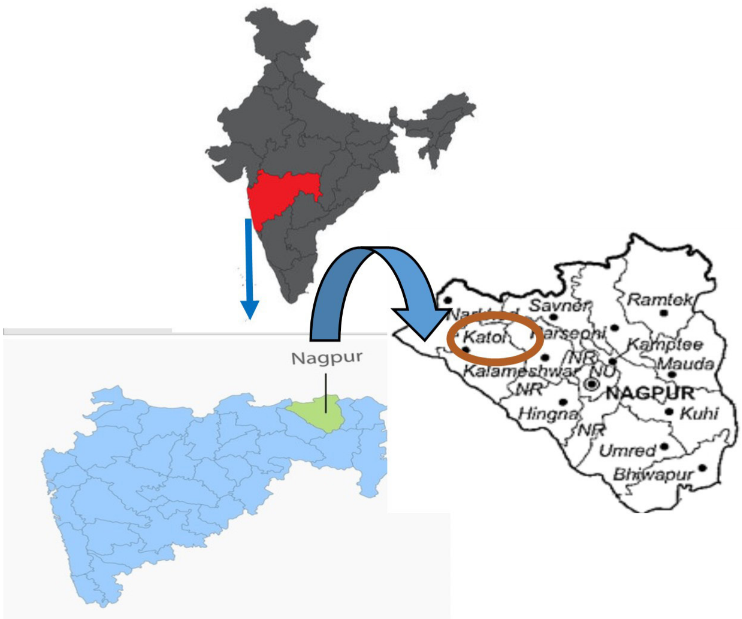


Fig. 1. Map showing the geographical location of the study area in the Nagpur district of Maharashtra

## Materials and methods

### *Study area*

The study was carried out in the rural area of Nagpur district in the state of Maharashtra, India, (Fig. 1) for twenty-four months during the year 2017-19 to assess the indoor air pollutants emitted during BMF use and its association on the lung function. All procedures followed the ethical standards of the Institutional Review Board and the Helsinki declaration of 1975 that revised in 2000. Ethical clearance was taken from the Institutional Ethics Committee of Rashtrasant Tukdoji Maharaj Nagpur University India. Informed consent was obtained from all subjects of the study.

### *Sampling method*

The study was cross-sectional and used the multi stage random sampling. District Nagpur was randomly selected from the districts of Maharashtra. Katol was selected randomly from 14 blocks in the district. Considering the distance from the highway as a confounding factor influencing the pollution, the villages were divided into 3 groups; less than 10 km from the highway, 10-20 km and more than 20 km from the highway. A third of the villages in each group were selected randomly. This resulted in the selection of unequal number of villages based on the distance from the highway.

### *Assessment*

Baseline information was collected using a pretested, semi-structured questionnaire consisting of information related to socio-demographic profile, average family income, cooking h/day, cooking years, type of cooking fuel used, family structure, other usage of chullah, and ventilation status of the house, location of chullah, overcrowding status, and type of house.

The study population was rural women who cook using the different types of fuel. Women aged 15 years and above involved in cooking who were non-smokers, non-pregnant were included in the study. For sample calculation, prevalence of three major diseases like Chronic Obstructive Pulmonary Disease (COPD), lower respiratory infection and low back pain was taken into consideration. Four hundred and fifty (450) households having at least one women cook were selected.

Indoor air quality in terms of $PM_{2.5}$, and $PM_{10}$ was determined for a continuous 8-h period in the household which consented for air quality assessment using personal sampler. The instrument was placed in the breathing zone to measure the direct exposure; the 8-h average was taken which included the morning cooking time and non-cooking period.

The age, gender, body mass index, the socioeconomic status, the cooking details, the smoking status (including exposure to environmental tobacco smoke), and the presence of respiratory symptoms were recorded for each woman participating in the study. Information about the prevalence of respiratory symptoms experienced in the past 1 year lasting for 3 months or more, the frequency of the signs and symptoms, were collected. Respiratory symptoms broadly included were dry cough, cough with phlegm, wheezing and chest discomfort, chest pain, and nasal obstruction. Chronic cough was defined as cough on most days for 3 consecutive months or more during the year for the past 2 years or more. Chronic sputum was defined as sputum on most days for 3 consecutive months or more during the year for the past 2 years or more. Dyspnea was defined as breathlessness when walking, which required the subject to stop or slow down for breathing while walking on the level (corresponding to grade 2 dyspnea by the MRC scale). Wheezing referred to the occurrence of wheezing/whistling sounds in breathing during exertion on most days or nights. Also, the prevalence of headaches, eye irritation, nausea, dizziness, shortness of breath, etc.was also evaluated. Lung function was measured on the completion of interviews. Lung function tests by spirometry was performed with the informed consent of the participant. The tests were performed according to the methods suggested by the American Thoracic Society using a portable, electronic spirometer [18]. Calibration checks were undertaken weekly. Before performing the pulmonary function test, each woman was subjected to a detailed history including the history of smoking, the kitchen's location, adequacy of ventilation, type of cooking fuel used. Exposure was calculated in each woman by the number of hours spent in a day for cooking. Height was measured in standing position and without shoes, and weight was recorded with minimal clothing. Body Mass Index (BMI) was calculated. For spirometry, participants were seated without nose clips. Measurements were classified as acceptable if the woman had at least three right blows. If best and second-best values of Forced Vital Expiratory Capacity (FVC) and Forced Expiratory Volume in 1 second (FEV 1), respectively, did not differ by more than 0.20 L. The data was compared with predictive values based on age, sex, and height.

### *Confounding factor*

Confounding factors like interference of ambient air pollutants and non-smoking women were selected for the study.

### *Outcome assessment and data analysis*

Statistical analysis was done using the IBM 21 version of SPSS and appropriate statistical tests were applied. The Chi-square test was used to test the association between self-reported symptoms and type of cooking fuel used by the respondents with the level of significance set at P-value less than 0.05. ANNOVA (variance analysis) was used to compare the mean FVC among the two fuel groups: Biomass fuel and clean fuel. It was used to predict the relationship between predictors (independent variables) and a predicted variable (the dependent variable). Logistic regression was used to predict the relationship between predictors like age, height, BMI, self-reported respiratory symptoms and irritation of eyes (independent variables) and a predicted variable like two different energy sources (the dependent variable). Biomass includes firewood, cow dung, agricultural waste, and coal. Non-biomass includes kerosene, LPG, and others, represented by “1” as a user and “0” otherwise. A further distinction was made by asking the type of fuel used for cooking and was further categorized into two different users as biomass and clean fuel. Biomass coded as “1” if the household is a frequent user and “0” for an occasional user. Similarly, the coding was done for the clean fuel user.

## Results and discussion

A total of 450 households were visited, all agreed for indoor air quality assessment. Most of the houses studied had a separate room for cooking, although often not adequately ventilated. Four hundred women agreed to take part in the questionnaire survey. (44.9%) of the respondents had physical access to LPG and half (50.9%) of them used mixed fuels as the primary source (i.e., LPG and firewood, crop residue, dung cakes). Only 10% of the respondents were using LPG alone for their energy requirements. Out of the 202 households with an LPG connection, only 40 households (8.89%) obtained their LPG supplies under the PMUY scheme to provide clean fuel to the low-income population. The most frequently used fuel for cooking was LPG (52.4%) combined with firewood (47.6%).

Fig. 2 presents the mean exposure levels of particulate matter ($PM_{2.5}$) concentrations in the kitchen/cooking area during cooking with various kinds of fuel. The variations in concentrations of PM during non-cooking and outdoor spaces is shown for different fuels. The figure indicate that the use of firewood resulted in the highest concentrations of the PM, followed by LPG. The cooking area affected the concentration of PM immensely as the concentrations were quite high when cooking was done indoors compared to when it was done outdoors using the same fuel/stove combinations. The PM concentrations during cooking ranged from 4.8 $ug/m^3$ to 11500 $ug/m^3$ and 10 to 4200 $ug/m^3$ when cooking was done indoors with wood and LPG using households, respectively.

Self-declared respiratory symptoms (cough, phlegm, nasal discharge, nasal obstruction, and sneezing) were present in 87.9% of women who cooked exclusively with BMF, in contrast to 11.7% of clean fuel-users. A most frequent complaint in the former two groups was shortness of breath (88.9% BMF, vs. 18.7% in clean fuel). Also, BMF users had a significantly higher prevalence of recurring headaches and dizziness.

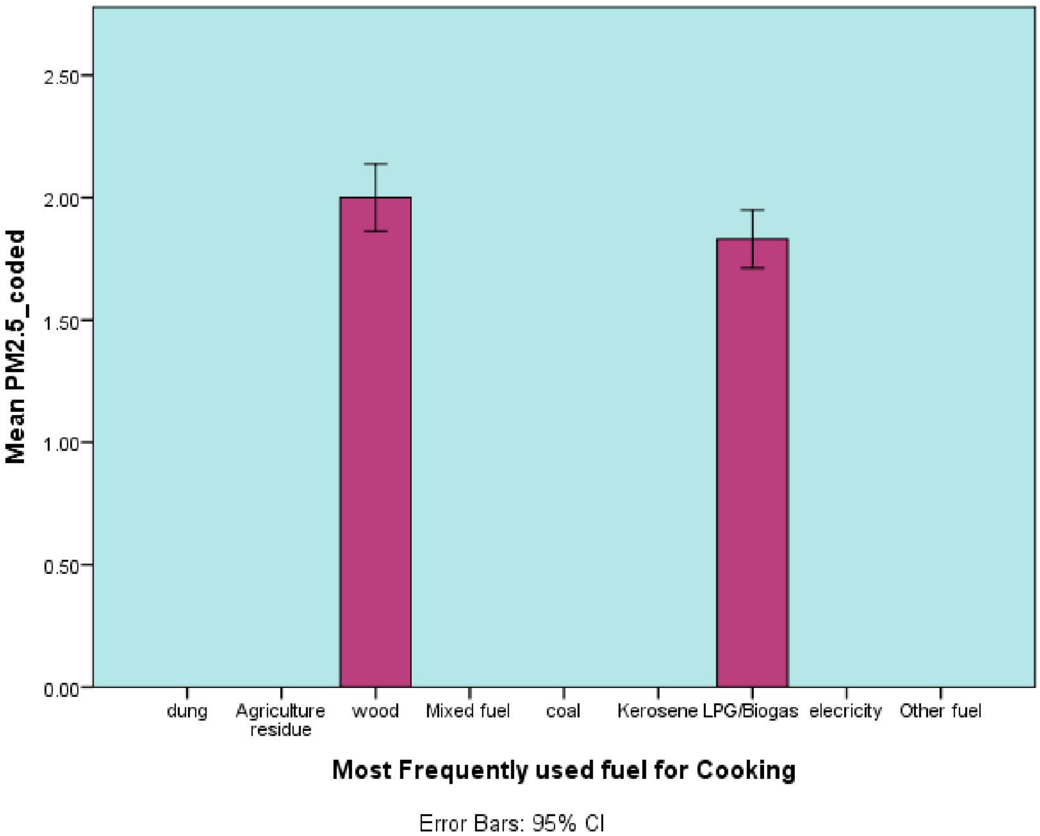


Fig. 2. Mean exposure levels of $PM_{2.5}$ ($ug/m^3$) for the different types of fuel used for cooking

Table 1. Comparison of symptoms/morbidities in different fuel users

| | | N | Mean | Std. Deviation | Sig. |
|---|---|---|---|---|---|
| FVC predicted | wood | 249 | 2.84 | .927 | .656 |
| | LPG/Biogas | 201 | 2.88 | 1.136 | |
| FVC measured | wood | 249 | 1.2935 | 1.37433 | .274 |
| | LPG/Biogas | 201 | 1.4411 | 1.48157 | |
| FVC percentage | wood | 249 | 44.26 | 44.745 | .201 |
| | LPG/Biogas | 201 | 49.91 | 48.624 | |
| FEV1 Predicted | wood | 249 | 2.3620 | .79359 | .770 |
| | LPG/Biogas | 201 | 2.3863 | .97336 | |
| FVC1 measured | wood | 249 | 1.1255 | 1.24093 | .715 |
| | LPG/Biogas | 201 | 1.1698 | 1.32366 | |
| FEV1% | wood | 249 | 47.4297 | 48.73128 | .228 |
| | LPG/Biogas | 201 | 53.2786 | 53.83198 | |
| FVC/FEV1 % | Wood | 249 | 89.0861 | 18.62043 | .031 |
| | LPG/Biogas | | | | |
| | - | 201 | 84.7500 | 23.94262 | - |

Table 1 shows the comparisons of symptoms/ morbidities in different fuel users for all the 450 study participants who were able to perform spirometry. The comparison was made for lung function parameters among women cooking with fuel in the two categories. Significance test at 5% level of significance was used to estimate the difference between the means of the three groups. The results showed that the mean values of FEV1 and the ratio of FEV1/FVC of clean fuel users were more than the corresponding values for BMF users. The analysis of variance shows that the difference was found statistically significant for and FVC/FEV% ratio for BMF users while for clean fuel users it was not significant.

Table 2 shows the lung function parameter FVC (observed and percent predicted) among participants with respiratory symptoms/ morbidities. The presence of symptoms/morbid conditions (dry cough, phelgm, abnormal pulmonary function, chronic bronchitis, bronchial asthma) was associated with lower values of FVC, FEV and FVC/FEV ratio (P There was a statistically significant positive correlation between the various respiratory symptoms with the various spirometric indices, suggesting a higher decline in lung function with exposure to higher concentrations of PM.

The regression analysis between BMF users and respiratory symptoms shows( Table 3) that the BMF users are more likely to be in the age group of 25-39 years compared to higher age group (45+). Regarding BMI, the bio-mass users are more likely to be under weight or normal (OR:1.06) BMI compared to Overweight/obese (BMI & height; 30). The likelihood of FVC is more than 4 times mild than the severe (OR:4.42). The likelihood of FEV is 94% more moderate (OR:1.94) compared to severe. Health issues indicates, the likelihood of sneezing is higher, while cough is more, headache is more, shortness of breath is lesser, chest illness is higher and irritation of eyes are more than two times among bio mass users.

The clean fuel users are more likely to be in the age group of less than 25 years (OR=2.3) compared to higher age group (45+). Regarding BMI, the clean fuel users are more likely to be normal (OR: 1.34) compared to Overweight/obese (BMI > 30). The likelihood of FVCR is more likely to be moderate than the severe (OR:1.06). The likelihood of FEVR is 93 percent higher to be mild (OR=1.93) and 63 percent more likely to be moderate (OR=1.63) than severe. As far as the health issues concerned, the likelihood of sneezing is lesser, likelihood of cough is also lesser among clean fuel users. The prevalence of headache is 76 percent lesser, shortness of breath more than 3 times lesser, chest illness is lesser and irritation of eyes are also lesser among clean fuel users.

Table 2. FVC,FEV and FVC/FEV ratio among study subjects with respiratory symptom/morbidities

| Symptoms | FEV/FVC ratio in % | FEV 1 | FVC |
|---|---|---|---|
| Cough | | | |
| Presence | 86.59±20.76 | 2.91±1.35 | 2.96±1.29 |
| Absence | 88.40±22.34 | 2.75±1.42 | 2.77±1.35 |
| Pvalue | >0.05 | >0.05 | >0.05 |
| Phelgm | | | |
| Presence | 89.25±13.94 | 2.94±1.33 | 3.12±1.28 |
| Absence | 84.59±27.48 | 2.78±1.41 | 2.60±1.33 |
| Pvalue | <0.001 | >0.05 | <0.001 |
| Cough Phelgm | | | |
| Presence | 89.25±13.93 | 2.93±1.35 | 3.06±1.30 |
| Absence | 84.59±27.48 | 2.78±1.35 | 2.70±1.31 |
| Pvalue | <0.05 | >0.05 | <0.05 |
| Wheezing | | | |
| Presence | 88.48±14.67 | 3.03±1.33 | 3.17±1.25 |
| Absence | 85.94±25.77 | 2.71±1.35 | 2.66±1.32 |
| Pvalue | >0.05 | <0.05 | <0.001 |
| Headache | | | |
| Presence | 86.91±21.79 | 2.95±1.32 | 2.99±1.27 |
| Absence | 90.93±7.52 | 1.46±1.10 | 1.46±1.10 |
| Pvalue | >0.05 | <0.001 | >0.001 |
| Chestpain | | | |
| Presence | 92.61±14.29 | 3±1.31 | 3.00±1.32 |
| Absence | 78.55±26.86 | 2.64±1.38 | 2.74±1.28 |
| Pvalue | <0.001 | <0.05 | <0.05 |
| Breathlessness | | | |
| Presence | 91.13±17.57 | 3.05±1.32 | 3.05±1.33 |
| Absence | 81.16±24.66 | 2.58±1.36 | 2.68±1.26 |
| Pvalue | <0.001 | <0.001 | <0.05 |
| Eye Irritation | | | |
| Presence | 92.02±14.35 | 3.04±1.31 | 3.05±1.33 |
| Absence | 79.09±27.27 | 2.55±1.37 | 2.63±1.26 |
| Pvalue | <0.001 | <0.001 | <0.001 |
| Blackout | | | |
| Presence | 91.80±14.55 | 3.07±1.28 | 3.10±1.30 |
| Absence | 80.78±26.68 | 2.59±1.40 | 2.63±1.28 |
| Pvalue | <0.001 | <0.001 | <0.001 |
| Snnezing | | | |
| Presence | 90.02±14.04 | 3.01±1.19 | 3.11±1.28 |
| Absence | 86.34±22.80 | 2.82±1.39 | 2.84±1.32 |
| Pvalue | >0.05 | >0.05 | >0.05 |
| Dizziness | | | |
| Presence | 90.76±15.93 | 3.23±1.17 | 3.28±1.20 |
| Absence | 84.01±24.56 | 2.54±1.41 | 2.580±1.32 |
| Pvalue | <0.05 | <0.001 | <0.001 |

Table 3. Regression Analysis of Biomass fuel/Clean fuel users with Respiratory Symptoms

| Variable | | Clean fuel Odds Ratio Exp(B) | Clean fuel P-value Sig. | Variable | Biomass Fuel Odds Ratio Exp(B) | Biomass Fuel P-value Sig. |
|---|---|---|---|---|---|---|
| Age Group | <25 | 2.30 (0.22 – 4.36) | 0.010* | <25 | .542 (0.19 – 1.49) | .237 |
| | 25-34 | 0.96 (0.51 – 1.78) | 0.890 | 25-34 | 1.064 (0.38 – 2.97) | .906 |
| | 35-44 | 0.71 (0.41 – 1.21) | 0.205 | 35-44 | .900 (0.38– 2.12) | .811 |
| | 45 and above ® | | 0.02* | 45 and above ® | | .653 |
| Height | Lower | 0.81 (0.47 – 1.41) | 0.454 | Lower | 1.130 (0.47 – 2.68) | .782 |
| | Normal ® | | | Normal ® | | |
| BMI | <18.5 | 1.17 (0.19 – 7.19) | 0.866 | <18.5 | 1.066 (0.05 – 24.78) | .968 |
| | 18.5-24.9 | 1.34 (0.23 – 7.78) | 0.748 | 18.5-24.9 | 1.066 (0.50 – 22.59) | .967 |
| | 25-29.9 | 0.85 (0.15 – 4.92) | 0.852 | 25-29.9 | .368 (0.18 – 7.62) | .518 |
| | >30 ® | | 0.469 | 30 ® | | .102 |
| Sneezing | no | 1.22 (0.66 – 2.25) | 0.522 | | | |
| | yes ® | | | no | .974(0.30 – 3.12) | .965 |
| Cough | yes | 0.46 (0.25 – 0.86) | 0.015* | yes ® | | |
| | no ® | | | yes | 1.400 (0.47 – 4.13) | .543 |
| Headache | no | 1.24 (0.72 – 2.14) | .0.437 | no ® | | |
| | yes ® | | | no | .232 (0.10 – 0.53) | .001 |
| Shortness of breathe | no | 3.06 (1.08 -8.67) | .035* | yes ® | | |
| | yes ® | | | no | 1.520 (0.42 – 5.54) | .526 |
| Chest Illness | no | 1.01 (0.54 – 1.88) | 0.982 | yes ® | | |
| | yes ® | | | no | 0.683 (0.19 – 2.47) | .562 |
| FVC | Mild | 0.43 (0.16 – 1.20) | 0.108 | yes ® | | |
| | Moderate | 1.06 (0.32 – 3.62) | 0.916 | Mild | 4.424 (0.42 – 46.58) | .216 |
| | Normal | 0.71 (0.19 – 2.53) | 0.592 | Moderate | 1.202 (0.13 – 11.32) | .872 |
| | Severe ® | | 0.383 | Normal | 1.321 (0.09 – 17.53) | .833 |
| FEV | Mild | 1.93 (0.55 – 6.8) | 0.306 | Severe ® | | .662 |
| | Moderate | 1.63 (0.55 – 4.87) | 0.379 | Mild | 1.244 (0.10 – 15.45) | .865 |
| | Normal | 1.56 (0.44 – 5.52) | 0.491 | Moderate | 1.937 (0.25 – 15.19) | .529 |
| | Severe ® | | 0.762 | Normal | 1.052 (0.08 – 13.97) | .969 |
| | | | | Severe ® | | .920 |
| $PM_{2.5}$ | <1 | 18.22 (5.15 – 64.42) | 0.000 | <1 | 20.22 (6.15 – 74.42) | 0.122 |
| | 1 to 1.99 | 21.13 (6.06 – 73.62) | 0.000 | 1 to 1.99 | 85.13 (8.06 – 73.62) | 1.08 |
| | 2 to 2.99 | 0.53 (0.14 – 2.11) | 0.166 | 2 to 2.99 | 0.53 (0.14 – 2.11) | 0.166 |
| | 3 and above | | 0.000 | 3 and above | | 0.000 |

### *Discussion*

The population based crosssectional study showed the increased prevalence of respiratory symptoms and lower pulmonary function among the women cooking on traditional chullahs using BMF as opposed to those using clean fuels. The study determined the role of domestic smoke on the health of 450 non-smoking rural women exposed to different types of cooking fuels. Women presenting with various symptoms/morbid conditions were older and had a greater duration of cooking.

In our study, average 9 h PM level observed in the households using BMF was 728.90 ± 50.20 $\mu g/m^3$, while it was 101.65±38.17 $\mu g/m^3$ in the clean fuel households; in both groups, which was above the recommended WHO standard of 25 $\mu g/m^3$ 24h mean. These high concentrations are due to the pollutants being generated during burning of the fuel, and also their persistence because of poor ventilation in the kitchen. In a study conducted in rural households of South India by [4] the levels of 24h average exposure to PM was reported to be 231 and 82 $\mu g/m^3$ in households using biomass and LPG, respectively. It was also seen that women exposed to BMF had higher odds of having an abnormal lung function test. Symptoms like eye irritation, headache, and diminution of vision were found to be significantly higher in biomass users (P<0.05). Abnormal pulmonary function, chronic bronchitis, and eye irritation in biomass users were substantially higher than other fuel users (P<0.05). Moreover, an increasing trend in the prevalence of symptoms/morbid conditions was observed with an increase in exposure. Other investigators have reported similar types of observations. A study carried out at the National Institute of Occupational Health, Ahmadabad, (NIOH) reported a higher incidence of cough, cough with expectoration, Dysnosea, and lung function abnormalities among housewives cooking with smoky fuels which also complained of pain and watering in the eyes while cooking [19]. A woman who cooks over a biomass fire has between two to four times more chances of suffering from COPD than a woman who uses gas for cooking. The WHO estimates that 22% of all COPD caused by exposure to indoor smoke from biomass fire. Cumulative exposure to biomass smoke was associated with a higher prevalence of respiratory symptoms, suggesting underlying respiratory illness. Another study conducted in North India on 3701 women using different types of cooking fuels found that women using mixed fuel experienced more respiratory symptoms (16.7%), followed by biomass (12.6%), stove (11.4%), and LPG (9.9%) users [20]. In another study done in Central India (Nagpur) reported an overall high prevalence of chronic bronchitis of 12.5% and when analyzed for different cooking devices, it was 16.7% for biomass users [5].This could be attributed to smoke emissions from biomass fuels (wood, agricultural waste, and animal dung).

When the pulmonary function of the participants was assessed, a significant decline in the respiratory indices was seen in the group using BMF. Similar findings of decreased PFT were reported by [21] in a study conducted on rural Nepalese population. In this study, the authors have reported a positive correlation between the use of BMF and lower lung function across all the age groups (OR = 2.10, 95% CI 1.47, 2.99).

Formal education was, surprisingly, a less significant factor in the study area. The results indicated that complete switching to clean fuel with an increase in income as described in the energy ladder had not taken place entirely in the study area because behavior change in the respondents has not taken place despite ascending the income ladder in the first and second quartile of the income group [22].Clean fuel was made available before programs like PMUY but it did not scale-up as the number of connections given were limited [23]. The number of connections given in the whole Nagpur district until 2018 is only 12,000 [24]. Since Nagpur has 14 blocks, these numbers are less compared to other parts of India. The findings also indicated widespread fuel stacking, as shown by the works of other researchers [25]. As a result, the full benefits of clean fuels were not achieved. Conversion to cleaner fuels has remained slow due to cost being the limiting factor. The health benefits of the PMUY scheme were not achieved as people are not using the gas connection solely.

## Conclusion

This study provides measurements of 8-h concentrations and estimated exposures to respirable particulate matter for a broad cross-section of rural homes in western India, using a variety of household fuels and under typical exposure conditions. Although the study design did not permit addressing temporal (intra-household) variations in each household, given the large sample size and the limited variability in weather conditions in this study zone, inter household differences are likely to contribute the most to the concentration and exposure profiles. The results of this study are likely to be useful as representing the HAP profile for the rural households of Nagpur district. The study confirms and expands upon what is available from studies in other parts of the world, i.e., that traditional use of biomass fuels exposes all family members daily to air pollution levels that well exceed available health guidelines for indoor air quality. More importantly, the study shows that this holds true even in a warm climate such as that of western India, where moderate space heating is required, and these fuels are used mostly for cooking. When cooking is done outside the house in a separate kitchen or the open air, a common practice of poor rural households, the resulting indoor levels of PM, and estimated exposure of all family members greatly exceed health guidelines for ambient air. This study highlights the critical gender and age dimensions of the HAP problem through a combination of monitoring and exposure- reconstruction techniques. The quantitative assessment results have also provided additional evidence of the importance of interventions other than fuel switching. Improved stoves, ventilation, and behavioral initiatives may offer substantial exposure reduction.

### *Limitations*

The study findings are based on a sample from 20 villages of a single agro-climatic zone and socio-cultural, housing, and climatic conditions are quite different across different parts of the country. Further, the monitoring was carried out only in the winter months, which may not reflect the household member's time-activity pattern or the nature of BMF used during other seasons.

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**Competing interests**

The authors declare they have no conflicts of interest or competing interests

**Authors' contributions**

The authors confirm contribution to the paper as follows: Study conception and design, data collection: Dr Vaishali Jaiswal; analysis and interpretation of results: Dr Vaishali Jaiswal and Dr Sherin Raj; draft manuscript preparation: Dr Vaishali Jaiswal and Dr Pravin Meshram. All authors reviewed the results and approved the final version of the manuscript.

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**Ethical considerations**

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

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