Respiratory Health Status of Rural Women Exposed to Liquefied Petroleum Gas and Solid Biomass Fuel Emissions

Authors: Kaur-Sidhu, Maninder, Ravindra, Khaiwal, Mor, Suman, John, Siby, and Aggarwal, Ashutosh N

Source: Air, Soil and Water Research, 12(1)

Published By: SAGE Publishing

URL: https://doi.org/10.1177/1178622119874314

Respiratory Health Status of Rural Women Exposed to Liquefied Petroleum Gas and Solid Biomass Fuel Emissions

Air, Soil and Water Research
Volume 12: 1–8

DOI: 10.1177/1178622119874314
SAGE

Maninder Kaur-Sidhu[1,2], Khaiwal Ravindra[1], Suman Mor[3,4], Siby John[2] and Ashutosh N Aggarwal[5]

[1]Department of Community Medicine and School of Public Health, Postgraduate Institute of Medical Education & Research (PGIMER), Chandigarh, India. [2]Department of Civil Engineering, PEC University of Technology, Chandigarh, India. [3]Department of Environment Studies, Panjab University (PU), Chandigarh, India. [4]Centre for Public Health, Panjab University (PU), Chandigarh, India. [5]Department of Pulmonary Medicine, Postgraduate Institute of Medical Education & Research (PGIMER), Chandigarh, India.

ABSTRACT: Combustion of solid biomass fuel (SBF) releases a high concentration of airborne pollutants, resulting in household air pollution (HAP). HAP is considered as a leading risk factor for the development of various respiratory diseases. The increased exposure to HAP significantly affects the health of the vulnerable population, including the women, elderly, and children who stay indoors for most of the time. Considering this, self-reported respiratory health symptoms were assessed using a standard American Thoracic Society (ATS) questionnaire, whereas lung function capacity of women using SBF, liquefied petroleum gas (LPG) and mix fuels were assessed using a cross-sectional study design. Lung function capacity was examined with help of spirometry. Results suggest that compared with LPG users, SBF and mix fuel users had a relatively high prevalence of phlegm (25.7%), cough (54%), and eye irritation (74.3%). Use of SBF was found to be associated significantly with lower forced expiratory volume in the first second of expiration (FEV_1) values ($P < .01$). The study concludes that women cooking with SBF and mix fuels have an impact on lung function and increased prevalence of respiratory symptoms. The findings suggest that women who cook using LPG have improved lung function and respiratory health status. Hence, it is suggested to increase the scope of clean fuel programmes such as Pradhan Mantri Ujjwala Yojana (PMUY) by identifying the barriers for the choice of clean fuel uses for household energy.

KEYWORDS: Household air pollution, PMUY, FEV_1/FVC, LPG, women health

RECEIVED: July 30, 2019. **ACCEPTED:** August 15, 2019.

TYPE: Original Research

FUNDING: The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study is linked to Indian Council of Medical Research (ICMR) project entitled 'Identification of the Barrier for the Choice of Clean Cooking Fuel and its Uses including Impact of Clean Cooking Fuel Programme (PMUY)' funded via letter no. 58/11/5/NTF-LPG/2019-NCD-II dated 28.05.2019.

DECLARATION OF CONFLICTING INTERESTS: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

CORRESPONDING AUTHOR: Khaiwal Ravindra, Department of Community Medicine and School of Public Health, Postgraduate Institute of Medical Education & Research (PGIMER), Chandigarh, Chandigarh 160012, India.
Emails: khaiwal@yahoo.com; khaiwal.ravindra@pgimer.edu.in

Introduction

Approximately 3 billion people worldwide burn solid biomass fuels (SBFs; agricultural residue, cow dung cake, wood, coal, etc) in inefficient and highly polluting traditional cookstoves used for cooking purposes.[1-3] These cookstoves are used in inadequately ventilated indoor kitchens resulting in an elevated concentration of pollutants and increased exposure level experienced by household members.[4] Thus, it leads to adverse human health effects. According to the latest Global Burden of Disease Study (2016) and World Health Organization (WHO), pre-mature deaths attributable to household air pollution (HAP) varies between 2.6 and 3.8 million.[5-9] Air pollution has been linked to various non-communicable diseases (NCDs), including chronic obstructive pulmonary disease (COPD), stroke, lung cancer, etc, and is an important risk factor for them. Furthermore, among women COPD and among children, aged <5 years, acute respiratory infections (ARIs) contributes mainly to the disease burden.[6,7] Household air pollution is ranked among the top 5 preventable risk factors leading to Global Burden of Disease.[10] Considering the adverse health effects of SBF uses, Government of India launched Pradhan Mantri Ujjwala Yojana (PMUY) to provide free liquefied petroleum gas (LPG) to the below poverty line (BPL) families.[3,11] Pradhan Mantri Ujjwala Yojana is the largest social intervention scheme that can be useful in preventing respiratory diseases and other NCDs.[11,12]

Several studies have reported an increased incidence of SBF combustion and COPD among women and ARIs in children.[13-15] SBF exposure is reported to be strongly associated with several other conditions, including asthma, tuberculosis, low birth weight, cataracts, and cancer of upper airways.[16-18] Cooking with SBF increases the probability of developing COPD (1.38 times) in non-smoking women.[19,20] Studies have reported a decline in forced vital capacity (FVC) and an increased history of respiratory diseases such as asthma, COPD, tuberculosis, and chronic bronchitis.[21-23] A meta-analysis shows that HAP has a range of short-term and long-term harmful respiratory impacts such as wheezing, cough, phlegm, asthma, and COPD.[24] In particular, COPD among non-smoking women has been linked to exposure to household SBF smoke in India and other parts of the world.[25-30] The prevalence of smoking among Indian women is low (3.4%) in comparison to men (26.25%); however, the prevalence of COPD found to be equivalent in both women (1.2%-19%) and men (2%-22%).[20,31,32] Thus, in Indian rural settings, SBF exposure may be a leading risk factor for COPD in women.[33,34]

Many efforts have been made in the past to measure the effect of exposure to SBF on pulmonary functions. Spirometric measurements, along with the respiratory questionnaire, are recommended to be the basic tool for diagnosis of respiratory illnesses.[35-37] Based on these recommended tools, Abbasi et al[35] carried out a cross-sectional survey in a rural community setting by using the American Thoracic Society (ATS) questionnaire (ATS-DLD-78A) and by conducting spirometric measurements. Previous studies have compared the exposure to mixed fuels (households using both SBF and LPG in combination) and LPG in outcomes on asthma, bronchitis, and respiratory symptoms.[38,39] Literature suggests higher risk in using mixed fuel rather than using SBF alone.[22] However, other studies report a higher risk among SBF users.[36,40] Although evidence exists that HAP increases the risk for respirable diseases, the impact of clean fuel intervention on lung function is lacking. Thus, improvement in respiratory health status (lung function and symptoms) associated with clean fuel use need to be evaluated to extend the scope of clean fuel programmes such as PMUY. Considering this, this study was conducted to know the prevalence of respiratory symptoms and to comparatively assess the lung function of women using SBF, mixed fuel, and LPG in rural households of Punjab.

Methodology

The study includes spirometry examination and collection of detailed personal and household information using a standard questionnaire. Study participants from Khera block of district Fatehgarh Sahib, Punjab, were interviewed using a standard respiratory questionnaire based on the ATS (1978) and a household questionnaire was adapted from WHO methods for 'evaluation of household energy and health interventions'.[37] The initial household assessment included a study on fuel use, and consumption pattern as detailed by Kaur-Sidhu et al.[4] Study participant recruitment criteria were non-smoking women aged between 30 and 60 years. The questionnaire and visual inspection method along with 24 hour daily activity pattern recall data in hourly increments of the participants were obtained to determine primary fuel/cookstove used, cooking/non-cooking periods, and housing and kitchen characteristics. Potential confounders, pathway variables were controlled by selecting the participants from the same socio-economic status and only non-smoking women with the same occupational status in the study.

The 65 study participants were divided into 3 groups, namely, LPG/Clean fuel users (15), mix fuel users (15), and SBF users (35). Users were categorized based on fuel type assessed from the questionnaire, and the same was confirmed during the field observation. The clean fuel users were exclusively using only LPG; those using only SBF were exclusive SBF users and those using both LPG and SBF were categorized in mixed fuel. One way analysis of variance (ANOVA) was used to determine the differences between the various groups (SBF, mix fuel, LPG).

Health assessment questionnaire included a detailed history of symptoms including cough, phlegm, cough with phlegm, wheezing breath, chest pain, shortness of breath, nasal obstruction, nausea, etc. Study participants performed spirometry with a calibrated portable electronic handheld spirometer (Micro-Medical Limited, UK) in accordance with ATS recommendations.[15,31,39,41] Study subjects performed at least 3 forced expiratory manoeuvres, and the highest values for FVC and forced expiratory volume in the first second of expiration (FEV_1) were recorded and compared with predicted norms. Subjects with decreased FEV_1/FVC ratio (observed value < 0.7) were categorized as having an obstructive defect, whereas those with normal FEV_1/FVC but decreased FVC were categorized as having a restrictive defect. Quality assurance was ensured by conducting frequent equipment calibration and by ensuring that expiratory manoeuvres met acceptability and reproducibility criteria as described in the standardized methodology guidelines by ATS. Data for age, sex, and height were entered before conducting the spirometry analysis. Height of each subject was measured with the subject standing bare feet on the floor.

The results of the women cook were described concerning COPD severity into the following cases: normal, mild, moderate, and severe as detailed in Global Initiative for Chronic Obstructive Lung Disease (GOLD).[39] Further based on the prevalence of self-reported respiratory symptoms using the SPSS software package (IBM SPSS Statistics 18), statistical analysis was done. One way ANOVA was used to determine the difference between the groups at 5% level of significance. Chi-square test was also performed at 5% and 1% level of significance for the prevalence of respiratory symptoms in different groups.

Results and Discussion

Prevalence of respiratory symptoms

Cough and chest pain. Cough was found to be more prevalent in SBF users (54.3%) as compared with mix fuel users (26%) and LPG users (20%). The difference was found to be significant ($P < .05$). Desalu et al[43] described symptoms of cough (13.7% vs 3.7%) and chest pain (7.5% vs 1.9%) 3-fold higher in SBF using women than those using non-SBF. However, the exposure to HAP was not significantly found to be associated with chest tightness in this study.

Phlegm and cough with phlegm. The prevalence of phlegm and cough with phlegm is shown in Table 1. The analysis shows that SBF users have more prevalence of cough and phlegm

Table 1. Prevalence of respiratory symptoms prevalence in women cook based on household fuel type.

SYMPTOMS	SBF USERS (N=35)	LPG/BIOGAS USERS (N=15)	MIX FUEL USERS (N=15)	CHI-SQUARE VALUE	*P* VALUE
	NO. (%)	NO. (%)	NO. (%)		
Cough	19 (54.3)	3 (20.0)	4 (26.7)	9.028	0.03*
Phlegm	9 (25.7)	1 (6.7)	1 (6.7)	4.169	0.12
Both cough phlegm	3 (20.0)	0 (0.0)	2 (13.3)	3.525	0.17
Wheezy or whistling	11 (31.4)	2 (13.3)	3 (20.0)	2.077	0.35
Headache	26 (74.3)	5 (33.3)	10 (66.7)	7.669	0.02*
Chest pain	10 (28.6)	1 (6.7)	2 (13.3)	8.270	0.08
Shortness of breath	15 (42.9)	3 (20.0)	4 (26.7)	2.899	0.23
Eye irritation	26 (74.3)	3 (20.0)	8 (46.7)	13.122	0.00**
Blackout	19 (54.3)	2 (13.3)	4 (26.7)	8.586	0.01**
Sneezing	9 (25.7)	2 (13.3)	5 (33.3)	1.666	0.43
Chest tightness	6 (17.1)	1 (6.7)	1 (6.7)	1.643	0.44
Joint pain	23 (65.7)	8 (53.3)	6 (40.0)	2.934	0.23
Dizziness	22 (62.9)	2 (13.3)	5 (33.3)	11.426	0.00**
Nausea	2 (5.7)	1 (6.7)	2 (13.3)	0.887	0.64
Nasal discharge	5 (14.3)	1 (6.7)	1 (6.7)	0.976	0.61
Nasal obstruction	6 (17.1)	1 (6.7)	2 (13.3)	0.970	0.62
Continuously sneezing	0 (0.0)	0 (0.0)	0 (0.0)	–	–
Tuberculosis	3 (8.6)	0 (0.0)	0 (0.0)	2.696	0.26
Heart disease	1 (2.9)	0 (0.0)	1 (6.7)	1.130	0.57

Abbreviations: LPG, liquefied petroleum gas; SBF, solid biomass fuel.
*Significant at .05 level; **Significant at .01 level.

(20%), but no significant difference was observed in mix fuel user groups (13%) as compared with LPG users. Regalado et al[42] reported that women exposed to SBF smoke have more frequent phlegm and cough with phlegm incidences in comparison to those cooking with gas.

Wheezing. The sound of whistling while breathing, called wheezing, was more prevalent in SBF users (31%) as compared with the other 2 groups (LPG 13%, mix fuel users 20%). In a Mexican study, 46% of women exposed to SBF reported having wheezing problem as compared with 21% biogas users.[42]

Headache and nausea. More than 75% of SBF users reported headache. Prevalence of headache was more common in SBF users, and the difference was also found to be significant ($P=.02$). Headache prevalence among mix fuel users and LPG users was 67% and 33%, respectively. Carbon monoxide released from incomplete combustion of SBF is reported to cause various short-term health effects including headache, dizziness, nausea, etc.[43-45] Symptoms of nausea were present in >15% in women who cooked exclusively with SBF against 6% in women using clean fuels.

Eye irritation and blackout. Solid biomass fuel users had more prevalence rate of having eye irritation and the occurrence of frequent blackouts. The occurrence of both these symptoms was found to be highly statistically significant ($P=.01$). West et al[46] summarized the evidence of the high prevalence of blindness and various other diseases (cataract, dry eye disease, age-related macular degeneration, etc) in women exposed to SBF combustion.

Joint pain. These symptoms were not found to be much associated with the type of fuel usage. The results indicate that symptoms were not statistically significant (Table 1). Hence, a detailed study is required to identify the association between joint pain and SBF uses.

Dizziness. Dizziness was highly present among SBF users (63%), as compared with mix fuel users (33%) and LPG users

(13%). The difference was found to be significant ($P = .01$). An almost similar observation was also made by Chakraborty et al[44] and Sinha et al[45] from India.

Lung function assessment

The study presents the results of lung function test measured by spirometry. In the SBF using group, 25 of 35 subjects (71.4%) had a normal pulmonary function. Of the 10 subjects with abnormal spirometry (Table 2), 7, 1, and 2, respectively, had mild, moderate, and severe obstruction. Among mix fuel users, 13 of 15 subjects (86.7%) had normal spirometry, and the remaining 2 (13.3%) show moderate obstruction. All LPG users had normal spirometry. Table 3 gives the summary findings for observed and predicted FEV_1, FVC, and FEV_1/FVC values stratified based on different fuel type. These results of lung function assessment indicate that mean FEV_1, FVC, and FEV_1/FVC was higher in LPG group (FVC: 2.83 ± 0.50; FEV_1: 2.35 ± 0.45; FEV_1/FVC: 82.53 ± 5.49) as compared with mix fuel (FVC: 2.71 ± 0.48; FEV_1: 2.18 ± 0.47; FEV_1/FVC: 79.58 ± 10.0) and SBF users (FVC: 2.54 ± 0.59; FEV_1: 2.00 ± 0.56; FEV_1/FVC: 78.8 ± 15.3). The decrease in lung functions in SBF and mix fuel users as compared with LPG users may be due to inhalation of household air pollutants form household cooking. The exposure measurements detailed by Kaur-Sidhu et al[4] from the same region reported the levels of respirable particulate matter ($PM_{2.5}$) and carbon monoxide (CO) about 5 times more in kitchens using SBF (549.6 µg/m^3 of $PM_{2.5}$; 4.24 ppm of CO) in comparison to LPG kitchens (78.8 µg/m^3 of $PM_{2.5}$; 1.05 ppm of CO). Similarly, studies from North India reported higher pollution levels in kitchens using SBFs (SBF: LPG-774:25 µg/m^3 of $PM_{2.5}$ and 33.5: 0.44 ppm of CO).[4,47,48,69] Statistically, a significant difference was found in FEV_1, whereas for FVC, the difference was not significant ($P = .08$). Moreover, the proportion of subjects with obstructive defects was higher among SBF and mix fuel users, as compared with LPG users. Hence, it could be inferred that the exposure to SBF pollutants had more effect on airflow limitation rather than the total lung volume of women cooks.

Similar findings were reported from rural Mexico by Regalado et al,[42] about 2.8% adjusted decline was seen in FEV_1/FVC ratio among SBF users. Reddy et al[49] reported that burning of SBF in poorly ventilated kitchens contributes to chronic bronchitis. In agreement with this study, several studies from developing countries also identify the linkage between SBF use and COPD.[4,46] Similarly, a study from North India, by Behera and Jindal,[47] on respiratory health of approximately 3700 women using various types of cooking fuels suggested that women relying on mixed fuel reported 16.7% occurrence of respiratory symptoms in comparison to LPG users (9.9%). Other studies originating from developing countries have recognized a linkage between SBF uses and COPD.[48-50] Reduced lung function parameters among SBF users have been reported from North India (Haryana, Delhi).[4,48,50,51] Women using SBF as primary fuel showed a decline of 7.62% in FEV_1/FVC ratio in comparison to clean fuel users.[52-55] Gupta and Kaul[56] also reported a considerable reduction in lung function values among the population dependent on SBF. Sana et al[16] summarized available studies on potential health risk associated with SBF uses and suggested to identify the chemical constituents of HAP for better understanding of biomass exposure and the onset as well as aggravation of respiratory diseases. Table 4 summarizes various epidemiologic studies providing an association between SBF use and impaired lung functions. Present study results also indicate that the decrease in lung function has some associated with the exposure to SBF smoke in Khera

Table 2. Comparison of lung functions among the SBF, mix fuel, and LPG fuel users.

STUDY POPULATION	NORMAL	NON-NORMAL
SBF users (N = 35)	25 (71.4%)	10 (28.6%)
LPG users (N = 15)	15 (100%)	0 (0%)
Mix fuel users (N = 15)	13 (86.7%)	2 (13.3%)

Abbreviations: LPG, liquefied petroleum gas; SBF, solid biomass fuel.

Table 3. Variation in lung function parameters in women exposed to various household fuel types.

TYPE OF FUEL	SBF USERS (N = 35)		LPG/BIOGAS USERS (N = 15)		MIX FUEL USERS (N = 15)		F VALUE	*P* VALUE
	MEAN	SD	MEAN	SD	MEAN	SD		
FVC observed, L	2.54	0.59	2.83	0.50	2.71	0.48	1.580	.21
FVC, % predicted	91.92	19.68	104.44	18.58	98.36	13.00	2.631	.08
FEV_1 observed, L	2.00	0.56	2.35	0.45	2.18	0.47	2.588	.08
FEV_1, % predicted	86.47	19.30	105.40	16.14	96.08	15.65	6.189	<.01*
FEV_1/FVC, %	78.80	15.32	82.53	5.49	79.58	10.00	0.466	.63

Abbreviations: FEV_1, forced expiratory volume in the first second of expiration; FVC, forced vital capacity; LPG, liquefied petroleum gas; SBF, solid biomass fuel; SD, standard deviation.
*Significant at .01 level.

Table 4. Lung function parameters in SBF and non-SBF users across the world.

LUNG FUNCTION PARAMETERS	SOLID BIOMASS FUEL USING GROUP	LPG USING GROUP	REFERENCE
FVC, % predicted	91.92 ± 19.68	104.4 ± 18.58	Current study
FEV_1, % predicted	86.47 ± 19.37	105.40 ± 16.14	
FEV_1/FVC, %	84.62 ± 3.95	87.54 ± 2.00	
FVC, % predicted	100.60 ± 10.36	107.18 ± 11.91	Revathi et al[57]
FEV_1, % predicted	106.8 ± 11.7	114.6 ± 11.9	
FEV_1/FVC, %	86.27 ± 5.71	87.49 ± 4.72	
FVC, % predicted	Adults: 99 ± 19.7	Adults: 87.6 ± 6.5	Kurti et al[54]
	Children: 86.8 ± 14.8	Children: 86.3 ± 10.3	
FEV_1, % predicted	Adults: 100.1 ± 14.6	Adults: 91 ± 5.6	
	Children: 86.8 ± 14.8	Children: 86.3 ± 10.3	
FEV_1/FVC	Adults: 100.8 ± 12.5	Adults: 103.6 ± 6.3	
	Children: 100.3 ± 12.8	Children: 104.0 ± 3.7	
FEV_1, L	2.65	2.83	Kurmi et al[33]
FVC, L	3.16	3.58	Rinne et al[58]
FVC, L	2.79 ± 0.52	2.76 ± 0.54	Reddy and Gupta[34]
FEV_1, L	2.27 ± 0.40	2.28 ± 0.43	
FVC, L	3.08 ± 0.43		Díaz et al[59]
FVC, % predicted	103.7 ± 10.7		Smith-Sivertsen et al[60]
FEV_1, L	2.68 ± 0.38		
FEV_1, % predicted	105.4 ± 11.3		
FEV_1/FVC	87.2 ± 5.53		
FEV_1, L	2.63 ± 0.32		
FVC, L	3.10 ± 0.36		Montaño et al[61]
FVC, % predicted	78 ± 19		
FEV_1, % predicted	62.1 ± 25.6		Orozco-Levi et al[62]
FEV_1, %	9.54 ± 17		
FEV_1/FVC	53 ± 16		
FEV_1, L	0.90		
FVC, % predicted	85.88 ± 10.39	88.40 ± 10.28	Whitehouse et al[63]
FEV_1, % predicted	87.62 ± 11.88	89.23 ± 9.6	
FEV_1/FVC	0.86 ± 0.06	0.86 ± 0.05	
FVC, % predicted	89.6 ± 18.2	114.5 ± 37.7	Umoh and Peters[64]
FEV_1, % predicted	77.8 ± 25.1	112.1 ± 39.0	
FEV_1/FVC	68.8 ± 15.3	78.3 ± 9.6	
FVC, L	81.6 ± 10.5	92.38 ± 12.2	Raj[65]
FEV_1, L	81.9 ± 11.7	92.9 ± 12.2	

Abbreviations: FEV_1, forced expiratory volume in the first second of expiration; FVC, forced vital capacity; LPG, liquefied petroleum gas; SBF, solid biomass fuel.

block of Fatehgarh Sahib district of Punjab, India. However, considering a limited sample size, a detailed study needs to be conducted to better understand the association between SBF uses and impaired lung function.

SBF vs clean fuel: the way forward. The study observes a higher prevalence of respiratory symptoms and lung function capacity impairment in SBF users as compared with clean fuel (LPG), users. This urges to have a greater emphasis on clean fuel programmes to improve the health of women cooks. As highlighted by Ravindra and Smith,[11] recently Government of India has launched various schemes to extend the uses of clean fuel such as PMUY, including Give-it-Up (GiU), and Pratyaksha Hastaantarit Laabh (PAHAL)-Direct Benefits Transfer for LPG (DBTL). These programmes helped to significantly increase the adoption of clean fuels, especially in lower-middle-income families and mainly in urban areas.[11,66] However, LPG uptake in rural areas remain a major challenge due to various behavioural, social, cultural, and economical factors such as taste, safety, refilling cost of LPG cylinder, and door-step delivery.[3,70] Hence, there is a need to extend the scope of clean fuel programme in rural and geographically inaccessible areas. Further, better understanding of the various health risks associated with the uses of SBF to be studied using advance modelling approaches.[67] Awareness activities about the adverse impact of HAP should be conducted to minimize the burden of respiratory diseases including the NCDs. This would bridge the gender disparity, end the drudgery of fuel collection and help in empowering marginalized women. Extension of clean fuel programme also provides an opportunity to timely attain Sustainable Development Goals (SDGs), which focus on gender equality, clean energy, better environment, and health for all.

Conclusions

The findings of this study indicate that SBF users have a reduction of lung functions than LPG users. Study data provide evidence on the association between clean fuel use and improved lung function. Lung function abnormalities were identified in 28% of SBF users, 13% in mix fuel users against all normal among clean fuel users. Furthermore, it was found that respiratory symptoms such as cough, headache, dizziness, eye irritation, and blackout were found to have more occurrence in women cooks using only SBF. The risk of respiratory diseases increases with the type of fuel used, ie, highest with SBF followed by mixed fuel use and having the lowest in LPG users. Forced expiratory volume in the first second of expiration ratio among LPG group was found to be more than 80% whereas in SBF users it was significantly reduced. No significant reduction was found in the FVC values of SBF users. The fair decline in FEV_1 values was observed among the SBF user group. Results indicate that use of SBF for cooking purposes increases the risk of COPD in women cooks. Extending community-wide adoption of LPG under PMUY may help to reduce the burden of respiratory and other NCDs. Hence, there is a need to increase the scope of clean, fuel programme by engaging and creating community awareness on harmful health effects of SBF uses to avert diseases pertaining to HAP and timely achieve SDGs.

Limitations of the study

The sample size for the study is small in comparison to the population size of the region. Further work can be done on comparatively large population for obtaining better statistically significant results. Other limitations are those associated with cross-sectional studies and issues with self-reported data. Self-reported symptoms are subjected to recall bias, self-reported replies may be overstated; respondents may be hesitant to reveal private details, which further may affect the results.[67] Also several false positives and false negatives are expected in similar surveys using self-reported measures.[68]

Author Contributions

RK, SJ, SM developed the theory, and supervised this study. MK-S performed the spirometry and collected household data. ANA provided training for conducting spirometry, verified the analytical methods and results.
All authors helped to develop the intellectual content of the manuscript including reviewing/ editing of the final manuscript.

ORCID iD

Khaiwal Ravindra https://orcid.org/0000-0002-1000-4844

REFERENCES

1. Bonjour S, Adair-Rohani H, Wolf J, et al. Solid fuel use for household cooking: country and regional estimates for 1980–2010. *Environ Health Perspect*. 2013;121:784-790.
2. Ravindra K, Kaur-Sidhu MK, Mor S, John S, Pyne S. Air pollution in India: bridging the gap between science and policy. *J Hazard Toxic Radioactive Waste*. 2015;20:A4015003.
3. Ravindra K, Kaur-Sidhu M, Mor S, John S. Trend in household energy consumption pattern in India: a case study on the influence of socio-cultural factors for the choice of clean fuel use. *J Clean Prod*. 2019;10:1024-1034.
4. Kaur-Sidhu MK, Ravindra K, Mor S, John S. Household air pollution from various types of rural kitchens and its exposure assessment. *Sci Total Environ*. 2017;586:419-429.
5. Vos T, Barber RM, Bell B, et al. Global, regional, and national incidence, prevalence, and years lived with disability for 301 acute and chronic diseases and injuries in 188 countries, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet*. 2015;386:743-800.
6. Ezzati M, Kammen DM. The health impacts of exposure to indoor air pollution from solid fuels in developing countries: knowledge, gaps, and data needs. *Environ Health Perspect*. 2002;110:1057-1068.
7. Vos T. Abajobir AA, Abate KH, et al. Global, regional, and national incidence, prevalence, and years lived with disability for 328 diseases and injuries for 195 countries, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet*. 2017;390:1211-1259.
8. Jain S, Khare M. Urban air quality in mega cities: a case study of Delhi City using vulnerability analysis. *Environ Monit Assess*. 2008;136:257-265.
9. World Health Organization (WHO). Global health estimates and world health statistics, 2016. Website. http://www.who.int/healthinfo/global_burden_disease/en/. Assessed May 30, 2019.
10. Mortimer K, Balmes JR. Cookstove trials and tribulations: what is needed to decrease the burden of household air pollution? *Ann Am Thorac Soc*. 2018;15:539-541.
11. Ravindra K, Smith KR. Better kitchens and toilets: both needed for better health. *Environ Sci Pollut Res Int*. 2018;25:12299-12302.

12. Kumar P, Ram U. Patterns, factors associated and morbidity burden of asthma in India. *PLoS ONE*. 2017;12:e0185938.
13. Ramírez-Venegas A, Velázquez-Uncal M, Pérez-Hernández R, et al. Prevalence of COPD and respiratory symptoms associated with biomass smoke exposure in a suburban area. *Int J Chron Obstruct Pulmon Dis*. 2018;13:1727-1734.
14. Sharma K, Ravindra K, Mor S, Kaur-Sidhu M, Sehgal R. Detection and identification of dust mite allergens in the air conditioning filters in Chandigarh, India. *Environ Sci Pollut Res Int*. 2019;26:24262-24271.
15. Van Vliet ED, Kinney PL, Owusu-Agyei S, et al. Current respiratory symptoms and risk factors in pregnant women cooking with biomass fuels in rural Ghana. *Environ Int*. 2019;124:533-540.
16. Sana A, Somda SMA, Meda N, Bouland C. Chronic obstructive pulmonary disease associated with biomass fuel use in women: a systematic review and meta-analysis. *BMJ Open Respir Res*. 2018;5:e000246.
17. Smith KR, Bruce N, Balakrishnan K, et al. Millions dead: how do we know and what does it mean? methods used in the comparative risk assessment of household air pollution. *Annu Rev Public Health*. 2014;35:185-206.
18. Balakrishnan K, Ghosh S, Thangavel G, et al. Exposures to fine particulate matter (PM2. 5) and birthweight in a rural-urban, mother-child cohort in Tamil Nadu, India. *Environ Res*. 2018;161:524-531.
19. Salvi SS, Barnes PJ. Chronic obstructive pulmonary disease in non-smokers. *Lancet*. 2009;374:733-743.
20. Pope D, Diaz E, Smith-Sivertsen T, et al. Exposure to household air pollution from wood combustion and association with respiratory symptoms and lung function in non-smoking women: results from the RESPIRE trial, Guatemala. *Environ Health Perspect*. 2015;123:285-292.
21. Sharma AK, Kalra OP, Saini NK, Kelkar H. Pilot study of chronic obstructive pulmonary disease in an industrial town in India. *J Health Pollut*. 2019;9:190304.
22. Kelkar H, Sharma AK, Chaturvedi S. Association of air pollution and lung function of young adult females in New Delhi. *J Health Pollut*. 2019;9: 190611.
23. Pope DP, Mishra V, Thompson L, et al. Risk of low birth weight and stillbirth associated with indoor air pollution from solid fuel use in developing countries. *Epidemiol Rev*. 2010;32:70-81.
24. Patel AB, Dhande LA, Pusdekar YV, Borkar JA, Badhoniya NB, Hibberd PL. Childhood illness in households using biomass fuels in India: secondary data analysis of nationally representative national family health surveys. *Int J Occup Environ Health*. 2013;19:35-42.
25. Schraufnagel DE, Balmes J, Cowl CT, et al. Air pollution and non-communicable diseases: a review by the forum of international respiratory societies' environmental committee. Part 2: air pollution and organ systems. *Chest*. 2019;155: 417-426.
26. Ravindra K. Emission of black carbon from rural households kitchens and assessment of lifetime excess cancer risk in villages of North India. *Environ Int*. 2019;122:201-212.
27. Golshan M, Faghihi M, Marandi MM. Indoor women jobs and pulmonary risks in rural areas of Isfahan, Iran, 2000. *Respir Med*. 2002;96:382-388.
28. Mannucci PM, Harari S, Martinelli I, Franchini M. Effects on health of air pollution: a narrative review. *Intern Emerg Med*. 2015;10:657-662.
29. Berend N. Contribution of air pollution to COPD and small airway dysfunction. *J Asian Pacific Soc Respirol*. 2016;21:237-244.
30. Peabody JW, Riddell TJ, Smith KR, et al. Indoor air pollution in rural China: cooking fuels, stoves, and health status. *Arch Environ Occup Health*. 2005;60: 86-95.
31. Liu S, Zhou Y, Wang X, et al. Biomass fuels are the probable risk factor for chronic obstructive pulmonary disease in rural South China. *Thorax*. 2007;62: 889-897.
32. Bentayeb M, Simoni M, Norback D, et al. Indoor air pollution and respiratory health in the elderly. *J Environ Sci Health A Tox*. 2013;48:1783-1789.
33. Kurmi OP, Devereux GS, Smith WCS, et al. Reduced lung function due to biomass smoke exposure in young adults in rural Nepal. *Eur Respir J*. 2013;41:25-30.
34. Reddy KS, Gupta PC. *Report on Tobacco Control in India*. New Delhi, India: Ministry of Health and Family Welfare, Government of India; 2004.
35. Abbasi IN, Ahsan A, Nafees AA. Correlation of respiratory symptoms and spirometric lung patterns in a rural community setting, Sindh, Pakistan: a cross-sectional survey. *BMC Pulm Med*. 2012;12:81.
36. Gerald LB, Tang S, Bruce F, et al. A decision tree for tuberculosis contact investigation. *Am J Respir Crit Care Med*. 2002;166:1122-1127.
37. World Health Organization (WHO). Evaluation household energy and health interventions: a catalogue of methods, 2008. Website. http://www.un-energy.org/publications/138-evaluating-household-energy-and-healthinterventions-a-catalogue-of-methods.
38. Gupta BG, Biswas JK, Agrawal KM. Air pollution from bleaching and dyeing industries creating severe health hazards in Maheshtala textile cluster, West Bengal, India. *Air Soil Water Res*. 2017;10:720787.
39. Global Initiative for Chronic Obstructive Lung Disease (GOLD). Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease, 2015. Website. http://www.goldcopd.org.
40. Mishra V, Smith KR, Retherford RD. Effects of cooking smoke and environmental tobacco smoke on acute respiratory infections in young Indian children. *Popul Environ*. 2005;26:375-396.
41. American Thoracic Society. Lung function testing: selection of reference values and interpretative strategies. *Am Rev Respir Dis*. 1991;144:1202-1218.
42. Regalado J, Pérez-Padilla R, Sansores R, et al. The effect of biomass burning on respiratory symptoms and lung function in rural Mexican women. *Am J Respir Crit Care Med*. 2006;174:901-905.
43. Desalu OO, Adekoya AO, Ampitan BA. Increased risk of respiratory symptoms and chronic bronchitis in women using biomass fuels in Nigeria. *J Bras Pneumol*. 2010;36:441-446.
44. Chakraborty D, Mondal NK, Datta JK. Indoor pollution from solid biomass fuel and rural health damage: a micro-environmental study in a rural area of Burdwan, West Bengal. *Int J Sustain Built Environ*. 2014;3:262-271.
45. Sinha SN, Kulkarni PK, Shah SH, et al. Environmental monitoring of benzene and toluene produced in indoor air due to combustion of solid biomass fuels. *Sci Total Environ*. 2006;357:280-287.
46. West SK, Bates MN, Lee JS, et al. Is household air pollution a risk factor for eye disease? *Int J Environ Res Public Health*. 2013;10:5378-5398.
47. Behera D, Jindal SK. Respiratory symptoms in Indian women using domestic cooking fuels. *Chest*. 1991;100:385-388.
48. Joon V, Kumari H, Chandra A, Bhattacharya M. Predicting exposure levels of respirable particulate matter (PM2.5) and carbon monoxide for the cook from combustion of cooking fuels. In: Joon V, Kumari H, Chandra A, Bhattacharya M, eds *International Conference on Chemistry and Chemical Process*. Vol 3. Singapore: IACSIT; 2011:229-232.
49. Reddy TS, Guleria R, Sinha S, Sharma SK, Pande JN. Domestic cooking fuel and lung functions in healthy non-smoking women. *Indian J Chest Dis Allied Sci*. 2004;46:85-90.
50. Schumacher KA, Shandas V. Rescaling air quality management: an assessment of local air quality authorities in the United States. *Air Soil Water Res*. 2019;12: 842125.
51. Ravindra K, Agarwal N, Kaur-Sidhu M, Mor S. Appraisal of thermal comfort in rural household kitchens of Punjab, India and adaptation strategies for better health. *Environ Int*. 2019;124:431-440.
52. Kar PS. *Air Pollution in Delhi and Six Blind Men* (SAGE Business Cases Originals). Thousand Oaks, CA: SAGE; 2019.
53. Mazumder S, Lee A, Dube B, et al. A clean fuel cookstove is associated with improved lung function: effect modification by age and secondhand tobacco smoke exposure. *Sci Rep*. 2019;9:2487.
54. Kurti SP, Kurti AN, Emerson SR, et al. Household air pollution exposure and influence of lifestyle on respiratory health and lung function in Belizean adults and children: a field study. *Int J Environ Res Public Health*. 2016;13:643.
55. Sumer H, Turaclar UT, Onarlioglu T, Ozdemir L, Zwahlen M. The association of biomass fuel combustion on pulmonary function tests in the adult population of Mid-Anatolia. *Soz Präventivmed*. 2004;49:247-253.
56. Gupta AB, Kaul N. Indoor air quality due to different kitchen fuels and its impact on human respiratory health–a case study. In: Gupta AB, Kaul N, eds Indo-French Indoor Air Quality Seminar. Jaipur: Malaviya National Institute of Technology Jaipur; 2010.
57. Revathi M, Kutty TK, Annamalai N. Pulmonary function in rural women exposed to biomass fuel. *J Pulmon Resp Med*. 2012;2:1-4.
58. Rinne ST, Rodas EJ, Bender BS, et al. Relationship of pulmonary function among women and children to indoor air pollution from biomass use in rural Ecuador. *Respir Med*. 2006;100:1208-1215.
59. Díaz E, Bruce N, Pope D, et al. Lung function and symptoms among indigenous Mayan women exposed to high levels of indoor air pollution. *Int J Tuberc Lung Dis*. 2007;11:1372-1379.
60. Smith-Sivertsen T, Diaz E, Pope D, et al. Effect of reducing indoor air pollution on women's respiratory symptoms and lung function: the RESPIRE Randomized Trial, Guatemala. *Am J Epidemiol*. 2009;170:211-220.
61. Montaño M, Sansores RH, Becerril C, et al. FEV 1 inversely correlates with metalloproteinases 1, 7, 9 and CRP in COPD by biomass smoke exposure. *Respir Res*. 2014;15:74.
62. Orozco-Levi M, Garcia-Aymerich J, Villar J, Ramirez-Sarmiento A, Anto JM, Gea J. Wood smoke exposure and risk of chronic obstructive pulmonary disease. *Eur Respir J*. 2006;27:52705.
63. Whitehouse AL, Miyashita L, Liu NM, et al. Use of cleaner-burning biomass stoves and airway macrophage black carbon in Malawian women. *Sci Total Environ*. 2018;635:405-411.
64. Umoh VA, Peters E. The relationship between lung function and indoor air pollution among rural women in the Niger Delta region of Nigeria. *Lung India*. 2014;31:110-115.

65. Raj TJ. Altered lung function test in asymptomatic women using biomass fuel for cooking. *J Clin Diagn Res*. 2014;8:BC01-BC03.
66. Ravindra K, Singh T, Mor S, et al. Real-time monitoring of air pollutants in seven cities of North India during crop residue burning and their relationship with meteorology and transboundary movement of air. *Sci Total Environ*. 2019;690:717-729.
67. Tilert T, Dillon C, Paulose-Ram R, Hnizdo E, Doney B. Estimating the U.S. prevalence of chronic obstructive pulmonary disease using pre- and post-bronchodilator spirometry: the National Health and Nutrition Examination Survey (NHANES) 2007–2010. *Respir Res*. 2013;14:103.
68. Health and Safety Executive. Review on the validity and reliability of self-reported work-related illness, 2012. Website. http://www.hse.gov.uk/research/rrpdf/rr903.pdf.
69. Joon V, Kumar K, Bhattacharya M, Chandra A. Non-invasive measurement of carbon monoxide in rural Indian woman exposed to different cooking fuel smoke. *Aerosol Air Qual Res*. 2014;14:1789-1797.
70. Sharma D, Ravindra K, Kaur M, et al. Cost evaluation of different household fuels and identification of the barriers for the choice of clean cooking fuels in India. *Sustain Cities Soc*. 2019. doi:10.1016/j.scs.2019.101825.