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Original Research Article

Cooking Microenvironment and Health: A Cross-Sectional Study of Solid Fuels Users in Urban Slums in India

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ABSTRACT

About half of the global population still depends on solid fuels for cooking and heating. Slum residents face a disproportionate risk to household air pollution (HAP) because of the dense population often residing in poorly ventilated houses. We conducted a cross-sectional study among solid fuel users to find out the association between 1) the cooking microenvironment and HAP related health symptoms and lung function 2) lung function (FEV1%pred) and shortness of breath among women. A total of 260 households were recruited. We found that leaks in the roof were significantly associated with higher odds of cough or cough while cooking, headache and burning eyes than no leaks in the roof. Dwelling type with an attached cooking area was significantly associated with higher odds of shortness of breath than dwelling type with cooking area within the living room. Objectively measured chronic obstruction of the lungs confirmed these observations. Interestingly, a higher FEV1%pred was associated with higher odds of shortness of breath. Our results indicate that people are less likely to experience HAP related symptoms when there is no or minimum exposure to outdoor air. Slums are complex settings where HAP cannot be addressed in isolation. Localized interventions such as, improved cookstoves in only a few slums may not considerably improve the ambient air quality, and thus, might not result in large health benefits for such densely-populated settings. We suggest housing structure improvements such as, completely closed walls and presence of windows for cross ventilation.

Keywords: [solid fuels, household air pollution, urban, slums, health]

INTRODUCTION

About half of the global population still depends on solid fuels for cooking and heating. [1] The desirability of these polluting fuels for domestic requirements stems among others from the cheap price point and widespread availability. [2,3,4] Pollutants such as carbon monoxide (CO) and particulate matter (PM) released from incomplete combustion of solid fuels indoor, lead to household air pollution (HAP). [5,6] Women and young children in particular, bear the brunt of HAP because of their proximity to the cooking area and the time they spend indoors. [2,3,5,7-10] HAP is recognized as a significant threat to the environment and public health globally. [11] Exposure to pollutants over a period of time increases the risk of respiratory infections among children and of chronic obstructive pulmonary disease (COPD) in adults. [5,12,13] The Global Burden of Disease Study reported of more than 600,000 deaths from HAP in India in 2019. [14]

Most of the studies on HAP are conducted in rural areas with little evidence from urban areas. [5] India has the world's second-largest urban population with 460 million residents. Among them, 161 million people (35%) live in overcrowded slums. [15] These numbers are underestimates as the official agencies may not include data from temporary or newer settlements. [16,17] Access to energy is a challenge in these communities. [17,18] Though the poor spend less on energy in comparison with the higher income households, the percentage of income that they spend is relatively greater. [19] A central government scheme, Pradhan Mantri Ujjwala Yojana (PMUY) has tried to address the high upfront cost of liquefied petroleum gas (LPG) by providing subsidised LPG connections to below poverty line (BPL) households, [17] but there are gaps to be filled in order to see a radical change. In 2018, 86.6 million people in urban India were still primarily dependent on polluting fuels and technologies for cooking. [20] LPG penetration has increased significantly since 2011, the exclusive use is however limited to half of the total households in urban slums. [17] Slum residents face a disproportionate risk to HAP because of the dense population often residing in poorly ventilated houses. [21] The houses are usually constructed at no or minimal distance from each other, sometimes sharing walls. This close proximity may lead to a 'neighbourhood effect' on the indoor air quality, with smoke from one household inevitably escaping to neighbouring houses). [21,22] Cooking preferences vary from cooking inside the house to cooking outside in the open air. A cooking space attached to the house is another common arrangement in the slums. This space is not fully enclosed, i.e., has three walls and an entirely open entrance which puts it in direct contact with the outdoor smoke. Nearly half of slum residents have respiratory diseases as a result of HAP. [23] Unfortunately, most people under-recognise the significance of respiratory symptoms, which are often considered a source of discomfort and annoyance rather than a health risk. [24] A study indicated that under-presentation of symptoms by patients might be related to a decreased perception of shortness of breath. [25] This can lead to under-diagnoses of COPD as physicians tend to diagnose COPD based on clinical symptoms and exposures. [26-28]

Cooking microenvironment can play an important role in determining HAP related health symptoms, [29] but there is a dearth of evidence. Out of the few studies among the urban poor in India, a small proportion has considered some housing structure factors while studying symptoms related to HAP. [8,30,31] We therefore, wish to understand the association between the cooking microenvironment and HAP related health symptoms and lung function among women. We consider cooking microenvironment characteristics as dwelling type, housing materials, indicators of cooking area ventilation, cooking location, and location of a separate stove for boiling water. In addition, we are interested in finding out the association between lung function, expressed as % of predicted forced expiratory volume in 1 second (FEV1%pred), and shortness of breath. A relatively low number of women with a reduced FEV1%pred reporting shortness of breath might be indicative of reduced perception of shortness of breath.

MATERIALS & METHODS

Study setting and design

In the current study, we focus on the cross-sectional analysis of the baseline data of a randomised controlled trial, [32] which was conducted in four slums in Bangalore, India (Supplementary Figure S1). Bangalore as a rapidly urbanising city attracts migrants from all over India, and because of a lack of proper infrastructure to accommodate this population; slums continue to crop up across the city. People come in search of promising job opportunities and settle in precarious locations. Most of the migrants who have settled here come from Northern Karnataka and have typical food habits. [24] The use of traditional cookstoves is common amongst this group.

There are notified and non-notified slums, the latter ones are not recognised by the government and associated municipalities, and thus, lack legal access to basic services such as water, sanitation, and secure tenure. [33,34] The slum in Ashrayanagar is a non-notified slum located in Bangalore (13°01'43.5"N 77°31'44.5"E) with an estimated 1100 households. The slum is dynamic in its composition, ranging from concrete houses to basic sheet houses, separated by alleys. The slum in Mathikere is a notified slum in Bangalore (13°02'12.6"N 77°33'51.9"E) with an estimated 200 households. There are concrete houses with sheeted roofs and sheeted houses (houses with sheets as walls) with sheeted roofs. The slum in Peenya (13°00'59.5"N 77°30'04.0"E) is a notified slum in Bangalore North with about 80 households arranged in parallel, separated by small alleys. The slum Muneshwaranagar is a notified slum in Bangalore (13°02'21.0"N 77°32'45.2"E) with an estimated 250 households. The layout is similar to the Ashrayanagar, a slum with houses ranging from concrete to tents. The living area arrangement in the slums is a feature with specific relevance in the current study.We define it as dwelling type categorised as-type A-a single structure with thecooking area in the same area (room) as the rest of the living areas/bedroom, type B-a single structure with the cooking area separated by a partial wall from the other main areas and/or bedroom, and type C-a single structure with the cooking area attached to the other main areas and/or bedroom (Supplementary Figure S2). The partial wall in dwelling type B does not make it different from type A in terms of exposure to smoke. Though the cooking area in type C is separated from the living area, it is exposed to the outdoor smoke (including smoke from neighbours' house and surrounding) because of an open entrance. There is hardly any space between neighbouring houses, and therefore, smoke easily travels from house to another if there are no intervening structures such as walls.

Recruitment

Households that cooked with an indoor chulha (traditional cookstove) or a combination of an indoor chulha and an indoor kerosene/diesel stove were included. Women ≥18 years who cooked more than half of the meals in the past month were considered as primary cooks. Houses with men as primary cooks were rare and were not included. Since the slum board did not have information on the non-notified slums, a mix of snowball and convenient sampling was used. We recruited 260 households with the same number of primary cooks. The sample was distributed as Ashrayanagar-44, Muneshwaranagar -84, Mathikere -64, and Peenya-68 households.

Assessments

Fieldwork took place between 2017 and 2019 through home visits made by the researcher and a few locally recruited Kannada speaking fieldworkers.

Socio-demographics and cooking microenvironment:

A structured questionnaire gathered information on socio-demographic data and cooking microenvironment (characteristics as dwelling type, housing materials, indicators of cooking area ventilation, cooking location, and location of a separate stove for boiling water). The housing materials included materials for the roof, floor, and the walls. Indicators of cooking area ventilation were (a) spaces between walls and roof, (b) any holes/ leaks in the roof, (c) presence of a chimney, (d) presence of a window, and (e) window/ door open during cooking. Cooking location and location of a separate stove for boiling water was categorised as inside or outside.

Respiratory and other symptoms in women: A health assessment questionnaire included a detailed history of self-reported symptoms including cough, cough during cooking, phlegm, shortness of breath, wheezing, headache, headache during cooking, burning eyes, and burning eyes during cooking.

Lung function in women: Lung function, expressed as FEV1%pred, for the primary cook was assessed using a portable spirometer (Spirodoc spirometer, MIR, Italy). Trained fieldworkers carried out spirometry. Each manoeuvre was performed at least three times to meet reproducibility criteria, and the best curve was selected for analysis. Data for age, sex, height, and weight were entered before conducting the spirometry. FEV1%pred is calculated as (FEV1 performed/FEV1 predicted) *100.

Statistical analysis

Data were analysed using IBM SPSS Statistics for Windows version 26.0 (IBM Corp., Armonk, NY. Released 2019). Descriptive statistics included the number of participants (%) for categorical variables and mean (SD) for numerical variables.

For primary cooks, the association between cooking microenvironmental characteristics (independent variables including dwelling type (A/B/C), wall materials (brick/others), wall-roof space (completely closed/partially open), leaks in the roof (yes/no), presence of windows (yes/no), cooking outside sometimes (yes/no), and separate stove for boiling water outside the house (yes/no)) and HAP related symptoms (dependent variables including cough, cough during cooking, shortness of breath, headache, headache during cooking, burning eyes, burning eyes during cooking) was first assessed in a univariable logistic regression analysis. The independent variables with a p-value $\leq$ of 0.20 were then included in a multivariable model as the number of events was too small to include all potential risk factors in one model. For the other HAP related symptoms (phlegm and wheezing), only univariable analyses were performed, as the number of primary cooks with these symptoms were too small to perform a reliable multivariable analysis. Some independent variables were not included in these analyses as the number of events were too small (only four households had a chimney, seven had other than asbestos or iron sheet roof, 12 had other than concrete floors, and nine did not have their door/window open while cooking). A sensitivity analysis was performed by adding two other independent variables to the multivariable model, i.e., ‘smoking inside the house’ and ‘smoke entering the house from the neighbor’s house, to see whether the cooking microenvironment factors remain significant or non-significant. As only a few subjects had missing values, no (multiple) imputation was performed.

The relation between cooking microenvironment characteristics and lung function (FEV_1%pred) for primary cooks was tested using multivariable linear regression analysis. The same sensitivity analyses as for HAP related symptoms was used for lung function.

As for the secondary research question, i.e., the association between FEV1%pred and shortness of breath in solid fuel using women, an independent-samples t-test was first used to assess the mean difference in FEV1%pred between women who did report shortness of breath compared to those who did not report it. In addition, a logistic regression analysis with shortness of breath as dependent variable and FEV1%pred as independent variable was conducted with correction for potential confounders, i.e. other microenvironment characteristics that are not mediators and are related to shortness of breath and FEV1%pred. Two-sided p-values ≤0.05 were considered statistically significant.

RESULTS

A total of 260 households with the same number of women in charge of cooking were included in the study. Table 1 represents the household, primary cook, and cooking microenvironment characteristics. The average (±SD) family size was 4.4 (±1.7). The mean age for the primary cook was 32.0 (±11.1) years. Most persons (n=218, 83.8%) stayed in dwelling type A. More than half of the houses (n=137, 52.7%) had no window at all. None of the women reported smoking habits for themselves, while 85 (35.1%) out of 242 households with male members reported them smoking currently and 73 (86%) out of these smoked inside the house. A majority of the households (n=219, 84%) reported of smoke entering their houses from neighboring houses. Table 2 represents the self-reported symptoms of women. About two-thirds of the participants (n=175, 67.5%) reported visiting a health facility during the past one year. The mean FEV1%pred for women was 77.31 (±17.5) (Table 2).

Table 1: Household and primary cook characteristics, cooking microenvironment

Household characteristics	**Frequency (%)**
Family size (n=260) (mean±SD)	4.39 ± 1.72
Socio-economic status/class† (n=258)	
Lower	5 (2.0)
Upper-lower	177 (68.6)
Lower-middle	74 (28.7)
Upper-middle	2 (0.7)
Caste of the household* (n=250)	
General	*48 (19.2)*
SC (Scheduled Caste)	77 (30.8)
ST (Scheduled Tribe)	19 (7.6)
OBC (Other Backward Classes)	106 (42.4)
House status (n=254)	
Owned	*113 (44.5)*
Rented	34 (13.4)
Neither rented nor owned	107 (42.1)
BPL ration card# (n=260)	
Yes	94 (36.0)
No	166 (64.0)
Primary cook characteristics	*Frequency (%)*
Age group (in years) (n=260)	
18-45	*234 (90.0)*
46 and more	26 (10.0)
Mean age (±SD) in years	32.0 ± 11.1
Current marital status (n=259)	
Married	*252 (97.3)*
Never married	7 (2.7)
Type of health facility referred to when ill (n=257)	
Government hospital	26 (10.1)
Private hospital/clinic	228 (88.7)
ESI††	3 (1.2)
Cooking microenvironment	Frequency (%)
Dwelling type (n=260)	
A single structure where the cooking area is the same area (room) as the rest of the living areas/bedroom (Type A)	*218 (83.8)*
A single structure with the area for cooking located in another room and separated by a partial wall from the other main areas and/or bedroom (Type B)	29 (11.2)
A single structure with the area for cooking attached to the other main areas and/or bedroom (Type C)	13 (5.0)
Material of roof (n=260)	
Asbestos/ Iron sheet	*253 (97.3)*
Other	7 (2.7)
Material of floor (n=260)	
Concrete	*248 (95.4)*
Other	12 (4.6)
Material of walls (n=260)	
Brick	*145 (55.8)*
Other	115 (44.2)

Table 1 To Be Continued…	
Space between walls and roof (n=260) Completely closed Partially open	*227 (87.3)* 33 (12.7)
Any holes/ leaks in roof (n=260) Yes No	 *20 (7.7)* *240 (92.3)*
Active chimney (n=259) Yes No	 3 (1.2) 256 (98.8)
Window (n=260) Yes No	 123 (47.3) 137 (52.7)
Cooking inside a completely closed room¶ (n=260) Yes No	 92 (35.4) 168 (64.6)
Door/window open while cooking (n=258) Yes No	 249 (96.5) 9 (3.5)
Place of separate stove for boiling water (n=43) Inside the house Outside the house	 5 (11.6) 38 (88.3)

†Kuppuswamy socio-economic classification based on socio-economic score (SES) which is the total of education, occupation, and income scores. Lower: SES <5, Upper-lower: SES 5-10, Lower-middle: SES 11-15, Upper-middle: SES 16-25, Upper: SES 26-29.
*SC, ST, and OBC are groups that have faced social and economic discrimination in the past and/or the present and were severely underrepresented in public life. Those who are not a member of these groups are lumped together in the General category, sometimes called the Open category. These are made up of mostly high castes who do not qualify for reservations. Information on cast is important for the current research as it represents vulnerability and might affect the study outcomes.
#Below Poverty Line (BPL) is a benchmark used by the government of India to indicate economic disadvantage and to identify individuals and households in need of government assistance and aid. They also serve as a common form of identification for many Indians.
††The employees registered under the Employees' State Insurance (ESI) scheme are entitled to medical treatment for themselves and their dependents.
¶Cooking area the same as the living/sleeping room, no windows or closed while cooking, no space between walls and roof, no holes in roof, no chimney.

Table 2: Self-reported symptoms (respiratory and other) and lung function for primary cook

Self-reported respiratory symptoms (n=259)		**Frequency (%)**
Cough	Yes	30 (11.6)
	No	229 (88.4)
Cough while cooking	Yes	43 (16.6)
	No	216 (83.4)
Phlegm	Yes	13 (5.0)
	No	246 (95.0)
Phlegm while cooking	Yes	8 (3.1)
	No	251 (96.9)
Shortness of breath	Yes	31 (12.0)
	No	228 (88.0)
Wheezing	Yes	8 (3.1)
	No	251 (96.9)
Self-reported other symptoms		**Frequency (%)**
Headache (n=259)	Yes	106 (41.0)
	No	153 (59.1)
Headache while cooking (n=257)	Yes	84 (32.3)
	No	173 (66.5)
Burning eyes (n=259)	Yes	63 (24.3)
	No	196 (75.6)
Burning eyes while cooking(n=254)	Yes	147 (57.8)
	No	107 (42.1)
Lung function		
Mean FEV1 % Pred (±SD) (n=129) 77.31±17.48		

Association between microenvironment factors and health symptoms among women in charge of cooking

The associations obtained in univariable analyses are presented in Supplementary Tables S1 and S2 and the ones from multivariable regression analyses are given in Tables 3 and 4. Based on the univariable analysis, wall material and leaks in the roof were included as variables in the analysis for cough; wall material, wall-roof space, leaks in the roof and window were included in the analysis for cough during cooking; and dwelling type, wall material, wall-roof space, leaks in the roof, window and cooking outside sometimes were included as variables in the analysis for shortness of breath (Table 3). In the multivariable regression, leaks in the roof were statistically significantly associated with higher odds of cough or cough while cooking than no leaks in the roof (OR 3.19, 95%CI 1.10, 9.28 and OR 5.55, 95%CI 1.81, 17.08, respectively). Dwelling types B and C were statistically significantly associated with higher odds of shortness of breath than type A (OR 4.00, 95%CI 1.35, 11.88 and OR 8.88, 95% 1.85, 42.65, respectively). A completely closed wall-roof was statistically significantly associated with lower odds of shortness of breath compared to a partially open wall-roof construction (OR 0.20, 95%CI 0.07, 0.58). Based on the univariable analysis, wall material and leaks in the roof were included in the multivariable analysis for headache; wall material and separate stove for boiling water outside were included in the analysis for headache while cooking; dwelling type, wall material, wall-roof space, leaks in the roof, and window were included in the analysis for burning eyes; and dwelling type, wall material, wall-roof space, leaks in the roof, and separate stove for boiling water outside were included in the multivariable analysis for burning eyes while cooking (Table 4). Table 4 shows that leaks in the roof were also statistically significantly associated with higher odds of headache (OR 2.66, 95%CI 1.03, 6.89) and burning eyes during cooking (OR 5.28, 95%CI 1.24, 22.46) than no leaks in the roof. None of the variables were significantly associated with headache during cooking and burning eyes (Table 4).

As for the sensitivity analysis, i.e. adding two variables (smoking inside the house and smoke entering the house from neighbors house), only leaks in roof was no longer significantly related to cough (OR 2.49 95%CI 0.81, 7.67) and dwelling type C was no longer significantly associated with higher odds of shortness of breath than type A (OR 4.08, 95%CI 0.73, 22.77; supplementary table S1a). Leaks in the roof remained significantly associated with higher odds of headache (OR 3.16, 95%CI 1.16, 8.62) and burning eyes during cooking (OR 5.72, 95%CI 1.31, 24.92; supplementary table S2a).

Table 3: Multivariable associations between microenvironment and respiratory symptoms in primary cooks

Dependent variables	**Cough (n=259)**			**Cough while cooking (n=259)**			**Shortness of breath (n=258)**		
Explanatory variables	**Adjusted OR**	**(95% CI)**	***P***	**Adjusted OR**	**(95% CI)**	***P***	**Adjusted OR**	**(95% CI)**	***P***
Dwelling type Type B vs type A Type C vs type A Type C vs type B Overall							 4.00 8.88 2.22	 (1.35,11.88) (1.85,42.65) (0.38,12.98)	 *0.013** *0.006** *0.37* *0.003**
Wall material Other vs brick	2.17	(0.97, 4.85)	*0.059*	1.89	(0.79, 4.51)	*0.15*	2.40	(0.67, 8.64)	*0.18*
Wall roof space Completely closed vs partially open				1.07	(0.37, 3.10)	*0.89*	0.20	(0.07, 0.58)	*0.003**
Leaks in roof Yes vs No	3.19	(1.10, 9.28)	*0.033**	5.55	(1.81, 17.08)	*0.003**	2.80	(0.80, 9.86)	*0.11*
Window Yes vs No				0.97	(0.40, 2.33)	*0.94*	0.57	(0.15, 2.09)	*0.39*
Cook outside sometimes Yes vs No							0.61	(0.07, 5.24)	*0.65*

Dwelling type A refers to a single structure where the cooking area is the same area (room) as the rest of the living areas/bedroom; dwelling type B refers to a single structure with the area for cooking located in another room and separated by a partial wall from the other main areas and/or bedroom; and dwelling type C refers to a single structure with the area for cooking attached to the other main areas and/or bedroom. This attached cooking area is open for smoke from neighbours. **p≤0.05*

Table 4: Multivariable associations between microenvironment and other HAP related symptoms in primary cooks

Dependent variables	**Headache (n=259)**			**Headache while cooking (n=257)**			**Burning eyes (n=259)**			**Burning eyes while cooking (n=254)**		
Explanatory variables	**Adjusted OR**	**(95% CI)**	***P***	**Adjusted OR**	**(95% CI)**	***P***	**Adjusted OR**	**(95% CI)**	***P***	**Adjusted OR**	**(95% CI)**	***P***
Dwelling type												
Type B vs type A							1.54	(0.65, 3.64)	*0.33*	1.62	(0.66, 3.98)	*0.29*
Type C vs type A							0.73	(0.18, 3.01)	*0.66*	0.29	(0.08, 1.11)	*0.070*
Type C vs type B							0.47	(0.10, 2.29)	*0.35*	0.18	(0.04, 0.84)	*0.030*
Overall									*0.53*			*0.094*
Wall material Other vs brick	0.63	(0.38, 1.06)	*0.082*	0.66	(0.39, 1.14)	*0.13*	1.06	(0.50, 2.24)	*0.87*	1.38	(0.78, 2.42)	*0.26*
Wall roof space Completely closed vs partially open							0.55	(0.22, 1.38)	*0.20*	0.77	(0.29, 2.07)	*0.60*
Leaks in roof Yes vs No	2.66	(1.03, 6.89)	*0.044**				1.33	(0.44, 3.98)	*0.61*	5.28	(1.24, 22.46)	*0.024**
Window Yes vs No							0.58	(0.28, 1.21)	*0.14*			
Separate stove for boiling water outside Yes vs No				1.49	(0.73, 3.04)	*0.27*				2.00	(0.93, 4.28)	*0.075*

Dwelling type A refers to a single structure where the cooking area is the same area (room) as the rest of the living areas/bedroom; dwelling type B refers to a single structure with the area for cooking located in another room and separated by a partial wall from the other main areas and/or bedroom; and dwelling type C refers to a single structure with the area for cooking attached to the other main areas and/or bedroom. This attached cooking area is open for smoke from neighbours. **p≤0.05*

Association between microenvironment factors and lung function among women in charge of cooking

A completely closed wall-roof was statistically significantly associated with a higher mean FEV1%pred compared to a partially open wall-roof construction (corrected mean difference (B) 8.22, 95%CI 0.11, 16.33; Table 5). In contrast, closed wall-roof was again statistically significantly associated with a higher mean FEV1%pred (B 9.07, 95%CI 1.00, 17.14; supplementary Table S3 for the sensitivity analysis including two additional variables (smoking inside the house and smoke entering the house from neighbour's house).

Table 5: Multivariable associations between microenvironment and lung function in primary cooks

Dependent variable	**Forced expiratory volume in 1 s (FEV1% pred) (n=129)**		
Explanatory variables	**Unstandardized Coefficients B**	**(95% CI) for B**	**P**
Dwelling type			
Type B vs type A	- 1.98	(- 10.72, 6.70)	*0.65*
Type C vs type A	- 0.67	(- 11.82, 10.48)	*0.90*
Type C vs type B	1.31	(- 12.02, 14.68)	*0.84*
Overall			*0.90*
Wall material Other vs brick	- 4.57	(- 12.43, 3.28)	*0.25*
Wall roof space Completely closed vs partially open	8.22	(0.11, 16.33)	*0.047**
Leaks in roof Yes vs No	3.36	(- 5.60, 12.32)	*0.46*
Window Yes vs No	- 5.77	(- 13.30, 1.78)	*0.13*
Cook outside sometimes Yes vs No	5.93	(- 5.37, 17.22)	*0.30*
Separate stove for boiling water outside Yes vs No	- 2.74	(- 11.71, 6.23)	*0.54*

Dwelling type A refers to a single structure where the cooking area is the same area (room) as the rest of the living areas/bedroom; dwelling type B refers to a single structure with the area for cooking located in another room and separated by a partial wall from the other main areas and/or bedroom; and dwelling type C refers to a single structure with the area for cooking attached to the other main areas and/or bedroom. This attached cooking area is open for smoke from neighbours. **p≤0.05*.

Association between FEV1% pred and shortness of breath among women in charge of cooking

Women who did report shortness of breath had a significantly higher mean FEV1%pred than those who did not report shortness of breath (mean (SD) = 85.82 (19.21) versus 75.46 (16.61), mean difference = -10.36, 95%CI -18.14, -2.58). Although the same positive association was found for univariable logistic regression, i.e., a higher FEV1%pred was significantly associated with a higher odd of shortness of breath (OR 1.04, 95%CI 1.01, 1.07), this association became insignificant after correcting for wall-roof space (OR 1.02, 95%CI 0.99, 1.05).

DISCUSSION

Most of the studies on HAP are conducted in rural areas with little evidence from urban areas [24] which have relatively better availability and affordability for cleaner fuels. However, we argue that this is not the case in slums or at least, not for the entire slum population. [17,35] The low income households continue using traditional methods of cooking despite the poor efficiency and health concerns. [1] The lack of adequate space, poorly ventilated houses, smoke travelling from one house to another, and the proximity to polluting factories, highway, dumping sites, and railway lines only adds to their vulnerability. In the present study, we explored the cooking microenvironment and health of women in urban slums of Bangalore.

We found that leaks in the roof were significantly associated with higher odds of cough or cough while cooking than no leaks in the roof. A similar study in slums by Maharana et al., [8] found leaky roofs to be positively associated with presence of HAP related health symptoms, including cough. On the contrary, a study by Das et al., [29] found that cooking area ventilation holes had a protective effect on the presence of HAP related health symptoms in children. Our counterintuitive finding can be explained by the exchange of indoor and outdoor air via the leaks in the roof, a process described as infiltration. Outdoor air, a mixture of different pollutants, can penetrate into the house and can either be diluted or accumulated according to the ventilation condition. [36] These air pollutants can cause daily irritation and inflammation of the nasal and oral mucosa leading to destruction of the cilia of the epithelial cells that line the respiratory tract. [37] Vent-holes may improve indoor air quality in settings where households are at a distance from each other, but in a clustered setting like slums, it is likely to worsen the ambient air [38] which is already affected by the factories, dumping sites, and the highway. It seems likely that this will enlarge the period of being exposed to HAP, assuming that the adjacent households will not all cook at exactly the same time period. Choi and Kang [39] suggested that a house with leaks would be more vulnerable to ambient air pollution. A qualitative study by Muindi et al., [40] reported of smoke travelling across households in slums via the vent-holes. Maharana et al., [8] also reported of the 'neighborhood effect' in the slums, i.e. since people kept their door open, vehicular smoke and fumes from neighboring houses entered their houses. Although in the present study, leaks in roof was not always significantly related to cough or cough while cooking in the sensitivity analyses, the observed effects were always in the same direction. The lost in efficiency in the sensitivity analyses might be explained by adding more independent variables to the model (smoke entering the house from neighbors' house). Correcting for these two variables is not a part of our main analysis as the information collected was self-reported. Since smoking is a taboo, women are likely to have reported socially desirable answers for smoking status of men in the house. Also, smoke from neighbors' house was measured on binary scale, i.e. yes/no, instead of amount and/or frequency.

In our study, dwelling types B (a single structure with the cooking area separated by a partial wall from the other main areas and/or bedroom), but especially, C (a single structure with the cooking area attached to the other main areas and/or bedroom) were significantly associated with higher odds of shortness of breath as compared to dwelling type A (a single structure where the cooking area is the same area (room) as the rest of the living areas/bedroom). This finding is also counterintuitive as dwelling type A is likely to be the most contained space and thus more harmful than type C, which is the most open space. Although this counterintuitive result was only found for shortness of breath and the 95% confidence intervals were wide, indicating that these results should be interpreted with care, we explain this by the structural arrangement of cooking area in dwelling type C- three walls (i.e., an entirely open entrance) placed it in direct contact with the surrounding smoke, including smoke from neighboring houses. Again, this might enlarge the period of being exposed to smoke, assuming that the adjacent households will not all cook at exactly the same time period. Dasgupta et al., [38] found that within-dwelling kitchens had PM concentrations 187 ug/m3 lower than detached or fully open kitchens, confirming this possible explanation. During high dust season, the outdoor air is contaminated and cooking outside does not prevent one from being exposed to pollutants. In such conditions, cooking in within-dwelling kitchens might be better as the walls of the house filter/ block the external air. [38] Chowdhury et al., [41] found high outdoor PM concentrations existing in the immediate vicinity of slums that contributed to HAP even in households using an improved cookstove. The direction of the association that we observed remained the same after the sensitivity analysis. Our finding that a completely closed wall-roof was significantly associated with a lower odds of shortness of breath compared to a partially open wall-roof space is also supported by Das et al., [29] who found a positive association between presence of a gap between walls and ceiling in the cooking area and respiratory infection, including reported dyspnoea. Muindi et al., [40] reported that people blocked the spaces between their roofs and walls to keep out the polluted outdoor air.

We found that leaks in the roof were significantly associated with higher odds of headache and burning eyes during cooking than no leaks. This is supported by Maharana et al., [8] who found leaky roofs to be positively associated with eye irritation. Our results remained the same after the sensitivity analysis pointing to the role of contaminated outdoor air in the experience of health symptoms.

Objectively measured chronic obstruction of the lungs assessed by spirometry confirmed these observations (completely closed wall roof was significantly associated with a higher FEV1%pred than partially open wall roof space). Interestingly, a higher FEV1%pred seemed to be associated with higher odds of shortness of breath. This might suggest that women with a lower FEV1%pred might underreport shortness of breath. During the initial stages of COPD, women might not experience significant symptoms prompting them to delay seeking healthcare. [42, 43] This can further lead to under-diagnoses of COPD at health facilities where it's often diagnosed based on clinical symptoms and exposure. [26] This is supported by a study in which more than 70% of women with no history of COPD were diagnosed with COPD. A mere 23% were "women with known COPD." [42]

Although we also wanted to see which factors are related to pneumonia in children, no inferential analysis could be performed due to the small number of children with pneumonia (n=7). We thus do not report on it in the current paper.

We attempt to list the limitations in our study which must be considered while interpreting the results. First, we cannot draw any causal conclusions because of the cross-sectional nature of our study. Second, most data were self-reported which might have induced a recall bias. Third, because of a relatively young study population (mean age 32 years), it is likely that women did not experience symptoms or did not report those. Fourth, the women had difficulty understanding some terms related to respiratory symptoms, in addition, a substantial number of women refused to perform spirometry, and there were data that we could not use in the analysis. Together, this might have lead to misclassification bias. Assessing health with respect to cooking is complex. Cooking is not the only source of HAP, other background sources, such as dust, burning of trash, fumes from kerosene-based lamps, cooking fires from the neighborhood, running diesel generators and grain mills, and the use of mosquito coils can contribute as well. [44] Lastly, we could not gather information on all the potential confounders and that might have influenced our results.

CONCLUSION

Our study highlights the importance of understanding the relationship between cooking microenvironment and health in relation to slums. Our results indicate that people are less likely to experience HAP related symptoms when there is no or minimum exposure to outdoor air (in the form of no leaks in roof, no gaps between walls and ceilings, and having cooking areas within the house). It seems likely that outdoor smoke is also a determinant, especially from the neighboring households, in experiencing HAP related symptoms. Slums are complex settings where HAP cannot be addressed in isolation. The exposures from surrounding factories, dumping sites, highway, and most of all, neighboring houses cooking with solid fuels, must be considered by the policy-makers when planning interventions to reduce HAP exposure. Localised interventions such as, improved cookstoves in only a few slums may not improve the ambient air quality to a considerable extent, and thus, might not result in large health benefits of the slum population or similar densely-populated settings. We suggest housing structure improvements such as, completely closed walls and presence of windows for cross ventilation. Having a dedicated cooking room within the house might help reduce the smoke exposure. Most importantly, there must be efforts towards encouraging these communities to switch to cleaner fuels.

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Ethical Approval: This study is registered with ClinicalTrials.gov (NCT02821650) and is approved the by Institutional Ethics Committee, Indian Institute of Public Health Bangalore campus IIPHHB/TRCIEC/ 094/2016. Necessary permissions were obtained from the Slum Development Board, Bangalore. All participants were informed well about the study purpose, and informed consent was obtained.

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Supplementary Information

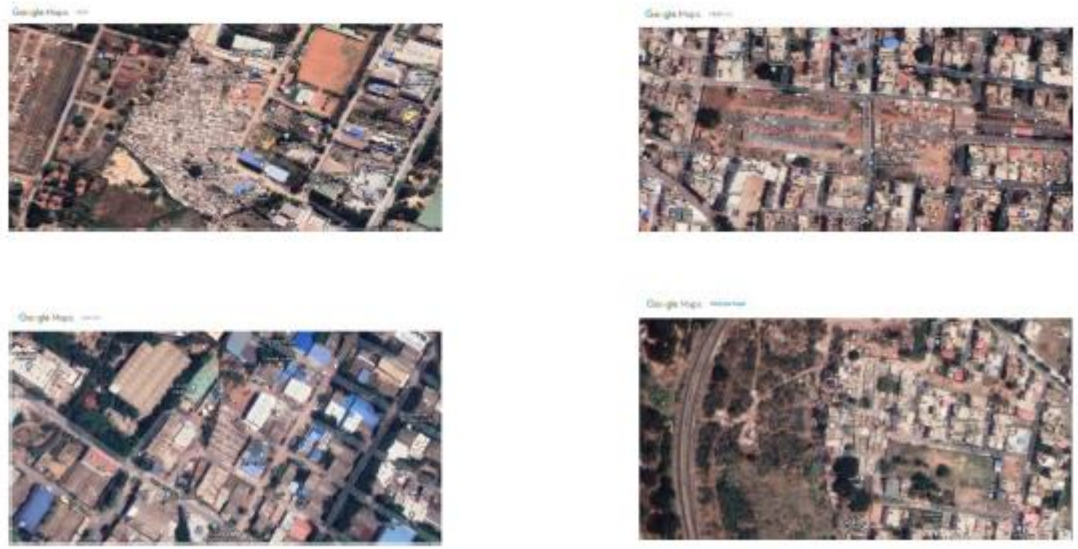

Figure S1: Study sites Ashrayanagar (top left), Mathikere (top right), Peenya (bottom left), and Muneshwaranagar (bottom right) – photos obtained from Google Maps

Figure S2: Dwelling types type A— a single structure where the cooking area is the same area (room) as the rest of the living areas/bedroom, type B— a single structure with the area for cooking separated by a partial wall from the other main areas and/or bedroom, and type C— a single structure with the area for cooking attached to the other main areas and/or bedroom. This attached cooking area is open for smoke from neighbours.

Table S1: Univariable associations between microenvironment and respiratory symptoms in primary cooks

Dependent variables	Cough (n=259)			Cough while cooking (n=259)			Phlegm (n=259)			Shortness of breath (n=259)			Wheezing (n=259)		
Explanatory variables	**Crude OR**	**(95% CI)**	***P***	**Crude OR**	**(95% CI)**	***P***	**Crude OR**	**(95% CI)**	***P***	**Crude OR**	**(95% CI)**	***P***	**Crude OR**	**(95% CI)**	***P***
Dwelling type															
Type B vs type A	1.35	(0.43, 4.22)	*0.60*	1.40	(0.53, 3.70)	*0.49*	1.71	(0.35, 8.34) (0.81,21.83)	*0.50*	7.08	(2.80, 17.93)	*<0.001**	0.00		
Type C vs type A	2.53	(0.65, 9.86)	*0.18*	1.61	(0.42, 6.17)	*0.48*	4.20	(0.30,19.67)	*0.088*	11.54	(3.44, 38.71)	*<0.001**	2.50	(0.28, 21.99)	*0.41*
Type C vs type B	1.87	(0.35, 9.93)	*0.46*	1.15	(0.24, 5.54)	*0.86*	2.45		*0.39*	1.63	(0.43, 6.17)	*0.47*	N/A		
Overall			*0.38*			*0.64*			*0.21*			*<0.001**			*0.71*
Wall material Other vs brick	2.43	(1.11, 5.35)	*0.027**	2.22	(1.14, 4.34)	*0.019**	4.55	(1.22, 16.95)	*0.024**	5.25	(2.17, 12.71)	*<0.001**	2.17	(0.51, 9.28)	*0.29*
Wall roof space Completely closed vs partially open	0.69	(0.24, 1.96)	*0.49*	0.39	(0.17, 0.90)	*0.027**	0.14	(0.04, 0.46)	*0.001**	0.06	(0.02, 0.15)	*<0.001**	0.42	(0.08, 2.18)	*0.30*
Leaks in roof Yes vs No	3.84	(1.35, 10.92)	*0.012**	6.24	(2.41, 16.15)	*<0.001**	6.39	(1.77, 23.03)	*0.005**	10.38	(3.88, 27.78)	*<0.001**	4.31	(0.81, 22.93)	*0.086**
Window Yes vs No	0.60	(0.27, 1.33)	*0.21*	0.53	(0.27, 1.06)	*0.073**	0.47	(0.14, 1.58)	*0.22*	0.18	(0.06, 0.48)	*0.001**	1.11	(0.27, 4.53)	*0.88*
Cook outside sometimes Yes vs No	0.39	(0.09, 1.73)	*0.21*	0.56	(0.19, 1.69)	*0.30*	0.00		*0.99*	0.17	(0.02, 1.34)	*0.093**	0.85	(0.10, 7.11)	*0.88*
Separate stove for boiling water outside Yes vs No	0.59	(0.17, 2.07)	*0.41*	0.89	(0.35, 2.29)	*0.82*	0.00		*0.99*	0.81	(0.27, 2.48)	*0.72*	0.80	(0.09, 6.69)	*0.84*

Dwelling type A refers to a single structure where the cooking area is the same area (room) as the rest of the living areas/bedroom; dwelling type B refers to a single structure with the area for cooking located in another room and separated by a partial wall from the other main areas and/or bedroom; and dwelling type C refers to a single structure with the area for cooking attached to the other main areas and/or bedroom. This attached cooking area is open for smoke from neighbours.

**$p \leq 0.20$*

Table S1 a: Sensitivity analysis (multivariable analysis using additional variables: smoking inside the house and smoke entering the house from neighbours house) for micro-environment and respiratory symptoms in primary cooks

Dependent variables	**Cough (n=257)**			**Cough while cooking (n=257)**			**Shortness of breath (n=256)**		
Explanatory variables	**Adjusted OR**	**(95% CI)**	***P***	**Adjusted OR**	**(95% CI)**	***P***	**Adjusted OR**	**(95% CI)**	***P***
Dwelling type									
Type B vs type A							4.00	(1.27, 12.61) (0.73, 22.77)	*0.018**
Type C vs type A							4.08	(0.15, 6.97)	*0.11*
Type C vs type B							1.02		*0.98*
Overall									*0.027**
Wall material Other vs brick	1.84	(0.80, 4.23)	*0.15*	1.76	(0.72, 4.29)	*0.21*	1.80	(0.47, 6.93)	*0.39*
Wall roof space Completely closed vs partially open				1.06	(0.37, 3.09)	*0.91*	0.19	(0.06, 0.58)	*0.004**
Leaks in roof Yes vs No	2.49	(0.81, 7.67)	*0.11*	5.15	(1.64, 16.23)	*0.005**	2.44	(0.68, 8.80)	*0.17*
Window Yes vs No				0.97	(0.40, 2.35)	*0.94*	0.51	(0.14, 1.91)	*0.32*
Cook outside sometimes Yes vs No							0.59	(0.07, 5.20)	*0.63*
Man smoking inside the house Yes vs No	0.56	(0.20, 1.58)	*0.27*	1.02	(0.46, 2.25)	*0.97*	1.29	(0.43, 3.86)	*0.65*
Smoke entering from neighbours' house Yes vs No	0.46	(0.18, 1.16)	*0.099*	0.74	(0.30, 1.80)	*0.50*	0.27	(0.09, 0.81)	*0.020**

Dwelling type A refers to a single structure where the cooking area is the same area (room) as the rest of the living areas/bedroom; dwelling type B refers to a single structure with the area for cooking located in another room and separated by a partial wall from the other main areas and/or bedroom; and dwelling type C refers to a single structure with the area for cooking attached to the other main areas and/or bedroom. This attached cooking area is open for smoke from neighbours.

*$p \leq 0.05$

Table S2: Univariable associations between microenvironment and other HAP related symptoms in primary cooks

Dependent variables	Headache (n=259)			Headache while cooking (n=257)			Burning eyes (n=259)			Burning eyes while cooking (n=254)		
Explanatory variables	**Crude OR**	**(95% CI)**	***P***	**Crude OR**	**(95% CI)**	***P***	**Crude OR**	**(95% CI)**	***P***	**Crude OR**	**(95% CI)**	***P***
Dwelling type												
Type B vs type A	1.21	(0.55, 2.65)	*0.62*	0.84	(0.36, 1.93)	*0.68*	2.09	(0.93, 4.73)	*0.075**	1.97	(0.83, 4.66)	*0.12**
Type C vs type A	2.28	(0.41, 3.94)	*0.66*	N/A†			1.03	(0.27, 3.88)	*0.96*	0.47	(0.15, 1.48)	*0.19**
Type C vs type B	1.05	(0.28, 3.92)	*0.93*	N/A†			0.49	(0.11, 2.18)	*0.35*	0.24	(0.06, 0.95)	*0.042**
Overall			*0.82*			*0.92*			*0.20**			*0.11**
Wall material Other vs brick	0.69	(0.42, 1.14)	*0.15**	0.63	(0.37, 1.08)	*0.095**	1.85	(1.04, 3.28)	*0.035**	1.58	(0.95, 2.63)	*0.073**
Wall roof space Completely closed vs partially open	0.70	(0.34, 1.46)	*0.34*	1.34	(0.59, 3.03)	*0.48*	0.37	(0.17, 0.80)	*0.012**	0.47	(0.21, 1.06)	*0.068**
Leaks in roof Yes vs No	2.31	(0.91, 5.87)	*0.078**	0.87	(0.32, 2.36)	*0.79*	2.23	(0.87, 5.73)	*0.096**	4.53	(1.29, 15.89)	*0.018**
Window Yes vs No	1.18	(0.72, 1.94)	*0.50*	1.37	(0.81, 2.31)	*0.23*	0.46	(0.25, 0.83)	*0.011**	0.85	(0.52, 1.40)	*0.53*
Cook outside sometimes Yes vs No	0.99	(0.48, 2.01)	*0.98*	1.29	(0.63, 2.67)	*0.48*	0.99	(0.44, 2.23)	*0.98*	0.94	(0.46, 1.89)	*0.85*
Separate stove for boiling water outside Yes vs No	1.00	(0.50, 2.01)	*0.99*	0.61	(0.79, 3.7)	*0.18**	0.92	(0.41, 2.06)	*0.84*	1.70	(0.81, 3.54)	*0.15**

Dwelling type A refers to a single structure where the cooking area is the same area (room) as the rest of the living areas/bedroom; dwelling type B refers to a single structure with the area for cooking located in another room and separated by a partial wall from the other main areas and/or bedroom; and dwelling type C refers to a single structure with the area for cooking attached to the other main areas and/or bedroom. This attached cooking area is open for smoke from neighbours.

**p≤0.20*

†There were no women with headaches from dwelling type C category

Table S2 a: Sensitivity analysis (multivariable analysis using additional variables: smoking inside the house and smoke entering the house from neighbours house) for micro-environment and other HAP related symptoms in primary cooks

Dependent variables	Headache (n=257)			Headache while cooking (n=255)			Burning eyes (n=257)			Burning eyes while cooking (n=252)		
Explanatory variables	**Crude OR**	**(95% CI)**	***P***	**Crude OR**	**(95% CI)**	***P***	**Crude OR**	**(95% CI)**	***P***	**Crude OR**	**(95% CI)**	***P***
Dwelling type												
Type B vs type A							1.54	(0.65, 3.67)	*0.33*	1.65	(0.66, 4.08)	*0.28*
Type C vs type A							0.87	(0.19, 4.01)	*0.86*	0.33	(0.08, 1.38)	*0.13*
Type C vs type B							0.57	(0.11, 2.95)	*0.50*	0.20	(0.04, 1.00)	*0.050*
Overall									*0.59*			*0.14*
Wall material Other vs brick	0.64	(0.37, 1.09)	*0.10*	0.75	(0.43, 1.31)	*0.31*	1.16	(0.54, 2.51)	*0.69*	1.50	(0.83, 2.69)	*0.18*
Wall roof space Completely closed vs partially open							0.55	(0.22, 1.39)	*0.20*	0.79	(0.29, 2.13)	*0.63*
Leaks in roof Yes vs No	3.16	(1.16, 8.62)	*0.024**				1.41	(0.46, 4.31)	*0.55*	5.72	(1.31, 24.92)	*0.02**
Window Yes vs No							0.58	(0.28, 1.23)	*0.15*			
Separate stove for boiling water outside Yes vs No				1.56	(0.75, 3.25)	*0.23*				1.89	(0.88, 4.09)	*0.10*
Man smoking inside the house Yes vs No	0.85	(0.48, 1.50)	*0.58*	0.98	(0.54, 1.78)	*0.96*	1.08	(0.56, 2.09)	*0.81*	1.26	(0.69, 2.28)	*0.45*
Smoke entering from neighbours' house Yes vs No	1.56	(0.72, 3.39)	*0.26*	2.01	(0.87, 4.65)	*0.10*	1.39	(0.55, 3.49)	*0.48*	1.28	(0.55, 2.98)	*0.57*

Dwelling type A refers to a single structure where the cooking area is the same area (room) as the rest of the living areas/bedroom; dwelling type B refers to a single structure with the area for cooking located in another room and separated by a partial wall from the other main areas and/or bedroom; and dwelling type C refers to a single structure with the area for cooking attached to the other main areas and/or bedroom. This attached cooking area is open for smoke from neighbours.

*$p \leq 0.05$

Table S3: Sensitivity analysis (multivariable analysis using additional variables: smoking inside the house and smoke entering the house from neighbours house) for microenvironment and lung function in primary cooks

Dependent variable	**Forced expiratory volume in 1 s % pred (FEV1% pred) (n=127)**		
Explanatory variables	**Unstandardized Coefficients B**	**(95% CI) for B**	***P***
Dwelling type			
Type B vs type A	- 1.29	(- 9.93, 7.36)	*0.77*
Type C vs type A	1.90	(- 10.08, 13.89)	*0.75*
Type C vs type B	3.19	(- 10.68, 17.06)	*0.65*
Overall			*0.89*
Wall material Other vs brick	- 4.86	(- 12.78, 3.07)	*0.22*
Wall roof space Completely closed vs partially open	9.07	(1.00, 17.14)	*0.028**
Leaks in roof Yes vs No	4.02	(- 4.97, 13.00)	*0.38*
Window Yes vs No	- 4.91	(- 12.41, 2.59)	*0.19*
Cook outside sometimes Yes vs No	6.45	(- 4.75, 17.64)	*0.25*
Separate stove for boiling water outside Yes vs No	- 3.86	(- 13.14,5.42)	*0.41*
Man smoking inside the house Yes vs No	3.97	(- 2.87, 10.82)	*0.25*
Smoke entering from neighbours' house Yes vs No	3.29	(- 4.14, 10.73)	*0.38*

Dwelling type A refers to a single structure where the cooking area is the same area (room) as the rest of the living areas/bedroom; dwelling type B refers to a single structure with the area for cooking located in another room and separated by a partial wall from the other main areas and/or bedroom; and dwelling type C refers to a single structure with the area for cooking attached to the other main areas and/or bedroom. This attached cooking area is open for smoke from neighbours.

*$p \leq 0.05$

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