ORIGINAL ARTICLE

Increased risk of respiratory illness associated with kerosene fuel use among women and children in urban Bangalore, India

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ABSTRACT

Background Kerosene is a widely used cooking and lighting fuel in developing countries. The potential respiratory health effects of cooking with kerosene relative to cooking with cleaner fuels such as liquefied petroleum gas (LPG) have not been well characterised.

Methods We sampled 600 households from six urban neighbourhoods in Bangalore, India. Each household's primary cook, usually the woman of the house, was interviewed to collect information on current domestic fuel use and whether there was any presence of respiratory symptoms or illness in her or in the children in the household. Our analysis was limited to 547 adult females (ages 18–85) and 845 children (ages 0–17) in households exclusively cooking with either kerosene or LPG. We investigated the associations between kerosene use and the likelihood of having respiratory symptoms or illness using multivariate logistic regression models.

Results Among adult women, cooking with kerosene was associated with cough (OR=1.88; 95% CI 1.19 to 2.99), bronchitis (OR=1.54; 95% CI 1.00 to 2.37), phlegm (OR=1.51; 95% CI 0.98 to 2.33) and chest illness (OR=1.61; 95% CI 1.02 to 2.53), relative to cooking with LPG in the multivariate models. Among children, living in a household cooking with kerosene was associated with bronchitis (OR=1.91; 95% CI 1.17 to 3.13), phlegm (OR=2.020; 95% CI 1.29 to 3.74) and chest illness (OR=1.70; 95% CI 0.99 to 2.90) after adjusting for other covariates. We also found associations between kerosene use and wheezing, difficulty breathing and asthma in adults and cough and wheezing in children, though these associations were not statistically significant.

Conclusions Women and children in households cooking with kerosene were more likely to have respiratory symptoms and illnesses compared with those in households cooking with LPG. Transitioning from kerosene to LPG for cooking may improve respiratory health among adult women and children in this population.

What this paper adds

- Kerosene is a widely used domestic fuel in India. Although the health impacts of exposure to kerosene combustion by-products are not well characterised, kerosene has been subsidised and promoted as an alternative to biomass, which has known adverse health consequences. Liquefied petroleum gas (LPG) is a cleaner burning domestic fuel.
- This study characterises potential respiratory health effects associated with the use of kerosene as a household fuel in comparison to LPG.
- Cooking with kerosene fuel is associated with increased prevalence of respiratory symptoms and conditions in urban-dwelling Indian women and children.
- The potential health effects of exposure to kerosene combustion by-products require further clarification to inform policies of subsidising kerosene as an alternative domestic fuel.

INTRODUCTION

Kerosene is a widely used cooking and lighting fuel in developing countries,[1 2] and is increasingly prominent as regions develop and urbanise.[3] Kerosene combustion is recognised to have pollution emissions and exposures that are typically intermediate between highly polluting solid fuels and clean-burning fuels such as liquefied petroleum gas (LPG).[2–4] Most epidemiological studies of kerosene have evaluated its health impacts relative to the health impacts of biomass fuel use.[5] In fact, a shift from biomass to kerosene was previously recommended as an approach to reduce air pollution exposures[6] and improve health.[5] Yet very little is known about the health risks associated with the use of kerosene stoves for cooking.[2]

Kerosene combustion emits many potentially health-damaging pollutants, including particulate matter (PM), carbon monoxide, polycyclic aromatic hydrocarbons and volatile organic compounds.[7 8] A recent review study found that kitchen PM concentrations from kerosene stoves ranged from 300 to 750 μg/m^3 during 6–48 h measurement periods.[2] Compared with LPG, use of kerosene for cooking is associated with 2–4 times higher PM emissions and indoor concentrations in laboratory and field studies.[2] Although laboratory studies suggest that shifting from biomass to kerosene fuel could achieve a 50–90% reduction in PM emissions,[9 10] the quality of kerosene fuel and stove may considerably impact its emissions. Kerosene stoves in urban Bangladesh emitted significantly higher

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concentrations of benzene, toluene, xylene and hexane than biomass stoves, a result likely due to the use of older, inefficient stoves.[11]

The health impacts of using kerosene stoves compared with cleaner-burning fuels are unclear. In high-income countries, use of kerosene space heaters was associated with respiratory illness in infants[12] and their mothers,[13] and with decreased lung function in adults[14] and school-aged children.[15] Limited evidence suggests that cooking with kerosene is associated with lower birth weight[16] and an increased risk of tuberculosis[17 18] and burns[19] compared with LPG use. In the few studies assessing the respiratory health impacts of kerosene relative to LPG, the use of kerosene stoves has been associated with reduced lung function[20] and increased risk of respiratory symptoms and illnesses in adults,[21 22] infants and children.[23–25] However, a lack of assessment for potentially important covariates (eg, household income, kitchen ventilation, use of other fuels, crowding and environmental tobacco smoke) is of concern for many of these studies.[20–23 26]

Considering this important gap, we investigated the effect of kerosene use on respiratory symptoms and illness among adult women and children in urban Bangalore, India. Specifically, we tested the hypothesis that women and children living in households that exclusively cook with kerosene fuel have an increased risk of respiratory symptoms and illness compared with those living in households exclusively using LPG for cooking, after accounting for important individual and household variables associated with fuel use and respiratory illness.

Study location and population

We conducted a cross-sectional study on household cooking fuel use and respiratory health between May 2004 and May 2005 in urban Bangalore (population 6.8 million), Karnataka State, India. Study participants were recruited from six neighbourhoods that were chosen to meet the prerequisite of a broad socioeconomic status (SES) representation, ranging from lower income (Sonnenahalli and Rajendra Nagar) to middle income (Jakkasandra and Venkatapura) to upper class neighbourhoods (Koramangala and Teacher's Colony). Except for Teacher's Colony, these neighbourhoods were within 3–5 km of each other. Knowledgeable community health workers at St John's Medical College in Bangalore helped identify the study neighbourhoods. We selected the neighbourhoods based on the community health workers' perceptions of their neighbourhood SES since income data at neighbourhood scales were not available at the time of our study.

We used a simple cluster sampling strategy to select 100 households in each of the six study neighbourhoods (600 households total). The study population was recruited by selecting a household located at the edge of each neighbourhood as a starting point. We then sought consent for participation from every tenth household along the road moving inward into the neighbourhood. The primary household cook (an adult female in all households) was recruited as the key informant for the household. We continued to recruit primary cooks until we reached a sample size of 100 informants in each of the six neighbourhoods, for a total of 600 key informants. The field staff did not collect information on the number of eligible cooks who declined to participate in the study.

Field staff obtained verbal informed consent at enrolment following an explanation of the purposes of the study and requirements for participation. A standardised questionnaire was then administered in the preferred language of the informant (English, Hindi or Kannada) during a home interview. The key informants in each of the 600 study households provided information on household demographics, fuel and energy-use patterns, home characteristics, and respiratory symptoms and illness for themselves and any children in the home; details are provided in the Questionnaire section below.

Questionnaire

Cooking fuel use was ascertained by asking informants about the types of fuel used for cooking in their households. During the home interview, field staff asked informants "What types of fuels do you use for cooking in your home?" and recorded all fuel types used for cooking at the time of the interview. The questionnaire listed fuels available in Indian urban centres, including kerosene, LPG, biomass (wood and crop residues) and electricity.

The health end points of interest were respiratory symptoms and illness for adult women and children in the household, obtained using standardised questionnaires prepared by the American Thoracic Society (ATS) and International Study of Asthma and Allergies in Childhood (ISAAC).[27 28] Clinicians from the Department of Chest Diseases at St John's Medical College Hospital in Bangalore trained the field interviewer to administer the questionnaire. Informants reported on illness for themselves and children in the household during the last year, including bronchitis, chest illness and wheezing, and previous diagnosis of asthma by a physician. The field interviewer was trained to explain these conditions in common terms. For bronchitis, for example, the interviewer asked informants if they had a persistent cough that produces sputum (phlegm) and mucus, for at least 3 months per year in two consecutive years. They were also asked if a physician had diagnosed them with the condition. Respondents also reported on the frequency of respiratory symptoms, including cough and phlegm, and whether they currently experienced difficulty breathing (adult women only).

The questionnaire also included questions on potential confounding variables, such as the fuel types used for boiling water, demographic characteristics of all household occupants (age, sex, education level, religion), the respondent's smoking status (current, previous, never), annual household income, family health history and allergies, home ownership, crowding (ie, the number of individuals living in the household divided by the number of rooms), housing type (apartment, single family house, extended family home), usual residence for ≥75% of the occupant's lifetime (urban, rural, both; adult women only), mode of personal transportation on most days, environmental tobacco smoke exposure (ie, number of indoor tobacco users in the household, cigarette or *beedi*), lighting source, kitchen ventilation (ie, presence of a window and/or fan) and other household PM sources (eg, burning mosquito coils or incense, mould, mildew and animal dander).

The English version of the questionnaire was translated into Hindi and Kannada languages by translators with public health experience, and then back-translated into English to ensure that the questions measured what they intended to measure. The survey was field tested with community health workers and in several Bangalore households prior to implementation.

Statistical analysis

We collected information for 600 non-smoking women and 945 children living in urban Bangalore. Our main analysis was restricted to 547 women and 845 children in households exclusively cooking with either kerosene or LPG. We excluded individuals in households primarily cooking with wood (n=4 women and n=11 children) or multiple fuel types (n=49 women and

n=89 children). Fuels for boiling water were not considered in this analysis.

Each respiratory symptom and illness was coded as a binary variable: never or ever experienced symptoms "during the past 12 months" for bronchitis, chest illness or wheezing. Cough was coded as 'absent' if the participant had a cold with cough less than four times in the last year and 'present' if the participant had a cold with cough four or more times in the last year. Phlegm was coded as 'present' if the participant reported bringing up phlegm from the chest on most of the mornings for at least three consecutive months in the previous year and as 'absent' for less frequent congestion. Asthma was coded as 'present' with a physician diagnosis and as 'absent' without a previous diagnosis of asthma by a physician. Difficulty in breathing in adult women was coded as 'absent' if they experienced no difficulty breathing while walking 2 km or completing daily household chores, and coded as 'present' if they experienced any difficulty breathing during these activities.

We calculated the prevalence of respiratory symptoms and illness by fuel type and other covariates. We then used multivariate logistic regression models to estimate prevalence ORs with the corresponding 95% CIs to describe associations between cooking fuel type (kerosene vs LPG) and having respiratory symptoms or illness, while accounting for other important risk factors. Separate analyses were conducted for women and children. We also included potential confounding by variables that were significantly different between the two exposure groups and which may have influenced respiratory outcomes, including age, gender (children only), years of education completed by the adult female participants and heads of household (<6, 6–12, >12 years), annual household income (quintiles), housing (own vs rent), environmental tobacco smoke exposure (none vs ≥1 tobacco or *beedi* smokers), crowding (number of persons in the household divided by the number of rooms; quintiles) and kitchen ventilation (none vs presence of windows or fan in the kitchen). Although the adult women in our study lived in urban Bangalore at the time of survey administration, we also assessed the location where they had lived for ≥75% of their lives (urban, rural or both) as a proxy for the likelihood of previously using biomass fuels, since rural India heavily relies on biomass for domestic energy.[29]

In a second analysis, we restricted our study sample to participants who lived in households that exclusively used LPG or kerosene for cooking as well as boiling water (n=219 adult women and n=338 children). We chose this sensitivity analysis because, compared with women cooking with LPG, a higher proportion of women cooking with kerosene also used biomass for boiling water (50% vs 22%). We conducted a final sensitivity analysis that excluded the small number of women who reported an allergic rash (n=22) or allergies (n=8) from the multivariate regression models.

We corrected for correlation in measurements among children in the same household using STATA's robust cluster estimator command with the vce (cluster *clustvar*) option, a 'sandwich' variance estimator that corrects for correlated observations from within an independent group.[30] Independent variables in the logistic regression models were considered to be statistically significant predictors of respiratory symptoms and illness if $p<0.05$. All statistical analyses were performed in STATA V.9.1 (StataCorp, College Station, Texas, USA).

RESULTS

Our study sample included 547 adult females aged 18–85 (mean 33 years) and 845 children and adolescents aged 0–17 (mean 8 years; 52% male) from households exclusively cooking with either LPG or kerosene. Kerosene was the primary household cooking fuel for 29% of women and 32% of children. The remaining 71% of women and 68% of children lived in households cooking with LPG. Thirty-eight per cent of women and 41% of children in our study lived in a household with one or more smokers; however, none of the study participants were current or previous smokers themselves (table 1).

Compared with participants in households cooking with LPG, women and children in households using kerosene had lower annual household income, were more likely to live with a smoker, lived in more crowded households and had lower education (adults). They were also less likely to have window or fan ventilation in their kitchen (table 1). We did not observe large differences between kerosene and LPG users in religion, housing type, or allergies. All participants reported exclusively using electricity for lighting.

Over half of the adult women in our study reported having experienced at least four episodes of cough or bronchitis in the last year (table 2). Phlegm and chest illness in the last year and current difficulty breathing were also frequently reported symptoms. Fewer women reported having physician-diagnosed asthma or wheezing. In the crude analysis, we observed a higher prevalence of all reported respiratory illnesses and symptoms, including cough (73% vs 55%), bronchitis (62% vs 47%), phlegm (53% vs 39%), wheezing (17% vs 10%), chest illness (40% vs 24%) and difficulty breathing (31% vs 22%) among women cooking with kerosene as compared with women cooking with LPG. The prevalence of physician-diagnosed asthma was also slightly higher among kerosene users (8% vs 5%; table 2).

Among children, the respiratory outcomes most commonly reported were bronchitis (51%), cough (42%), phlegm (37%) and chest illness (31%), with only a very small proportion of children reporting wheezing (3%) or physician-diagnosed asthma (1%). Compared with children in households using LPG, children in households cooking with kerosene had a higher prevalence of cough (49% vs 38%), bronchitis (62% vs 46%), phlegm (49% vs 31%) and chest illness (42% vs 25%) than children in LPG households in the crude analysis. The prevalence of wheezing and asthma was similarly low (<3%) in both exposure groups (table 3).

In the multivariate logistic regression models, women cooking with kerosene were more likely to have had multiple episodes of cold with cough (OR: 1.88; 95% CI 1.19 to 2.99) and chest illness (OR: 1.61; 95% CI 1.02 to 2.53) in the last year, compared with women cooking with LPG. Though not statistically significant, our data are suggestive that women cooking with kerosene may be more likely to have experienced bronchitis in the last year (OR: 1.54; 95% CI 1.00 to 2.37), been diagnosed with asthma by a physician (OR: 1.26, 95 CI 0.49 to 3.25), and currently experience respiratory symptoms of frequent phlegm (OR: 1.51; 95% CI 0.98 to 2.33), wheeze (OR: 1.45; 95% CI 0.78 to 2.69) and breathing difficulties during certain tasks (OR: 1.51; 95% CI 0.90 to 2.52; table 4).

After adjusting for other risk factors in the multivariate models, children in homes cooking with kerosene were more likely to have had bronchitis (OR: 1.91; 95% CI 1.17 to 3.13) during the previous year. They were also more likely to currently experience frequent phlegm (OR: 2.20; 95% CI 1.29 to 3.74) compared with children in households cooking with LPG. Our data are suggestive that children in homes cooking with kerosene may be more likely to have been diagnosed with chest illness (OR: 1.70; 95% CI 0.99 to 2.90) in

Table 1 Characteristics of study participants by cooking fuel type, Bangalore, India

Characteristic	Children			Adult women		
	Kerosene (n=274) N (%)	LPG (n=571) N (%)	Total (n=845) N (%)	Kerosene (n=161) N (%)	LPG (n=386) N (%)	Total (n=547) N (%)
Age (years)						
0–4	81 (29.6)	168 (29.4)	249 (29.5)			
5–8	66 (24.1)	135 (23.6)	201 (23.8)			
9–12	67 (24.4)	119 (20.8)	186 (22.0)			
13–17	60 (21.9)	149 (26.0)	209 (24.7)			
18–29				71 (44.1)	170 (44.0)	241 (44.0)
30–39				44 (27.3)	114 (29.5)	158 (28.9)
40–49				32 (19.9)	65 (16.8)	97 (17.7)
50+				14 (8.7)	37 (9.6)	51 (9.3)
Gender						
Female	138 (50.4)	265 (46.4)	403 (47.7)			
Male	136 (49.6)	306 (53.6)	442 (52.3)			
Mother's education (kids) or education (adult women; years)						
<6	167 (60.9)	197 (34.5)	364 (43.1)	91 (56.5)	133 (34.4)	224 (41.0)
6–12	96 (35.0)	307 (53.8)	403 (47.7)	63 (39.1)	196 (50.8)	259 (47.3)
>12	11 (4.0)	67 (11.7)	78 (9.2)	7 (4.3)	57 (14.8)	64 (11.7)
Head of household's education (years)						
<6	119 (43.4)	154 (27.0)	273 (32.3)	65 (40.4)	108 (28.0)	173 (31.6)
6–12	147 (53.6)	360 (63.0)	507 (60.0)	93 (57.8)	236 (61.1)	329 (60.1)
>12	8 (2.9)	57 (10.0)	65 (7.7)	3 (1.9)	42 (10.9)	45 (8.2)
Annual household income (Indian Rupees, quintile)						
<42 000	79 (28.8)	143 (25.0)	222 (26.3)	41 (25.5)	86 (22.3)	127 (23.2)
42 000–60 000	91 (33.2)	113 (20.0)	204 (24.1)	49 (30.4)	75 (19.4)	124 (22.7)
60 001–81 600	30 (10.9)	78 (13.7)	108 (12.8)	24 (14.9)	54 (14.0)	78 (14.3)
81 601–120 000	50 (18.2)	123 (21.5)	173 (20.5)	35 (21.7)	89 (23.1)	124 (22.7)
>120 000	24 (8.8)	114 (20.0)	138 (16.3)	12 (7.5)	82 (21.2)	94 (17.2)
Housing						
Own	129 (47.0)	275 (48.2)	368 (43.6)	68 (42.2)	158 (40.9)	226 (41.3)
Rent or Lease	145 (52.9)	296 (51.8)	441 (52.2)	93 (57.8)	228 (59.1)	321 (58.7)
Religion						
Hindu	196 (71.5)	446 (78.1)	642 (76.0)	120 (74.5)	311 (80.6)	431 (78.8)
Muslim	67 (24.5)	33 (5.8)	100 (11.8)	17 (10.6)	31 (8.0)	48 (8.8)
Other*	45 (16.4)	58 (10.2)	103 (12.2)	24 (14.9)	44 (11.4)	68 (12.4)
Predominant lifetime area of residence						
Rural				37 (23.0)	106 (27.5)	143 (26.1)
Urban				109 (67.7)	246 (63.7)	355 (64.9)
Both				15 (9.3)	34 (8.8)	49 (9.0)
Environmental tobacco smoke						
No	126 (46.0)	376 (65.8)	502 (59.4)	81 (50.3)	257 (66.6)	338 (61.8)
Yes	148 (54.0)	195 (34.2)	343 (40.6)	80 (49.7)	129 (33.4)	209 (38.2)
Crowding† (quintile)						
<0.015	10 (3.6)	98 (17.2)	108 (12.8)	19 (11.8)	94 (24.4)	113 (20.7)
0.015–0.021	25 (9.1)	114 (20.0)	139 (16.4)	18 (11.2)	88 (22.8)	106 (19.4)
0.021–0.026	42 (15.3)	108 (18.9)	150 (17.8)	31 (19.3)	79 (20.5)	110 (20.1)
0.027–0.036	68 (24.8)	133 (23.3)	201 (23.8)	35 (21.7)	74 (19.2)	109 (19.9)
>0.036	129 (47.1)	118 (20.1)	247 (29.2)	58 (36.0)	51 (13.2)	109 (19.9)
Kitchen ventilation						
No	248 (90.5)	325 (56.9)	573 (67.8)	145 (90.1)	230 (59.6)	375 (68.6)
Yes	26 (9.5)	246 (29.1)	272 (32.2)	16 (9.9)	156 (40.4)	172 (31.4)
Allergic rash						
No				154 (95.7)	371 (96.1)	525 (96.0)
Yes				7 (4.3)	15 (3.9)	22 (4.0)
Pollen allergy						
No				157 (97.5)	382 (99.0)	539 (98.5)
Yes				4 (2.5)	4 (1.0)	8 (1.5)

*The 'Other' category for religion includes Jain, Buddhist, Christian and Sikh.
†Crowding is defined by the number of household occupants divided by number of rooms in the home.
LPG, liquefied petroleum gas.

Table 2 Prevalence (%) of respiratory illness and symptoms by individual and household characteristics for adult women

	Cough	Bronchitis	Phlegm	Wheezing	Chest illness	Breathing difficulty	Asthma
Total	60.3	51.6	43.5	12.2	29.1	24.3	5.7
Age (years)							
18–29	60.2	54.4	43.6	10.8	27.4	14.5	4.1
30–39	58.9	43.7	34.2	7.6	20.3	17.1	2.5
40–49	59.8	54.6	51.5	19.6	43.3	43.3	12.4
50+	66.7	56.9	56.9	19.6	37.3	56.9	9.8
Education (years)							
<6	69.6	59.4	51.3	15.6	35.3	32.6	6.7
6–12	54.8	46.3	40.9	10.8	27.8	20.8	5.8
>12	50.0	45.3	26.6	6.3	12.5	9.4	1.5
Head of household's education (years)							
<6	67.1	62.4	49.7	16.8	38.2	32.4	7.5
6–12	59.9	46.5	41.0	10.9	26.1	21.6	4.6
>12	37.8	46.7	37.8	4.4	15.6	13.3	6.7
Annual household income (Indian Rupees, quintile)							
<42 000	62 .2	44.9	40.2	14.2	28.3	18.1	6.3
42 000–60 000	58.9	56.5	50.8	10.5	29.8	21.8	2.4
60 001–81 600	57.7	47.4	44.9	15.4	30.8	38.5	9.0
81 601–120 000	67.7	57.3	40.3	12.1	30.6	25.0	6.5
>120 000	52.1	50.0	41.5	9.6	25.5	23.4	5.3
Home ownership							
Own	68.1	53.5	50.9	13.7	35.0	22.6	4.9
Rent or Lease	54.8	50.2	38.3	11.2	24.9	25.5	6.2
Predominant lifetime area of residence							
Rural	56.6	42.7	38.5	6.3	25.9	15.4	2.1
Urban	63.7	52.7	43.7	13.5	30.1	27.6	6.2
Both	46.9	49.0	57.1	20.4	30.6	26.5	12
Environmental tobacco smoke							
No	58.0	50.6	42.9	11.2	27.2	22.2	5.0
Yes	64.1	53.1	44.5	13.9	32.1	27.8	6.7
Crowding* (quintile)							
<0.015	59.3	47.8	43.4	14.2	24.8	23.0	5.3
0.015–0.021	57.5	45.3	37.7	9.4	27.4	19.8	3.8
0.021–0.026	61.8	52.7	44.5	16.4	30.0	21.8	10.0
0.027–0.036	56.9	55.0	46.8	6.4	29.4	30.3	1.9
>0.036	66.1	56.9	45.0	14.7	34.0	26.6	7.3
Kitchen ventilation							
No	62.1	54.1	46.1	13.0	33.3	24.3	5.3
Yes	55.9	45.9	38.2	11.1	19.4	24.1	5.9
Cooking fuel							
LPG	54.9	47.4	39.4	10.4	24.4	21.5	4.9
Kerosene	73.3	61.5	53.4	16.8	40.4	31.1	7.5

*Crowding is defined by the number of household occupants divided by number of rooms in the home.
LPG, liquefied petroleum gas.

the last year and to experience symptoms of cough (OR: 1.29; 95% CI 0.85 to 1.96), though these results are not statistically significant (table 4).

Restricting our analysis to women exclusively using LPG or kerosene for cooking as well as boiling water (40% of the original sample) did not change our overall findings for the effects of kerosene use on most respiratory symptoms and illnesses (table 4). However, kerosene use was no longer positively associated with wheezing (OR: 0.79; 95% CI 0.24 to 2.62) or asthma in adult women (OR: 0.37; 95% CI 0.04 to 3.14), and only the estimates for bronchitis in women and for phlegm in children both remained positively associated with kerosene use and statistically significant with the considerably decreased sample size. Excluding adult women who reported having an allergic rash (n=22) or allergies (n=8) did not appreciably change our estimated effects of kerosene use (results not presented).

DISCUSSION

We found that women in urban Bangalore cooking with kerosene were more likely to have experienced frequent cough and chest illness relative to women cooking with LPG, after adjusting for other important covariates. Similarly, children in households cooking with kerosene were more likely to have bronchitis and phlegm. Kerosene use was also associated with bronchitis, phlegm, wheezing, difficulty breathing and physician-diagnosed asthma in women, and with cough, wheezing and chest illness

Table 3 Prevalence (%) of respiratory illness and symptoms by individual and household characteristics of the children and adolescents

	Cough	Bronchitis	Phlegm	Wheezing	Chest illness	Asthma
Total	41.9	50.8	36.9	3.1	30.9	1.1
Age (years)						
0–4	51.0	53.2	37.0	2.8	34.8	0.1
5–8	47.3	54.0	44.5	4.0	35.9	1.5
9–12	40.3	49.7	40.0	2.7	26.8	1.1
13–17	24.9	46.4	27.8	1.9	23.2	1.0
Gender						
Female	41.7	53.5	35.4	2.5	31.4	0.8
Male	41.0	48.4	38.7	3.2	29.5	1.4
Mother's education (years)						
<6	44.2	53.4	34.9	1.1	36.8	0.6
6–12	40.4	50.6	40.6	3.6	27.4	0.8
>12	32.1	42.1	29.5	7.7	16.7	5.1
Head of household's education (years)						
<6	49.1	58.2	38.5	1.9	39.4	0
6–12	37.3	47.5	35.7	2.6	26.9	0.9
>12	40.0	48.3	42.9	9.2	20.0	8.8
Annual household income (Indian Rupees; quintile)						
<42 000	43.7	50.0	35.9	1.8	33.3	0.9
42 000–60 000	44.1	50.0	45.3	3.5	39.4	1.0
60 001–81 600	33.3	49.0	30.6	4.7	30.8	1.9
81 601–120 000	41.6	50.7	31.4	1.7	21.2	1.2
>120 000	39.1	55.3	39.4	3.6	23.5	0.7
Home ownership						
Own	40.8	55.5	33.3	1.9	27.7	0.9
Rent or Lease	41.7	47.4	40.1	3.6	32.5	1.4
Environmental tobacco smoke						
No	41.4	51.6	36.8	3.2	29.8	1.2
Yes	41.1	49.8	37.6	2.4	31.3	0.9
Crowding* (quintile)						
<0.015	33.3	45.5	32.5	3.7	25.9	3.7
0.015–0.021	40.3	47.6	28.8	4.3	26.1	1.5
0.021–0.026	35.3	43.9	30.9	2.7	27.8	1.4
0.027–0.036	40.8	56.3	40.0	2.5	28.4	0.0
>0.036	49.4	55.6	45.5	2.1	38.1	0.4
Kitchen ventilation						
No	44.2	52.8	39.7	3.0	34.3	0.9
Yes	35.3	46.9	31.7	2.6	22.2	1.5
Cooking fuel						
LPG	37.7	45.8	31.4	3.2	24.9	1.4
Kerosene	48.9	62.1	49.1	2.2	41.9	0.4

*Crowding is defined by the number of household occupants divided by number of rooms in the home.
LPG, liquefied petroleum gas.

among children, though these differences were not statistically significant.

To the best of our knowledge, this is one of very few studies specifically designed to examine the effect of cooking with kerosene on respiratory symptoms and illness in adult women and children relative to cooking with LPG. Notable strengths of this study include the large population of adult women and children who live in homes exclusively cooking with either LPG or kerosene and the assessment of important individual and household covariates associated with fuel use, air pollution and respiratory illness.

Our results for children are consistent with a previous study among school-aged children in urban Lagos, which found a positive association between cooking with kerosene and having phlegm (OR=2.83; 95% CI 0.85 to 9.44) compared with cooking with gas, but did not find an association between kerosene use and wheezing.[25] The small but non-significant association between cooking with kerosene and recent episodes of wheezing (OR=1.45; 95% CI 0.78 to 2.69) among adult women in our study is larger than the association between kerosene heater use and wheezing (RR=1.06; 95% CI 1.01 to 1.11) in adult women in the USA,[13] but considerably smaller than the effect of cooking with kerosene on wheezing (OR=2.57; 95% CI 1.76 to 3.75) in adults and children in urban Ethiopia,[22] though many homes in the latter study were also using highly polluting biomass fuels.

Triche *et al*[13] did not find significantly positive associations between kerosene heater use and other respiratory symptoms (eg, chest illness, phlegm, cough) as we did in our study. Kerosene users in our study may be more likely to have

Table 4 Associations between kerosene use and respiratory symptoms and illness in women and children in homes (A) exclusively using kerosene for cooking and (B) exclusively using kerosene for cooking and also water boiling

	ORs (95% CI)†			
	Women‡		Children¶	
Variable	Cooking with kerosene††	Cooking and water boiling with kerosene‡‡	Cooking with kerosene††	Cooking and water boiling with kerosene‡‡
Cough	1.88 (1.19 to 2.99)**	1.95 (0.90 to 4.25)	1.29 (0.85 to 1.96)	1.34 (0.63 to 2.85)
Bronchitis	1.54 (1.00 to 2.37)§	2.19 (1.05 to 4.55)*	1.91 (1.17 to 3.13)*	1.76 (0.81 to 3.81)
Phlegm	1.51 (0.98 to 2.33)§	1.82 (0.86 to 3.87)	2.20 (1.29 to 3.74)**	3.07 (1.27 to 7.42)*
Wheezing	1.45 (0.78 to 2.69)	0.79 (0.24 to 2.62)	1.08 (0.35 to 3.38)	1.21 (0.31 to 4.66)
Chest illness	1.61 (1.02 to 2.53)*	1.51 (0.68 to 3.35)	1.70 (0.99 to 2.90)§	1.22 (0.54 to 2.78)
Breathing difficulty	1.51 (0.90 to 2.52)	1.30 (0.51 to 3.34)	–	–
Asthma	1.26 (0.49 to 3.25)	0.37 (0.04 to 3.14)	–	–

§p<0.10 *p<0.05; **p<0.01.
†The ORs were adjusted for age, gender (children only), education (adults only), mother's education (children only), head of household's education, annual household income, home ownership, predominant lifetime area of residence (adults only), presence of a smoker in the home, crowding and kitchen ventilation.
‡For women: n=545 for cooking only analysis with two women were excluded from the analysis due to incomplete covariate data; n=219 for cooking and water boiling fuel analysis.
¶For children cooking fuel only analysis: n=845 for cough, n=745 for bronchitis, n=840 for phlegm, n=837 for wheezing and n=835 for chest illness; for cooking and heating fuel analysis: n=338 for cough, n=330 for bronchitis, n=338 for phlegm, n=334 for wheezing and n=337 for chest illness.
††The comparison group is comprised of participants living in homes exclusively using liquefied petroleum gas (LPG) for cooking.
‡‡The comparison group is comprised of participants living in homes exclusively using LPG for cooking and also water boiling.

previously cooked with biomass than have women kerosene heater users in the USA. Daily cooking with kerosene may also result in higher and more consistent air pollution exposures compared with seasonal use of kerosene heaters as secondary energy sources.

We did not find even a borderline significant ($p<0.10$) relationship between kerosene use and wheezing or physician-diagnosed asthma among women. The low prevalence of diagnosed asthma among women in this study (5.7%), despite a higher prevalence of related self-reported symptoms such as wheezing (12.2%), may be an indicator of undiagnosed asthma. A Nigerian study[25] noted that factors such as limited healthcare access and a lack of awareness may lead to under-reporting by respondents or hesitancy by physicians to attribute the diagnosis of 'asthma' to asthma-like symptoms.[31] These factors may also explain the low prevalence of asthma among children in our study (1%), though the prevalence of wheezing was also lower (3%).

Kerosene and LPG are the two main fuels that have substituted biomass for cooking in urban India. Government policies have played a key role in this transition through subsidised prices and controlled availability. Subsidised kerosene has been distributed to homes through the public distribution system according to various criteria, including whether or not the household has an LPG connection.[32] LPG is distributed by dealers belonging to state-owned oil companies and also subsidised; however, its use by lower-income households remains greatly limited by cost. The price per unit of energy from LPG is higher than kerosene across India. LPG requires the combined upfront costs of connection and stove, both of which are more expensive than what is required for kerosene. LPG also typically requires the purchase of larger minimum fuel quantities compared with kerosene.[33] As households urbanise and transition away from biomass fuels, policies that shift fuel consumption patterns away from kerosene and increase LPG accessibility to the urban poor may provide a population health benefit.

There are several limitations to consider in interpreting our findings. One is the reliance on self-reported measurement of domestic fuel types and respiratory health. We ensured that respondents did not know the hypothesis of the study and have no reason to suspect that households would misreport their cooking fuels. While self-report of respiratory health symptoms and conditions is always problematic, this was likely minimised by using structured respiratory surveys based on the ATS[28] and ISAAC[27] criteria that left little room for a biased interpretation of the information provided by the respondent.

Another limitation of the study is that we did not have detailed census data to enable a statistical sampling design of the various neighbourhoods. We adopted the cluster sampling strategy based on convenience, however, that also enables sufficient representativeness. We corrected for clustering in children living in the same household, but did not investigate clustering by area.

Although we did not measure air pollution in this study, our previous study found significantly higher personal PM exposure among kerosene users compared with LPG users among women cooks in urban Mysore, Karnataka (mean exposure of 177 vs 71 $\mu g/m^3$ in winter).[34] The cooking practices, housing conditions, and other behavioural and cultural factors that impact cooking exposures at that study site are very similar to this study site in urban Bangalore.

The cross-sectional nature of the study also makes it impossible to properly decipher the causal sequences occurring over time. It is possible that a woman's respiratory health or that of her child might impact the choice of fuel if she is aware of the potential health benefits of transitioning from kerosene to LPG, resulting in an underestimation of the risk of kerosene use. In addition, kerosene users in urban India are more likely than LPG users to have previously cooked with biomass fuels.[4] Since exposure to biomass smoke is causally linked with respiratory illness,[6] our effect estimates for kerosene could be overestimated if a large number of individuals in households using kerosene were previous long-time biomass users. However, over 80% of the kerosene users in our study reported having used it as their primary cooking fuel for >40% of their lifetime spent cooking. Further, a larger percentage of LPG users spent >75% of their lifetime in a rural area (28% vs 23% of kerosene users), and adjusting for time lived in a rural area (our proxy measure for previous biomass exposure) did not modify the effect of fuel type on any respiratory health end points.

We cannot rule out the possibility of residual confounding by household SES, which has been associated with fuel use[35] and also with respiratory health,[36] and can be challenging to quantify in developing countries.[37] Annual household income was indeed lower among kerosene than LPG users in our study with median yearly income 18% higher in LPG users (₹71 000) compared with kerosene users (₹60 000). However, other variables related to household wealth such as household square footage (306 vs 367 m^2 for kerosene and LPG users, respectively), home ownership and educational attainment of household occupants were similar between our exposure groups (table 1). Similarly, nutritional status is a poverty-related factor that is associated with respiratory illness in children[38] and adults[39] but was not considered in our study. Nutritional deficiencies may be less common among low-income Bangalore residents than rural populations or even urban populations in other Indian regions,[40] though future studies on this topic would still benefit from measurement of nutritional status.

Finally, households using kerosene are more likely to reside in lower SES neighbourhoods than LPG users,[41] which has been associated with elevated neighbourhood pollution in other regions of the world.[42] With one exception, our study neighbourhoods were located within several kilometres of each other and we included multiple indicators of SES in our multivariate models, however, we cannot rule out the possibility of residual confounding by neighbourhood pollution.

Household kerosene combustion for cooking and lighting is widespread in India and many other developing countries as they urbanise and develop. While kerosene is offered as a substitute for biomass as a domestic fuel, there is little epidemiological evidence describing the health impacts of kerosene use despite the potential risks suggested by a small number of existing studies. Our present study adds to a small but increasing body of evidence[20–25] that identifies kerosene as another cooking fuel that may impact the respiratory health of adult women and children. Future longitudinal investigations are warranted to explore the causal link between kerosene use and respiratory health and minimise the potential of misclassifications of fuel type and respiratory symptoms.

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REFERENCES

1 Mills E. The specter of fuel-based lighting. *Science* 2005;308:1263–4.
2 Lam NL, Smith KR, Gauthier A, *et al*. Kerosene: a review of household uses and their hazards in low-and middle-income countries. *J Toxicol Environ Health* 2012;15:396–432.
3 Barnes DF, Krutilla K, Hyde WF. *The urban household energy transition: social and environmental impacts in the developing world*. Routledge, 2013.
4 Kandlikar M, Ramachandran G. The causes and consequences of particulate air pollution in urban India: a synthesis of the science. *Ann Rev Energy Environ* 2000;25:629–84.
5 Torres-Duque C, Maldonado D, Perez-Padilla R, *et al*. Biomass fuels and respiratory diseases: a review of the evidence. *Proc Am Thorac Soc* 2008;5:577–90.
6 Smith KR, Mehta S, Maeusezahl-Feuz M. Indoor air pollution from household solid fuel use. In: Ezzati M, Lopez AD, Rodgers A, Murray CJL, eds. *Comparative quantification of health risks: global and regional burden of disease attributable to selected major risk factors*. Geneva: World Health Organization, 2004:1435–93.
7 Leaderer BP. Air pollutant emissions from kerosene space heaters. *Science* 1982;218:1113–15.
8 Leaderer BP, Naeher L, Jankun T, *et al*. Indoor, outdoor, and regional summer and winter concentrations of PMJ F PM2.5′, S 42−, H+, NH4+, NO3−, NH3, and Nitrous acid in homes with and without kerosene space heaters. *Environ Health Pespect* 1999;107:223–31.
9 Habib G, Venkataraman C, Bond TC, *et al*. Chemical, microphysical and optical properties of primary particles from the combustion of biomass fuels. *Environ Sci Technol* 2008;42:8829–34.
10 MacCarty N, Still D, Ogle D. Fuel use and emissions performance of fifty cooking stoves in the laboratory and related benchmarks of performance. *Energy Sustainable Dev* 2010;14:161–71.
11 Khalequzzaman M, Kamijima M, Sakai K, *et al*. Indoor air pollution and its impact on children under five years old in Bangladesh. *Indoor Air* 2007;17:297–304.
12 Triche EW, Belanger K, Beckett W, *et al*. Infant respiratory symptoms associated with indoor heating sources. *Am J Respir Crit Care Med* 2002;166:1105–11.
13 Triche EW, Belanger K, Bracken MB, *et al*. Indoor heating sources and respiratory symptoms in nonsmoking women. *Epidemiology* 2005;16:377–84.
14 Piitulainen E, Tornling G, Eriksson S. Environmental correlates of impaired lung function in non-smokers with severe α1-antitrypsin deficiency (PiZZ). *Thorax* 1998;53:939–43.
15 Ghairaibeh NS. Effects of indoor air pollution on lung function of primary school children in Jordan. *Ann Trop Paediatr* 1996;16:97–102.
16 Epstein M, Bates M, Arora N, *et al*. Household fuels, low birth weight, and neonatal death in India: the separate impacts of biomass, kerosene, and coal. *Int J Hyg Environ Health* 2013;216:523–32.
17 Pokhrel AK, Bates MN, Verma SC, *et al*. Tuberculosis and indoor biomass and kerosene use in Nepal: a case-control study. *Environ Health Perspect* 2010;118:558–64.
18 Perez-Padilla R, Perez-Guzman C, Baez-Saldana R, *et al*. Cooking with biomass stoves and tuberculosis: a case-control study. *Int J Tuberc Lung Dis* 2001;5:441–7.
19 Peck MD, Kruger GE, van der Merwe AE, *et al*. Burns and fires from non-electric domestic appliances in low and middle income countries: part I. The scope of the problem. *Burns* 2008;34:303–11.
20 Dutt D, Srinlvasa D, Rotti S, *et al*. Effect of indoor air pollution on the respiratory system of women using different fuels for cooking in an urban slum of Pondicherry. *Natl Med J India* 1996;9:113–17.
21 Behera D, Jindal SK. Respiratory symptoms in Indian women using domestic cooking fuels. *Chest* 1991;100:385–88.
22 Venn AJ, Yemaneberhan H, Bekele Z, *et al*. Increased risk of allergy associated with the use of kerosene fuel in the home. *Am J Respir Crit Care Med* 2001;164:1660–4.
23 Sharma S, Sethi GR, Rohtagi A, *et al*. Indoor air quality and acute lower respiratory infections in Indian urban slums. *Environ Health Perspect* 1998;106:291–7.
24 Bates MN, Chandyo RK, Valentiner-Branth P, *et al*. Acute lower respiratory infection in childhood and household fuel use in Bhaktapur, Nepal. *Environ Health Perspect* 2013;121:637–42.
25 Mustapha BA, Blangiardo M, Briggs DJ, *et al*. Traffic air pollution and other risk factors for respiratory illness in schoolchildren in the Niger-Delta Region of Nigeria. *Environ Health Pespect* 2011;119:1478–82.
26 Bruce N, Neufeld L, Boy E, *et al*. Indoor biofuel air pollution and respiratory health: the role of confounding factors among women in highland Guatemala. *Int J Epidemiol* 1998;27:454–8.
27 Asher MI, Keil U, Anderson HR, *et al*. International study of asthma and allergies in childhood (ISAAC): rationale and methods. *Eur Resp J* 1995;8:483–91.
28 American Thoracic Society (ATS). Standards for the diagnosis and care of patients with chronic obstructive pulmonary disease (COPD) and asthma. *Am Rev Respir Dis* 1986;136:225–44.
29 Rehman IH, Malhotra P, Pal RC, *et al*. Availability of kerosene to rural households: a case study from India. *Energy Policy* 2005;33:2165–74.
30 Williams RL. A note on robust variance estimation for cluster-correlated data. *Biometrics* 2000;56:645–46.
31 Van Sickle D. Diagnosis and management of asthma in the medical marketplace of India: implications for efforts to improve global respiratory health. In: Hahn RA, Inhorn MC, eds. *Anthropology and public health: bridging differences in culture and society*. 2nd edn. New York: Oxford University Press, 2009:65–93.

32 Gangopadhyay S, Ramaswami B, Wadhwa W. Reducing subsidies on household fuels in India: how will it affect the poor? *Energy Policy* 2005;33:2326–36.
33 World Bank Energy Sector Management Assistance Programme (ESMAP). *India: access of the poor to clean household fuels*. Washington, DC: World Bank, 2003. http://go.worldbank.org/RO5BWUED10
34 Andresen PR, Ramachandran G, Pai P, *et al*. Women's personal and indoor exposures to PM2.5 in Mysore, India: impact of domestic fuel usage. *Atmospheric Environ* 2005;39:5500–8.
35 Lewis JJ, Pattanayak SK. Who adopts improved fuels and cookstoves? A systematic review. *Environ Health Perspect* 2012;120:637–45.
36 Evans GW, Kantrowitz E. Socioeconomic status and health: the potential role of environmental risk exposure. *Annu Rev Public Health* 2002;23:303–31.
37 Montgomery MR, Gragnolati M, Burke KA, *et al*. Measuring living standards with proxy variables. *Demography* 2000;37:155–74.
38 Victora CG, Kirkwood BR, Ashworth A, *et al*. Potential interventions for the prevention of childhood pneumonia in developing countries: improving nutrition. *Am J Clin Nutr* 1999;70:309–20.
39 Schwartz J, Weiss ST. Dietary factors and their relation to respiratory symptoms: the second national health and nutrition examination survey. *Am J Epidemiol* 1990;132:67–76.
40 Muthayya S, Thankachan P, Zimmermann M, *et al*. Low anemia prevalence in school-aged children in Bangalore, South India: possible effect of school health initiatives. *Eur J Clin Nutr* 2007;61:865–69.
41 Pohekar SD, Kumar D, Ramachandran M. Dissemination of cooking energy alternatives in India—a review. *Renew Sust Energ Rev* 2005;9:379–93.
42 Dionisio KL, Rooney MS, Arku RE, *et al*. Within neighborhood patterns and sources of particle pollution: mobile monitoring and GIS analysis in four Accra communities. *Environ Health Perspect* 2010;118:607–13.