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REGULAR ARTICLE

Indoor air pollution and health of children in biomass fuel-using households of Bangladesh: comparison between urban and rural areas

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Abstract

Objectives Indoor air pollutants from biomass combustion pose a risk for respiratory diseases in children. It is plausible that distinct differences in the indoor air quality (IAQ) exist between urban and rural areas in developing countries since the living environment between these two areas are quite different. We have investigated possible differences in IAQ in urban and rural Dhaka, Bangladesh and the association of such differences with the incidence of respiratory and some non-respiratory symptoms in children of families using biomass fuel.

Methods Indoor air concentrations of carbon monoxide (CO), carbon dioxide (CO_2), dust particles, volatile organic compounds (VOCs), and nitrogen dioxide were measured once in the winter and once in the summer of 2008. Health data on 51 urban and 51 rural children under 5 years of age from 51 families in each area were collected once a week starting in the winter and continuing to the summer of 2008.

Results Mean concentrations of CO, CO_2,, dust particles, and major VOCs were significantly higher in urban kitchens than in rural ones ($p < 0.05$). The incidence rate ratio (IRR) suggests that compared to the urban children, the children in the rural area suffered significantly more from respiratory symptoms [IRR 1.63, 95% confidence interval (CI) 1.62–1.64], skin itchiness (IRR 3.3, 95% CI 1.9–5.7), and diarrhea (IRR 1.8, 95% CI 1.4–2.4), while fewer experienced fever (IRR 0.5, 95% CI 0.4–0.6). No difference was observed for other symptoms.

Conclusions We found lower IAQ in the homes of urban biomass fuel-users compared to rural ones in Bangladesh but could not attribute the occurrence of respiratory symptoms among children to the measured IAQ. Other factors may be involved.

Keywords Indoor air pollution · Biomass · Children · Environmental · Bangladesh

Introduction

Burning biomass fuel emits high levels of particulate matter, carbon monoxide (CO), carbon dioxide (CO_2), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and volatile organic compounds (VOCs) [1–3]. These pollutants are risk factors of a number of diseases and poor health, such as acute respiratory tract infection (ARI), chronic obstructive pulmonary disease (COPD), low birth weight, cataract, and blindness, especially in developing countries [4, 5]. A total disease burden of 3.6% is associated with indoor air pollution worldwide [6]. One of the problems associated with biomass fuel combustion is that the exposure of women and their children to the above-mentioned pollutants is reported to be higher because they spend

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3–7 h per day indoors, near the stove [7]. These children, whose respiratory systems are not fully developed, are considered to be a "high risk" group [8–10]. A previous study carried out by our group in urban Dhaka, Bangladesh, showed a significant association between choice of biomass fuel and a number of prior respiratory symptoms in children less than 5 years of age [11]. In Bangladesh, almost 92% of the households use biomass as their main cooking fuel [12], and about one-quarter of the deaths among children under 5 years of age are associated with ARI [13], which is responsible for nearly 43% of post-neonatal (29 days–11 months) deaths [12]. Thus, indoor air pollution due to use of biomass fuel is an important public health issue.

In those developing countries where biomass fuel is used as a domestic source of energy, differences in the indoor air quality (IAQ) between urban and rural areas can be greater than those expected in developed countries since the gaps between urban and rural areas in the former countries are comparatively larger in terms of factors contributing to the IAQ, such as house structure, ventilation, lifestyle, and source of outdoor air pollutants. The density of the population is much higher and the spaces between the houses are smaller in urban areas than in rural areas. Thus, an understanding the factors affecting IAQ in both urban and rural areas in developing countries is one of the fundamental steps towards being able to assign priorities for countermeasures to prevent prevalent diseases in these countries.

The study reported here was designed to clarify the IAQ of biomass fuel-using households in both urban and rural areas of Bangladesh during the winter and summer. It is generally accepted that the levels of most of indoor air pollutants, especially VOCs, are highest in winter and lowest in summer [14–17]. The health conditions of the children were then followed between the seasons, i.e., for about 6 months. This study design made it possible not only to obtain an overview of IAQ in both urban and rural areas but also to reliably clarify differences in the health conditions of children between the areas. Based on these comparisons of the two areas, our aim was to determine if possible differences in IAQ contributed to the incidence of respiratory and non-respiratory symptoms in children of biomass-users in a developing country.

Methods

Study population

Bangladesh, which has a total surface area of 147,570 km^2 and a population of about 130 million, is located in the northeastern part of South Asia. The country experiences a hot and humid summer season from March to June, and a cool, dry winter from November to the end of February. At the present time, the urban population accounts for about 24% of the total population, with between 30 and 50% of this urban population living in informal settlements and slums.

The locations chosen for our study on IAQ among biomass fuel-users in Bangladesh were Bawniabad (urban) and Lohajong (rural). The study period began in the winter, with winter measurements collected between January 21 and 28, 2008, and extended into the summer, with summer measurements taken between June 10 and 23, 2008. The urban site of Bawniabad is situated in Mirpur Pallabi Thana, Dhaka. It was established in an 89-acre area as a special resettlement for the poor in Dhaka by the Government of Bangladesh in collaboration with international development. The plots are arranged in five blocks. Each block has 22 lanes. There are about 24 houses on each lane, and the total population is around 90,000. We randomly selected two blocks and then four lanes from each block as the urban study site.

Rural Lohajong thana of Munshigonj district is located about 50 km south of Bawniabad. Of the 12 unions of Lohajang, we studied villagers in Konokshar union, which has a population of about 20,000. There is a long street running north to south inside the village and households from both sides of the street were selected for inclusion in the study.

From each area, we recruited subjects for the study with the following inclusion criteria: (1) biomass fuel-using family having at least one child under 5 years of age; (2) no previous history of respiratory disease/symptoms or non-respiratory symptoms, such as redness of eye, eye itchiness, skin itchiness, diarrhea, dysentery, and fever within the past 1 month. Ultimately, 102 biomass fuel-using families, 51 in the urban area and 51 in the rural area, volunteered to participated in this study. To apply the same selection rule throughout the subject recruitment, we considered the oldest child when more than one child was eligible. Socio-demographic data of the respondents were collected from mothers of the children during the winter using questionnaires and observation checklists. Air pollution data were collected from 32 urban and 49 rural families; the remaining families refused to use environmental monitoring devices at home. To gather health-related information on the children, the interviewers visited the households every weekend for the entire study period. Symptom-related information on one child from each household was collected from mothers using the questionnaire. For respiratory symptoms, questions were asked if the children had a runny nose, cough, shortness of breath, or throat pain within the preceding 7 days. If any question was answered in the affirmative, the respondents were asked about the duration of the symptom. Non-respiratory symptom information was also gathered using the questionnaire. One episode was considered to be the continuous presence of the symptom, including a gap of 1 day; if the gap was $\geq$2 days, the symptom was considered to be a new episode. This study was conducted with all participants' informed consent and was approved by the ethical committee of Nagoya University Graduate School of Medicine.

Monitoring of indoor air quality

Temperature, humidity, CO, CO_2 levels, and dust particles were measured in the kitchen during the interviews with the respondents. CO and CO_2 concentrations were measured with detector tubes (type 106SC for CO and type 126SF for CO_2; Komyo Rikagaku Kogyo, Kawasaki, Japan) for 4 and 2 min, respectively. The concentrations of dust particles were measured with a digital dust monitor (model LD-3; Sibata Scientific Technology, Tokyo, Japan), and the mean of five 1-min measurements was used for the statistical analysis. For measuring CO, CO_2, and dust particles, we chose a point 1 m distant from the cooking stove at a height of 80–90 cm for measurement as this is the average breathing height of children less than 5 years old. Since the kitchen air quality was measured during the interview and the cooking time varied from household to household, during the interview some mothers were cooking while others were not; the time of the measurements also varied among kitchens. Formaldehyde (HCHO) and NO_2 were collected using a diffusion sampler packed with silica gel containing tri-ethanolamine (passive gas tube for HCHO and NO_2; Sibata Scientific Technology). A diffusion sampler packed with activated charcoal (passive gas tube for organic solvents; Sibata Scientific Technology) was used to collect 14 VOCs. The samplers were placed for approximately 24 h in the kitchen at a height of 80–90 cm. Since the households we studied were in clusters, the outdoor air pollutant concentrations of one household which we measured in one cluster were considered to be almost the same as the concentrations of the other households of that cluster. For outdoor air pollutant measurement, we placed the diffusion samplers on the outer wall of the houses for approximately 24 h at about 80–90 cm above the ground (approximately same height as in the kitchen).

Analytical methods

The samplers used in Bangladesh were transported to Japan by air and analyzed by the same researchers. HCHO and NO_2 were extracted with distilled water and analyzed using spectrophotometry by the 4-amino-3-hydrazino-5-mercapto-1,2,4-triazole method and sulfanilamide method, respectively [18]. VOCs were analyzed by the method reported by Sakai et al. [19]. Briefly, the adsorbent in the diffusive sampler was transferred into 7-ml vials, and 2 ml carbon disulfide (CS_2 for assessment of the working environment; Wako Pure Chemical Industries, Japan) was added. The vials were then shaken, left for 2 h, and then centrifuged for 10 min at 3000 rpm. A 1-ml sample of a supernatant together with 5 μl of an internal standard solution (200 μg/ml; toluene-d8, Sigma-Aldrich, St. Louis, MO) was then analyzed by gas chromatography/mass spectrometry (GC–MS). The GC–MS (5980 Series II/5971A; Hewlett Packard, Palo Alto, CA) apparatus was equipped with a 60 m × 0.25-mm (i.d.) capillary column coated with a 1.5-μm film of NB-1 (GL Sciences, Tokyo, Japan). The GC oven temperature was first maintained at 45°C for 5 min, then programmed to 300°C at 10°C/min, and lastly maintained at 300°C for 7 min. For some samples, the analysis was performed under a total-ion monitoring mode in order to examine all of the major peaks, following selected-ion monitoring mode targeting 14 VOCs.

Statistical methods

Continuous variables, appropriately transformed when necessary, were statistically compared by Student's *t* test between the urban and rural areas. The frequencies of findings were compared using chi-square test or Fisher's exact test. The significance of differences in urban and rural areas for measurements during cooking or non-cooking time was calculated using a two-way analysis of variance (ANOVA). The Mann–Whitney *U* test was performed to calculate the significance of monthly income. A two-tailed p value <0.05 was considered to indicate a statistically significant difference. The mean concentrations of 14 VOCs, HCHO, and NO_2, which were approximately log-normally distributed, were calculated as geometric means. When the concentrations were below the detection limit, they were set at half of the detection limit for calculating the geometric mean. Multivariate regression analysis was conducted to estimate the crude and adjusted relative risks (RRs) and their 95% confidence intervals (95% CIs) for children's symptoms with/without adjustment for potential confounders, including education, cooking hours, main wall material of house, number of family members per room, and location of kitchen. The incidence rate was calculated using the following formula:

$$\begin{aligned}\text{Incidence rate} = {} & (\text{total number of new episodes of} \\ & \text{symptoms occurring during the specified} \\ & \text{period/ total person} - \text{time in days}) \times 1000.\end{aligned}$$

Calculations were performed with the Statistical Package for the Social Sciences (SPSS) for Windows, ver. 16.0 software (SPSS, Chicago, IL).

Results

Socio-demographic data on the respondents is tabulated in Table 1. Educational background was significantly higher in the rural households than in the urban ones ($p < 0.01$). There was a significant difference in the number of rooms in the dwellings ($p < 0.01$), with most (74%) of the rural households having only one room, whereas 63% of the urban households had two or more rooms. Thus, the number of family members per room was significantly higher in rural than urban areas ($p < 0.01$). We found a significant difference in the fuel material used for cooking ($p < 0.01$), with wood used by 100 and 74% of the urban and rural households, respectively, as the main material for cooking. There was a significant difference in the mean number of cooking hours between urban (2.4 h/day) and rural areas (3.6 h/day) ($p < 0.01$). A significant difference was also found in the fuel cost between urban (US$ 5.2/month) and rural areas (US$ 7.1/month) ($p < 0.05$).

Since the kitchens were not necessarily located in the main houses, the house and kitchen characteristics of the respondents are shown in Table 2. There was a significant difference in the type of bearing wall materials and floor materials between urban and rural houses ($p < 0.01$). The bearing wall material in urban the houses was brick and tin, while that in the rural area was primarily tin. While 61% of house floors in urban areas were made of concrete, 81% of house floors in rural areas were made of wood or bamboo. There were significant differences in the types of material used for the main roof, wall, and floor between urban and rural kitchens ($p < 0.01$). Although most (63%) urban kitchens had no roof, only 12% of rural kitchens had no roof. In those kitchens without a roof, the dwellers were able to cook there during the entire dry winter season, while during the rainy summer, they moved their cooking stove into the bedroom for the few days of rain. Tin was the main wall material for 63% of urban kitchens, while 69% of kitchens in rural areas were made of mud/bamboo/straw/jute sticks.

Temperature, humidity, CO, CO_2, and dust particles are shown in Table 3. In winter, all of the measurements taken during non-cooking time were significantly higher in urban than rural kitchens ($p < 0.05$). For CO_2 and dust particles, the levels during cooking time were also significantly higher in urban than in rural area ($p < 0.05$). In the rural area, the level of dust particles measured during cooking time was significantly higher than that measured during non-cooking time ($p < 0.05$). In the summer, the CO and CO_2 levels in the urban area during both cooking and non-cooking times were significantly higher than those in the rural area ($p < 0.05$). The levels of CO during cooking time in the urban and rural areas and of dust particles during cooking time in the rural area were significantly higher than those during non-cooking time ($p < 0.05$).

The airborne concentrations of VOCs and NO_2 are given in Table 4. During the winter, the geometric mean

Table 1 Socio-demographic conditions of the respondents

Factor	Urban ($n = 51$)	Rural ($n = 51$)	p value
Age (years, mean ± SD)	26.9 ± 5.9	27.9 ± 6.2	0.23
Education, n (%)			<0.01
No education	41 (80)	24 (47)	
Primary	8 (16)	11 (22)	
Secondary	2 (4)	16 (31)	
Monthly income in US$, median (min/max)	58.4 (29.2/145.9)	58.4 (21.9/291.9)	<0.05
Number of rooms, n (%)			<0.01
One room	19 (37)	38 (74)	
Two or more rooms	32 (63)	13 (26)	
Number of family members per room (mean ± SD)	3.6 ± 1.7	4.7 ± 1.9	<0.01
Cooking hours (h/day, mean ± SD)	2.4 ± 1.1	3.6 ± 0.8	<0.01
Fuel material used for cooking, n (%)			<0.01
Wood	51 (100)	38 (74)	
Dung cake	0 (0)	11 (22)	
Others	0 (0)	2 (4)	
Fuel costs in US$/month (mean ± SD)	5.2 ± 2.5	7.1 ± 4.6	<0.05
Sleeping in cooking room, n (%)			0.08
Yes	3 (6)	0 (0)	
No	48 (94)	51 (100)	

SD Standard deviation, *Max* maximum, *min* minimum

Table 2 Characteristics of houses and kitchens

Factor	Urban ($n = 51$)	Rural ($n = 51$)	p value
House			
Main roof material, n (%)			0.32
Concrete	0 (0)	1 (2)	
Corrugated tin	51 (100)	50 (98)	
Main wall material, n (%)			<0.01
Brick	24 (47)	1 (2)	
Tin	21 (41)	35 (69)	
Wood/bamboo	6 (12)	15 (29)	
Floor material, n (%)			<0.01
Concrete	31 (61)	1 (2)	
Mud	20 (39)	9 (17)	
Wood/bamboo	0 (0)	41 (81)	
Kitchen			<0.01
Main roof material, n (%)			
Concrete	0 (0)	1 (2)	
Tin	19 (37)	14 (27)	
Bamboo/thatch	0 (0)	20 (39)	
Polythene	0 (0)	10 (20)	
No roof	32 (63)	6 (12)	
Main wall material, n (%)			<0.01
Brick	15 (29)	0 (0)	
Tin	32 (63)	3 (6)	
Wood	0 (0)	1 (2)	
Mud/bamboo/straw Jute stick	2 (4)	35 (69)	
Polythene	1 (2)	5 (10)	
No wall	1 (2)	7 (13)	
Floor material, n (%)			<0.01
Concrete	16 (31)	0 (0)	
Mud	33 (65)	48 (94)	
Wood/bamboo	2 (4)	3 (6)	

concentrations of hexane, benzene, toluene, xylene, tetrachloroethylene, and methyl ethyl ketone in the kitchens were significantly higher in the urban area than in the rural area ($p < 0.05$). The outdoor concentrations of hexane, benzene, toluene, xylene, tetrachloroethylene, methyl ethyl ketone, formaldehyde, and NO_2 were also significantly higher in the urban area than in the rural area ($p < 0.05$). During the summer, the geometric mean concentrations of toluene, xylene, and tetrachloroethylene in the kitchens were significantly higher in the urban area than in the rural area ($p < 0.05$), whereas hexane and butyl alcohol levels were significantly higher in the rural area than in the urban area ($p < 0.05$). Also during the summer, the outdoor concentrations of benzene, toluene, xylene, formaldehyde, and NO_2 were significantly higher in the urban area than in the rural area ($p < 0.05$). A comparison of the seasons revealed that, in urban kitchens, there were significantly higher concentrations of hexane, benzene, xylene, tetrachloroethylene, and NO_2 in the winter than in summer ($p < 0.05$); in rural kitchens, the concentrations of hexane, benzene, and butyl alcohol were significantly lower in the winter than the summer ($p < 0.05$). The urban outdoor concentrations of benzene, toluene, xylene, tetrachloroethylene, methyl ethyl ketone, formaldehyde, and NO_2 were significantly higher in the winter than summer ($p < 0.05$). In the rural outdoor environment, toluene and NO_2 levels were significantly higher, and hexane was significantly lower, in the winter than in the summer ($p < 0.05$). No other VOCs had higher peaks, other than the 14 VOCs targeted in samples analyzed under a total-ion monitoring mode.

Table 5 shows the cumulative incidence of symptoms and signs of infection in children under 5 years old. The crude RRs of cumulative incidence show that children living in the rural area had a significantly higher cumulative incidence of respiratory symptoms, skin itchiness, and diarrhea compared with those in the urban area. Following adjustment with potential confounders, there was no significant difference between the groups in terms of symptoms.

Table 6 presents data on the pattern of the observed symptoms. The incidence rate ratios (IRRs) of the symptoms indicate that the children in the rural area suffered significantly more than those in the urban area from respiratory symptoms (IRR 1.63, 95% CI 1.62–1.64), skin itchiness (IRR 3.3, 95% CI 1.9–5.7), and diarrhea (IRR 1.8, 95% CI 1.4–2.4). In contrast, urban children significantly suffered more from fever (IRR = 0.5, 95% CI 0.4–0.6).

Discussion

In this study, most of the pollutant levels were higher in the urban area than in the rural area in both winter and summer. We found significant differences in the building material between urban and rural areas. Whereas the main wall material for 92% of urban kitchens was brick or tin, 69% of rural kitchen walls were made of mud, bamboo, straw, or jute sticks. Very often, parts of the walls of rural kitchens were broken down, promoting natural ventilation. Moreover, houses in the urban area were very close to each other, while those in the rural area where more widely spaced apart, thereby allowing more wind flow and, consequently a more rapid diffusion of pollutants. A previous investigation revealed that the pollutant concentration is strongly affected by structural factors, such as cooking

Table 3 Indoor air quality in kitchens

Indicators	Urban ($n = 32$)		Rural ($n = 49$)	
	During cooking ($n = 13$)	During non-cooking ($n = 19$)	During cooking ($n = 15$)	During non-cooking ($n = 34$)
Winter				
Temperature (°C)	27.7 ± 2.6	27.8 ± 2.9$^{\#}$	27.2 ± 3.7	25.8 ± 1.9
Humidity (%)	49.3 ± 8.2	48.9 ± 7.2$^{\#}$	54.1 ± 8.9	55.1 ± 7.5
CO (ppm)	7.6 ± 11.2	3.2 ± 4.3$^{\#}$	2.8 ± 3.7	0.4 ± 0.6
CO_2 (ppm)	662 ± 215$^{\#}$	687 ± 253$^{\#}$	497 ± 13	500.0 ± 0.0
Dust particles (mg/m^3)	1.051 ± 1.106$^{\#}$	0.477 ± 0.311$^{\#}$	0.250 ± 0.049*	0.151 ± 0.071
Summer				
Temperature (°C)	31.0 ± 1.6	31.9 ± 1.6	31.7 ± 1.3	31.0 ± 2.0
Humidity (%)	81.2 ± 7.2	75.8 ± 7.7	78.3 ± 5.3	78.0 ± 10.3
CO (ppm)	19.6 ± 15.1$^{\#,*}$	5.4 ± 8.9$^{\#}$	1.3 ± 1.1*	0.1 ± 0.3
CO_2 (ppm)	858 ± 278$^{\#}$	878 ± 310$^{\#}$	600 ± 197	539 ± 154
Dust particles (mg/m^3)	0.633 ± 0.727	0.238 ± 0.260$^{\#}$	0.196 ± 0.137*	0.087 ± 0.091

$^{\#}$ $p < 0.05$ compared with rural area; *$p < 0.05$, compared with non-cooking time

Data are given as the mean ± SD

Table 4 Airborne concentrations (µg/m^3) of volatile organic compounds and nitrogen dioxide (NO_2) in kitchens and the outdoors

Class	Compounds	DL	Concentration (µg/m^3)[a]							
			Winter				Summer			
			Kitchen		Outdoor		Kitchen		Outdoor	
			Urban[b] ($n = 32$)	Rural[b] ($n = 49$)	Urban ($n = 6$)	Rural ($n = 10$)	Urban ($n = 32$)	Rural ($n = 49$)	Urban ($n = 6$)	Rural ($n = 8$)
Alkanes	Hexane	3.2	9.3 (2.3)$^{\#,*}$	<DL*	22.4 (1.8)$^{\#}$	<DL*	5.3 (2.2)$^{\#}$	12.4 (2.3)	6.7 (3.0)	16.1 (1.7)
Aromatics	Benzene	7.6	54.8 (2.4)$^{\#,*}$	13.3 (2.8)*	85.7 (1.5)$^{\#,*}$	8.4 (2.9)	33.2 (2.9)	23.9 (4.2)	20.8 (2.7)$^{\#}$	4.2 (1.3)
	Toluene	1.6	50.7 (3.3)$^{\#}$	6.6 (2.0)	105.3 (1.4)$^{\#,*}$	5.2 (2.4)*	32.1 (2.9)$^{\#}$	7.8 (3.9)	15.7 (2.5)$^{\#}$	1.1 (1.6)
	Xylene	3.3	23.2 (2.2)$^{\#,*}$	2.9 (2.2)	35.9 (1.2)$^{\#,*}$	2.8 (3.0)	10.9 (3.2)$^{\#}$	3.3 (2.4)	5.1 (2.0)$^{\#}$	< DL
Chlorinated	Trichloroethylene	5.3	<DL	<DL	<DL	<DL	3.4 (2.1)	<DL	<DL	<DL
Hydrocarbons	Tetrachloroethylene	1.4	3.8 (1.9)$^{\#,*}$	<DL	6.5 (1.4)$^{\#,*}$	<DL	1.1 (3.0)$^{\#}$	<DL	0.8 (1.5)	<DL
	Chloroform	4.7	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
	1,1,1-Trichloroethane	5.7	3.0 (1.3)	<DL	<DL	<DL	<DL	<DL	<DL	<DL
	1,2-Dichloroethane	2.3	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
	Carbon tetrachloride	2.7	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
	p-Dichlorobenzene	2.2	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
Esters	Butyl acetate	2.9	<DL	<DL	<DL	<DL	1.7 (2.0)	1.6 (1.2)	<DL	<DL
Alcohols	Butyl alcohol	9.3	<DL	<DL*	<DL	<DL	<DL$^{\#}$	5.1 (1.3)	<DL	<DL
Ketones	Methyl ethyl ketone	8.1	7.7 (2.0)$^{\#}$	4.3 (1.4)	10.7 (2.3)$^{\#,*}$	4.8 (1.7)	5.9 (1.9)	4.7 (1.5)	<DL	<DL
Aldehydes	Formaldehyde		28.2 (2.2)	13.9 (4.4)	61.1 (1.7)$^{\#,*}$	4.1 (1.2)	19.4 (2.3)	7.1 (10.8)	10.9 (2.6)$^{\#}$	0.3 (5.6)
NO_2			80.2 (2.0)*	60.7 (2.5)	132.4 (1.3)$^{\#,*}$	28.5 (1.3)*	46.3 (1.8)	55.2 (3.6)	49.0 (1.7)$^{\#}$	6.6 (1.8)

$^{\#}$ $p < 0.05$ compared with level in rural area; *$p < 0.05$ compared with level in the summer

DL Detection limit

[a] Values are given as the geometric mean, with the geometric SD given in parenthesis. Concentrations below the detection limit were set at half of the detection limit for calculating geometric means

[b] Data of some urban and rural kitchens were not available because the dwellers refused to use diffusion samplers

Table 5 Relative risk of symptoms in urban and rural children

Symptoms	Urban[a], *n* (%)	Rural[a], *n* (%)	Crude RR			Adjusted RR[b]		
			RR	95% CI	*p* Value	RR	95% CI	*p* Value
Respiratory symptoms	40 (78)	49 (96)	6.7	1.4–32.2	<0.05	0.5	0.1–3.8	0.50
Non-respiratory symptoms								
Redness of eye	4 (8)	6 (12)	1.6	0.4–5.9	0.52	1.4	0.03–77.4	0.87
Eye itchiness	3 (6)	3 (6)	1.0	0.2–5.2	1.00	NC	NC	NC
Skin itchiness	14 (28)	32 (63)	4.4	1.9–10.3	<0.01	3.6	0.7–19.6	0.13
Diarrhea	25 (49)	38 (75)	3.0	1.3–7.0	<0.01	0.9	0.1–5.6	0.92
Dysentery	6 (12)	9 (18)	1.6	0.5–4.9	0.40	0.1	0.0–51.0	0.52
Fever	38 (75)	29 (57)	0.5	0.2–1.0	0.06	0.2	0.03–1.1	0.06

RR Relative risk, 95% *CI* 95% confidence interval, *NC* not calculated due to small number of children with symptoms

[a] The number of children observed in the urban and rural areas was 51 each

[b] Adjusted for education, cooking hour, main wall material of house, number of family members per room, and location of kitchen

Table 6 Pattern of symptoms observed among children under 5 years of age

Symptoms	Urban ($n = 51$)		Rural ($n = 51$)		IRR	95% CI
	IR	Duration/episode[a]	IR	Duration/episode[a]		
Respiratory symptoms	17.5	4.7	28.6	3.8	1.63	1.62–1.64
Non-respiratory symptoms						
Redness of eye	1.0	1.5	0.9	3.4	0.9	0.3–3.0
Eye itchiness	0.6	5.2	0.4	5.7	0.6	0.1–3.2
Skin itchiness	2.2	10.3	7.2	5.1	3.3	1.9–5.7
Diarrhea	5.7	3.3	10.4	3.3	1.8	1.4–2.4
Dysentery	0.7	2.7	1.9	4.2	2.6	0.96–8.1
Fever	11.4	4.8	5.6	4.7	0.5	0.4–0.6

IR Incidence rate. IR is expressed as the number of new episodes per 1000 person-days. The incidence rate ratio (IRR) is calculated as the IR in rural area divided by the IR in the urban area

[a] Duration/episode is calculated in days

locations, building materials, and ventilation practices [20]. In the present study, the outdoor concentrations of a majority of pollutants were significantly higher in the urban area than in the rural area—in both winter and summer. Hence, the outdoor concentration of pollutants might influence the indoor air pollutant concentrations, which was also suggested in our previous study [17]. Fuel material difference among the biomass users may be another possible reason for difference in the level of pollutants between the areas.

In light of the United Nations Development Programme (UNDP)/World Energy Council/United Nations Department of Economic and Social Affairs world energy statement [21], we found that the mean concentration of CO was higher than the stated standard allowable limit of 8.7 ppm. Except in rural kitchens at a non-cooking time, the mean concentrations of dust particles in both urban and rural areas were higher than the standard allowable limit of 0.1 mg/m^3. The geometric mean concentrations of formaldehyde were below the standard allowable limit of 100 μg/m^3, while those of benzene were much higher than the standard allowable limit of 2 μg/m^3 in all kitchens and outdoors in both areas. The high benzene concentration may increase the risk of leukemia in Bangladesh and underscores the need for future research in this area.

The relationship between indoor air pollution and respiratory symptoms has been shown by many researchers. Mishra [22] found a significant association with the cooking smoke from biomass combustion and the prevalence of asthma (OR = 2.2, 95% CI 1.2–4.2) and other respiratory diseases in young children. WHO/UNDP stated that indoor air pollution doubles the risk of pneumonia in children under 5 years old [21]. A study conducted on children aged 4–6 years in Guatemala showed the higher prevalence of asthmatic symptoms in biomass fuel using households with odds ratios of more than 2.0 [23]. Etiler et al. [24], in their prospective cohort study in Turkey, found a significant association between symptoms of ARI in infants and the use of biomass fuel (RR = 1.8, 95% CI 1.3–2.5). Awasthi et al. [25] found a significant positive association of respiratory symptoms with the choice of biomass fuel (OR = 2.7, 95% CI 1.4–5.3). Some other studies also demonstrated a positive relationship between air pollution from biomass combustion and child health [26–28]. In our study, we found that the levels of most of the indoor air pollutants were higher in urban area but that the occurrences of respiratory symptoms were higher in rural area. Wafula et al. [29] found no relationship between indoor air pollution and episodes of ARI. Our study generally corresponds with their finding, though incidence of fever was higher in the urban area, which warrants further studies.

One of the possible reasons for the higher IRRs of symptoms in the rural area found in our study may be the difference in building materials. The dominance of wood and bamboo as building materials in rural areas may increase the possibility of fungal and mold growth facilitated by the high humidity. Dales and Miller [30] found a significant association between mold exposure and school children's health with odds ratios ranging from 1.5 to 2.3. Thus, the excess of symptoms might be related to fungus and molds propagated on the building materials. The use and handling of dung cakes as cooking fuel could also be a possibility related to the higher incidence of alimentary symptoms, such as diarrhea, in rural area. Daily living factors may be another major contributory factor to the poorer health situation in the rural area as unlike the urban area, they are generally deprived of municipal facilities, such as water, gas, electricity supply, and sewage disposal. These points need to be explored in future studies.

In our study, although the median monthly income appeared to be similar between urban and rural residents, in general, urban dwellers spend a relatively larger proportion of their income on their house rent, which results in the economic condition of the rural resident being relatively better. The dietary intake and nutritional status of the children in our study were generally related to educational background and income. However, in contrast to the better educational background and income, the health condition of the children was poorer in the rural area. In our separate cross-sectional study we found no difference in the prevalence of symptoms among children under 5 years old in a rural area far from the capital city of Dhaka where the pollutant levels were lower (unpublished data). Thus, other factors, such as hand-washing, should be considered in the future studies along with the use of biomass fuel.

It should be noted that there are some limitations to our study. First, the sample size was relatively small. Second, we could not control the number of kitchens in terms of cooking and non-cooking time because the cooking time varied between houses. Third, the measured concentrations of CO, CO_2, and dust particles may have been different had we visited at a different time point because the measurements were made within a very short period of time. Fourth, information related to ventilation and personal exposure time to indoor air pollutants was not gathered. Fifth, dietary intake and nutritional status information on the children was not gathered. Despite these limitations, our study gives an overview of the difference in IAQ and incidence of respiratory and non-respiratory symptoms among residents of urban and rural areas of Bangladesh.

Conclusions

We found the IAQ to be lower among urban biomass fuel-users than among rural biomass fuel-users in Bangladesh but could not attribute the occurrence of respiratory symptoms among children to the measured IAQ. Further research is warranted to clarify other possible factors affecting the health of children in Bangladesh.

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