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Household air pollution from cooking fuels and its association with under-five mortality in Bangladesh

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ABSTRACT

Background: Solid fuel use was found to be associated with under-five mortality in low- and lower-middle income countries (LMICs) though current understanding is lacking for Bangladesh. This study investigated the associations between HAP and neonatal, infant and under-five child mortality in Bangladesh.

Methods: We analysed 4189 mother-child dyads data extracted from the 2017/18 Bangladesh Demographic and Health Survey data. Fuel types and levels of exposure to HAP (unexposed, moderately exposed, highly exposed) were considered as exposure variables and several forms of child mortality was considered as outcome variables. Relationships between the exposure and outcome variables were explored by using the multilevel mixed-effect logistic regression model adjusting for possible confounders.

Results: Solid fuels were found to be used in nearly 80% of the total mothers analysed. A higher likelihood of mortality was found among neonates (aOR, 3.78; 95% CI, 1.14–12.51) and infants (aOR, 2.93; 95% CI, 1.60–6.15) of the women who used solid fuels as compared to the mothers who used clean fuel. The association was found strongest when we considered solid fuel used together with place of cooking. The likelihood of neonatal and infant mortality was found 4.33 (95% CI, 1.16–16.23) and 2.05 (95% CI, 1.18–7.23) times higher among mothers who were highly exposed to solid fuel used as compared to the mothers who were unexposed to solid fuel used.

Conclusion: Solid fuels used is an important cause of neonatal and under-five mortality in Bangladesh. Administrative initiatives to increase clean fuel use are need to be prioritized in the national level policies and programs. Awareness building programs covering adverse effects of solid fuels used on human health, particularly child health, should also be taken to motivate mothers not to bring their under-five aged children in the cooking place.

1. Introduction

Household air pollution (HAP) is a significant public health concern in low- and lower-middle-income countries (LMICs).[1,2] It causes in several routes, however, the use of solid cooking fuels, e.g., peat, wood and coal, is the most common route. About 2.6 billion people worldwide use solid fuels for cooking, and a majority of them live in LMICs.[3] Consequently, of the 3.8 million premature deaths that occur worldwide every year because of HAP, almost all of them occur in LMICs.[3] HAP from solid fuel use was also found to be associated with several serve childhood morbidity, including childhood pneumonia, intrauterine growth restriction, preterm birth, and low birth weight.[3–12] There are also evidence that HAP is linked with the rising rate of pregnancy complications, which further increase maternal hospitalization and caesarean section delivery.[4–12]

Bangladesh has been achieved significant progress in reducing under-five mortality during the Millennium Development Goals periods between 2000 and 2015.[13] However, the rate is still very high at 45 and 30 per 1000 live births for under-five mortality and neonatal mortality, respectively.[13,14] This presents a challenge in achieving the Sustainable

Abbreviations: HAP, Household air pollution; LMICs, Low- and lower-middle-income countries; DHS, Demographic and Health Survey; NIPROT, National Institute of Population Research and Training; PSU, Primary Sampling Unit; OR, Odds Ratio; SDGs, Sustainable Development Goals.

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Development Goal 3 (SDGs 3, health and wellbeing for all), in particular, its targets to reduce under-five (25 per 1000 live births) and neonatal (12 per 1000 live births) mortality rates by 2030.[13,14] It indicates the need to scaling up the current policies and programs to reduce under-five mortality by covering every possible area that causes under-five mortality.

In Bangladesh, as with other LMICs, solid fuels are the primary element of cooking or heating with around 80% prevalence. The rate is even higher for rural area (92%).[15] Traditionally, women in LMICs, including women in Bangladesh, are mainly involved in cooking activities and often they are accompanied by their young children at the time of cooking.[16] This makes young children highly vulnerable to HAP which could be one important cause of the current higher rate of under-five mortality in Bangladesh. This was found true in previous studies of Bangladesh conducted based on the data collected a decade ago from now along with other adverse consequences including low birth weight and pre-term birth.[8,17–21] Moreover, available studies were also limited in several areas, including small geographic areas, small scale institutional-level data, and small sample sizes.[8,17–20,22,23]

Following this study period, a number of national-level policies and programs to increase awareness about the adverse effect of solid fuel use as well as to reduce the use of solid fuel have been taken in Bangladesh. As such, along with the country's rapid socio-economic development, significant progress has been made in household cooking fuel using patterns, including rising dependency on electric and gas stoves.[24] Moreover, awareness of the adverse effects of solid fuel use also motivates people in changing their solid fuel using place, from inside to outside of the living room or corner of the yard. This could alternate or reduce the strength of the reported association between HAP and under-five mortality in Bangladesh. However, there is no recent evidence covering this issue. Moreover, evidence showing the association between the level of HAP exposure and under-five mortality has not been investigated in Bangladesh so far. However, this was even found as the strongest determinant of under-five mortality in other LMICs, including Myanmar and Afghanistan.[25,26] Therefore, this association needs to be explored as a significant portion of the Bangladeshi population who uses solid fuel in indoor places, such as in the living room or close to the living room, which further increases their HAP exposure level.[8,21]

We conducted this study to fill these gaps. We explored the associations of solid fuel use and level of HAP from solid fuel used with under-five, infant and neonatal mortality in Bangladesh by using the most recent nationally representative survey data. The findings will help the policymakers to know the current situation of the associations of solid fuel use and level of HAP from solid fuel used with under-five, infant and neonatal mortality in Bangladesh. This will also be a learning point for other LMICs as like Bangladesh about whether the focus on HAP from solid fuel use could bring significant progress in reducing the country's under-five mortality rate.

2. Methods

2.1. Study design and sample

Data for this study were extracted from the most recent Bangladesh Demographic and Health Survey (BDHS) conducted in 2017/18. The survey is conducted every three years as part of the Demographic and Health Survey (DHS) program of the USA. The National Institute of Population Research and Training (NIPORT), a government organization that works under the Ministry of Health and Family Welfare of Bangladesh, conducted this survey. International development partners including UNFPA, and USAID provide other supports including financial and technical supports. The survey selected a list of nationally representative sample of households from where the eligible women (reproductive-aged married women who are a usual resident of the selected household or passed their most recent night at the selected household) were included. The households were selected by using two-stage stratified random sampling methods. At the first stage of sampling, 675 Primary Sampling Units (PSUs) were selected covering every administrative divisions of Bangladesh and rural and urban areas. The PSU was selected from a list of 293,579 PSUs of Bangladesh which were generated by the Bangladesh Bureau of Statistics as part of the 2011 Bangladesh National Population Census. A total of 672 PSUs were retained finally after excluding 3 PSUs because of extreme flooding. A fixed number of 30 households were selected at the second stage from each selected PSU. Finally, the survey was conducted in 19,457 households with an over 96% inclusion rate. There were 20,376 women in these selected households, of them, 20,127 women were interviewed with a response rate of 98.8%. Informed written consent were obtained all participants. A detailed description of the sampling procedure is available elsewhere.[26]

2.2. Study sample

We analysed 4189 mother-child dyads data. The sample was extracted from the original sample based on the following inclusion criteria: (i) mothers had at least one birth within five years of the survey date, (ii) reported survival status of their children, and (iii) reported type of cooking fuels they used and the place where they cooked.

2.3. Outcome variables

We considered three outcomes' variables: neonatal mortality (death occurred within 1 month of live birth; Yes(1) *vs* No (0)), infant mortality (deaths occurred within 12 months of live birth; Yes(1) *vs* No (0)) and under-five mortality (death occurred within 60 months of live births; Yes(1) *vs* No (0)). The BDHS recorded these mortality data by asking women whether she had any live birth within five years of the survey date and survival status of the respective child. In the occurrence of more than one live birth within five years, survival status data were collected for every children. These data were then recategorized by following relevant guidelines of the WHO to generate outcomes variables.

2.4. Exposure variables

Two exposure variables were considered: (i) type of cooking fuels used (solid fuel, clean fuel) and (ii) level of exposure to HAP through solid fuels used (unexposed, moderately exposed, highly exposed). The BDHS recorded the type of fuels that used in the respondents' households for cooking through asking "*What type of fuel does your households mainly used for cooking?*". A list of fuel was provided to give the response. In case, the fuel used by the respondents was not in the list, they were allowed to write the name of the fuel. We reclassified these responses as solid fuel used (if the respondents recorded coal, lignite, charcoal, wood, straw, shrubs, grass, agricultural crop and animal dung) and clean fuel used (electricity, liquid petroleum gas, natural gas and biogas) to generate the first exposure variable. Respondents were also asked about place of cooking in their households through asking "*Is the cooking usually done in the house, in a separate building, or outdoors?*". Responses recorded for this question were considered along with the type of cooking fuel respondents used to generate the second exposure variable. The respondents were considered as *unexposed,* if respondents recorded clean fuels use in their households for cooking purpose; *moderately exposed*, if respondents recorded solid fuels use in their households for cooking purpose, and, the cooking conducts in a separate building or outdoor; and *highly exposed*, if respondents recorded solid fuels use in their households for cooking purpose, and, the cooking conducts inside their houses. We generate this variable by following previous studies conducted in LMICs.[8,17–19,21,26,28,29]

2.5. Confounding adjustment

Individual-, household-, and community level factors were considered as confounding factors. We selected confounding factors in three stages. We first generate a list of confounding variables by reviewing the relevant studies conducted in LMICs, particularly Bangladesh.[8,17–20,22,23,30] The availability of these selected confounding variables in the dataset we analysed were then checked and the available variables were initially selected to be consider in this study. At the third stage of selection, we determined the associations of initially selected variables with the outcomes variables considered. The variables those were found significant at this stage ($p < 0.20$) were then entered into a multivariate model where further exclusion was done based on p-value of the reported adjusted associations ($p > 0.20$) and multicollinearity (VIF>10). The variables whose are found significantly associated with the outcomes variables at $p < 0.20$ with acceptable range of multicollinearity were finally selected to be considered as confounding variables in the multilevel model used to determine associations of outcomes variables with exposure variables. The individual level variables were mothers' ages at birth (≤24 years, 24–35 years, and >35 years), mothers' education (illiterate, primary, secondary, higher), and birth interval (<24 months, ≥24 months). Child's gender (male, female) was the child level variable. The household level factors were exposure to mass media (not exposed, moderately exposed, highly exposed) and household wealth quintile (poor, middle, richer). Urbanicity (urban, rural) and place of region (Barishal, Chattogram, Dhaka, Khulna, Mymensingh, Rajshahi, Rangpur, Sylhet) were included as community level factors.

2.6. Statistical analysis

Descriptive statistics was used to describe the characteristics of the respondents. Separate multilevel mixed-effect logistic regression model was used to assess the associations of type of cooking fuels used and exposure level of HAP through solid fuels used with neonatal, infant and under-five mortality adjusted for individual, household and community level factors. The reason for using this model was nesting structure of the BDHS data where the previous studies found multilevel modelling produce comparatively better finding.[31] Survey weight was also considered. Results were recorded as Odd Ratio (OR) with its 95% Confidence Interval (95% CI). We performed all descriptive statistics using the Stata software version 15.1 (Stata corporation, college station, Texas, USA).

3. Results

Table 1 presents background characteristics of the mothers and under-five children. The mean (±SD) age of the mothers was 26.80 (±5.08) years and mean year of education was 5.79 (±3.68) years. The mean age of the children we analysed was 2.05 ((±1.44) years. Nearly 47% of the total children analysed were girls.

The distribution of the type of cooking fuel used in the household and the place of household's cooking are presented in Table 2. We found wood as major type of cooking fuel in Bangladesh with around 45% of the total use following agricultural crop (27%) and liquid petroleum gas/natural gas (19.11%). Nearly 3% of the total respondents analysed reported indoor cooking place. When we considered fuel using pattern together, we found solid fuels used were around 80% of the total respondents' households. Around 79% of the total respondents' households were found to be moderately exposed to HAP through using solid fuel used and 1.21% of the total respondents' households were found highly exposed to HAP through solid fuel used.

Table 1
Background characteristics of the respondents (N = 4189).

Demographics of mothers	Statistics
Mean age in years at birth (mean ± SD)	26.80 (±5.08)
Mean weight in kilograms (mean ± SD)	52.02(±10.25)
Mean years of education (mean ± SD)	5.79(±3.68)
Demographics of under-five children	
Mean age in years (mean ± SD)	2.05 ((±1.44)
Girls	47.41 (45.12–48.98)

Table 2
Distribution of exposures and outcomes variables, BDHS, 2017/18 (N = 4189).

Types of cooking fuels	percentage
Electricity	0.37
Liquid petroleum gas + natural gas	19.11
Charcoal	0.11
Wood	44.79
Agricultural crop	27.12
Coal, lignite + straw/shrubs/grass + others	8.44
Cooking place	
Indoor	2.77
Outdoors	97.23
Categorization of exposure variables	
Type of cooking fuels used	
Solid fuel use	80.48
Clean fuel use	19.52
Level of exposure to HAP through cooking fuels used	
Unexposed	19.52
Moderately exposed	79.27
Highly exposed	1.21
Outcome variables	
Neonatal mortality per 1000 live births	25.1
Infant mortality per 1000 live births	34.5
Under-five mortality per 1000 live births	37.8

The distribution of the neonatal mortality, infant mortality and under-five mortality in Bangladesh are also presented in Table 2. We reported 38 under-five deaths per 1000 live births following infant mortality of 34 per 1000 live births and neonatal mortality of 25 per 1000 live births.

We also explored distribution of neonatal, infant and under-five mortality per 1000 across confounding variables considered in the analysis. Relevant results are presented in Table 3. A higher rates of neonatal, infant and under-five mortality were found among the children of the mothers who were aged 25–35 years, primary or secondary educated, moderately exposed to mass media and poor. Each form of mortality was also found higher among male children. A higher proportion of the neonatal, infant and under-five mortality was also found among the children of the rural mothers or mothers of the Rangpur and Dhaka divisions.

The adjusted associations between exposure and outcome variables are presented in Tables 4 and 5. The likelihoods of neonatal mortality (adjusted OR (aOR) 3.44; 95% CI, 1.17–10.13) and infant mortality (aOR, 2.39, 95% CI 1.03–6.84) were found higher among mothers reported use of solid fuels as compared to the mothers reported use of clean fuel. The likelihood of neonatal mortality was even found strongest when we considered solid fuel used together with place of cooking. We found 4.33 times (95% CI, 1.16–16.23) higher likelihood of neonatal mortality among neonates of the mothers classified as highly exposed to HAP through solid fuel used as compared to the mothers classified as unexposed to HAP through solid fuel used. However, for infant mortality, the odds was 2.05 times (95% CI, 1.18–7.23) higher among infants of the mothers classified as highly exposed to HAP through solid fuel used as compared to the mothers classified as unexposed to HAP through solid fuel used. We did not find any significant association of under-five mortality with exposure variables considered though the relevant odds were higher.

4. Discussion

In this nationally representative study by analysing the most recent 2017/18 BDHS data, we examined the associations of household

Table 3
Distribution of **neonatal, infant and under-five mortality per 1000 live births by confounding variables, BDHS, 2017/18.**

Maternal age Mothers' ages at birth	Neonatal mortality, per 1000	Infant Mortality, per 1000	Under-five mortality, per 1000
≤24 years	33.91	32.39	32.52
25–35 years	61.72	64.42	64.44
>35 years	4.37	3.18	3.04
Mother's education			
Illiterate	14.11	12.35	14.06
Primary	36.48	38.05	37.22
Secondary	42.31	42.41	41.24
Higher	7.10	7.18	7.48
Child's gender			
Male	57.34	56.88	54.61
Female	42.66	43.12	45.39
Birth interval			
<24 months	18.83	15.31	15.05
≥24 months	81.17	84.68	84.95
Exposure to mass media			
Not exposed	37.53	38.58	41.60
Moderately exposed	55.43	55.16	52.69
Highly exposed	7.04	6.26	5.71
Household wealth quintiles			
Poor	53.77	54.42	55.50
Middle	18.81	16.46	15.88
Richer	27.41	29.12	28.62
Urbanicity			
Urban	29.96	28.83	27.30
Rural	70.04	71.17	72.70
Place of region			
Barishal	7.78	6.86	7.04
Chattogram	16.23	14.48	16.01
Dhaka	21.07	23.39	22.83
Khulna	10.80	9.44	8.61
Mymensingh	3.71	4.95	4.51
Rajshahi	11.35	11.99	13.06
Rangpur	20.36	15.42	15.09
Sylhet	9.00	13.47	12.85

Note: All estimated presented in this table are column percentage.

Table 4
Results of the adjusted multilevel mixed-effect logistic regression model in assessing the association of household cooking fuels used with neonatal, infant, and under-five child mortality, Bangladesh, 2017/18.

Exposure	Neonatal mortality OR (95% CI)	Infant mortality OR (95% CI)	Under-five mortality OR (95% CI)
Type of cooking fuels used			
Clean fuel (ref)	1.00	1.00	1.00
Solid fuel	3.44 (1.17–10.13)**	2.39 (1.03–6.84)**	2.08 (0.73–5.93)
Mothers' ages at birth			
≤24 years (ref)	1.00	1.00	1.00
25–35 years	0.80 (0.52–1.23)	0.75 (0.52–1.08)	0.77 (0.54–1.09)
>35 years	0.72 (0.27–1.93)	0.50 (0.19–1.32)	0.45 (0.18–1.16)
Mother's education			
Illiterate (ref)	1.00	1.00	1.00
Primary	0.78 (0.42–1.46)	0.92 (0.53–1.61)	0.78 (0.47–1.30)
Secondary	0.71 (0.37–1.35)	0.85 (0.48–1.51)	0.71 (0.42–1.21)
Higher	0.57 (0.21–1.59)	0.75 (0.31–1.79)	0.72 (0.32–1.62)
Child's gender			
Male (ref)	1.00	1.00	1.00
Female	0.85 (0.57–1.25)	0.85 (0.61–1.20)	0.94 (0.68–1.30)
Birth interval			
<24 months (ref)	1.00	1.00	1.00
≥24 months	2.31 (1.38–3.90)**	1.69 (1.04–2.73)**	1.63 (1.03–2.59)**
Exposure to mass media			
Not exposed (ref)	1.00	1.00	1.00
Moderately exposed	1.36 (0.86–2.16)	1.33 (0.90–1.98)	1.17 (0.80–1.70)
Highly exposed	1.65 (0.65–4.21)	1.37 (0.60–3.14)	1.14 (0.50–2.57)
Household wealth quintiles			
Poor (ref)	1.00	1.00	1.00
Middle	1.08 (0.62–1.90)	1.29 (0.78–2.14)	1.29 (0.80–2.10)
Richer	0.62 (0.31–1.24)	0.74 (0.40–1.34)	0.83 (0.47–1.47)
Urbanicity			
Urban (ref)	1.00	1.00	1.00
Rural	0.64 (0.38–1.09)	0.72 (0.45–1.13)	0.76 (0.49–1.18)
Place of residence			
Barishal (ref)	1.00	1.00	1.00
Chattogram	0.55 (0.23–1.32)	0.54 (0.25–1.18)	0.61 (0.29–1.26)
Dhaka	0.56 (0.23–1.37)	0.70 (0.32–1.51)	0.72 (0.35–1.49)
Khulna	0.93 (0.37–2.41)	0.88 (0.38–2.07)	0.81 (0.36–1.86)
Mymensingh	0.29 (0.08–1.01)	0.43 (0.16–1.14)	0.38 (0.14–1.00)
Rajshahi	0.74 (0.29–1.87)	0.86 (0.38–1.93)	0.95 (0.44–2.04)
Rangpur	1.31 (0.56–1.35)	1.05 (0.48–2.28)	1.01 (0.49–1.12)
Sylhet	0.68 (0.26–1.80)	1.19 (0.54–2.64)	1.10 (0.51–2.36)

cooking fuels used and the level of exposure to HAP through cooking fuels used with the neonatal, infant, and under-five child mortality in Bangladesh. We found solid fuels were used by nearly 80% of the mothers' households and nearly 3% used indoor places for cooking. The rates of under-five, infant and neonatal mortality were found around 38, 34, and 25 per 1000 live births, respectively. We found a higher probability of neonatal and infant mortality in mothers who used solid fuels as compared to the clean fuel used. The associations were even found strongest for the mothers classified as highly exposed to solid fuels used as compared to the unexposed mothers. These findings are robust since the findings of this study were generated by using advanced statistical modelling through analysing the nationally representative survey data along with consideration of the comprehensive range of confounding factors selected systematically. Therefore, the findings are expected to help the policymakers to create evidence-based policies and programs to achieve SDGs targets of reducing under-five and neonatal deaths in Bangladesh by 2030.

As reported in this study, infant and under-five mortality rates are higher in rural areas and among poor mothers. These are identical to the findings of other studies conducted in Bangladesh.[8,14,32] In terms of the place of residence, neonatal, infant and under-five mortality rates were found higher among children of rural mothers or mothers residing in the Dhaka and Rangpur divisions. They contradict with the available studies' findings conducted by using the 2014 BDHS data while the prevalence of child mortality was found higher in the Sylhet division.[8,14]

Previous studies in Bangladesh reported HAP because of using solid fuels was associated with an increased risk of neonatal and infant mortality,[21,27] which coincides exactly with this updated analysis. Studies conducted in other LMICs like Myanmar and India also reported a similar association.[26,33] However, the current association is found stronger than the previous evidence from Bangladesh as this study used the most updated data and rigorous statistical methods with a potential list of confounders.[8,23] For the first time in Bangladesh, we also found likelihoods of neonatal and infant mortality increased with the increasing level of exposure to HAP through solid fuel used. These associations were consistent with the recently reported association for Myanmar and Afghanistan.[25,26]

Respiratory systems of the neonatal and infants are comparatively weaker and they comparatively breathe a higher volume of air.[16] Even if solid fuels are being used indoors it drastically increases the airborne toxic pollutants' concentration in the household and ambient air.[8,21] These increase occurrence of respiratory diseases, including acute lower respiratory infection, pneumonia, and asthma.[3,34] The occurrence of such morbidities at a very early stage then led to an increased risk of mortality. This mechanism can also explain our reported findings of insignificant associations between under-five mortality and solid fuel use. The respiratory system of the under-five aged children is comparatively strongest than that of neonates and infants.[19,35] Besides, the

Table 5
Results of the adjusted multilevel mixed-effect logistic regression model in assessing the association of level of exposure to HAP through cooking fuels used with neonatal, infant, and under-five child mortality, Bangladesh, 2017/18.

Exposure	Neonatal mortality OR (95% CI)	Infant mortality OR (95% CI)	Under-five mortality OR (95% CI)
Level of exposure to HAP through cooking fuels used			
Unexposed	1.00	1.00	1.00
Moderate	1.05 (0.58–1.87)	0.98 (0.61–1.58)	1.10 (0.69–1.75)
High	4.33 (1.16–16.23)**	2.05 (1.18–7.23)**	1.99 (0.57–6.99)
Mothers' ages at birth			
≤24 years (ref)	1.00	1.00	1.00
25–35 years	0.69 (0.41–1.15)	0.70 (0.45–1.08)	0.65 (0.43–1.01)
>35 years	0.74 (0.25–1.25)	0.56 (0.19–1.62)	0.48 (0.17–1.40)
Mother's education			
Illiterate (ref)	1.00	1.00	1.00
Primary	0.88 (0.41–1.85)	0.87 (0.44–1.69)	0.74 (0.40–1.37)
Secondary	0.72 (0.33–1.56)	0.93 (0.47–1.82)	0.76 (0.41–1.42)
Higher	0.73 (0.24–2.18)	0.77 (0.29–2.06)	0.64 (0.25–1.66)
Child's gender			
Male (ref)	1.00	1.00	1.00
Female	0.70 (0.44–1.12)	0.59 (0.39–0.90)**	0.60 (0.41–0.89)**
Birth interval			
<24 months (ref)	1.00	1.00	1.00
≥24 months	2.47 (1.35–4.52)**	1.71 (0.98–3.02)	1.79 (1.04–3.08)**
Exposure to mass media			
Not exposed (ref)	1.00	1.00	1.00
Moderately exposed	1.28 (0.73–2.22)	1.21 (0.75–1.95)	1.09 (0.69–1.73)
Highly exposed	1.33 (0.46–3.88)	1.19 (0.47–3.00)	1.10 (0.44–2.76)
Household wealth quintiles			
Poor (ref)	1.00	1.00	1.00
Middle	1.49 (0.74–3.00)	1.63 (0.88–3.00)	1.58 (0.88–2.84)
Richer	0.76 (0.34–1.71)	0.73 (0.36–1.48)	0.70 (0.35–1.39)
Urbanicity			
Urban (ref)	1.00	1.00	1.00
Rural	0.66 (0.36–1.21)	0.70 (0.41–1.20)	0.70 (0.41–1.17)
Place of residence			
Barishal (ref)	1.00	1.00	1.00
Chattogram	0.75 (0.26–2.19)	0.67 (0.25–1.78)	0.64 (0.26–1.61)
Dhaka	0.79 (0.27–2.33)	1.06 (0.41–2.75)	1.04 (0.43–2.54)
Khulna	1.21 (0.39–3.82)	1.20 (0.43–3.38)	1.07 (0.40–2.86)
Mymensingh	0.18 (0.02–1.32)	0.34 (0.08–1.44)	0.29 (0.07–1.19)
Rajshahi	1.01 (0.31–3.29)	0.95 (0.32–2.78)	0.92 (0.33–2.52)
Rangpur	1.39 (0.46–4.16)	1.18 (0.43–3.25)	1.05 (0.40–2.73)
Sylhet	0.83 (0.26–2.64)	1.43 (0.54–3.80)	1.26 (0.50–3.17)

neonates and infant are more susceptible to HAP through solid fuel used due to their underdeveloped epithelial linings of the lungs. Furthermore, infants and neonates are often carried on their mothers' backs or stand beside their mothers when cooking.[19,26] However, with increasing children's age, mothers may leave their under-five children to other family members before entering the cooking place. This reduces under-five children's exposure level to HAP through solid fuels used as compared to the neonates and infants. Such lower exposure level along with a comparatively strong respiratory system could then lead to the insignificant association between solid fuels used and under-five mortality.

Our results suggest that the likelihood of neonatal and infant mortality increased with the increased level of exposure to HAP through cooking fuels. The effect size was even higher than the effects of solid fuel used on neonatal and infant mortality. This is possibly due to the fact that the effects of fumes from solid fuel are substantially higher when they are inhaled during indoor cooking.[8] Moreover, poor people are usually considered the indoor cooking places because of their poverty they could not make their houses with enough space to make a separate room for cooking.[20] Additionally, the indoor cooking places usually does not have adequate fumes ventilation systems.[8] Besides these, lower breastfeeding, immunization, child malnutrition, and inappropriate or inadequate food taking behaviour are also found higher among poor people in Bangladesh as well as other LMICs. Therefore, their pooled effects could be responsible for the rising occurrence of neonatal or infant mortality with the increased exposure to HAP through solid fuel used.

This study has several strengths and some limitations. First, we analysed large-scale nationally representative research data that is desirable for policy and programs making at the national level. Advanced statistical modelling was used in this study, along with a precious list of confounding factors. Therefore, the current research results are the most accurate than the available findings. The major limitation of this study is analysis of the cross-sectional data; therefore, the findings are correlational only rather than casual. All data were self-reported, therefore, recall biased may raise. However, any of such bias is likely to be random. Given the nature of the association we explored, the reasons for child deaths to be occurred should be considered important for adjustment. However, the survey did not record such information, as such, we could not adjust this in the model. Kitchen ventilation system should also be considered important for adjustment for the association we measured. However, this data was also not available in the survey we analysed. Moreover, we found only 1.21% of the total respondents were highly exposed to HAP though cooking fuel used. Though this finding generated systematically which ensure its validity, however, because of such extremely lower sample size the reported estimates should be overestimated.

5. Conclusion

Solid fuels were found to be used around 80% of the total households in Bangladesh. Indoor use of solid fuel was reported for around 3% of the total respondents. We found solid fuels used and level of HAP through solid fuel used were associated with neonatal and infant mortality, but not with under-five mortality. This indicates cooking fuels is an important factor to be considered in the national level policies and programs to reduce under-five mortality which Bangladesh is now trying to do in order to achieve the relevant SDGs' targets. Focus should be given to ensure clean fuels used and increase awareness about the adverse effects of solid fuels used. Particular attention needs for the mother having under-five aged children.

Ethical statement

This study analysed secondary data publicly available. Ethical approval for this survey was provided by the Bangladesh Medical research counsel and Demographic and Health Survey Program of the USA. No additional ethical approval is required to conduct this study.

Human and animal right

No animals were used for this study. All human procedure were in accordance with the ethical standard of the ethical approval broad.

Consent for publication

Informed written consent was obtained from all participants.

Availability of data and materials

The Demography and Health Survey (DHS) program of the USA is the custodian of 2017 BDHS data. It is freely available for the user upon submission reasonable request to the DHS.

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Authors' contribution

Khan MN, Islam MS, and Khan MM designed this study. Alam MB and Acharjee S analyzed the data. Alam MB, Mahmud SMA, and Tania JA write the first draft of this manuscript. Khan MN, Islam MS, and Khan MM critically revised this manuscript. All authors approved this submitted version of the manuscript.

Declaration of competing interest

The authors declare that they do not have any conflict of interest.

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