**Title Page**

Household fuel types and its associated risk with childhood acute respiratory illness in Bangladesh: a propensity score matching study to complex surveys

**Authors and affiliations**

Mohammad Nayeem Hasan1,2, Tanvir Ahammed1, Aniqua Anjum1, Sabrin Sultana3,

M. Noor-E-Alam Siddiqui1, Sohan Sarwar4

1Department of Statistics, Shahjalal University of Science & Technology, Sylhet, Bangladesh.

2Joint Rohingya Response Program, Food for the Hungry, Cox’s Bazar, Bangladesh.

3Department of Banking and Insurance, University of Chittagong, Chittagong, Bangladesh.

4School of Accounting and Finance, University of Greenwich, London, United Kingdom.

**Correspondence:**

Mohammad Nayeem Hasan

Department of Statistics, Shahjalal University of Science and Technology, Sylhet 3114, Bangladesh.

Email: [nayeem5847@gmail.com](mailto:nayeem5847@gmail.com); [nhasan@fh.org](mailto:nhasan@fh.org)

**Research article**

Household fuel types and its associated risk with childhood acute respiratory illness in Bangladesh: a propensity score matching study to complex surveys

**Abstract**

**Aim:** The most common cause of death among Bangladeshi children under the age of five is acute respiratory infection (ARI). For cooking, low-income families frequently rely on wood, coal, and animal excrement. It's unclear whether using alternative fuels offers a health benefit over solid fuels. Therefore, we aim to conduct a study to detect the effects of fuel usage on ARI in children. **Materials and Methods:** Using the Bangladesh Demographic & Health Survey (BDHS) 2017-18 data, to emulate a propensity score weighted population, we employed propensity score weighting to reweight both unexposed (clean fuels) and exposed (solid fuels) groups. The propensity scores were used to evaluate the risk factors for ARI due to fuel use using multivariable logistic regression. **Results:** From the analysis, we found the crude (the only type of fuel in the model) odds ratios (OR) for the ARI were 1.693 (95% confidence interval (CI): 1.058-2.709). This suggests that children in families using contaminated fuels were 69.3% more likely than children in households using clean fuels to experience an ARI episode. After adjusting for cooking fuel, type of roof material, child's age (months), and sex of the child, the effect of solid fuels was also more acute as the adjusted odds ratio (AOR) for the ARI was 1.692 (95% CI: 1.053-2.718) or when compared to the effect of clean fuel, an ARI occurrence is 69.2% more likely. **Conclusion:** The study has found a significant association between the use of solid fuels and the presence of ARI of a child in the household. The link between indoor air pollution and clinical parameters of acute respiratory illness needs further investigations.

**Keywords:** Solid fuels; Clean fuels; Under-five children; Acute Respiratory Infection (ARI).

**Introduction**

Children under the age of five in underdeveloped countries around the world, acute respiratory infection (ARI) is the leading cause of death. In the present circumstances, it is one of the major causes of permanent damage and communicable disease death [1]. Acute respiratory infection is a severe infection that makes it difficult to breathe normally. Though it is nearly impossible to prove that viruses and bacteria, the main risk factors for developing an acute respiratory illness, start in the nose, trachea (windpipe), or lungs [2]–[4]. Children, the elderly, and persons with immune system abnormalities are especially vulnerable.

On March 12, 2003, the World Health Organization (WHO) issued a global alert about a common pneumonia called severe acute respiratory syndrome [5]. According to the WHO, an estimated 2.6 million children die each year as a result of acute respiratory infections. Outpatient clinic visits by children with respiratory illnesses account for 20% to 40% of all visits, whereas hospital admissions account for 12% to 35% of all admissions [6]. In developing countries, 500 to 900 million instances of acute respiratory infection occur each year. Also, around 5 million children who are under five die of this infection annually, of which 90% occur in developing countries [7]. The precise magnitude of ARI in Bangladesh is unknown. ARI, which is already at a very large scale, is increasing at the double. Unlike cholera or acute malnutrition, there are no acceptable benchmarks for ARI, making it difficult to measure case management quality using established criteria. Several studies stated that there are high correlations between environmental risk factors, such as smoke, outdoor air pollution, indoor pollution, passive smoking, overcrowding and risk factors in the child, such as low birth weight, malnutrition, measles, breastfeeding, and vitamin ‘A’ deficiency, stunting, wasting, type of cooking fuel, toilet facilities, mothers literacy, medication for the intestinal parasite, place of residence, BMI, wealth index, media exposure, size of childbirth with the infections, are potential risk factors for pneumonia/ARI in developing countries

The burning of cooking fuel is not necessarily the only source of indoor air pollution, although it is considered the major source. Pollutants from dirty fuel sources used for indoor space heating and lighting are among the other sources [15]. Because of the scarcity and difficulty in obtaining non-solid or clean fuels such as electricity and natural gas, low-income families in many developing countries rely on the use of low-cost but high-pollution solid fuels such as wood, coal, straws, and animal dung as their primary sources of energy for cooking and heating, yet 19.0%, 6.8%, and 50.9% of households in Bangladesh used crops, animal dung, and wood, respectively, these fuels for cooking, heating and lighting, even when access to electricity was available [16]. The fuels are primarily used in simple, inefficient, and mostly unvented family cooking stoves, resulting in enormous amounts of indoor smoke due to poor ventilation [17].

In Bangladesh, 80% of households use solid fuel for cooking (coal/lignite, charcoal, wood, straw/shrubs/grass, agricultural crops, and animal dung), while 20% use clean fuel (electricity, and liquid petroleum gas/natural gas/biogas) [18]. However, no studies have been undertaken in Bangladesh to investigate the link between ARI in children and solid fuel exposure, to the authors' knowledge. Therefore, using the most up-to-date data available, this study looked at the link between solid fuel exposure and ARI in Bangladeshi children under the age of five.

**Materials and Methods**

**Study area**

Bangladesh is one of the most densely-populated countries in the world, with a delta of rivers that flows down in the Bay of Bengal [19]. It is low-lying, primarily riverine country in South Asia's tropical monsoon region, with a mean elevation of 85 meters above sea level and a climate marked by high temperatures, heavy rainfalls, cyclones, tidal bores, often excessive humidity, and fairly marked seasonal variations [20], [21].

**Data source and Study design**

For this investigation, we used data from the Bangladesh Demographic and Health Survey (BDHS) 2017-18. In the first step, 675 enumeration areas (EA) were chosen with a probability proportionate to EA size (250 in urban regions and 425 in rural areas). A systematic sample of 30 households per EA was chosen in the second step of sampling to give statistically credible estimates of key demographic and health characteristics. A total of 20,250 residential households were chosen based on this concept. About 20,100 ever-married women aged 15 to 49 were expected to complete the interviews. Mothers of 8347 children younger than 5 years were questioned about demographic, economic, pregnancy, postnatal care, immunization, and health issues, including ARI symptoms. After limiting our sample to children for whom complete data on the outcome and predictors included for the study were available, we ended up with 8321 (weighted) children for analysis. After eliminating non-eligible cases (such as other fuel types, guests, and non-surviving children) as well as observations with missing information on the child's age. Figure 1 illustrates the sampling technique. The 2017-18 BDHS report includes a detailed discussion of the sample design and technique [18].

**Outcome variable**

The outcome variable of interest was ARI in children under the age of five. ARI is defined in this survey as a mother's or caregiver's perception of whether their child had a cough accompanied by chest-related short, rapid breathing in the two weeks before to the survey [18]. When respondents said yes, the ARI variable was classified as 1, and when they said no, it was coded as 0.

**Exposure variable**

The exposure variable was solid fuel, which was determined by the type of fuel used for cooking or heating. Each household's type of cooking fuel was collected by the BDHS. 'What type of fuel does your home primarily use for cooking?' survey respondents were asked [18]. Fuel types were classified into coal/lignite, charcoal, wood, straw/shrubs/grass, agricultural crops, animal dung, electricity, and liquid petroleum gas/natural gas/biogas. The exposure variable was a binary variable that indicates types of cooking fuel: clean fuel versus solid fuel. Coal/lignite, charcoal, wood, straw/shrubs/grass, agricultural crops, and animal dung were considered as solid fuels. The use of electricity and liquid petroleum gas/natural gas/biogas were classified as clean fuels. The fuel type variable is coded as 1 if the household uses clean fuel, otherwise 0 (solid fuel).

**Covariates**

By reviewing the valid literature, the most potentially related and assumed variables associated with ARI were included in this study. Household related factors (residence, region, mass media, source of drinking water, facility of toilet, wealth status, electricity, type of flooring material, type of wall material, type of roof material, and number of household member), parents/caregivers related factors (having vaccination card, mother’s age, mother’s education level, mother’s BMI, number of living children, mother’s occupation, mother’s work for, household head’s occupation, household head’s education, and type of household head’s education), and child-related factors (child’s age, child’s sex, order of birth, delivery place, birth weight, C-section delivery, season of birth, medication for intestinal parasites, vitamin A supplementation, and nutritional status).

In this study, participants were asked how often they listened to the radio or watched television. Those who responded at least once a week are regarded to be routinely exposed to that type of media [18]. Sources of drinking water, piped water (piped water, piped in dwellings, piped to a yard / plot, public tap / standpipe), tube well (tube well water, tube well or borehole), and other sources of drinking water, were listed (e.g., rainwater, river) , Protected or unprotected well) [22]. Some of the toilet facilities used in this study have been improved (flush toilets, flush in a piped sewer system, flush in septic tanks, flush from pit latrines, pit latrines with slabs, and ventilated pit latrines), shared (improved but shared) with other households. With), and not advanced (no flush toilet, no flush in piped sewerage system, no flush in septic tank (e.g., hanging toilet, open hole) [23]. The wealth index was reclassified into upper economic class (upper 20% asset value), middle economic class (middle 40% asset value) and lower economic class (lower 40% asset value) [24]. The survivor also observed the main material of the floor/roof/wall of the dwelling. The floor/roof/wall was classified as natural (earth/sand and dung), rudimentary (wood planks and palm/bamboo), and finished (vinyl or asphalt strips, ceramic tiles, cement, and carpet) [18].

The BDHS obtained vaccination coverage data in two methods in 2017-18: from immunization cards provided to interviewers and from mothers' verbal remarks. The interviewers transcribed the vaccination dates straight into the questionnaire if the cards were available. The respondent was asked to recollect the immunizations administered to her child if there was no vaccination card for the child if the vaccination card was unavailable for the child or if a vaccine had not been noted as being given on the vaccination card [18]. Mother's/household head’s occupation categorized as agricultural/skilled worker (farming/agricultural work and semi-skilled labor/service), household/unskilled worker (unskilled labor, home-based manufacturing, domestic service, and other), industrial worker (Professional/technical, business, factory work or blue-collar service, poultry or cattle raising).

In this study, weight at birth was classified as low if the weight of the child was less than 2500 grams and normal if greater than 2500 grams. Two anthropometric indices, height-for-age and weight-for-height z-scores, were used to assess a child's nutritional status, as suggested by the WHO [25]. The z-score indicates how far a given result deviates from the mean, and it is commonly used to normalize data. The z-score was used in this study to compare stunting and wasting in children under the age of five by gender and age group. If a child's weight-for-height z-score was less than -2, they were called wasted, and if their height-for-age z-score was less than -2, they were considered stunted.

**Statistical analyses**

To illustrate the distribution of variables, descriptive statistics were utilized. In this study, numbers and percentages were used for categorical variables. We used Chi-square tests to identify factors associated with ARI in the children and P-value <0.05 was taken as statistically significant. We fitted the design-based binary logistic regression [26] to assess the association between child ARI and types of cooking fuel in a household. For the adjusted association, the model was adjusted for type of cooking fuel, type of roof material, child's age (months), and sex of the child. The crude odds ratio (COR) and adjusted odds ratio (AOR) were calculated, along with the 95% confidence interval (CI) and p-values. The specified predictor variables were used in multiple logistic regression. Survey package in R was used to conduct the statistical analyses and data management for this study.

**Variable selection**

The variables were chosen in two steps. In the first stage, the Rao and Scott Chi-squared test (a design-adjusted variation of the Pearson Chi-squared test) [27] was employed to account for the data's cluster-design effect. In total, 21 variables were significant with ARI at p-value less than 0.200 (Table 1, 2, and 3). Bivariate logistic regression was carried out independently for each of the selected factors in the second stage, and 16 variables were determined to be significant at the 5% significance level. The final model (full multivariable model) was then created using a manual stepwise backward elimination approach. The least significant variable was eliminated at each phase of the stepwise elimination process, and this process was repeated until all of the variables in the model were significant at the 5% significance level. In this stage, 4 variables were found to be significant at the 5% significance level.

With a cut-off value of 4.00, we used the variance inflation factor (VIF) value to analyze multicollinearity in the final model (Table 4). The area under the curve (AUC) of the receiver operating characteristic curve was used to verify the prediction accuracy of the final model (Table 5). We also utilized the Hosmer and Lemeshow goodness-of-fit test to get a sense of the final model's overall fit (Table 5).

**Propensity score calculation**

The robustness of the findings from our main analyses was assessed using the propensity score approach. The propensity score approach allows us to mimic some of the characteristics of a randomized trial in an observational study context and can be used as an alternative confounding adjustment tool to the regression adjustment method [28]. We used the propensity score weighting to reweight both unexposed (household water E. coli contamination level<1 CFU/100 ml) and exposed (household water E. coli contamination level 1–10 and>10 CFU/100 ml) groups to emulate a propensity score weighted population [29]. We estimated the propensity scores using the multinomial logistic regression with the same covariates used in the main analysis. The standardized mean difference (SMD) of 0.1 among exposed and non-exposed was considered a good covariate balancing [30]. The outcome model was the design-based binary logistic regression on the weighted data, where we multiplied the survey weights and propensity score weights to get national-level estimates [31]. We adjusted the model for potential confounders to remove the small residual covariate imbalance between the exposed and non-exposed [32].

**Results**

**Study sample characteristics**

The study team approached 20250 houses, and 20160 households were eligible for interview. Floodwater totally undermined three clusters, resulting in the loss of 90 households. As such, 20160 households with 8347 children were enrolled in the study from those 26 children eliminated due to visitors and non-surviving children. Finally, 8321 observations were obtained for conducting this study (Figure 1).

**Socio-demographic characteristics**

Table 1 contains the results of chi-square analysis for identifying household factors associated with ARI. The results of the chi-square analysis indicated that types of the region of the country, media accessibility, toilet facility, types of cooking fuel, wealth index, electricity accessibility, types of roof material, types of wall material are significant factors as the p-value is less than 0.05. Among 8321 children, 25.38% were from Dhaka, 51.76% of the household had media accessibility, 70.52% had unimproved toilet facilities, 41.77% were from the poorest households, 78.97% used solid cooking fuel, and 82.32% had electric accessibility.

Most of the mothers (79.68%) of the children are from the 15-24 years’ age group, and a large group of mothers was vaccinated. As for parents’ characteristics, 48.64% of respondents were primarily completed, 77.89% of household heads were industrial workers, and 49.29% of household heads had no education (Table 2).

In total, 58.47% of children were included from the 24-59 age group. There were 52.16% of male children, and 30.72% were a stunt. The birth order distribution of children was 87.5% in the 1-3 group, 59.3% born at a health facility, 69.95% delivered at a normal weight, and 66.61% children were delivered by normal delivery (Table 3).

**Use of biomass fuel at household level**

In total, 78.97% of households used solid fuel: 43.8% used wood, 0.6% used straw, 27.9% used crops, and 0.1% used cow dung (Figure 2). Rangpur and Barisal regions of Bangladesh had the highest prevalence of solid fuel, whereas the lowest prevalence was seen in Dhaka (Figure 3).

The prevalence of ARI is significantly associated (P<0.05) with the type of fuel used in the home, according to the results of the Rao-Scott Chi-squared independence test (Table 1).

**Model evaluation**

The VIF result demonstrated no multicollinearity in the final multivariable logistic model (Table 4). The classification accuracy is acceptable, with an AUC value of 0.61. The model also passed the Hosmer and Lemeshow goodness-of-fit test (value = 8.2419, degrees of freedom = 8, P-value = 0.760), indicating that there was no lack of fit (Table 5).

**Association between the prevalence of ARI and solid fuel**

Table 6 shows the crude and adjusted association between household fuel use and ARI among under 5 years’ children in Bangladesh. In crude analysis, the solid fuel risk group in household fuel type was associated with 1.693 times higher odds of ARI than the clean fuel risk group (COR: 1.693; 95% CI: 1.058–2.709). After adjusting the model for potential confounders and risk factors, we observed 1.692 times the odds of ARI among those children from the solid fuel risk group in households than those from clean fuel (AOR: 1.692; 95% CI: 1.053–2.718).

**Discussion**

Of the study households, solid fuel (coal/lignite, charcoal, wood, straw/shrubs/grass, agricultural crops, and animal dung) was the most widely used fuel for cooking in Bangladesh. These findings show an association between the usage of solid fuel in the household and ARI episodes in children under five years old. The prevalence of ARI was greater in children who lived in a household that used solid fuel. A recent national representative sample of a Bangladesh Urban Health Survey conducted in 2013 reported 39.5% of solid fuel users in urban areas while 60.5% are clean fuel users [33]. More than half of households in India and Nepal used solid fuel for cooking: 54% in India (2015-2016) and 66% in Nepal (2016). In 2016, Indonesia had the lowest amount of household air pollution, with 23% [34].

In our study, we found that ARI is more frequent in case of the children of the uneducated mother.

According to a study conducted by Johns Hopkins University's Department of International Health, most mothers believed that a "wind-carrying sickness" may kill their kid, but ARI is deemed to be more controllable, and this is due to illiteracy [35]. Government’s effort to educate girls beyond a secondary level is therefore called for. In this instance, the government's free primary and secondary education program is extremely important, and it should be strengthened and expanded [36]. This is likely due to the fact that moms who use vaccination programs are more aware of health-care facilities and are more likely to seek early consultation for their children's illnesses, perhaps avoiding serious disease [37].

Our findings show that women in older age cohorts, as compared to those in the 15-24 age group, and those with higher birth order, as compared to the first, have a lower risk of ARI. This can be due to older women's collected childcare expertise and experience, which unmistakably gives them an advantage over younger women [36].Household wealth was defined according to the respondent’s reported household assets, was assigned a standardized score, and was categorized into three categories, namely, lower, middle, and higher. Being overweight (BMI 25 kg/m2) is a growing problem that has been associated with a risk for acute respiratory infections [38].

In our study, the incidence of ARI was higher in stunted infants, wasted infants, and infants that have low birth weight. Stunting is linked to a long period of time spent in poor environmental circumstances and having a low socioeconomic level as a child [39]. ARI bouts that are more frequent and last longer may cause growth retardation. Moreover, other nutritional disorders are also associated with ARI. Malnutrition was found to be strongly related with ARI in this investigation, as it has been in prior studies [15]. A study in the Philippines included age stratified risks in children less than 23 months of age and reported the highest risk of death from ARI due to malnutrition among those aged 12-22 months [14]. A study in New Delhi revealed severe malnutrition as the predictor of mortality in ARI in 2 weeks to 5 years old children. Overall, malnutrition has been associated with a two- to three-fold increase in ARI mortality [40].

Although the studies differ in terms of design, exposure measurement, and outcome evaluation, the current findings concerning the relationship between solid fuel consumption and ARI incidence are similar to most studies from India (OR 4.0, 95% CI 2.0e7.9), Nepal (OR 2.3, 95% CI 1.8-2.9) Zimbabwe (OR 2.1, 95% CI 1.5-3.1), Gambia (OR 5.2, 95% CI 1.7-15.9), and a meta-analysis of these studies (OR 2.3, 95% CI 1.9-2.7)

**Strengths and limitations**

To the best of our knowledge, this is the first study to assess the association between exposure to solid fuel and ARI episodes among children aged under 5 years in Bangladesh. We used a sufficiently large nationally representative dataset that reflects Bangladesh's whole population. We also considered a wide range of factors that influence the public's knowledge of the issue. We also looked at model-fitting criteria, which were mostly absent in the literature. Despite this, there were certain limits to our research. Because we used secondary data, we had no control over the variable selection, data quality, or measurement indication. In this study, environmental and behavioral factors were missing, which is important in exposure assessment. Furthermore, the study was performed three years ago; in that period, the level of fuel used among households may have shifted.

**Conclusion**

The current study yields solid evidence that solid fuel significantly augments children’s risk of ARI in Bangladesh. Despite the limitations talked over in the above discussions, the strength of the association and the frequency of reporting of fuel type as the main reason for ARI are remarkable enough to warrant the conclusion that solid fuel is a main driver of ARI in Bangladesh. This finding underscores the demand of bettering the cooking fuel in order to reduce ARI disease in many parts of the country. Our study also suggests that ARI, which is already at a very large scale, is increasing at double. Government should invest greater resources in ARI prevention and control and explicitly consider ARI as a top priority phase and scenario.

**Conflict of interest**

No conflict of interest

**Author`s contribution**

**Mohammad Nayeem Hasan:** Conceptualization, Supervision, Methodology, Formal Analysis, Writing- Original draft, Reviewing and Editing. Tanvir Ahammed: Methodology, Formal Analysis, Writing- Reviewing and Editing. Aniqua Anjum: Methodology, Writing-Reviewing and Editing. Sabrin Sultana: Writing-Reviewing and Editing. M. Noor-E-Alam Siddiqui: Methodology, Writing-Reviewing and Data curation. Sohan Sarwar: Methodology, Writing-Reviewing and Data curation.

**Acknowledgment**

We acknowledge MEASURE DHS, NIPORT, and Bangladesh Bureau of Statistics for allowing us to use the data

**Funding statement:** This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sector

**References**:

[1] M. Chan-Yeung and W. C. Yu, “Outbreak of severe acute respiratory syndrome in Hong Kong Special Administrative Region: Case report,” *Bmj*, vol. 326, no. 7394, pp. 850–852, 2003, doi: 10.1136/bmj.326.7394.850.

[2] V. Sehgal, G. R. Sethi, and L. Satyanarayana, “PREDICTORS OF MORTALITY IN SUBJECTS HOSPITALIZED WITH,” vol. 34, no. March, 1997.

[3] S. F. Rashid, A. Hadi, K. Afsana, and S. Ara Begum, “Acute respiratory infections in rural Bangladesh: Cultural understandings, practices and the role of mothers and community health volunteers,” *Trop. Med. Int. Heal.*, vol. 6, no. 4, pp. 249–255, 2001, doi: 10.1046/j.1365-3156.2001.00702.x.

[4] R. Juvonen *et al.*, “Risk factors for acute respiratory tract illness in military conscripts,” *Respirology*, vol. 13, no. 4, pp. 575–580, 2008, doi: 10.1111/j.1440-1843.2008.01299.x.

[5] R. Gonzales *et al.*, “Principles of appropriate antibiotic use for treatment of nonspecific upper respiratory tract infections in adults: background.,” *Ann. Intern. Med.*, vol. 134, no. 6, pp. 490–4, Mar. 2001, doi: 10.7326/0003-4819-134-6-200103200-00015.

[6] M. R. Savitha, S. B. Nandeeshwara, M. J. Pradeep Kumar, Farhan-Ul-Haque, and C. K. Raju, “Modifiable risk factors for acute lower respiratory tract infections,” *Indian J. Pediatr.*, vol. 74, no. 5, pp. 477–482, 2007, doi: 10.1007/s12098-007-0081-3.

[7] R. Gonzales, D. C. Malone, J. H. Maselli, and M. A. Sande, “Excessive antibiotic use for acute respiratory infections in the United States.,” *Clin. Infect. Dis.*, vol. 33, no. 6, pp. 757–62, Sep. 2001, doi: 10.1086/322627.

[8] H. Sanbata, A. Asfaw, and A. Kumie, “Association of biomass fuel use with acute respiratory infections among under- five children in a slum urban of Addis Ababa, Ethiopia,” *BMC Public Health*, vol. 14, no. 1, 2014, doi: 10.1186/1471-2458-14-1122.

[9] N. Z. Janjua, B. Mahmood, V. K. Dharma, N. Sathiakumar, and M. I. Khan, “Use of biomass fuel and acute respiratory infections in rural Pakistan,” *Public Health*, vol. 126, no. 10, pp. 855–862, Oct. 2012, doi: 10.1016/J.PUHE.2012.06.012.

[10] E. J. da Fonseca Lima *et al.*, “Risk factors for community-acquired pneumonia in children under five years of age in the post-pneumococcal conjugate vaccine era in Brazil: A case control study,” *BMC Pediatr.*, vol. 16, no. 1, pp. 1–9, Sep. 2016, doi: 10.1186/S12887-016-0695-6/TABLES/4.

[11] V. Mishra, “Indoor air pollution from biomass combustion and acute respiratory illness in preschool age children in Zimbabwe,” *Int. J. Epidemiol.*, vol. 32, no. 5, pp. 847–853, Oct. 2003, doi: 10.1093/IJE/DYG240.

[12] M. Dherani, D. Pope, M. Mascarenhas, K. R. Smith, M. Weber, and N. Bruce, “Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: a systematic review and meta-analysis,” *Bull. World Health Organ.*, vol. 86, no. 5, pp. 390–394, May 2008, doi: 10.2471/BLT.07.044529.

[13] A. De Francisco, J. Morris, A. J. Hall, J. A. Schellenberg, and B. M. Greenwood, “Risk factors for mortality from acute lower respiratory tract infections in young Gambian children,” *Int. J. Epidemiol.*, vol. 22, no. 6, pp. 1174–1182, 1993, doi: 10.1093/IJE/22.6.1174.

[14] I. Rudan, C. Boschi-Pinto, Z. Biloglav, K. Mulholland, and H. Campbell, “Epidemiology and etiology of childhood pneumonia,” *Bull. World Health Organ.*, vol. 86, no. 5, 2008, doi: 10.2471/BLT.07.048769.

[15] R. Goyal and M. Khare, “Indoor air pollution and health effects,” in *Air Pollution: Health and Environmental Impacts*, Marcel Dekker, 2010, pp. 109–134.

[16] C. I. A. Siddiky, “Energy scenario of Bangladesh,” *Geopolit. Energy South Asia*, pp. 96–110, 2021, doi: 10.4324/9781003110057-5.

[17] J. Wichmann and K. V. V. Voyi, “Impact of cooking and heating fuel use on acute respiratory health of preschool children in South Africa,” *South. African J. Epidemiol. Infect.*, vol. 21, no. 2, pp. 48–54, Jan. 2006, doi: 10.1080/10158782.2006.11441264.

[18] DHS, “The DHS Program - Bangladesh: Standard DHS, 2017-18,” 2018. https://www.dhsprogram.com/methodology/survey/survey-display-536.cfm (accessed Feb. 10, 2022).

[19] BBC, “Bangladesh country profile - BBC News,” *Bbc*, 2019. https://www.bbc.com/news/world-south-asia-12650940 (accessed Feb. 10, 2022).

[20] “Climate - Banglapedia,” *National Encyclopedia of Bangladesh*. Accessed: Feb. 10, 2022. [Online]. Available: https://en.banglapedia.org/index.php/Climate.

[21] “Geography of Bangladesh (Wikipedia),” *Wikipedia*. 2017, Accessed: Feb. 10, 2022. [Online]. Available: https://en.wikipedia.org/wiki/Geography\_of\_Bangladesh.

[22] DHS, “Household Drinking Water,” *Guide to DHS Statistics DHS-7*, 2019. https://dhsprogram.com/data/Guide-to-DHS-Statistics/Household\_Drinking\_Water.htm (accessed Feb. 13, 2022).

[23] DHS, “Type of Sanitation Facility,” 2019. https://dhsprogram.com/data/Guide-to-DHS-Statistics/Type\_of\_Sanitation\_Facility.htm (accessed Feb. 13, 2022).

[24] The Demographic and Health Surveys, “The DHS Program - Research Topics - Wealth Index,” 2019. https://dhsprogram.com/topics/wealth-index/ (accessed Feb. 13, 2022).

[25] M. De Onis and M. Blössner, “WHO Global Database on Child Growth and Malnutrition,” *Program. Nutr. World Heal. Organ. Geneva*, 1997, Accessed: Feb. 13, 2022. [Online]. Available: https://www.who.int/teams/nutrition-and-food-safety/databases/nutgrowthdb.

[26] M. N. Hasan, M. Abdul Baker Chowdhury, J. Jahan, S. Jahan, N. U. Ahmed, and M. J. Uddin, “Cesarean delivery and early childhood diseases in Bangladesh: An analysis of Demographic and Health Survey (BDHS) and Multiple Indicator Cluster Survey (MICS),” *PLoS One*, vol. 15, no. 12 December, pp. 1–13, 2020, doi: 10.1371/journal.pone.0242864.

[27] J. N. K. Rao and A. J. Scott, “The analysis of categorical data from complex sample surveys: Chi-squared tests for goodness of fit and independence in two-way tables,” *J. Am. Stat. Assoc.*, vol. 76, no. 374, pp. 221–230, 1981, doi: 10.1080/01621459.1981.10477633.

[28] P. C. Austin, “An Introduction to Propensity Score Methods for Reducing the Effects of Confounding in Observational Studies,” *https://doi.org/10.1080/00273171.2011.568786*, vol. 46, no. 3, pp. 399–424, May 2011, doi: 10.1080/00273171.2011.568786.

[29] K. Yoshida *et al.*, “Matching weights to simultaneously compare three treatment groups comparison to three-way matching,” *Epidemiology*, vol. 28, no. 3, pp. 387–395, May 2017, doi: 10.1097/EDE.0000000000000627.

[30] Z. Zhang, H. J. Kim, G. Lonjon, Y. Zhu, and written on behalf of A. B.-D. C. T. C. Group, “Balance diagnostics after propensity score matching,” *Ann. Transl. Med.*, vol. 7, no. 1, pp. 16–16, Jan. 2019, doi: 10.21037/ATM.2018.12.10.

[31] E. H. Dugoff, M. Schuler, and E. A. Stuart, “Generalizing Observational Study Results: Applying Propensity Score Methods to Complex Surveys,” *Health Serv. Res.*, vol. 49, no. 1, pp. 284–303, Feb. 2014, doi: 10.1111/1475-6773.12090.

[32] U. Benedetto, S. J. Head, G. D. Angelini, and E. H. Blackstone, “Statistical primer: propensity score matching and its alternatives,” *Eur. J. Cardio-Thoracic Surg.*, vol. 53, no. 6, pp. 1112–1117, Jun. 2018, doi: 10.1093/EJCTS/EZY167.

[33] NIPORT, “Bangladesh Urban Health Survey 2013 Final Report — MEASURE Evaluation.” 2015, Accessed: Mar. 26, 2022. [Online]. Available: https://www.measureevaluation.org/publications/tr-15-117.html.

[34] W. Wang, S. Assaf, B. M. Lwendo, and M. Davis, “Household Air Pollution: National and Subnational Estimates in Bangladesh, India, Indonesia, Nepal, and the Philippines,” 2020.

[35] P. Srivastava, A. K. Mishra, and A. Kumar Roy, “Predisposing Factors of Community Acquired Pneumonia in Under-Five Children,” *J. Lung Dis. Treat.*, vol. 1, no. 1, 2015, doi: 10.4172/2472-1018.1000101.

[36] E. Bbaale, “Determinants of diarrhoea and acute respiratory infection among under-fives in uganda,” *Australas. Med. J.*, vol. 4, no. 7, pp. 400–409, 2011, doi: 10.4066/AMJ.2011.723.

[37] B. Mengistie, Y. Berhane, and A. Worku, “Prevalence of diarrhea and associated risk factors among children under-five years of age in Eastern Ethiopia: A cross-sectional study,” *Open J. Prev. Med.*, vol. 03, no. 07, pp. 446–453, 2013, doi: 10.4236/ojpm.2013.37060.

[38] B. G. Williams, E. Gouws, C. Boschi-Pinto, J. Bryce, and C. Dye, “Estimates of world-wide distribution of child deaths from acute respiratory infections,” *Lancet Infectious Diseases*, vol. 2, no. 1. Lancet Publishing Group, pp. 25–32, Jan. 01, 2002, doi: 10.1016/S1473-3099(01)00170-0.

[39] H. J. Zar and T. W. Ferkol, “The global burden of respiratory disease - Impact on child health,” *Pediatric Pulmonology*, vol. 49, no. 5. Wiley-Liss Inc., pp. 430–434, 2014, doi: 10.1002/ppul.23030.

[40] Y. Benguigui, “Acute respiratory infections control in the context of the IMCI strategy in the Americas,” *Rev. Bras. Saúde Matern. Infant.*, vol. 3, no. 1, pp. 25–36, Mar. 2003, doi: 10.1590/s1519-38292003000100005.

**Tables and figures**

Table 1 Frequency distribution of households (weighted\*) on use of solid fuel and acute respiratory infection (ARI) among children younger than 5 years in Bangladesh.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Factors | ARI | | | |  |
| Yes, N (%) | | No, N (%) | Total, N (%) | P-value |
| **Total** | **250 (3.00)** | | **8071 (97.00)** | **8321 (100.00)** |  |
| **Place of residence** |  | |  |  |  |
| Urban | 57 (2.56) | | 2186 (97.44) | 2243 (26.96) | 0.188 |
| Rural | 192 (3.17) | | 5885 (96.83) | 6078 (73.04) |  |
| **Region of the country** |  | |  |  |  |
| Barisal | 19 (4.16) | | 443 (95.84) | 462 (5.55) | <0.001 |
| Chittagong | 48 (2.76) | | 1698 (97.24) | 1746 (20.99) |  |
| Dhaka | 42 (1.97) | | 2070 (98.03) | 2111 (25.38) |  |
| Khulna | 13 (1.74) | | 754 (98.26) | 768 (9.23) |  |
| Mymensingh | 17 (2.38) | | 688 (97.62) | 705 (8.48) |  |
| Rajshahi | 38 (3.94) | | 933 (96.06) | 971 (11.67) |  |
| Rangpur | 53 (5.98) | | 826 (94.02) | 879 (10.56) |  |
| Sylhet | 20 (2.95) | | 658 (97.05) | 679 (8.15) |  |
| **Media accessibility** |  | |  |  |  |
| Yes | 139 (3.65) | | 3661 (96.35) | 3800 (51.76) | 0.002 |
| No | 80 (2.26) | | 3461 (97.74) | 3541 (48.24) |  |
| **Source of drinking water** |  | |  |  |  |
| Piped water | 5 (1.12) | | 481 (98.88) | 486 (6.63) | 0.089 |
| Tube well | 206 (3.11) | | 6423 (96.89) | 6629 (90.30) |  |
| Other | 7 (3.13) | | 219 (96.87) | 226 (3.07) |  |
| **Toilet facility** |  | |  |  |  |
| Improved | 43 (2.01) | | 2121 (97.99) | 2164 (29.48) | 0.002 |
| Unimproved | 175 (3.39) | | 5001 (96.61) | 5177 (70.52) |  |
| **Type of cooking fuel** | |  |  |  |  |
| Clean fuel | 30 (1.95) | | 1512 (98.05) | 1542 (21.03) | 0.027 |
| Solid fuel | 189 (3.25) | | 5603 (96.75) | 5792 (78.97) |  |
| **Wealth index** |  | |  |  |  |
| Higher | 74 (2.27) | | 3201 (97.73) | 3276 (39.36) | 0.001 |
| Middle | 40 (2.56) | | 1529 (97.44) | 1569 (18.86) |  |
| Lower | 135 (3.89) | | 3341 (96.11) | 3476 (41.77) |  |
| **Electricity accessibility** |  | |  |  |  |
| No | 56 (4.11) | | 1315 (95.89) | 1371 (18.68) | 0.023 |
| Yes | 162 (2.72) | | 5808 (97.28) | 5970 (81.32) |  |
| **Type of flooring material** |  | |  |  |  |
| Natural | 155 (3.35) | | 4472 (96.65) | 4672 (63.02) | 0.091 |
| Rudimentary | 2 (2.80) | | 68 (97.20) | 68 (0.96) |  |
| Finished | 62 (2.33) | | 2582 (97.67) | 2582 (36.02) |  |
| **Type of roof material** |  | |  |  |  |
| Natural | 1 (2.69) | | 50 (97.31) | 51 (0.69) | 0.008 |
| Rudimentary | 1 (27.26) | | 2 (72.74) | 3 (0.04) |  |
| Finished | 217 (2.97) | | 7071 (97.03) | 7287 (99.27) |  |
| **Type of wall material** |  | |  |  |  |
| Natural | 24 (3.88) | | 605 (96.12) | 629 (8.57) | 0.042 |
| Rudimentary | 17 (5.48) | | 298 (94.52) | 315 (4.29) |  |
| Finished | 177 (2.77) | | 6220 (97.23) | 6397 (87.13) |  |
| **Number of household member** |  | |  |  |  |
| Below median | 80 (2.94) | | 2653 (97.06) | 2733 (32.85) | 0.855 |
| Above median | 169 (3.03) | | 5418 (96.97) | 5588 (67.15) |  |

\*Frequencies are weighted using sample weight

Table 2 Frequency distribution of parents (weighted\*) on use of solid fuel and acute respiratory infection (ARI) among children younger than 5 years in Bangladesh

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Factors | ARI |  |  |  |
|  | Yes, N (%) | No, N (%) | Total, N (%) | P-value |
| **Total** | **250 (3.00)** | **8071 (97.00)** | **8321 (100.00)** |  |
| **Mothers age group (in years)** |  |  |  |  |
| 15-24 | 126 (3.19) | 3824 (96.81) | 3950 (47.47) | 0.722 |
| 25-34 | 105 (2.81) | 3613 (97.19) | 3718 (44.68) |  |
| 45+ | 19 (2.97) | 634 (97.03) | 654 (7.86) |  |
| **Vaccination** |  |  |  |  |
| Yes | 43 (3.33) | 1252 (96.67) | 1295 (79.68) | 0.014 |
| No | 3 (0.77) | 328 (99.23) | 330 (20.32) |  |
| **Mother’s education level** |  |  |  |  |
| Secondary or Higher | 29 (2.18) | 1287 (97.82) | 1316 (15.81) | 0.221 |
| Primary | 127 (3.14) | 3920 (96.86) | 4047 (48.64) |  |
| No Education | 94 (3.18) | 2864 (96.82) | 2958 (35.55) |  |
| **Mother’s BMI** |  |  |  |  |
| Obese | 10 (2.07) | 477 (97.93) | 487 (5.96) | 0.719 |
| Overweight | 54 (3.20) | 1624 (96.80) | 1678 (20.53) |  |
| Normal Weight | 150 (3.07) | 4734 (96.93) | 4734 (59.73) |  |
| Under Weight | 34 (3.04) | 1093 (96.96) | 1093 (13.79) |  |
| **Number of living children** |  |  |  |  |
| <=2 | 178 (3.00) | 5751 (97.00) | 5929 (71.26) | 0.990 |
| 3-4 | 62 (3.03) | 1994 (96.97) | 2056 (24.71) |  |
| 5+ | 10 (2.88) | 326 (97.12) | 336 (4.03) |  |
| **Mother’s occupation** |  |  |  |  |
| Agriculture | 87 (3.64) | 2314 (96.36) | 2401 (28.86) | 0.026 |
| Don’t work | 121 (2.52) | 4670 (97.42) | 4791 (57.59) |  |
| Industires | 42 (3.72) | 1085 (96.28) | 1127 (13.55) |  |
| **Mother’s work for** |  |  |  |  |
| Family | 88 (4.05) | 2077 (94.95) | 2165 (61.43) | 0.111 |
| Else | 15 (2.23) | 641 (97.77) | 655 (18.59) |  |
| Self | 27 (3.83) | 677 (96.17) | 704 (19.98) |  |
| **Household head’s occupation** |  |  |  |  |
| Agriculture | 62 (3.73) | 1590 (96.27) | 1651 (19.89) | 0.185 |
| Don’t work | 4 (1.95) | 181 (98.05) | 184 (2.22) |  |
| Industries | 185 (2.86) | 6283 (97.14) | 6468 (77.89) |  |
| **Household head’s education** |  |  |  |  |
| Secondary or Higher | 25 (1.70) | 1436 (98.30) | 1461 (17.87) | 0.017 |
| Primary | 85 (3.15) | 2600 (96.85) | 2685 (32.84) |  |
| No Education | 137 (3.40) | 3892 (96.60) | 4029 (49.29) |  |
| **Type of household head’s education** |  |  |  |  |
| School | 216 (3.10) | 6766 (96.90) | 6982 (90.36) | 0.969 |
| Madrasha | 23 (3.13) | 721 (96.87) | 745 (9.64) |  |

\*Frequencies are weighted using sample weight

Table 3 Frequency distribution of children (weighted\*) on use of solid fuel and acute respiratory infection (ARI) among children younger than 5 years in Bangladesh

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Factors | ARI |  |  |  |
|  | Yes, N (%) | No, N (%) | Total, N (%) | P-value |
| **Total** | **250 (3.00)** | **8071 (97.00)** | **8321 (100.00)** |  |
| **child's age (months)** |  |  |  |  |
| 24-59 | 112 (2.29) | 4753 (97.71) | 4865 (58.47) | <0.001 |
| 12-23 | 69 (4.09) | 1611 (95.91) | 1680 (20.19) |  |
| 0-11 | 70 (3.92) | 1706 (96.08) | 1776 (21.34) |  |
| **Sex of Child** |  |  |  |  |
| Male | 155 (3.58) | 4185 (96.42) | 4340 (52.16) | 0.003 |
| Female | 95 (2.38) | 3886 (97.62) | 3981 (47.84) |  |
| **Birth Order** |  |  |  |  |
| 1-3 | 210 (2.88) | 7074 (97.12) | 7284 (87.54) | 0.074 |
| 4-6 | 39 (4.04) | 935 (95.96) | 935 (11.71) |  |
| 6+ | 1 (0.98) | 62 (99.02) | 62 (0.75) |  |
| **Place of delivery** | | | | |
| Home | 93 (3.62) | 2468 (96.38) | 2561 (50.09) | 0.337 |
| Hospital | 79 (3.09) | 2472 (96.51) | 2551 (59.91) |  |
| **Weight at birth** | | | | |
| Low birth weight | 21 (3.03) | 677 (96.97) | 698 (30.05) | 0.762 |
| Normal birth weight | 53 (3.29) | 1572 (96.71) | 1625 (69.95) |  |
| **Delivery by C-section** |  |  |  |  |
| Yes | 49 (2.86) | 1656 (97.14) | 1705 (33.39) | 0.208 |
| No | 123 (3.61) | 3278 (96.39) | 3401 (66.61) |  |
| **Season of birth** |  |  |  |  |
| Summer | 73 (3.40) | 2077 (96.60) | 2150 (25.84) | 0.051 |
| Autumn | 46 (2.46) | 1829 (97.54) | 1875 (22.53) |  |
| Winter | 75 (3.70) | 1942 (96.30) | 2016 (24.23) |  |
| Spring | 56 (2.45) | 2224 (97.55) | 2279 (27.39) |  |
| **Medication for intestinal parasites** |  |  |  |  |
| No | 168 (3.41) | 4759 (96.59) | 4927 (59.24) | 0.145 |
| Yes | 82 (2.41) | 3301 (97.59) | 3382 (40.71) |  |
| **Vitamin A supplementation** |  |  |  |  |
| No | 66 (2.96) | 2170 (97.04) | 2236 (26.95) | 0.883 |
| Yes | 184 (3.03) | 5879 (96.97) | 6063 (73.05) |  |
| **Stunting** |  |  |  |  |
| No | 159 (2.94) | 5258 (97.06) | 5417 (69.28) | 0.217 |
| Yes | 85 (3.54) | 2316 (96.46) | 2402 (30.72) |  |
| **Wasting** |  |  |  |  |
| No | 221 (3.09) | 6924 (96.91) | 7145 (91.56) | 0.496 |
| Yes | 24 (3.60) | 635 (96.40) | 659 (8.44) |  |

\*Frequencies are weighted using sample weight

Table 4Generalized variance inflation (GVIF) value of the final model of ARI among under 5 years children in Bangladesh

|  |  |  |
| --- | --- | --- |
| Variables | Degrees of freedom | GVIF |
| **Type of cooking fuel** | 1 | 1.01 |
| **Type of roof material** | 2 | 1.02 |
| **child's age (months)** | 2 | 1.02 |
| **Sex of Child** | 1 | 1.02 |

Table 5Test for goodness of fit and predictive accuracy of the final model

|  |  |  |
| --- | --- | --- |
| Hosmer and Lemeshow goodness of fit test | | |
| Value | df | P-value |
| 8.2419 | 8 | .760 |
| Area under the curve (AUC) of the receiver operating characteristic curve (ROC) | | |
| Value | 0.61 | |

Table 6 Association between household type of fuel use and ARI among under 5 years children in Bangladesh

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Unadjusted model | | | Adjusted model1 | | |
| Variables |  | COR | 95% CI | P-value | AOR | 95% CI | P-value |
| **Type of cooking fuel** | Solid fuel | 1.693 | [1.058, 2.709] | 0.028 | 1.692 | [1.053, 2.718] | 0.030 |
|  | Clean fuel | 1 |  |  | Ref. |  |  |

*COR crude odds ratio, AOR adjusted odds ratio, CI confdence interval, Ref. reference*

1The adjusted analysis using the design-based binary logistic regression, adjusted for type of cooking fuel, Type of roof material, child's age (months), and sex of child.

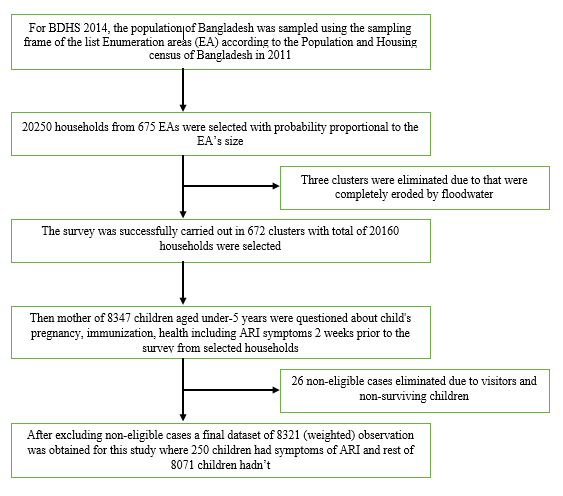


Figure 1 Sample procedure of 2017 BDHS and selection of sample for the study



Figure 2 Fuel types used in study area. LPG, liquefied petroleum gas



Figure 3 Prevalence of acute respiratory infection (ARI) in different regions of Bangladesh