Association Between Household Air Pollution and Infant and Child Mortality in Myanmar: Evidence From The First Demographic and Health Survey

Juwel Rana (juwel.rana01@northsouth.edu)
North South University https://orcid.org/0000-0001-5597-664X
Md Nuruzzaman Khan
JKKNIU: Jatiya Kabi Kazi Nazrul Islam University
Rakibul M Islam
Monash University
Razia Aliani
Pakistan Ministry of Health: Pakistan Ministry of National Health Services Regulations and Coordination
Youssef Oulhote
University of Massachusetts Amherst

Research

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Abstract

Background: Household air pollution (HAP) from solid fuel use (SFU) for cooking has been considered a public health threat, particularly for women and children in low and middle-income countries (LMICs), with limited evidence. This study was undertaken to investigate the effects of HAP on neonatal, infant, and under-five child mortality in Myanmar.

Methods: This cross-sectional study employed data from the Myanmar Demographic and Health Survey (MDHS), the first nationally representative survey conducted in 2016. Data were collected from MDHS based on stratified two-stage cluster sampling design applied in urban and rural areas. The sample consists of 3249 under-five children in the household with a 98% response rate. Exposure measures were HAP (coal and biomass) and level of exposure to HAP (no exposure, moderate and high exposure). The main outcomes were neonatal, infant, and under-five child mortality reported by mothers presented in rates and risk ratios with 95% confidence intervals, accounting for survey weight and cluster variation.

Results: The prevalence of SFU was 79.0%. The neonatal, infant and under-five child mortality rates were 26, 45, and 49 per 1,000 live births, respectively. The risks of infant (aRR 2.02; 95% CI: 1.01-4.05) and under-five mortality (aRR 2.16; 95% CI: 1.07-4.36) mortality were higher among children from households with SFU compared to children from households using clean fuel. When applying an augmented measure of exposure to HAP by incorporating SFU and the kitchen's location, the likelihoods of infant and under-five mortality were even higher among moderate and highly exposed children than unexposed children with similar trends. Neonatal mortality was not associated with either HAP exposure or levels of exposure to HAP.

Conclusion: Infants and under-five children are at higher risk of mortality from exposure to HAP. Increasing access to cookstoves and clean fuels is imperative to reduce the risk of infant and under-five child mortality in LMICs, including Myanmar.

Background

Household air pollution (HAP) is one of the world's major environmental threats, causing about 4 million premature deaths annually [1]. HAP related mortality is disproportionately higher in low and middle-income countries (LMICs). In 2017, almost 70% of all deaths related to HAP occurred in LMICs [2]. About 3 billion people use solid fuels for cooking, including coal and biomass (wood, animal dung, lignite, charcoal, straw/shrubs, grass, and agricultural crop) [3,4], which are the major sources of HAP [1].

Alternative fuel (clean fuel) such as liquefied petroleum gas and electricity is often unavailable and/or unaffordable in LMICs [5]. Therefore, households opt to collect solid fuels [3], which are burned indoors in conventional cookstoves as a pit, pieces of brick, or U-shaped mud construction. Duflo et al. illustrate via energy ladder that households with the lowest income levels use the most inefficient and the dirtiest types of fuels [6]. These solid fuels emit damaging airborne pollutants, including PM10, NOx, CO, SOx, formaldehyde, and many toxic polycyclic aromatic hydrocarbons and other organic matter due to inefficient combustion [7–9]. The amount of exposure to an individual in such settings has been measured to be much higher than the World Health Organization (WHO) guidelines and standards [10].

In LMICs, women and children are at higher risk of exposure to HAP [6,11,12] due to women's role in household chores, cooking, and caring for infants in most South Asian culture. Women spend about three to seven hours per day near the stove, sometimes carrying their infants for care and warmth during cooking that leads children exposed to biomass fuel at similar levels [3]. This exposure level increases in households with limited ventilation and poor design of the stove that do not have flues or hood to move out the smoke from living places [13].

The majority of households in Myanmar use solid fuels for cooking as easy access to biomass for domestic cooking, which is a convention [14]. Clean Cooking Alliance, Myanmar estimated that more than 95% of the rural and 88% of the urban population use solid fuels for cooking[14,15], which might be one of the contributing factors of more than 3,500 annual infant and children died from acute lower respiratory infections (ALRIs) and pneumonia in Myanmar. It could also be one of the reasons that Myanmar was unable to achieve the Millennium Development Goals (MDGs) (between 2000 and 2015) of reducing infant and child mortality [16]. Importantly, this indicates an important area to address for achieving the Sustainable Development Goals (SDGs) of reducing neonatal (12 per 10000 live birth) and infant (25 per 10000 live births) deaths between 2015 and 2030.

To our knowledge, no study has evaluated the effect of HAP from SFU on neonatal, infant, and under-five mortality rates in Myanmar using nationally representative data. The first Demographic Health Survey (DHS) in Myanmar was conducted in 2016 that provides an opportunity to examine the effect and extent of HAP on neonatal, infant, and under-five child mortality.

Methods

Study Design and Setting

Given the focus on improving maternal and child health, the Myanmar Demographic and Health Survey (MDHS) 2016 was the first nationally representative cross-sectional survey conducted in Myanmar. Data were collected from 12,885 women from the sampled households based on stratified two-stage cluster sampling design from December 2015 to July 2016. Using the 2014 Myanmar census sampling units, 442 clusters (123 urban, 319 rural) were selected in the first stage from 4,000 clusters based on the probability proportional to the size. In the second stage, 30 households from each selected cluster were selected in the first stage by using systematic random sampling. The overall response rate was approximately 98%. The survey was funded by the United States Agency for International Development and implemented by the Ministry of Health and Sports, Myanmar, in coordination with the Millennium Development Goals. Technical support was provided by ICF international. Detail of the survey sampling procedure has been published in the MDHS report [17].

Characteristics of Participants

A total of 3,249 under-five children was included in the final analysis based on their retrospective birth histories after limiting to singleton births living with their mothers at the time of the survey and excluding children with missing information on SFU (Figure 1)[17,18]. The inclusion criteria were: i) children born within five years before the date of survey (only last child and singleton births were considered in case of multiple children in five years); ii) most recent children with information of survival status (alive/death at the time of the survey); iii) children with the date of death if applicable; iv) children with complete information of household cooking fuels use[17].

Measures of Child Mortality Outcomes

We considered neonatal mortality (deaths occurred during the first 28 days of life), infant mortality (deaths occurred during the first one year (0-11 months) of life), and under-five mortality (deaths occurred during the first five years (0-59 months) of life) as outcome variables [17,19,20].

Measures of HAP Exposure

The analysis was carried out for two exposure variables: Solid Fuel Use (clean fuel *vs.* solid fuel) and level of exposure to SFU induced HAP (non-exposure, moderate exposure, and high exposure). The MDHS collected information on the types of cooking fuels by asking women- *what type of fuel does your household mainly use for cooking?* Responses were coded as clean fuel =0 (if responses were electricity, liquid petroleum gas, and natural gas) and solid fuel =1 (if responses were coal, lignite, charcoal, wood, straw/shrubs, grass, and agricultural crop). Children's levels of exposure to HAP were generated from the women's responses to the place of cooking and the type of cooking fuel use. The responses were categorized as non-exposure =0 (if women reported not using solid fuel), moderate exposure =1 (if women reported using solid fuel, but in a separate building or outdoors), and high exposure =2 (if women reported using solid fuel inside the house).

Confounder Adjustment

Different sociodemographic factors contributing to neonatal, infant, and under-five child mortality were included as confounders (Figure 2). These were age at child deaths, child sex, parental education, interval of last two succeeding births, breastfeeding status, household wealth quintiles, urbanity, geographic regions, and seasons (Figure 2). The birth interval variable was generated based on women's response to the birth date of the last two children and categorized by following the World Health Organization guidelines[17]. The wealth quintile was reconstructed from the women's household durable and non-durable assets (e.g., televisions, bicycles, sources of drinking water, sanitation facilities, and construction materials of houses) using principal components analysis, excluding the types of cooking fuels as this was the main exposure of interest [17,21].

Note: HAP is exposure, and child mortality is the outcome. The minimal and sufficient adjustment set contains child age, child sex, breastfeeding status, maternal education, household wealth quintiles, urbanicity, geographic region, preceding birth interval, and season. This figure was constructed through DAG (http://www.dagitty.net/dags.htm).

Statistical Analysis

Descriptive statistics were reported as frequency and percentage to characterize the demographic profile of the study sample. Differences in neonatal, infant, and under-five child mortality across sociodemographic factors were presented using the chi-square test. The associations between exposure to HAP and child mortality outcomes were investigated using both univariable and multilevel Poisson regression models. As an additional analysis, effect modification by sex of the child was also tested for all models. The univariate models included only the exposure variable and the outcome variable. These associations were then progressively adjusted for potential confounders in the multivariable models, including child age, child sex, breasting status, maternal education, household wealth quintiles, urbanicity, geographic region, preceding birth interval, and season. However, birth weight and wasting were not adjusted in the models as they are likely to be on the causal pathway between exposure to HAP and mortality [22–24].

Furthermore, information on exact birth weight was unavailable for most of the children[17]. Multilevel Poisson models with robust error variance to minimize the overestimation of binary outcome were developed for complex survey design effects, adjusting clustering effects, individual and household characteristics of the children[18,21]. Results were reported as adjusted relative risks (aRRs) with 95% confidence intervals (CIs). All statistical tests were two-sided, and a *p*-value < 0·05 was considered statistically significant.

Results

Characteristics of sample, exposures, and outcomes are presented in Table 1. The mean (SD) age of the mothers was 31.1 (±6.0) years. The mean years of education were 4.4 (±3.5) years. The mean age of the child was 2.1 (±0.04) years, and 47.6% of the child were girls. More than three-quarters (77.8%) of the study households used solid fuels for cooking, of which 61.5% used solid fuels at the indoor cooking places. About two-thirds (64.5%) of the women reported indoor place of cooking. Nearly half of the children (47.7%) were highly exposed to HAP during the survey (Table 1).

The rate of neonatal, infant, and under-five child mortality was 26 (95% CI: 19-53), 45 (95% CI: 35-57), and 49 (95% CI: 38-62) per 1000 live births, respectively (Table 1). Infant and under-five child mortality were slightly higher in girls, while neonatal mortality was higher in boys. A similar increasing trend was observed for infant and under-five child mortality for rural residents. Compared with ever but not current breastfeeding status, neonatal (415.6, 95% CI: 279.5-565.9), infant (465.8, 95% CI: 325.3-611.9) and under-five child mortality (465.8, 95% CI: 325.3-611.9) per 1000 live births were very high amongst mothers who never breastfeed their child. Neonatal, infant, and under-five child mortality were higher amongst richer and the richest compared with the poorest households. Infant and under-five child mortality were higher among children whose mother had no education, resided in Shan, Chin, and Teninthayi regions, and were born in the short birth interval (Table 2).

The unadjusted and adjusted associations between HAP and child mortality are presented in Table 3. The likelihood of infant mortality (2.02, aRR 95% CI: 1.01-4.05) and under-five mortality (aRR 2.16, 95% CI: 1.07-4.36) were higher for children from households who used solid fuel for cooking compared with children from households who used clean fuel. The likelihoods were even higher when we considered the augmented measure of exposure to HAP. Compared with unexposed children, infant mortality risks were 1.94 (95% CI: 0.92-4.08) and 2.15 (95% CI: 1.04-4.43) times higher among moderately and highly HAP exposed children, respectively.

A similar higher likelihood of under-five mortality was observed among children with moderate (aRR 2.11; 95% CI: 1.02-4.36) and high (aRR 2.25, 95% CI: 1.08-4.69) exposure to HAP than their counterparts. There was no association between neonatal mortality with HAP exposure and levels of exposure to HAP. As an additional analysis (not shown), we have statistically tested the effect modification of sex of children, but there were no significant sex differences in the mortality outcomes of under-five children in Myanmar.

Discussion

The first-ever nationally representative survey suggests that neonatal, infant, and under-five child mortality rates were relatively higher in Myanmar compared with other Southeast Asian countries [16,19]. Most of the households were dependent on SFU for cooking and heating purposes, and almost half of the study children were highly exposed to HAP in Myanmar. The study demonstrates that HAP and moderate and high levels of exposure to HAP increased the risk of infant and under-five child mortality, but not neonatal mortality in Myanmar.

Previous studies reported comparable results that HAP exposure from SFU increases the risk of infant and child mortality in LMICs [19,25–28]. Evidence suggests that the combustion of SFU emits multiple pollutants such as fine particles, carbon monoxide, formaldehyde, and many more toxic chemicals, which increase the risk of mortality from ALRIs, asthma, and pneumonia among infants and young children exposed to these pollutants [3,7,8,21,29–34]. Exposure to these toxic pollutants also increases the risk of stillbirth, low birth weight, and preterm birth, including acute and chronic health problems, all of which are considered leading causes of child mortality [19,28,35,36].

Previous studies suggest considering cooking place along with SFU to examine its effects on child-mortality because cooking inside the house with solid fuels maximizes the concentrations of airborne toxic pollutants in the household and ambient air [19–21,37,38]. We employed an augmented SFU exposure measure combining SFU and cooking place following the previous study and found stronger effects of high exposure to HAP on infant and child mortality [21]. Consistent with our study, previous studies showed that children were exposed to higher concentration of pollutants from SFU because of high proximity to pollutants and spending much time in the kitchen during heating and cooking, which intensifies the risk of child mortality from ALRI, including other adverse health outcomes [21,25,29]. The plausible explanation is that young children are more susceptible to HAP-induced mortality than their older counterparts due to their underdeveloped epithelial linings of the lungs [21,39]. Furthermore, infants at their early age are often carried on their mothers' backs or placed to sleep or stand beside their mother when cooking, a common practice in Southeast Asian countries, including Myanmar [19,20,40,41].

In a healthy condition, infants and young children have higher respiration, and they breathe 50% more polluted air due to their narrower airways and large lung surface. Children have a weak immune system in their early years of life, making them vulnerable to HAP induced mortality, especially from ALRI [39,42–44].

However, neonatal mortality was not significantly associated with SFU and exposure to HAP in our study, consistent with previous studies conducted in LMICs [25,45]. Several biological factors, such as low birth weight, prematurity, and complications associated with pregnancy and delivery, might be responsible for the null association between HAP and neonatal mortality [19,35,36]. Additionally, breastfeeding could work as a protective factor diminishing the effect of HAP on neonatal mortality. Moreover, neonates and mothers might live in a conducive environment right after delivery, as well as mothers usually stay away from any cooking activities during the neonatal period, which is a common cultural practice in Asia. However, few studies claim that neonates are at higher risk of HAP induced mortality [28,41], which warrant further studies.

The main strength of the study was a nationally representative survey with a 98% response rate. The analysis of large-scale data with an appropriate statistical method and adjustments for potential confounders makes the study findings more reliable for policymaking. However, the main weakness is that the temporal association between HAP exposure and child mortality outcomes cannot be established due to its cross-sectional nature. Second, the associations could be affected by unmeasured confounders and different health outcomes such as preterm birth, low birth weight, and other morbidity factors despite HAP exposure. Third, information related to the children's birth and death was reported by mothers that may introduce recall bias. However, it is unlikely that the mother would incorrectly report their children's birth and death. Fourth, there might be a source of exposure measurement error as we used two proxy measures such as SFU and combining SFU and cooking place to measure the associations between HAP exposures [21] and child mortality. However, this is the available robust and established measurement of HAP exposures because DHS does not objectively measure the level and duration of HAP exposures [20,21]. Further studies may include questions related to ventilation in the kitchen, duration of cooking, proximity to the kitchen, or heating areas to better measure children's exposure to HAP.

Conclusion

The study demonstrates that HAP is a significant risk factor for infant and under-five child mortality but not neonatal mortality. Furthermore, both moderate and high levels of exposure to HAP, such as the combination of SFU and cooking inside the kitchen, increase the risk of infant and child mortality in

Myanmar. Policymakers should take both short-term and long-term strategies through socio-environmental pathways for addressing the problem of the higher rate of child mortality in Myanmar. To reduce child mortality, the government in Myanmar should implement national policies related to clean fuels, cookstoves, and green energy and reduce the level of exposure to HAP, which will ultimately help them meet several sustainable development goals.

Abbreviations

HAP: Household Air Pollution

SFU: Solid Fuel Use

LMICs: Low and middle-income Countries

MDHS: Myanmar Demographic and Health Survey

WHO: World Health Organization

ALRIs: Acute Lower Respiratory Infections

MDGs: Millennium Development Goals

SDGs: Sustainable Development Goals

DHS: Demographic Health Survey

Declarations

Ethics approval and consent to participate

The ICF Institutional Review Board (IRB) and the Ministry of Health and Sports, Myanmar, approved the primary data collection survey protocol. We obtained the de-identified data from the DHS online archive. This is a public-use dataset. Informed consent was taken from each participant before the enrolment.

Consent for publication

Not applicable

Availability of data and materials

Myanmar Demographic Household Survey (MMDHS) data were obtained from the MEASURES DHS. The datasets generated and/or analyzed during the current study are available in the 2015-16. https://dhsprogram.com/pubs/pdf/FR324/FR324.pdf.

Code availability: All analyses were carried out using statistical software packages Stata version 16.0 [46].

Competing interests: The authors declare that they have no competing interests.

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Authors' Contribution: JR, MNK, RI developed the study concepts. JR and MNK analyzed the data. JR, MNK, RI, and RA wrote the original draft of the manuscript. RI and YO supervised, reviewed, and revised the manuscript. All authors critically read, reviewed, and approved the submitted version.

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References

1. World Health Organization. Household air pollution and health: Fact sheet [Internet]. 2018 [cited 2019 Apr 10]. Available from: https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health
2. Roser M, Ritchie H. Indoor Air Pollution [Internet]. Our World Data. 2019 [cited 2019 Apr 10]. Available from: https://ourworldindata.org/indoor-air-pollution
3. Po JYT, FitzGerald JM, Carlsten C. Respiratory disease associated with solid biomass fuel exposure in rural women and children: systematic review and meta-analysis. Thorax. BMJ Publishing Group Ltd; 2011;66:232–9.
4. Smith KR, Mehta S. Indoor air pollution from household use of solid fuels. In: Ezzati MLA, Rodgers A MC, editor. Comp Quantif Heal Risks Glob Reg Burd Dis Due to Sel Major Risk Factors Glob Reg Burd Dis Attrib to Sel Major Risk Factors. Geneva: World Health Organization; 2004. p. 1435–93.
5. Torres-Duque C, Maldonado D, Perez-Padilla R, Ezzati M, Viegi G, Forum of International Respiratory Studies (FIRS) Task Force on Health Effects of Biomass Exposure. Biomass Fuels and Respiratory Diseases: A Review of the Evidence. Proc Am Thorac Soc. 2008;5:577–90.
6. Duflo E, Greenstone M, Hanna R. Indoor air pollution, health and economic well-being. S.A.P.I.EN.S. 2008.
7. Lai AM, Carter E, Shan M, Ni K, Clark S, Ezzati M, et al. Chemical composition and source apportionment of ambient, household, and personal exposures to PM2.5 in communities using biomass stoves in rural China. Sci Total Environ [Internet]. 2019 [cited 2019 Aug 6];646:309–19. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0048969718328183
8. Kodros JK, Carter E, Brauer M, Volckens J, Bilsback KR, L'Orange C, et al. Quantifying the Contribution to Uncertainty in Mortality Attributed to Household, Ambient, and Joint Exposure to PM $_{2.5}$ From Residential Solid Fuel Use. GeoHealth [Internet]. 2018 [cited 2019 Aug 6];2:25–39. Available from: http://doi.wiley.com/10.1002/2017GH000115

9. Agrawal S, Yamamoto S. Effect of Indoor air pollution from biomass and solid fuel combustion on symptoms of preeclampsia/eclampsia in Indian women. Indoor Air [Internet]. John Wiley & Sons, Ltd (10.1111); 2015;25:341–52. Available from: http://doi.wiley.com/10.1111/ina.12144
10. Bonjour S, Adair-Rohani H, Wolf J, Bruce NG, Mehta S, Prüss-Ustün A, et al. Solid fuel use for household cooking: Country and regional estimates for 1980-2010. Environ Health Perspect. 2013;121:784–90.
11. Baumgartner J, Schauer JJ, Ezzati M, Lu L, Cheng C, Patz J, et al. Patterns and predictors of personal exposure to indoor air pollution from biomass combustion among women and children in rural China. Indoor Air [Internet]. John Wiley & Sons, Ltd (10.1111); 2011;21:479–88. Available from: http://doi.wiley.com/10.1111/j.1600-0668.2011.00730.x
12. Kodgule R, Salvi S. Exposure to biomass smoke as a cause for airway disease in women and children. Curr Opin Allergy Clin Immunol [Internet]. 2012;12:82–90. Available from: https://insights.ovid.com/crossref?an=00130832-201202000-00015
13. Fullerton DG, Bruce N, Gordon SB. Indoor air pollution from biomass fuel smoke is a major health concern in the developing world. Trans R Soc Trop Med Hyg. Elsevier; 2008;102:843–51.
14. Myanmar factsheet - Clean Cooking Alliance [Internet]. Glob. Alliance Clean Cookstove. 2018 [cited 2019 May 5]. Available from: https://www.cleancookingalliance.org/binary-data/RESOURCE/file/000/000/508-1.pdf
15. Clean Cooking Alliance- Myanmar [Internet]. United Nations Found. 2019 [cited 2019 Apr 4]. Available from: https://www.cleancookingalliance.org/country-profiles/58-myanmar.html
16. CESD and the International Management Group. Myanmar's Experiences with the Millennium Development Goals and Perspectives on the Post 2015 Agenda [Internet]. 2014. Available from: https://mdricesd.files.wordpress.com/2014/02/publication-experiences-with-mdgs-2014-en-sm.pdf
17. Ministry of Health and Sports (MoHS) and ICF. Myanmar Demographic Household Survey 2015-16 [Internet]. Nay Pyi Taw, Myanmar, and Rockville, Maryland USA; 2017. Available from: https://dhsprogram.com/pubs/pdf/FR324/FR324.pdf
18. Kleimola LB, Patel AB, Borkar JA, Hibberd PL. Consequences of household air pollution on child survival: evidence from demographic and health surveys in 47 countries. Int J Occup Environ Health [Internet]. Taylor & Francis; 2015;21:294–302. Available from: http://dx.doi.org/10.1179/2049396715Y.0000000007
19. Khan MN, B. Nurs CZ, Mofizul Islam M, Islam MR, Rahman MM. Household air pollution from cooking and risk of adverse health and birth outcomes in Bangladesh: a nationwide population-based study. Environ Heal [Internet]. 2017 [cited 2019 Aug 6];16:57. Available from: http://ehjournal.biomedcentral.com/articles/10.1186/s12940-017-0272-y
20. Naz S, Page A, Agho KE. Household air pollution from use of cooking fuel and under-five mortality: The role of breastfeeding status and kitchen location in Pakistan. PLoS One. 2017;12.
21. Rana J, Uddin J, Peltier R, Oulhote Y. Associations between Indoor Air Pollution and Acute Respiratory Infections among Under-Five Children in Afghanistan: Do SES and Sex Matter? Int J Environ Res

Public Health. 2019;16:2910.

22. Kirk R Smith, Jonathan M Samet, Isabelle Romieu NB. Indoor Air Pollution in Developing Countries and Acute Respiratory Infection in Children. Thorax. 2000;55:518–32.
23. Vanderweele TJ, Mumford SL, Schisterman EF. Conditioning on intermediates in perinatal epidemiology. Epidemiology. 2012;23:1–9.
24. Hernández-Díaz S, Schisterman EF, Hernán MA. The birth weight “paradox” uncovered? Am J Epidemiol. 2006;164:1115–20.
25. Kingsley Ezeh O, Agho KE, Dibley MJ, Hall JJ, Page AN. The effect of solid fuel use on childhood mortality in Nigeria: evidence from the 2013 cross-sectional household survey. Environ Heal [Internet]. 2014 [cited 2019 Aug 10];12:113. Available from: http://www.ehjournal.net/content/13/1/113
26. Balakrishnan K, Dey S, Gupta T, Dhaliwal RS, Brauer M, Cohen AJ, et al. The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: the Global Burden of Disease Study 2017. Lancet Planet Heal. 2019;3:e26–39.
27. Bassani DG, Jha P, Dhingra N, Kumar R. Child mortality from solid-fuel use in India: A nationally-representative case-control study. BMC Public Health. 2010;10.
28. Kleimola LB, Patel AB, Borkar JA, Hibberd PL. Consequences of household air pollution on child survival: evidence from demographic and health surveys in 47 countries. Int J Occup Environ Health [Internet]. 2015;21:294–302. Available from: http://www.ncbi.nlm.nih.gov/pubmed/25843087
29. Gordon PSB. Europe PMC Funders Group Respiratory risks from household air pollution in low and middle income countries. Lancet Respir Med [Internet]. 2016;2:823–60. Available from: http://pubmedcentralcanada.ca/pmcc/articles/PMC5068561/pdf/emss-70175.pdf
30. Secrest MH, Schauer JJ, Carter EM, Baumgartner J. Particulate matter chemical component concentrations and sources in settings of household solid fuel use. Indoor Air [Internet]. 2017 [cited 2019 Aug 6];27:1052–66. Available from: http://doi.wiley.com/10.1111/ina.12389
31. Bartington SE, Bakolis I, Devakumar D, Kurmi OP, Gulliver J, Chaube G, et al. Patterns of domestic exposure to carbon monoxide and particulate matter in households using biomass fuel in Janakpur, Nepal. Environ Pollut. 2017;220:38–45.
32. Dherani M, Pope D, Mascarenhas M, Smith K, Weber M, Bruce N. 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 [Internet]. 2008;86:390-398C. Available from: http://www.ncbi.nlm.nih.gov/pubmed/18545742
33. Misra P, Srivastava R, Krishnan A, Sreenivaas V, Pandav CS. Indoor Air Pollution-related Acute Lower Respiratory Infections and Low Birthweight: A Systematic Review. [cited 2019 Aug 10]; Available from: https://academic.oup.com/tropej/article-abstract/58/6/457/1677194
34. Perera FP. Multiple threats to child health from fossil fuel combustion: Impacts of air pollution and climate change. Environ Health Perspect. 2017;125:141–8.

35. Mugo NS, Mya KS, Raynes-Greenow C. Exploring causal pathways for factors associated with neonatal, infant and under-five mortality, analysis of 2015-2016 Myanmar Demographic Health Survey. J Glob Heal Reports. 2019;3:1–17.
36. Pope DP, Mishra V, Thompson L, Siddiqui AR, Rehfuess EA, Weber M, et al. Risk of Low Birth Weight and Stillbirth Associated With Indoor Air Pollution From Solid Fuel Use in Developing Countries. Epidemiol Rev [Internet]. 2010 [cited 2019 Aug 10];32:70–81. Available from: http://www.who.int/indoorair/publications/fuelforlife/en/index.html
37. Yu K, Qiu G, Chan KH, Lam KBH, Kurmi OP, Bennett DA, et al. Association of solid fuel use with risk of cardiovascular and all-cause mortality in rural China. JAMA - J Am Med Assoc. 2018;319:1351–61.
38. Gutman R, Rubin DB, Vansteelandt S. Analyses that Inform Policy Decisions [with Discussions] [Internet]. 2012. Available from: https://about.jstor.org/terms
39. Khalequzzaman M, Kamijima M, Sakai K, Chowdhury NA, Hamajima N, Nakajima T. Indoor air pollution and its impact on children under five years old in Bangladesh. Indoor Air. 2007;17:297–304.
40. Gouveia N, Junger WL, Romieu I, Cifuentes LA, de Leon AP, Vera J, et al. Effects of air pollution on infant and children respiratory mortality in four large Latin-American cities. Environ Pollut. 2018;232:385–91.
41. Naz S, Page A, Agho KE. Household Air Pollution and Under-Five Mortality in Bangladesh (2004-2011). Int J Environ Health Res [Internet]. 2015 [cited 2019 Aug 10];12:12847–62. Available from: www.mdpi.com/journal/ijerphArticle
42. Mishra V, Smith KR, Retherford RD. Effects of cooking smoke and environmental tobacco smoke on acute respiratory infections in young Indian children. Popul Environ. 2005;26:375–96.
43. Sonego M, Chiara Pellegrin M, Becker G, Lazzerini M. Risk Factors for Mortality from Acute Lower Respiratory Infections (ALRI) in Children under Five Years of Age in Low and Middle-Income Countries: A Systematic Review and Meta-Analysis of Observational Studies. PLoS One [Internet]. 2015 [cited 2019 Aug 10];10. Available from: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0116380
44. Gordon SB, Bruce NG, Grigg J, Hibberd PL, Kurmi OP, Lam K bong H, et al. Respiratory risks from household air pollution in low and middle income countries. Lancet Respir. Med. 2014. p. 823–60.
45. Epstein MB, Bates MN, Arora NK, Balakrishnan K, Jack DW, Smith KR. Household fuels, low birth weight, and neonatal death in India: The separate impacts of biomass, kerosene, and coal. Int J Hyg Environ Health [Internet]. Urban & Fischer; 2013;216:523–32. Available from: https://www.sciencedirect.com/science/article/pii/S1438463912001423?via%3Dihub
46. StataCorp. Stata Statistical Software: Release 16. College Station, TX: StataCorp LP; 2019.

Tables

Table 1: Key information about the study participants, exposure, and outcome variables

Demographics of mothers	**Frequency (n= 3249)**	**Mean (SD)**
Mean age in years	3249	31.1 (±6.0)
Mean weight in kilograms	3249	53.9 (±10.9)
Mean year of education	3249	4.4 (±3.5)
Demographics of under-five children		
Mean age in years	3249	2.1 (±0.04)
Girl % (95% CI)	1559	47.6 (45.4-49.8)
Exposure to HAP		**Weighted % (95% CI)**
Solid fuel use	2560	77.8 (74.1-81.1)
Indoor solid fuel use	1579	61.5 (57.7-65.2)
Level of exposure to HAP		
No exposure	689	22.4 (19.1-26.1)
Moderate exposure	956	29.9 (26.8-33.0)
High exposure	1579	47.7 (43.9-51.6)
Outcomes		**Weighted % (95% CI)**
Neonatal mortality per 1000 live birth	89	26.0 (19.0-35.0)
Infant mortality per 1000 live birth	144	45.0 (35.0-57.0)
Under-five mortality per 1000 live birth	158	49.0 (38.0-62.0)

SD= standard deviation, CI= confidence interval, HAP= household air pollution

Table 2: Neonatal, infant, and under-five child mortality rates by sociodemographic and spatial factors (Weighted)

Sociodemographic and spatial factors	Neonatal mortality per 1000 (95% CI)	Infant Mortality per 1000 (95% CI)	Under-five mortality per 1000 (95% CI)
Mothers' mean (±SD) age at childbirth	31.8 (±0.66)	31. 48 (±0.53)	31.78 (0.51)
Mean (±SD) age of the child	0 (±0.24)		3.93 (±0.65)
Sex of child			
Male	27.0 (19-39.1)	44.0 (32.1-60.1)	48.2 (35.1-65.2)
Female	25.1 (16.2-40.1)	46.4 (33.3-63.1)	49.2 (36.2-67.3)
Breastfeeding status			
Never	415.6 (279.5-565.9)	465.8 (325.3-611.9)	465.8 (325.3-611.9)
Ever	26.9 (18.7-38.6)	59.2 (44.2-78.7)	66.0 (49.2-88.1)
Mothers' education			
None	44.2 (28.3-68.4)	77.4 (52.2-112.4)	83.3 (55.1-124.3)
Primary	18.4 (11.2-31.4)	36.1 (25.2-52.2)	40.0 (29.1-56.3)
Secondary	21.4 (12.0-37.3)	29.3 (18.1-48.3)	30.0 (19.0-49.1)
Higher	51.3 (15.2-161.3)	51.2 (15.2-161.1)	51.2 (15.1-161.1)
Wealth quintile			
Poorest	19.3 (08.1-39.2)	40.4 (24.0-66.3)	42.3 (26.0-68.1)
Poor	21.4 (11.0-41.4)	32.4 (19.4-55.5)	38.2 (22.1-66.3)
Middle	32.0 (18.3-56.4)	48.2 (31.6-73.4)	54.2 (36.1-80.1)
Richer	27.3 (16.1-48.2)	55.3 (35.1-85.2)	59.2 (39.2-90.1)
Richest	28.3 (15.3-49.4)	45.2 (29.2-71.2)	45.2 (29.1-71.6)
Urbanicity			
Urban	28.3 (16.6-48.4)	43.8 (27.5-68.6)	46.4 (29.3-71.5)
Rural	26.4 (18.5-36.6)	46.6 (34.0-61.6)	50.3 (37.2-66.4)
Geographic region			
Kachin	24.4 (10.5-57.4)	03.1 (01.4-07.0)	35.5 (16.5-75.3)

Kayah	22.5 (11.4-45.7)	02.9 (01.5-05.6)	29.5 (15.4-57.4)
Kayin	19.6 (05.0-71.9)	31.0 (12.7-76.4)	35.4 (14.3-86.5)
Chin	53.4 (36.5-79.5)	75.3 (53.0-106.4)	83.3 (55.4-122.1)
Sagaing	24.3 (08.5-69.3)	28.5 (11.3-72.4)	32.3 (13.3-76.6)
Tenintha	17.5 (06.5-50.4)	52.3 (20.4-127.9)	69.6 (32.2-143.2)
Bago	21.4 (08.0-57.4)	33.2 (15.1-69.6)	33.2 (15.3-69.4)
Magway	24.4 (10.5-59.6)	37.6 (19.8-67.4)	43.2 (22.4-84.6)
Mandalay	13.5 (03.5-50.4)	38.4 (16.4-86.4)	38.8 (16.6-86.4)
Mon	18.3 (07.3-45.3)	37.1 (16.4-81.4)	43.5 (18.1-101.1)
Rakhine	33.5 (14.6-76.6)	38.6 (18.6-76.4)	38.4 (18.3-76.4)
Yangon	27.3 (06.1-119.4)	43.1 (14.5-122.5)	43.4 (14.2-122.5)
Shan	38.2 (20.0-70.6)	79.5 (45.5-135.5)	84.5 (45.6-151.4)
Ayeyarwa	32.1 (13.0-73.5)	55.6 (28.4-103.6)	60.0 (32.4-108.5)
Naypyiataw	07.5 (0.9-40.4)	20.0 (06.0-56.5)	20.4 (07.4-57.4)
Birth interval			
First birth	20.7 (12.9-33.2)	31.9 (21.8-46.3)	35.0 (24.6-49.7)
≥24 months	23.1 (16.4-33.3)	39.3 (30.4-50.5)	43.4 (33.6-55.5)
<24 months	47.5 (25.4-84.5)	83.5 (51.8-131.1)	88.6 (55.4-136.6)
Seasons			
Summer (March-April)	15.6 (08.4-28.5)	46.4 (28.5-75.0)	51.5 (30.5-87.4)
Rainy (May-July)	10.4 (03.5-40.6)	18.7 (0.7-40.6)	20.6 (08.3-47.5)
Winter (December-February)	33.3 (23.4-46.3)	48.6 (36.4-64.6)	51.5 (39.4-67.5)

Table 3: Associations between HAP exposure and risk of neonatal, infant, and under-five child mortality in Myanmar

Exposures	Neonatal Mortality		Infant Mortality		Under-five Mortality	
	RR (95% CI)	aRR (95% CI)++	RR (95% CI)	aRR (95% CI)++	RR (95% C)	aRR (95% CI)++
Exposure to HAP						
Clean fuel	1.00	1.00	1.00	1.00	1.00	1.00
Solid fuel	1.53 (0.69-3.38)	0.95 (0.64-1.40)	1.59 (0.85-2.98)	2.02 (1.01-4.05)*	1.77 (0.93-3.32)	2.16 (1.07-4.36)*
Levels of exposure to HAP						
No exposure	1.00	1.00	1.00	1.00	1.00	1.00
Moderate	1.72 (0.73-4.08)	0.96 (0.66-1.39)	1.66 (0.82-3.33)	1.94 (0.92-4.08)	1.83 (0.93-3.61)	2.11 (1.02-4.36)*
High	1.41 (0.63-3.15)	1.02 (0.67-1.54)	1.56 (0.83-2.94)	2.15 (1.04-4.43)*	1.73 (0.91-3.31)	2.25 (1.08-4.69)*

*p<0.05, **p<0.01, aRR=adjusted Relative Risks, CI= confidence interval; ++ Multilevel Poisson Regression models were adjusted for child age, child sex, breasting status, maternal education, household wealth quintiles, urbanicity, geographic region, preceding birth interval and season.

Figures

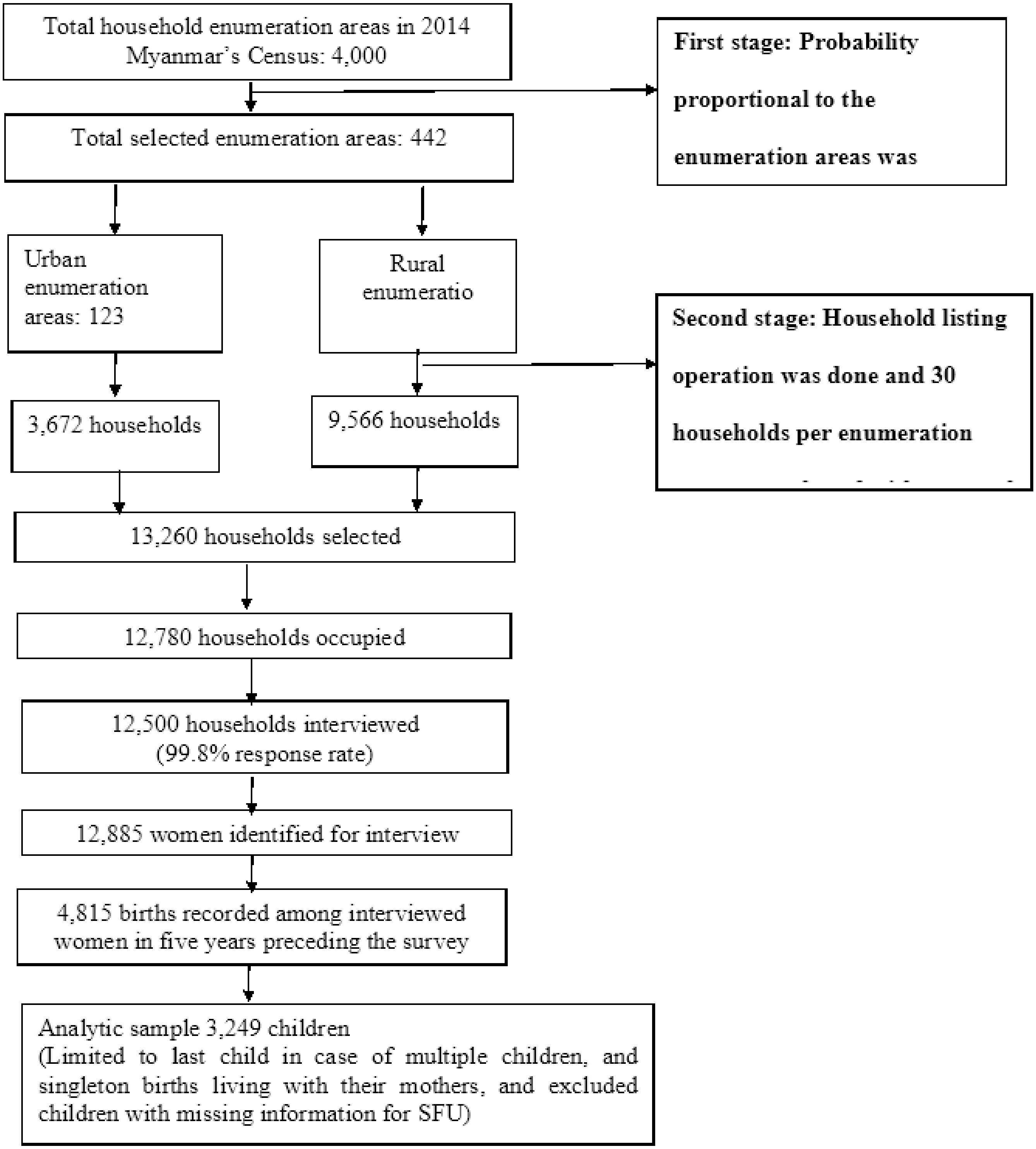

Figure 1

Schematic of the analytic sample selection process for child mortality in Myanmar

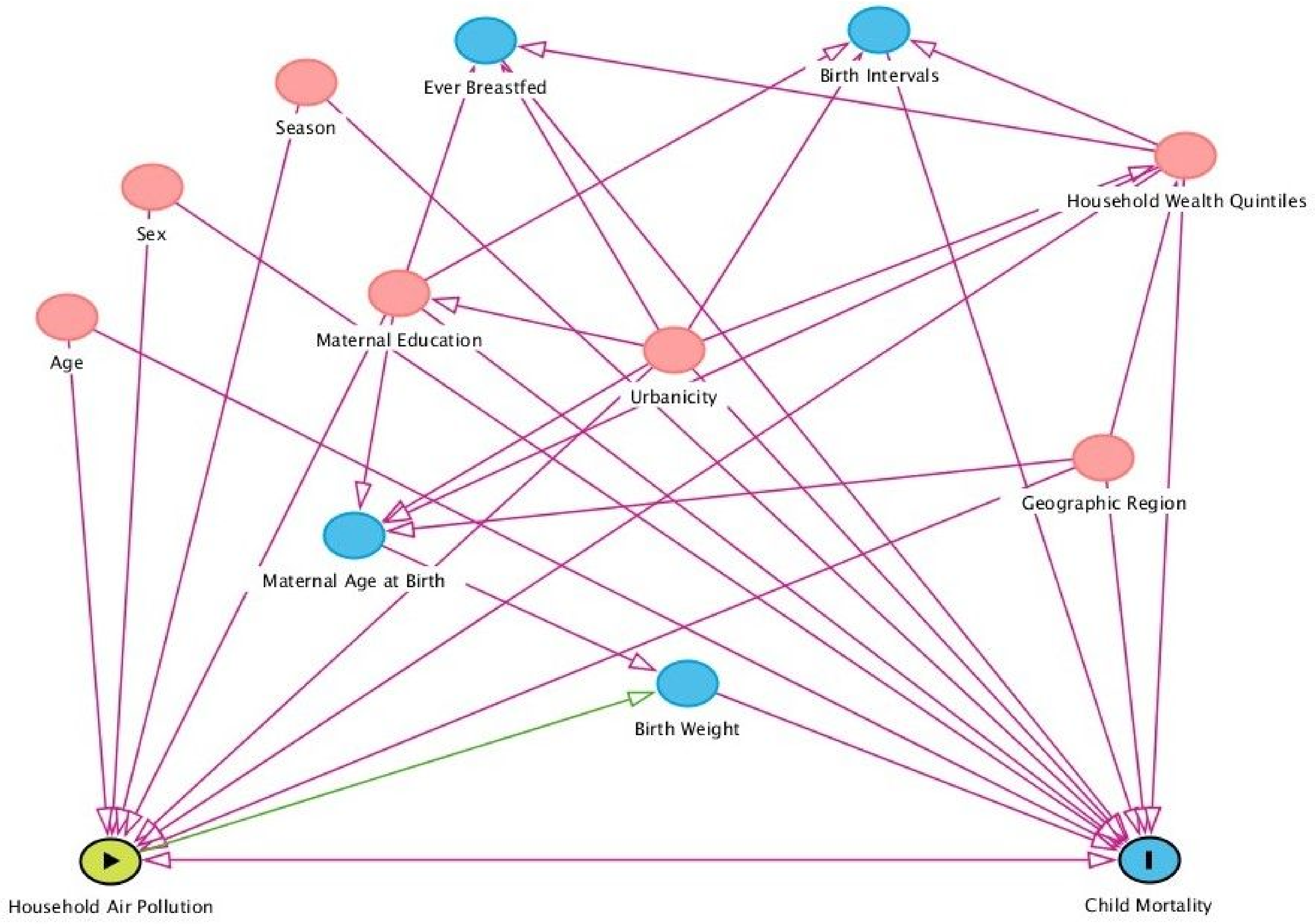

Figure 2

A directed acyclic graph (DAG) for evaluation of covariates selection in the analysis of effects of HAP on child mortality.