The association between indoor air pollution and low birth weight in Delhi and Himachal Pradesh, India: a cross-sectional study

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Abbreviations

AAP - Ambient Air Pollution

ANC - Antenatal Care

AP - Air Pollution

AQI - Air Quality Index

BMI - Body Mass Index

CO - Carbon Monoxide

COPD - Chronic obstructive pulmonary disease

DHS - Demographic and Health Survey

GA - Gestational Age

HAP - Household Air pollution

IAP - Indoor Air pollution

LBW - Low Birth Weight

LPG - Liquified Petroleum Gas

NBW - Normal Birth Weight

NLBW- Normal Birth Weight

NPTB - Non- Preterm Birth

$PM_{2.5}$ - Particulate matter smaller than 2.5 microns

PTB - Preterm Birth

SGA - Small for gestational age

SHS - Second-hand smoke

WHO - World Health Organization

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Abstract

Background: Low birth weight (LBW) is a serious public health problem associated with increased risk for many diseases including cardiovascular, neurodevelopmental and multiple organ system disorders. India has the highest number of preterm births and newborn deaths globally. There are several risk factors associated with LBW, including indoor air pollution. Indoor air pollution has multiple causes, including use of solid fuels for cooking, which emit particulate matter polluting the indoor air. Tobacco exposure via maternal smoking or passive smoking can cause adverse health effects for the mother and the fetus, including LBW. Smoking inside households, absence of ventilation in households and use of polluting fire stoves significantly contribute to deterioration of indoor air quality.

Aim: The aim of this study was to investigate the association between indoor air pollution (IAP) and LBW among infants born during 2014-2016 to mothers living in Delhi and Himachal Pradesh, India. Additionally, the study investigated the association between indoor exposure to tobacco smoke and LBW among the study sample.

Methods: The National Family Health Survey-4 dataset was used to conduct secondary data analysis. All the analyses were weighted for sampling to ensure the representativeness of the study sample and reduce sampling error. The variables significantly associated with the outcome in the descriptive analysis were included in univariate regression analysis with the two independent variables to identify the confounders of the associations of interest, and on the basis of the results, the adjusted associations between the outcome of LBW and each of the independent variables – indoor air pollution score and exposure to second-hand smoke, were investigated by performing multivariable logistic regression analysis to control for the identified confounders of each association.

Results: Women with LBW babies constituted 22% of the study sample. The study sample included 74% residing in Delhi and 26% in Himachal Pradesh. The mean age of women included in the sample was 26 years. Multivariable logistic regression analysis revealed an insignificant association between the IAP score and odds of having a LBW baby when adjusted for available confounders. A significant association was observed in the adjusted multivariable logistic regression analysis between second-hand smoke (SHS) exposure inside the household and odds of having a LBW baby. Women who were exposed to indoor SHS weekly or more frequently, showed a 42% higher odds of having a LBW baby as compared to those women who were exposed to indoor SHS monthly or less frequently.

Conclusion: Interventions targeting reduction of SHS exposure to vulnerable groups like pregnant women could greatly decrease the LBW prevalence attributable to SHS exposure in India. The lack of association between IAP score and LBW could be due to some construct deficiencies of the score used in this study. Therefore, further research using particulate matter monitors to directly quantify the quality of indoor air in India is recommended to determine the true association between IAP and LBW.

1. Introduction

1.1 Background

Birth weight and infant gestational age influence the health and survival of a newborn infant.[1,2] The birth weight of a healthy infant ranges from 2.5 kg to 4 kg and is considered the normal birth weight (NBW) of an infant.[3] This weight is deemed appropriate for gestational age (AGA) when the baby is born after 37 weeks of gestation.[3,4] Low birth weight (LBW), as defined by WHO, is when a baby weighs less than 2.5 kg.[5] Low birth weight can be further categorized into "very low birth weight for babies weighing less than 1.5 kg (up to, and including 1.49 kg)" and "extremely low birth weight for babies weighing less than 1kg (up to, and including 0.999 kg)."[3,6] The gestational age (GA) is defined as the time interval from conception to birth, typically ranging from 38 to 40 weeks.[3] The GA is considered to be at term (at the expected time of delivery for the normal duration of a healthy pregnancy) within this duration.[3] GA is considered preterm for babies born before 37 weeks.[3,7] A baby weighing less than 2.5 kg at term (delivery at 38-40 weeks) is considered "small for gestational age" (SGA). [3] A baby that weighs more than 4 kg after 37 weeks of gestation is considered "large for gestational age".[3]

LBW is primarily caused because of premature births and intrauterine growth restriction.[8,9] Factors that considerably increase LBW risk include multiple births, belonging to a certain race or ethnicity, frequency of antenatal care visits (ANC), and maternal factors such as young age and poor nutrition.[10–12] Babies who are born SGA are more common among preterm birth (PTB).[13,14]

1.2 Global burden

Approximately "one million children die every year due to preterm birth complications, and it is the leading cause of mortality for children under 5 years of age."[7] Among all global births, 15 – 20% are LBW.[5] According to WHO, "there are 15 million cases of preterm births every year." [7,15] About 90% of urban women worldwide deliver with professional medical assistance and an estimated 72% of rural women deliver at home, indicating an urban-rural gap of approximately 18%.[16,17] Lower than half of the births in low-income and lower middle income countries have medical assistance, and as a result many LBW cases are underreported since the babies are not weighed at birth at healthcare institutions.[16,18] Numerous studies demonstrate morbidities related to LBW, including neurodevelopmental, cardiovascular, respiratory, periodontal, multiple organ system disorders, and metabolic conditions such as type 2 diabetes.[7,19–22] Some of these diseases include chronic kidney disease, respiratory distress syndrome, hypoglycemia, and patent ductus arteriosus.[19–21,7] Studies also demonstrate that LBW babies have a 20-times higher chance of fatality than NBW babies.[23] One study states that hyperbilirubinemia (increased bilirubin level in blood) is the most common cause of LBW morbidity.[24]

Approximately 3 billion people utilize solid fuels and polluting open fires for cooking.[25] According to WHO's 2016 "Global Burden of Disease" study, IAP, also known as household air pollution (HAP), takes place when household's indoor air quality is affected. IAP is a major environmental risk factor, and exposure to IAP caused significant associations with risk factors contributing to disease development.[26] Approximately, 2.6% of global disease is attributable to IAP from combustion of solid fuels.[27] Annually, "3.8 million people prematurely die from diseases caused by IAP".[25]

Worldwide, 22% of the population over 15 years of age, practice cigarette smoking.[28] Cigarette smoke contains more than 7000 chemicals, and approximately 250 of them are known to cause health problems.[29] One of these chemicals is nicotine, which is the most studied chemical and is associated with LBW. [30] Nicotine exposure in any form causes a decrease in uteroplacental blood circulation, which results in a reduction in fetal weight gain due to insufficient provision of nutrients.[30] This causes improper fetal growth and thus results in adverse birth outcomes such as SGA, LBW, stunting, diminished fetal neural development, etc.[30] WHO recommends smoking cessation and minimum to no exposure to tobacco smoke during pregnancy as the safest environment for a pregnant mother.[28]

2. Conceptual framework

Two conceptual frameworks were analyzed to identify the risk factors associated with LBW. These two frameworks cover different aspects of LBW determinants. Both frameworks were utilized to look at all possible LBW dimensions, and both frameworks are inter-related to each other on every level. These frameworks were developed using findings from previously conducted studies that identified factors associated or possibly lying in the causal pathway of LBW, and their influence on the infant's health.[31,32] (Appendix 5, Appendix 6) The primary framework used to determine risk factors in this study is the framework by Magadi et al.[33] This framework was developed by analysing the pathways of determinants of unfavourable birth outcomes in Kenya, and significant associations were grouped and mapped into pathways. The main groupings included socio-economic and demographic factors, factors related to reproductive behavior and access to maternal care facilities, maternal health care and nutritional status, as well as multiple births and child's sex (Appendix 6).

2.1 Maternal risk factors associated with LBW

2.1.1 Maternal health and nutritional status

Factors associated with LBW include maternal age, maternal nutritional status, maternal weight, and genetic predispositions of mothers, including having a family history of PTB.[34–37] Studies show that maternal anemia also contributes to LBW births.[38,39]

A study conducted in Italy which included 9 maternity hospitals, showed a positive correlation between risk for preterm births for mothers involved in heavy load work.[40] The same study also showed that mothers who had a body mass index (BMI) > 25 were at an increased risk for PTB.[40]

Metabolic disorders (e.g., chronic hypertension), gestational diabetes, glucose metabolism disorders (e.g., maternal hypoglycemia or relative hyperinsulinemia), endocrinological diseases (e.g., hyperthyroidism), renal diseases, genitourinary anomalies, cardiorespiratory diseases, diseases inducing hypoxemia (low blood oxygen saturation) and autoimmune disorders like systemic lupus erythematosus and antiphospholipid syndrome all are found to be associated with LBW.[51–53,41,42,43–50] Uterine malformations, whether congenital or acquired, also show a significant association with delivering LBW children.[54,55]

2.1.2. Reproductive behavior and accessibility of a maternal health care facility

Primiparity (giving birth to the first child) and multiparity (giving birth to multiple children, not during a single delivery) after the fourth child are associated with a higher risk for delivering LBW babies.[56] However, many studies conclude that birth order is positively associated with LBW therefore, the existing evidence is contradictory, which makes the association uncertain.[39,57,58] A study conducted in Germany found that children born after third pregnancy weighed 180 grams heavier on average than the first-born children. [57] The study also found that the pre-pregnancy BMI of mothers was higher in subsequent pregnancies but a decrease in maternal weight gain by an approximate of 2 kgs was observed with increase in the birth order.[57] A systematic review of 15 studies found that the odds of LBW and PTB cases were higher in the population with unintended pregnancies than in the population with intended pregnancies, which suggests that "desirability of pregnancy" is also a potential risk factor associated with LBW.[59] A short interval between two consecutive pregnancies also poses a higher risk for LBW.[60,39] WHO guidelines state that practicing a healthy timing and spacing of pregnancy of at least 24 months after a live birth could significantly decrease the risk of post-partum complications in subsequent pregnancies.[61] The number of Antenatal Care (ANC) visits significantly affects the birth outcome, and lower numbers of ANC visits are significantly associated with LBW births.[62,63] WHO recommends having at least 8 ANC visits during a pregnancy.[64] Maternal obstetrical history of repeated abortions, miscarriages, and cesarean sections is also associated with having LBW babies.[36,65,56,40]

Poor access to healthcare services which could be due to longer transportation time to the nearest healthcare or obstetrical care facility could lead to poor utilization of healthcare services, which results in receiving less prenatal care than a mother requires.[66] This can be a cause for ineffective screening and treatment for the mothers, which might lead to LBW births.[66]

2.1.3 Sex of child and multiple births

Although not in the pathway of association with the rest of the risk factor categories, sex of the child and multiple births are associated with LBW. Giving birth to multiple children during a single pregnancy, i.e., twins, triplets, etc., is seen to physiologically cause a decrease in the birth weight of the children.[67] A possible explanation may be the sharing of maternal nutrition among babies.[68,67] Studies also show that the weight among these babies can be non-equally distributed among each of these babies in-utero and often the one with the lower birth weight has less chance to survive.[68–70] Female babies have a higher risk of being low birth weight than male babies, in studies conducted in Nigeria and China.[71,63]

2.1.4. Sociodemographic risk factors

According to the conceptual framework by Magadi et al., socioeconomic and demographic factors are the primary determinants for adverse birth outcomes.[32]

Socioeconomic status

According to the existing evidence from Mexico, an estimated 40% of variation in fetal growth and birth weight are attributable to genetic factors, and the remaining 60% is attributable to environmental factors.[72,73] There is a significant association of women belonging to a lower socioeconomic status with being at a higher risk for having babies with

PTB and SGA.[73,74] Women belonging to a lower socioeconomic status are less likely to take proper dietary supplementations such as Iron and folate (B_9) and consume fewer fresh green vegetables and red meat, which are required for proper fetal growth.[75,76] Habits such as alcohol consumption, drug abuse, and smoking are also more common among lower socioeconomic groups.[75,76] Along with lower access to healthcare, women belonging to lower socioeconomic status have an increased stress level, which influences fetal growth.[76,75] Many factors related to having LBW infants, such as maternal education level, marital status, maternal weight, and having a healthy and safe living environment such as one with proper insulation from outdoor air pollution, are all reflective of the socioeconomic status.[77]

Education level of mothers

Education increases awareness and improves intention to act.[78] In a study conducted in the US that compared women of different races and different educational levels, the risk for LBW delivery was higher among white women who had an education level of lower than high school than for women who were college graduates.[11,76] Studies conducted in Northern India show that the education level of mothers is significantly associated with LBW. [79]

Ethnicity

Certain castes/tribes are more likely to be grouped among different levels of socioeconomic status.[80,77,81] Although there have been many attempts to remove this barrier, certain communities continue to face adverse income issues and employment disparities due to being grouped among a particular caste or tribe, particularly those belonging to "lower castes" and other backward castes such as scheduled caste and scheduled tribe.[77,80–82] This socioeconomic disparity can affect multiple strata of factors associated with LBW births, such as access to healthcare, insurance coverage, healthy nutritional supplementation, etc.

Marital Status

Mothers who are unmarried are more likely to have children with adverse birth outcomes than married mothers.[83] A possible explanation could be that unmarried mothers with a premarital sexual history have an increased rate of abortions or following improper or non-conventional birth control methods.[84–86] This could be due to the fear of facing stigma for "birth out of wedlock." [84–86]

Maternal smoking and alcohol consumption

Maternal smoking is a significant risk factor associated with LBW and PTB, among other adverse birth outcomes.[87–89] A systematic review and meta-analysis of 36 studies found that heavy maternal alcohol consumption was significantly associated with LBW when compared to abstainers.[90] Prenatal maternal exposure to more than one cigarette daily, as well as passive smoking and wood smoke exposure in the household are associated with a significant decrease in the birth weight of babies.[91] A dose-response relationship has been observed between cigarette smoke exposure and LBW, where higher number of cigarettes smoked increases the risk of LBW births.[91]

2.1.5 Air pollution

Air pollution (AP) is a significant risk factor associated with LBW.[23] AP, in general, can be categorized into ambient air pollution (outdoor air pollution) and indoor air pollution (IAP). Particulate matter (PM) are the harmful particles in air pollution, also containing other disease-causing elements like carbon monoxide, etc., and is a mixture of harmful solid and liquid components suspended in the air.[92] The solid particles can include anything from macroscopic to microscopic particles. The two most frequently studied PM are PM_{10} and $PM_{2.5}$. PM_{10} are "inhalable particles with a diameter of 10µm or less", and $PM_{2.5}$ are "inhalable particles with a diameter of less than 2.5µm".[92] The microscopic particles which are less than 2.5 µm are the most harmful and cannot be seen by the naked eye.[92] $PM_{2.5}$ are often absorbed by the lungs, and since these particles are extremely small, they can overcome the air-blood barrier and enter the endothelial lining of the blood vessels.[92,93] This causes damage through the cardiovascular system, influencing all parts of the body. [92,93] In general, the smaller the respired particles are, the more harm they cause to the respiratory system.[92,93] Studies show that chronic and sometimes even acute exposure to AP can affect the body. [94] PM of different sizes, particularly $PM_{2.5}$ can cause severe health consequences, which include inflammatory, autoimmune, cardiovascular, respiratory, and neurological system disorders.[93–99] Diseases like cancers and atherosclerosis are also associated with chronic exposure to PM.[100,101]

$PM_{2.5}$ also influence the intrauterine growth of the fetus in a pregnant woman, eventually contributing to LBW.[93,102] A novel study analyzing teflon filters from regulatory monitors found that the level of $PM_{2.5}$ exposure during pregnancy was significantly associated with LBW.[103] WHO conducted a study on the association between the use of solid fuel for cooking and having adverse birth outcomes of low birth weight and stillbirth.[104] In this study, IAP caused by the cooking fuel type used was analyzed by measuring the absorbed emissions of carbon monoxide (CO) via the use of CO tubes attached to the pregnant mother at least once during their pregnancy. It was found that the use of a "plancha" a heating device which significantly improves the thermal efficiency and reduces PM emission levels, when compared to an open fire use, significantly decreased CO exposures and improved birth weight.[104]

A. Ambient (outdoor) air pollution

According to WHO, Ambient Air Pollution (AAP) is the release of potentially harmful pollutants via industrial, vehicular, and household emissions, and from any source that contributes to the decrement of outdoor air quality.[105] AAP causes harm through particulate matter and other harmful substances suspended in outdoor air, which are released through industrial and vehicular emissions. These include carbon monoxide, arsenic, etc., and contribute to the harmful nature of AAP. One in every eight deaths worldwide can be attributable to AAP.[106] AAP contributes to 7.6% of deaths worldwide, and 4.2% of global DALYs.[107] Air pollution exposure is associated with diseases such as stroke, respiratory infections, lung cancer, vitamin D deficiency in children, etc. [108,109] Seven million people die each year due to exposure to particulate matter in outdoor air.[110] Studies also show that exposure to ambient air pollution can cause LBW.[111,112] A study conducted in Guangdong, China showed that exposure to AAP (i.e., $PM_{2.5}$) is significantly associated with LBW when adjusted for confounders, especially during the second and third trimesters.[111]

B. Indoor air pollution

According to the United States Environmental Protection Agency, IAP is the "air quality within and around buildings and structures especially, as it relates to the health and comfort of the building occupants." [113] Use of certain cooking fuels and improper particulate matter evacuation measures such as poor ventilation during cooking are major contributors to IAP.[114,115] Fuels used for cooking can be broadly categorised into solid and non-solid fuels (which include liquid, gaseous fuels, and electricity used to operate stoves).[116] Different fuels have different combustion values and differ by their particulate matter concentrations contributing to IAQ.[116] WHO constructed an energy ladder which analysed the use of solid or non-solid fuels by people from different socioeconomic groups, which gives a better idea of their relative efficiency and cleanliness.[117](Appendix 7) This report states that crop waste and dung are the worst type of solid fuels used for cooking followed by wood, charcoal, and coal.[117] The cleanest type of cooking fuel used is considered to be electricity due to its null PM emissions and efficient energy level.[117] Use of solid fuels is one of the main contributors for IAP, and approximately half of the world's households utilize solid fuels for cooking, and heating necessities.[118] Solid fuel use is a major risk factor for many diseases such as acute lower respiratory tract illnesses, low birth weight, cardiovascular diseases, diabetes, cancers, dyslipidemia, etc.[114,119,118](Appendix 1) One study concluded that having a kitchen within the same household is significantly associated with LBW when compared to having a kitchen separated from the household.[10] Certain religious or cultural practices such as incense stick burning, which is a widely used practice in many households in India, has also been seen to significantly contribute to LBW cases.[120]

Indoor exposure to tobacco smoke is also a major risk factor contributing to LBW cases. Tobacco smoke exposure during pregnancy can cause congenital heart defects and neurological damage, fetal growth and developmental disorders such as cleft palate and multiple chronic and incurable diseases from birth to adulthood whose root cause stems from prenatal tobacco smoke exposure.[121–124] Risk of PTB and still-birth is also higher among tobacco smokers.[125,126] Significant associations between Second-hand smoke (SHS) and LBW have been highlighted throughout literature, and WHO states that even a brief exposure to SHS can cause serious health problems related to tobacco smoke exposure as mentioned above.[91,127] More than 1% of all deaths in the world is attributable to SHS exposure.[128]

3. Situation in India

India ranks 1st among top 10 countries worldwide with the highest preterm birth cases.[7] India also ranks 1st on the top 10 countries in the world with the highest number of newborn deaths in 2019.[15] A study that analysed the National Family Health Survey-4 (a demographic and health survey conducted in India) data, found that the prevalence of LBW in India was 37.3%.[129] India had an infant mortality rate of 29.85 deaths per 1000 live births in 2020, and the United Nations has predicted that this will rise in the future.[130,131] UNICEF states that in 2016, 79.7% of children under 5 had their births registered in the government registry, leaving 20.3% of under 5 children with no birth registration data.[132] A study that analysed the NFHS 3&4 dataset revealed that each fifth infant born in West Bengal, India was LBW.[133] The prevalence of LBW in Northern India (32.3%) was even higher than the prevalence of LBW in West Bengal.[133,79] It was also found that LBW prevalence is the highest in the state of Uttar Pradesh, and is the lowest in the state of Mizoram.[129] The prevalence of LBW in the state of Himachal Pradesh was 44.3%, and 41.1% in the state of Delhi.[129] A study that analysed the National Family Health Survey (NFHS 3&4) dataset also found that female children are at a higher risk for LBW in India.[134]

AP was ranked as the second highest risk factor for disease burden in India following malnutrition in 2016.[135] In India, 64% of the population use solid fuels in their households.[136,106] India represents 18.1% of the global population but its contribution to global air pollution DALYs in 2017 was 26.2%.[106]

A study conducted among non-residential buildings in Delhi, where students and working population spend the majority of their time, found a significant deterioration in the quality of air inside homes.[137] The AAP with outdoor air PM concentrations in hazard levels (WHO ranking) has affected the AQI in Delhi's ambient air, and is seeping into homes which is a serious concern as there are multiple health risks associated with the exposure to $PM_{2.5}$.[137–139] The government has taken steps to decrease the use of solid fuels for cooking by subsidizing the access to cleaner fuels, resulting in a 50% decrease in solid fuel use. [140–143] However, a large proportion of population continues to depend on solid fuel use for survival although the exact number is unknown.[140–143] A study conducted in India showed that solid fuel use was the highest among scheduled castes and scheduled tribes.[144]

The prevalence of tobacco smoking in India is around 13.5%.[145] Tobacco smoking in India is more common among the families belonging to poor quintile of the wealth index than those belonging to the rich quintile.[146] Use of smokeless tobacco (use of tobacco in forms other than cigarettes used for smoking) is also more common in the lower socioeconomic strata in India.[146,147] Approximately, 29.2% of the population in India is exposed to SHS in their homes.[148] In attempts of reducing the exposure to SHS, a smoke-free law was levied in 2003 by the Indian government, banning smoking in public places.[149]

4. National Family Health Survey- 4 (NFHS-4)

The national family health survey (NFHS) is a standard DHS survey conducted exclusively in India, focusing on collecting data related to health, nutrition, family planning, household practices, etc. The five datasets available for public research are those for women, men, households, biomarkers and birth records. NFHS is conducted under the Ministry of Health and Family Welfare, Government of India.[150,151]

The NFHS-4 survey was conducted during 2015-16 throughout India in 19 languages, and the total sample size was 616,346 occupied households.[151,152] The household survey included a final sample size of 601,509 eligible households with a 98% response rate, and the women's survey included a final sample size of 699,686 eligible women with a 97% response rate.[152]

The survey respondents were household members and visitors staying in the household on the night before the survey.[152] The women's survey included women aged 15-49. For children under the age of 5 years, their birth record was based on the household member's recall.[152]

5. Rationale of the study

LBW, PTB and SGA are serious public health problems that need to be addressed.[5,7] India has the highest number of PTB and infant mortality cases in the world, which poses a gravid public health threat.[7,15]

IAP levels in India have been investigated, but there are very few studies investigating IAP and exposure to second hand smoke during pregnancy, and their impact on birth weight.[153,33] For this study, Delhi was initially chosen as the sole study setting, however after applying the inclusion and exclusion criteria to the dataset, the sample size was inadequate. Because Delhi is a union territory with the highest proportion of urban population, inclusion of another state in India with the highest proportion of rural population was considered.[154] Himachal Pradesh was chosen, as it is the state with the lowest proportion of urban population.[154] This inclusion added a diversity of socioeconomic backgrounds in the study sample, which is important as literature suggests that practices related to maintenance of quality of indoor air highly differ between people from rural and urban backgrounds. Presumably, both of the areas are at high risk of indoor air pollution. The hazardous AQI of AAP in Delhi impacting IAQ is one of the major reasons for choosing Delhi as a study setting. Himachal Pradesh was chosen due to the high percentage of the population relying on firewood use, which was much higher than in Delhi.[155] A study conducted in India measuring the relationship between household energy consumption and respiratory diseases stated that areas with a high rural population are more dependent on solid fuel use, supporting our assumption of the widespread firewood use in Himachal Pradesh.[144,156] There is a higher risk of rural population of being exposed to SHS as compared to urban population, according to a study conducted in India.[157] Female population has also been associated with a higher SHS exposure than male, which makes this target population more vulnerable.[158] In this study we aim to further explore the association that IAP has on the LBW of babies born in Delhi and Himachal Pradesh, India.

6. Aim of the study

The aim of this study is to investigate the association between Indoor Air Pollution score (Appendix 2) and birth weight of infants born during 2014-2016 in Delhi and Himachal Pradesh, India. The study also aims to investigate the association between indoor exposure to tobacco smoke with the birth weight of babies born in Delhi and Himachal Pradesh, India during the years 2014-2016, who were included in NFHS-4.

6.1 Hypothesis

Primary research question

Is there an association between the household's indoor air pollution score during pregnancy and delivering low birth weight infant in Delhi and Himachal Pradesh, India, during 2014-

2016?

Secondary research question

Is there an association between the indoor exposure to tobacco smoke during pregnancy and delivering low birth weight infants in Delhi and Himachal Pradesh, India, during 2014-2016?

7. Methods

This study was a quantitative study based on a cross-sectional survey dataset and followed a professional publication framework.

7.1 Data source used for the study

National Family Health Survey-4 (NFHS-4) dataset was used to conduct secondary data analysis. The women's dataset for the birth records was used to determine the birth weight of babies born in Delhi and Himachal Pradesh, India. The household survey dataset was utilized for the types of cooking fuels used, location of cooking (indoors, outdoors, separate building), if cooking is done in a separate room (i.e., a kitchen), and if someone in the household smokes inside the house. These variables from the household dataset were used to construct the "IAP score." All intervening variables were taken from the women's dataset and the household dataset.

7.2 Target population and study population

The target population for this study included children born in Delhi and Himachal Pradesh, India. The study population were mothers who had given birth during 2014-2016 in Delhi and Himachal Pradesh, who were included in the NFHS-4.

7.3 Study variables

7.3.1 Dependent variables

The birth weight variable was the dependent variable. It was continuous in the dataset but was dichotomised into LBW for birth weights below 2.5 kg, and normal birth weight (NBW) for birth weights of 2.5 kg and above.

7.3.2 Independent variables

The type of cooking fuel used, the type of ventilation maintained during cooking, location of cooking (i.e., cooking done in a ventilated area (outdoors)), cooking done in separate kitchen, and smoking inside the household are all variables that contribute to the Indoor Air Quality (IAQ) (Appendix 2, Appendix 3). Since specific PM data was not available from each household for the analysis, the aforementioned variables contributing to IAQ were combined into a single proxy variable called Indoor Air Pollution score (IAP score). The responses to these variables were weighed according to their level of efficiency, and contribution to IAQ due to PM and their energy efficiency capabilities.[25,159] (Appendix 3) The score was computed by summing up these variables and covered a range from least harmful (0) to most harmful (8).

In a WHO publication, the cooking fuel type was compared with the prosperity index, which ranks from low socioeconomic status to high, creating an energy ladder when cross tabulated (Appendix 7). This energy ladder was used to assign weights to the IAP score construct variables.

For the second research question, smoking frequency inside the home was dichotomized to smoking never, less than monthly or monthly versus smoking daily or weekly.

7.3.3 Intervening variables

A literature review highlighted key intervening variables (Appendix 2), which are maternal age, family's socioeconomic status, maternal smoking status at the time of the interview, maternal presence of chronic illnesses, maternal alcohol consumption at the time of the interview, maternal anemia status at the time of interview, marital status, maternal and paternal educational level, birth order of the child, inter-birth interval before the last pregnancy, parity, gender of the baby, number of ANC visits, mother's religion, mother's caste, place of residence of the mother (urban/rural, Delhi/ Himachal Pradesh), mother's employment, place of delivery (Institutional birth or home birth), maternal height, maternal weight, undergoing cesarean section, maternal BMI, and maternal supplementation of iron and folate.

7.4 Sample size calculation

The sample size was calculated using a two sample proportion formula.

$$n_1 = n_2 = \frac{\left(Z_{\alpha/2}\sqrt{2\,\bar{p}\bar{q}} + Z_{\beta}\sqrt{p_1 q_1 + p_2 q_2}\right)^2}{d^2}$$

Where,

$\alpha = 0.05$

Power (P) = 80 % = 0.80

$\beta = (1 - P) = 0.20$

We intended to detect at least 7% difference in the proportion of LBW children between non-polluted and polluted settings.

Proportion of LBW babies in polluted settings[160] (p_1): 71.83% = 0.72

Proportion of LBW babies in non-polluted settings (p_2): 65% = 0.65

$q_1 = 1 - p_1$

$q_2 = 1 - p_2$

$\bar{q} = 1 - \bar{p}$

$Z_{\alpha/2} = 1.96$ for 95% confidence interval

$Z_{\beta} = 0.84$ for 80% study power

$$\bar{p} = \frac{p_1 + p_2}{2} = 0.685$$

$\bar{q} = 0.315$

d (marginal error) = $p_1 - p_2 = 0.07$

The required sample size will be,

$$n_1 = n_2 = \frac{\left(1.96\sqrt{2(0.685)(0.315)}+0.84\sqrt{(0.72)(0.28)+(0.65)(0.35)}\right)^2}{(0.07)^2}$$

$$n_1 = n_2 = 683.44 \cong 684$$

$$n = n_1 + n_2 = 1368$$

We require approximately 1368 participants to detect a change of 7% between the LBW and NBW groups with an 80% power, and a level of significance of 95%.

7.5 Inclusion and exclusion criteria

The inclusion criteria were mothers who had given birth to children from 2014-2016. Mothers who had given birth before 2014 were excluded to reduce recall bias. Multiple births (twins, triplets, etc.) were also excluded as they physiologically give rise to LBW babies, and hence, only singleton births were included. Only the youngest child was included in the study to avoid recall bias and to allow the inclusion of maternal risk factor variables (i.e., type of cooking fuel used, maternal anemia level, smoking status, etc.) which could be more relevant for the youngest child in the family. Inclusion of multiple children from the same family would also include the same woman and her associated risk factor being analysed multiple times, which would create selection bias and skew the results of the study.

7.6 Ethical considerations

The Institutional Review Board (IRB) of the American University of Armenia granted this study an exempt status, a no-risk study that did not involve any direct contact with the participants and applied only secondary data analysis of a de-identified dataset.

8. Data analysis

SPSS software was used to analyse the data. Sampling weights were assigned to the variables according to the women's representative weight variable available in the dataset, to ensure a representative sample of the population being studied and reduce selection bias due to over or under sampling of a particular study setting. Descriptive analysis was done on each variable in the groups of women with LBW of youngest child, with normal birth weight of youngest child, and in the total sample. Groups were compared by each variable using t-test for means and chi^2 tests for proportions. Logistic regression analysis was used to analyze the data, as the outcome variable (LBW) was dichotomised for the analysis. An empirical approach was used to identify the potential confounding variables for each association. For this purpose, univariate logistic regression was initially done between all potential confounding variables (based on literature evidence) and the outcome (LBW). On the basis of the results, the variables that were significantly associated with LBW were further examined to identify their association with each of the independent variables (indoor smoking exposure and IAP score). Hence, a univariate logistic regression analysis was done between each of these variables and indoor smoking exposure, and those variables significantly associated with indoor smoking exposure as well, were treated as confounders for the association between indoor smoking exposure and LBW. A univariate linear regression analysis was also performed between each of the variables significantly associated with LBW and the IAP score, and those variables significantly associated with IAP score as well, were treated as confounders for the association between IAP score and LBW. Then multivariable logistic regression analyses were performed to look at the association between the dependent and independent variables while adjusting for respective confounders of each association.

9. Results

After applying the inclusion and exclusion criteria, the total sample size constituted 1700 women. After applying sampling weights, the final sample size was reduced to 1554 women.

9.1 Descriptive analysis

All the study variables were compared descriptively between the groups (Table 1 and Table 2). Women with LBW children constituted 22.2% of the study sample. The mean age of the study participants was approximately 26 years (mean: 25.61, SD: 4.51) and 75.5% of the women lived in an urban setting. The place of residence of the women included 73.9% living in Delhi and 26.1% in Himachal Pradesh. The sample had majority of women (99.3%) who were married, and most women had a secondary level of education (53.4%). However, nearly one-fourth (23.7 %) of women had no or primary education. Almost all women denied consumption of alcohol and the use of tobacco with negligible difference between both groups. Approximately 9 out of 10 women did not have an occupation with no difference between the groups.

Only 1.2% of the study participants used electricity for cooking and majority (80.3%) of the participants used liquified petroleum gas (LPG) and natural gas as a cooking fuel. The second most common type of cooking fuel was wood (18.2%). Animal dung, straw/shrubs/grass, charcoal were the least used fuel types and were utilized by less than 0.5% of participants. The groups were significantly different in terms of the outcome variables: IAP score and smoking frequency in the household. Compared to women with NBW babies, significantly higher proportion of women with LBW babies were exposed to tobacco smoke inside the household (55.4% versus 39.6%). IAP score was also significantly associated with LBW status in unadjusted comparison, and was higher for women with LBW babies when compared to women with NBW babies. However, of the household air quality-related characteristics included in the IAP score, only the presence of a separate room as a kitchen, and the frequency of smoking in the household were significantly different between the groups. Compared to women with NBW babies, significantly lower proportion of women with LBW babies lived in households which had a separate room used as a kitchen (LBW – 54.6%, NBW – 71.0%). The percentage of those with daily indoor exposure to tobacco smoke was much higher among LBW group (41.3%) than among NBW group (31.6%).

Of the sociodemographic characteristics, maternal education level, wealth index of the household, maternal age, maternal weight, maternal BMI, maternal haemoglobin level were significantly different between the groups of mothers. The proportion of those having no education or primary level of education was significantly higher among mothers with LBW babies (37.1%) when compared to mothers with NBW babies (19.9%). The percentage of women belonging to poorest, poorer or middle wealth index group was significantly higher in LBW group (31.3%) when compared to NBW group (18.7%). Pregnancy characteristics significantly associated with the child's birth weight included the number of ANC visits during pregnancy, having institutional vs. home deliveries, delivering by caesarean section, inter-birth interval, timing of the1st ANC visit, maternal iron supplementation during pregnancy, and blood sample taken during pregnancy. The proportions of those women who had less than eight ANC visits during the pregnancy, who gave birth in an institution i.e. public sector, private sector or NGO versus giving birth at home, and who delivered by caesarean section were higher in the LBW group compared to the NBW group. Having an inter-birth interval of 24 months or more, having no maternal supplementation of iron and folate, and not giving a blood sample during pregnancy were also related to higher rates of LBW births in descriptive comparisons.

9.2 Testing for confounders

Variables significantly different between the groups were included in univariate logistic regression analysis with LBW. Table 3 shows the univariate logistic regression analysis of potential confounding variables with LBW status.

Among variables significantly associated with LBW, the confounders which were also significantly associated with frequency of indoor exposure to smoking (more than weekly vs. less than weekly) in the univariate logistic regression analysis are shown in Table 4. The confounders for the association between LBW and indoor exposure to tobacco smoke included: maternal age at the time of the interview, maternal height, maternal weight, maternal BMI, wealth index, maternal education level, maternal hemoglobin level, number of ANC visits, and presence of a separate room as a kitchen in the household.

Among variables associated with LBW, the confounders which were also significantly associated with IAP score in the univariate linear regression analysis are shown in Table 5. The confounders for the association between LBW and IAP score included: maternal age, maternal weight, maternal BMI, wealth index of the household, maternal education level, maternal haemoglobin level, number of ANC visits during pregnancy, timing of the 1st ANC visit, and delivery by caesarean section.

9.3 Association of LBW with independent variables

For the primary research question

Table 6 shows the results of multivariable logistic regression analysis of the association between LBW status and IAP score when adjusted for confounders. The model indicates that the adjusted association is insignificant. The significant covariates in the model include maternal age, maternal weight, maternal education level, and delivery by caesarean section.

For the secondary research question

Table 7 shows the results of multivariable logistic regression analysis between LBW status and smoking frequency inside the household (less than weekly vs. more than weekly) when adjusted for significant confounders found from the previous analyses. The results indicate that women's daily or weekly indoor exposure to tobacco smoke is associated with 42% higher odds of having LBW baby (OR = 1.42 CI: 1.06 - 1.90) as compared to being exposed to indoor smoking monthly or less. Other than the main association, only maternal education level is significant in the adjusted model.

10. Discussion

As inferred from the study results, LBW prevalence in the study sample was 22%, which was lower than the rates found in northern India (32.3%) and nationwide (37.3%).[79,129] This indicates that the sample selected for this study was somewhat different from the general population in India. Still, the prevalence of LBW in Himachal Pradesh and Delhi was higher than the global estimate of LBW cases (14.6%) in 2015.[161] As previously mentioned, this could be due to inadequate awareness and educational levels of mothers and their families about appropriate lifestyle, nutrition, and the need for adequate ANC during pregnancy.[37,62,63,162] India has one of the lowest female literacy rates in Asia, which could be a possible explanation for the high LBW rates in India.[162] India is a lower-middle income country, and when comparing its LBW rate to the rates in other low-middle income countries such as China (2.3%), Sri Lanka (16.6%) or Papua New Guinea (8%),[163] the prevalence of LBW in India is higher.

Being exposed to indoor smoking more than weekly, when adjusted for confounders, showed significantly higher odds of having a LBW infant, which was consistent with the literature, as tobacco smoke contains more than 250 known harmful disease-causing elements, some of which affect the fetal growth.[29,127] This suggests an immediate need for planning interventions targeting the reduction of indoor SHS exposure of household members, and especially pregnant women, to reduce their risk of having LBW deliveries attributable to indoor SHS exposure.

The IAP score showed an insignificant association with LBW when adjusted for confounders, even though each individual construct of the score such as the type of cooking fuel used, smoking frequency inside households, presence of a separate room used as a kitchen in the household, and location of cooking (indoors/outdoors) had significant associations with LBW in other studies.[10,91,127,104] In this study, only two of the four constructs of the IAP score were significantly associated with the outcome variable in descriptive comparisons. Type of cooking fuel used and location of cooking (indoors/outdoors) were found to be insignificant in this study. This insignificance could potentially be due to the presence of another significant confounder that was not accounted for, such as the presence of an indoor ventilation plan or could be due to a low proportion of participants present per group of these constructs to detect a change. This especially relates to the proportion of those who used lowest quality fuel, such us dung cake or crop waste for cooking, which was negligible in this study sample. Even though sample size calculation was done, it was not possible to account for the number of people per group being lower than needed. The construct regarding the location of cooking (outdoors/indoors) could also be misinterpreted for its contribution to IAQ, as for cooking done outside the house but in its vicinity, the lower SES population might be more vulnerable to a higher exposure level. This can happen when the houses do not have proper insulation in their households to prevent the outdoor air from seeping inside, resulting in a biased result of the construct. This suggests potential deficiencies of the score in this particular study sample. Additionally, some potential confounders of the association between IAP score and LBW, such as genetic predisposition of mothers for having LBW babies, maternal nutrition during pregnancy or maternal anemia during pregnancy, etc. were unavailable in the NFHS-4 dataset. Hence, it was not possible to adjust the association between LBW and IAP score for these important variables. Other issues could include possible measurement bias or recall bias. Hence, the IAP score that we used might not accurately reflect the level of IAQ in the households. All of the listed issues might be responsible for the discrepancy between our finding and the literature evidence about the association between IAP and delivering LBW infant, suggesting the need for a better-planned future study on the subject.

10.1 Strengths of the study

All the analysis was conducted with a weighted sample to ensure representativeness of the results for the two study areas – Delhi and Himachal Pradesh. The DHS dataset utilizes rigorous data collection methods and data entry checking at multiple levels, which have been carried out by trained personnel. This is a significant strength which improves data quality and accuracy. Sample size was calculated to ensure that the study had sufficient power to detect differences between the groups. Measures were taken to reduce maternal recall bias by limiting the study sample to the youngest child in the household, and multiple births were excluded as they are physiological confounders.

10.2 Weaknesses of the study

The birth weight data obtained was based on maternal recall and this could pose a threat to the internal validity of the study due to recall bias. This study utilised a proxy measure to assess the IAP level exposure, which might not be the most accurate method of measuring the exposure levels. Since the study utilized a pre-existing dataset, there was a lack of other needed variables in the dataset, which placed constraints on the ability to adjust for other intervening variables, which are seen to be associated with LBW, such as the presence of chronic maternal illnesses (maternal anemia, hypertension, etc.) during pregnancy, the mother being born as LBW herself, maternal genetic predisposition, maternal stress during pregnancy, maternal diet during pregnancy, etc. Their availability could have helped in better adjustment of the logistic regression models. Variables contributing to IAP such as the use of incense sticks in household or living near an industrial site, if available, could have been added to the IAP score for a better representation of the IAQ inside the household. Also, the results of this study were not able to determine a causal relationship of LBW with smoking frequency, as observational cross-sectional studies do not imply causation and experimental clinical studies need to be conducted to evaluate the causal pathway.

10.3 Conclusions and recommendations

Better targeted and effective interventions aimed at increasing awareness among mothers and families about the risks associated with smoking and SHS exposures might aid in decreasing the LBW prevalence in India. Encouraging mothers and household members to enrol in smoking cessation programs is recommended, and this could be supported with provision of incentives to increase the participation rate. For people who are not willing to quit smoking, temporary measures could be undertaken, such as persuading household members to smoke outside the household in ventilated areas to protect family members, especially pregnant women, from harmful effects of SHS exposure. Crafting good ventilation plans in households could help in reducing the disease burden associated with poor IAQ. Implementing effective policies and guidelines to provide help, assist and encourage families to quit smoking could greatly contribute to reducing LBW rates in India.

The IAP score utilized in this study consists of construct deficiencies and future research using primary data collection of variables adding to the score could be done to investigate the true association. Research done using PM monitors to quantify the IAQ of households accurately would be most helpful in determining a direct association between IAP and LBW. This could help fill the gaps in the score constructs, providing a direct and more accurate estimation of IAP levels in the households.

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Tables

Table 1.

Descriptive analysis of categorical variables among groups of mothers with recent (2014-2016) last singleton delivery outcome of low birth weight versus normal birth weight infant, residing in Delhi and Himachal Pradesh, based on NFHS-4 survey data.

Variable	Sub-category	Birth weight of the youngest child				P-value	Total % (n) N= 1554	
		Low birth weight, % (n) N= 345		Normal birth weight, % (n) N= 1209				
<u>Sociodemographic factors</u>								
Type of place of residence	*Urban*	78.6	(271)	74.6	(902)	0.133	75.5	(1173)
	Rural	21.4	(74)	25.4	(307)		24.5	(381)
Family's place of residence	*Delhi*	77.4	(267)	73.0	(882)	0.098	73.9	(1149)
	Himachal Pradesh	22.6	(78)	27.0	(327)		26.1	(405)
Maternal education level	*No/Primary*	37.1	(128)	19.9	(240)	< 0.001	23.7	(368)
	Secondary	49.9	(172)	54.4	(658)		53.4	(830)
	Higher	13.0	(45)	25.7	(311)		22.9	(356)
Husband/partner's education level	*No/Primary*	15.8	(9)	11.0	(27)	0.260	11.9	(36)
	Secondary	70.2	(40)	66.1	(162)		66.9	(202)
	Higher	14.0	(8)	22.9	(56)		21.2	(64)
Religion	*Muslim*	14.2	(49)	11.2	(136)	0.135	11.9	(185)
	Others (Hindu, Christian, Jain etc.)	85.8	(296)	88.8	(1073)		88.1	(1369)
Caste	*Schedule caste, Schedule tribe, or OBC*	57.3	(164)	57.1	(659)	0.930	57.1	(823)
	Other castes	42.7	(122)	42.9	(496)		42.9	(618)
Current marital status	*Single, widowed, divorced, etc.*	0.9	(3)	0.7	(8)	0.685	0.7	(11)
	Married	99.1	(342)	99.3	(1201)		99.3	(1543)
Wealth index of household	*Poorest/Poorer/ Middle*	31.3	(108)	18.7	(226)	< 0.001	21.5	(334)
	Richer/Richest	68.7	(237)	81.3	(984)		78.5	(1221)
Maternal occupation	*Working*	14.0	(8)	13.4	(33)	0.902	13.5	(41)
	Not in work force	86.0	(49)	86.6	(213)		86.5	(262)
<u>Health-related factors</u>								
Current maternal alcohol consumption	*Any amount*	0.0	(0)	0.5	(6)	0.190	0.4	(6)
	None	100.0	(332)	99.5	(1204)		99.6	(1549)

Variable	Sub-category	Birth weight of the youngest child		P-value	Total % (n) N= 1554
		Low birth weight, % (n) N= 345	Normal birth weight, % (n) N= 1209		
Current tobacco consumption	*Yes*	1.2 (4)	0.2 (3)	0.026	0.5 (7)
	No	98.8 (341)	99.8 (1206)		99.5 (1547)
Maternal presence of chronic illnesses	*Presence of one or more chronic diseases*	6.4 (22)	5.1 (62)	0.372	5.4 (84)
	No chronic diseases present	93.6 (324)	94.9 (1147)		94.6 (1471)
Insurance coverage	*Yes*	5.2 (18)	7.5 (91)	0.138	7.0 (109)
	No	94.8 (327)	92.5 (1118)		93.0 (1445)
Pregnancy-related factors					
Timing of 1st ANC (months)	*0-3 months of pregnancy*	26.0 (85)	30.1 (343)	0.146	29.2 (428)
	After 3 months (up to 10)	74.0 (242)	69.9 (795)		70.8 (1037)
ANC visits during pregnancy	*0-7 visits*	76.7 (263)	68.6 (821)	0.004	70.4 (1084)
	8 and more visits	23.3 (80)	31.4 (375)		29.6 (455)
Sex of the child	*Male*	53.6 (185)	56.2 (679)	0.402	55.6 (864)
	Female	46.4 (160)	43.8 (530)		44.4 (690)
Institutional births	*Public/Private sector/NGO*	95.4 (329)	91.6 (1108)	0.021	92.5 (1437)
	Delivered at home	4.6 (16)	8.4 (101)		7.5 (117)
Delivery by caesarean section	*Yes*	37.4 (129)	29.8 (360)	0.007	31.5 (489)
	No	62.6 (216)	70.2 (849)		68.5 (1065)
Inter-birth interval	*Less than 24 months*	9.9 (34)	16.1 (195)	0.001	14.7 (229)
	24 or more months	53.6 (185)	43.1 (521)		45.4 (706)
	Primigravida	36.5 (126)	40.8 (494)		39.9 (690)
Desirability of pregnancy	*Wanted then*	83.2 (288)	86.4 (1045)	0.217	85.7 (1333)
	Wanted later	10.7 (37)	7.8 (94)		8.4 (131)
	Unwanted	6.1 (21)	5.9 (71)		5.9 (92)
Iron and folate supplementation during pregnancy	*Yes*	16.2 (54)	28.6 (338)	< 0.001	25.9 (392)
	No	83.8 (279)	71.4 (845)		74.1 (1124)
Blood sample taken during pregnancy	*Yes*	97.0 (320)	98.6 (1123)	0.049	98.2 (1443)
	No	3.0 (10)	1.4 (16)		1.8 (26)

Variable	Sub-category	Birth weight of the youngest child		P-value	Total % (n) N= 1554
		Low birth weight, % (n) N= 345	Normal birth weight, % (n) N= 1209		
<u>Household air-related factors</u>					
Type of cooking fuel used at household	*Non-solid fuel use*	83.4 (282)	79.4 (911)	0.098	80.3 (1193)
	Solid fuel use	16.6 (56)	20.6 (237)		19.7 (293)
Household has separate room used as a kitchen	*Yes*	54.6 (165)	71.0 (770)	< 0.001	67.5 (935)
	No	45.4 (137)	29.0 (314)		32.5 (451)
Location of cooking food	*In the house*	87.6 (303)	89.7 (1085)	0.303	89.2 (1388)
	In a separate building	10.4 (36)	9.3 (112)		9.5 (148)
	Outdoors	2.0 (7)	1.1 (13)		1.3 (20)
Smoking frequency in household	*Daily*	41.3 (143)	31.6 (382)	< 0.001	33.8 (525)
	Weekly	14.2 (49)	8.0 (97)		9.4 (146)
	Monthly	3.8 (13)	2.2 (26)		2.5 (39)
	Less than monthly, never	40.8 (141)	58.2 (704)		54.3 (845)

*P-values from chi^2 tests

Table 2.

Descriptive analysis of continuous variables among groups of mothers with recent (2014-2016) last singleton delivery outcome of low birth weight versus normal birth weight infant, residing in Delhi and Himachal Pradesh, based on NFHS-4 survey data.

Characteristic	**LBW (Birth weight <2499)**		**NLBW (Birth weight ≥ 2500)**		**P-value***		**Total**	
	Mean	**(SD)**	**Mean**	**(SD)**		**Number**	**Mean**	**(SD)**
IAP score	4.20	(1.11)	3.82	(1.02)	< 0.001	1554	3.90	(1.05)
Maternal factors								
Maternal age	25.61	(4.51)	27.38	(4.77)	< 0.001	1554	26.98	(4.77)
Maternal height (cm)	150.50	(6.53)	152.90	(21.70)	0.050	1360	152.30	(19.20)
Maternal weight (kg)	49.50	(9.32)	53.18	(11.07)	< 0.001	1358	52.30	(10.79)
Maternal BMI	27.07	(19.93)	33.91	(27.35)	< 0.001	1554	32.39	(26.03)
Maternal hemoglobin level (g/dl)	18.65	(23.93)	26.75	(33.15)	< 0.001	1554	24.95	(31.51)
Pregnancy								
Birth order number	1.94	(1.04)	1.92	(1.02)	0.752	1554	1.92	(1.03)
Timing of 1st antenatal check (months)	3.49	(9.63)	2.40	(3.86)	0.002	1445	2.64	(5.70)
Family								
Husband's/ partner's age	30.62	(5.83)	31.64	(5.00)	0.183	303	31.45	(5.17)

*Equal variances were assumed
** P-values from ANOVA test

Table 3.

Univariate logistic regression of selected intervening variables with low birth weight of singleton babies born in Delhi and Himachal Pradesh during 2014-2016.

Variables	Odds ratio	Confidence Interval (95%)		P-value
		Lower	Upper	
IAP score	1.40	1.25	1.56	< 0.001
Maternal factors				
Age of mother at the time of interview	0.92	0.89	0.94	< 0.001
Maternal height	1.00	0.99	1.00	< 0.001
Maternal weight	1.00	1.00	1.00	< 0.001
Maternal BMI	1.00	0.98	0.99	< 0.001
Wealth Index				
Poorer, Poorest, Middle	1.99	1.52	2.61	< 0.001
Richer, Richest	1.00	*Reference*		
Mother's education level				
No education, Primary	3.66	2.50	5.34	< 0.001
Secondary	1.80	1.26	2.56	0.001
Higher	1.00	*Reference*		
Maternal hemoglobin level	1.00	1.00	1.00	< 0.001
Pregnancy-related factors				
1st ANC visit timing (months)	1.03	1.01	1.05	0.017
Number of ANC visits during pregnancy				
8 and more visits	0.66	0.50	0.88	0.004
0-7 visits	1.00	*Reference*		
Maternal Iron and folate supplementation during pregnancy				
Yes	0.49	0.36	0.67	< 0.001
No	1.00	*Reference*		
Blood sample taken during pregnancy				
Yes	1.27	0.96	1.69	0.094
No	1.00	*Reference*		
Delivery by caesarean section				
Yes	1.41	1.10	1.82	0.007
No	1.00	*Reference*		
Institutional births				
Public sector, private sector, NGO	1.01	0.52	1.94	0.986
Delivered at home	1.00	*Reference*		
Household air-related factors				
Household has a separate room as a kitchen				
Yes	0.49	0.38	0.64	< 0.001
No	1.00	*Reference*		
Smoking frequency				
Daily, weekly	1.89	1.49	2.41	< 0.001
Never, less than monthly, Monthly	1.00	*Reference*		

Table 4.
Univariate logistic regression between variables significantly associated with LBW (from table 3) and frequency of exposure (more than weekly versus less than weekly) to tobacco smoke inside households in Delhi and Himachal Pradesh, India.

Variables	**Odds ratio**	**Confidence Interval (95%)**		**P-value**
		Lower	**Upper**	
<u>*Maternal factors*</u>				
Age of mother at the time of interview	0.94	0.92	0.96	< 0.001
Maternal height	1.00	1.00	1.00	< 0.001
Maternal weight	1.00	1.00	1.00	< 0.001
Maternal BMI	0.99	0.98	0.99	< 0.001
Wealth Index				
Poorer/Poorest/Middle	2.02	1.62	2.51	< 0.001
Richer/Richest	1.000		*Reference*	
Mother's education level				
No education/Primary	1.59	1.20	2.10	0.001
Secondary	2.09	1.62	2.69	< 0.001
Higher	1.00		*Reference*	
Maternal hemoglobin level	1.00	1.00	1.00	< 0.001
<u>*Pregnancy-related factors*</u>				
1st ANC visit timing	1.01	0.99	1.02	0.505
Maternal Iron and folate supplementation during pregnancy				
Yes	0.88	0.70	1.10	0.256
No	1.00		*Reference*	
Number of ANC visits during pregnancy				
8 and more visits	0.67	0.54	0.83	< 0.001
0 – 7 visits	1.00		*Reference*	
Delivery by caesarean section				
Yes	0.92	0.75	1.14	0.439
No	1.00		*Reference*	
<u>***Household air-related factors***</u>				
Household has a separate room as a kitchen				
Yes	0.59	0.48	0.72	< 0.001
No	1.00		*Reference*	

Table 5.
Univariate linear regression between IAP score and significant variables from univariate logistic regression with low birth weight of singleton babies born in Delhi and Himachal Pradesh, India (Table 3).

Variables	**β-coefficient**	**Confidence Interval (95%)**		**P-value**	**Adjusted R^2**
		Lower	**Upper**		
Maternal factors					
Age of mother at the time of interview	- 0.17	- 0.05	- 0.03	< 0.001	0.027
Maternal height	- 0.04	0.00	0.00	0.144	0.001
Maternal weight	- 0.12	- 0.00	0.00	< 0.001	0.014
Maternal BMI	- 0.21	- 0.02	- 0.01	< 0.001	0.043
Wealth Index					
Poorer/Poorest/Middle	0.30	0.63	0.85	< 0.001	0.091
Richer/Richest	1.00			*Reference*	
Mother's education level					
No education/Primary	0.07	0.05	0.28	< 0.001	0.038
Secondary	1.00			*Reference*	
Higher	- 0.16	- 0.55	- 0.30	< 0.001	
Maternal hemoglobin level	- 0.16	- 0.00	0.00	< 0.001	0.024
Pregnancy-related factors					
Number of ANC visits during pregnancy					
8 and more visits	- 0.19	- 0.56	- 0.34	< 0.001	0.035
0 – 7 visits	1.00			*Reference*	
1st ANC visit timing	0.05	0.00	0.02	0.033	0.002
Delivery by caesarean section					
Yes	- 0.09	- 0.31	- 0.09	< 0.001	0.007
No	1.00			*Reference*	
Maternal Iron and folate supplementation during pregnancy					
Yes	- 0.03	- 0.18	0.05	0.283	0.000
No	1.00			*Reference*	

***** R^2 values from ANOVA test.

Table 6.
Multivariable logistic regression of low birth weight of singleton babies born in Delhi and Himachal Pradesh, India with IAP score while adjusting for confounders found from univariate linear regression analysis

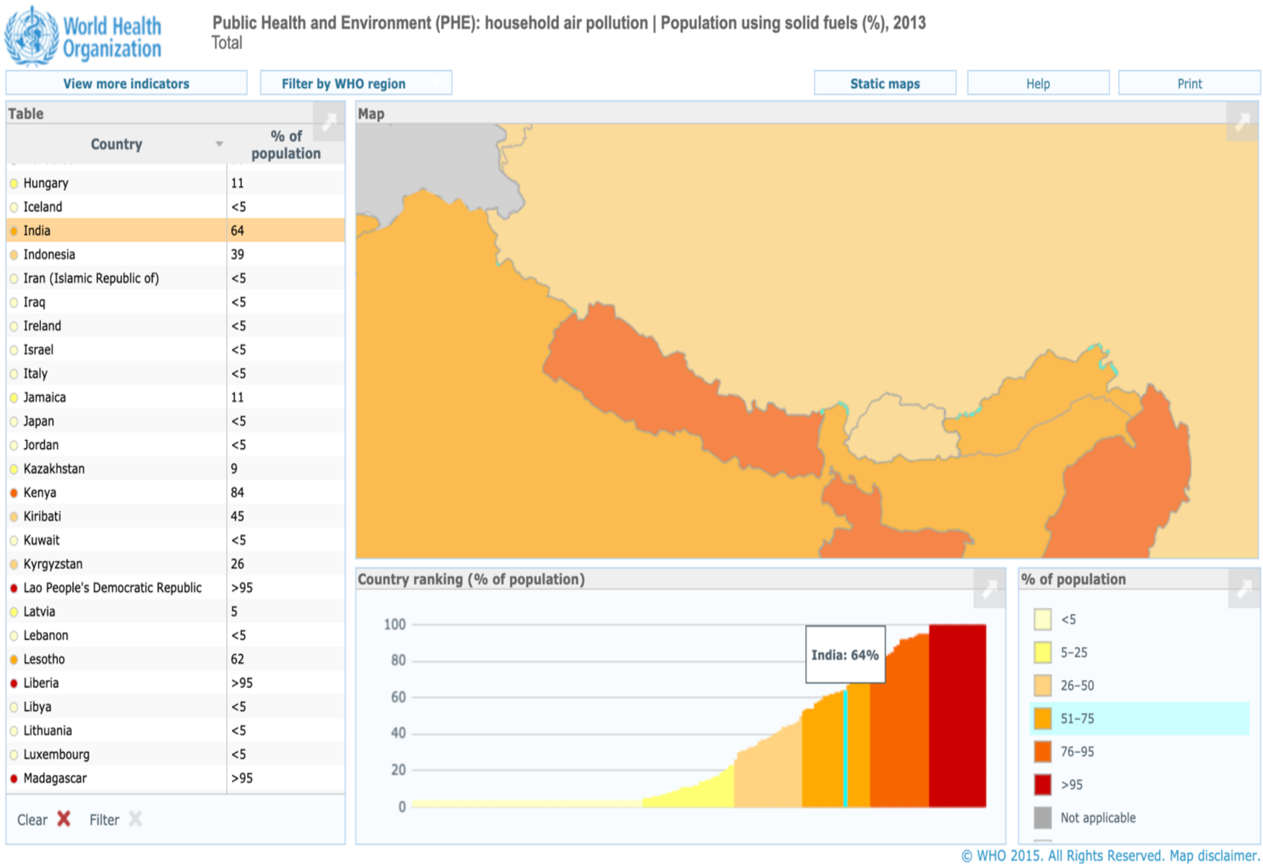
Variables	Odds ratio	Confidence Interval (95%)		P-value
		Lower	Upper	
IAP score	1.01	0.92	1.11	0.881
Age of mother at the time of interview	0.97	0.94	1.00	0.039
Maternal weight	1.00	1.00	1.00	0.007
Wealth Index				
Poorer, Poorest, Middle	0.94	0.67	1.32	0.727
Richer, Richest	1.00	*Reference*		
Mother's education level				
No/primary education	3.75	2.37	5.93	< 0.001
Secondary	1.65	1.11	2.45	0.014
Higher	1.00	*Reference*		
Number of ANC visits during pregnancy				
8 and more visits	0.82	0.60	1.13	0.230
0 – 7 visits	1.00	*Reference*		
Delivery by caesarean section				
Yes	1.77	1.33	2.35	< 0.001
No	1.00	*Reference*		
Maternal hemoglobin level	1.00	1.00	1.00	0.099

Table 7.
Multivariable logistic regression of low birth weight of singleton babies born in Delhi and Himachal Pradesh, India with smoking frequency in households while adjusting for confounders found from univariate logistic regression analysis

Variables	Odds ratio	Confidence Interval (95%)		P-value
		Lower	Upper	
Smoking frequency				
Daily, weekly	1.42	1.06	1.90	0.019
Never, less than monthly, monthly	1.00	*Reference*		
Age of mother at the time of interview	0.97	0.93	1.00	0.079
Maternal height	1.00	1.00	1.00	0.426
Maternal weight	1.00	1.00	1.00	0.170
Wealth Index				
Poorer, Poorest, Middle	0.92	0.63	1.32	0.636
Richer, Richest	1.00	*Reference*		
Mother's education level				
No/primary education	3.62	2.20	5.95	< 0.001
Secondary	1.33	0.87	2.02	0.190
Higher	1.00	*Reference*		
Number of ANC visits during pregnancy				
8 and more visits	0.84	0.60	1.19	0.320
0 – 7 visits	1.00	*Reference*		
Household has a separate room as a kitchen				
Yes	0.99	0.70	1.39	0.932
No	1.00	*Reference*		
Maternal hemoglobin level	1.00	1.00	1.00	0.323

Appendices:

Appendix 1.
Household air pollution levels due to solid fuel use among all countries in the world.



Source: https://gamapserver.who.int/gho/interactive_charts/phe/iap_exposure/atlas.html

Appendix 2.

Data extraction guide

Dependent variable

Variable	Type	Measure
Birth weight	Binary (dichotomous)	0 = < 2500 grams 1 = > 2500 grams

Independent variables

Variable	Type	Measure
Indoor air pollution score	Continuous	0- 9 (appendix 3)
Indoor exposure to cigarette smoke	Binary (dichotomous)	0 = Monthly, less than monthly, never 1 = Daily, weekly

Intervening variables

Variable	Rationale	Variable type	Variable coding
Socioeconomic status	Women of lower socioeconomic status are at a higher risk.	Categorical (ordinal)	Wealth index 0 – Poorest, poorer 1 – Middle 2- Richer, Richest
Current maternal smoking status	Mothers who smoke have an increased risk.	Binary (dichotomous)	0 – No 1- Yes
Maternal age	Increased maternal age contributes to higher LBW cases.	Continuous	-
Maternal alcohol consumption (current)	Heavy maternal alcohol consumption is associated with LBW.	Binary (dichotomous)	0 – None 1 – Any amount
Gender of the baby	Female babies have a higher risk for LBW.	Binary (dichotomous)	0 – Male 1 – Female
Maternal education level	Uneducated mothers have a higher risk. Education increases awareness and improves intention to act.	Categorical (ordinal)	0 – No education 1 – Primary 2 – Secondary 3 – Higher
Paternal education level	Education increases awareness of the family.	Categorical (ordinal)	0 – No education 1 – Primary 2 – Secondary 3 – Higher

Variable	Rationale	Variable type	Variable coding
Maternal presence of chronic illnesses	Presence of diseases such as diabetes, hypertension, anaemia cause an increased risk of LBW babies.	Binary (dichotomous)	1 - Presence of one or more of following diseases *a. Heart disease* *b. Thyroid disorders* *c. Asthma* *d. Diabetes* *e. Cancer* 0 – No chronic diseases present.
Mother's marital status	Married mothers have a decreased tendency to give birth to LBW babies in India.	Binary (dichotomous)	0 – Not married 1 – Married
Mother's current hemglobin level	Maternal anemia status during pregnancy is associated with LBW births.	Continuous	-
Inter-birth interval	A short inter-birth interval of less than 2 years is associated with LBW babies.	Binary (dichotomous)	0 – Less than 2 years 1 – Two years/more
Birth order of child	Contradicting evidence was presented in the literature review. Some studies show an increase in birth weight with third or later born and first born children to be at a higher risk.	Continuous	-
Delivery by cesarean section	Cesarean section births are at a higher risk of LBW than vaginal births.	Binary (dichotomous)	0 – Vaginal delivery 1 – Cesarean section delivery
Number of ANC visits	At least 8 ANC visits are recommended by WHO during a pregnancy.	Binary (dichotomous)	0 – Less than 8 visits 1 – Eight and more visits
Religion of household	Certain religious practices such as incense stick burning is associated with LBW.	Categorical	0 – Muslim 1 – Others
Mother's caste	Scheduled castes and scheduled tribes are at a higher risk of LBW births.	Binary (dichotomous)	0 – Others 1 – Scheduled caste, scheduled tribe, OBC
Place of residence	Mothers residing in rural areas are at a higher risk.	Binary (dichotomous)	0 – Urban 1 - Rural
Mother's employment	Heavy load work involvement and physically straining jobs have an association with LBW births.	Binary (dichotomous)	0 – Employed 1 - Unemployed
Maternal BMI	Mothers with BMI < 25 are at a higher risk.	Continuous	-

Variable	Rationale	Variable type	Variable coding
Maternal supplementation of iron and folate during pregnancy	Iron supplementation influences the anemia level of mothers. Mothers need additional supplementation of iron during pregnancy due to the increased need by the fetus.	Binary (dichotomous)	0 – No 1 - Yes

Appendix 3.

<u>Indoor air pollution score</u> [25,159]

1. <u>Type of cooking fuel used</u>
(What type of fuel does your household mainly use for cooking?)

Cooking fuel type	**IAP score point(s)**
A. Electricity	0
B. LPG/Natural Gas, Biogas, Kerosene	1
C. Charcoal, Wood, Coal /lignite	2
D. Agricultural crop waste, Dung cakes, Straw/shrubs/grass	3
E. Other	--
F. No food cooked in household	0

2. Location of cooking
(Is the cooking usually done in the house, a separate building, or outdoors?)

Location of cooking	**IAP score point(s)**
1. Inside the house	2
2. Separate building	1
3. Outdoors	0
4. Others	--

3. Cooking done in separate kitchen
(Do you have a separate room which is used as a kitchen?)

Use of a separate room for cooking	**IAP score point(s)**
1. Yes	0
2. No	1

4. Smoking done inside the house
(How often does someone smoke inside your house? Would you say daily, weekly, monthly, less than monthly, or never?)

Smoking done inside the house	**IAP score point(s)**
1. Daily	3
2. Weekly	2
3. Monthly	1
4. Less than monthly, Never	0

Appendix 4.

National family health survey - 4 Household questionnaire[164]

Household questionnaire

22. How often does anyone smoke inside your house?

- ☐ Daily
- ☐ Weekly
- ☐ Monthly
- ☐ Less than monthly
- ☐ Never

38. What type of fuel does your household mainly use for cooking?

- ☐ Electricity
- ☐ LPG/ Natural gas
- ☐ Biogas
- ☐ Kerosene
- ☐ Coal/lignite
- ☐ Charcoal
- ☐ Wood
- ☐ Straw/shrubs/grass
- ☐ Agricultural crop waste
- ☐ Dung cakes
- ☐ No food cooked in household
- ☐ Other ___________________ Specify

39. In this household, is food cooked on a stove, a chullah or an open fire?

- ☐ Stove
- ☐ Chullah
- ☐ Open fire
- ☐ Other ___________Specify

40. Is the cooking usually done in the house, in a separate building or outdoors?

- ☐ In the house
- ☐ In a separate building
- ☐ Outdoors
- ☐ Other_____________Specify

41. Do you have a separate room which is used as a kitchen?

- ☐ Yes
- ☐ No

Woman's questionnaire

114. What is your religion?

- ☐ Hindu
- ☐ Muslim
- ☐ Christian
- ☐ Sikh
- ☐ Buddhist/ Neo-buddhist
- ☐ Jain
- ☐ Jewish
- ☐ Parsi/ Zaraostrian
- ☐ No religion
- ☐ Other

115. What is your caste or tribe?

116. Do you belong to scheduled caste, a scheduled tribe, other backward classes or none of these?

- ☐ Scheduled caste
- ☐ Scheduled tribe
- ☐ OBC
- ☐ None of these

301. What is your current marital status?

- ☐ Currently married
- ☐ Married, gauna not performed
- ☐ Widowed
- ☐ Divorced
- ☐ Separated
- ☐ Deserted
- ☐ Never married

417. How many times did you receive antenatal care for this pregnancy?
_______ number

446. Where did you give birth to _____(name) ?

- ☐ Home
- ☐ Public Health sector
- ☐ Private Health sector

705. Do you currently smoke cigarettes?

- ☐ Yes
- ☐ No

707. Do you currently smoke bidis?

- ☐ Yes
- ☐ No

716. Do you drink alcohol?

- ☐ Yes
- ☐ Do

723. Do you currently have:

- ☐ Diabetes
- ☐ Asthma
- ☐ Goiter or thyroid disorder
- ☐ Any heart diseases
- ☐ Cancer

724. Are you covered by any health scheme or any health insurance?

- ☐ Yes
- ☐ No

Appendix 5.

Conceptual framework of LBW risk factor determinants by Culhane and Elo.[31]

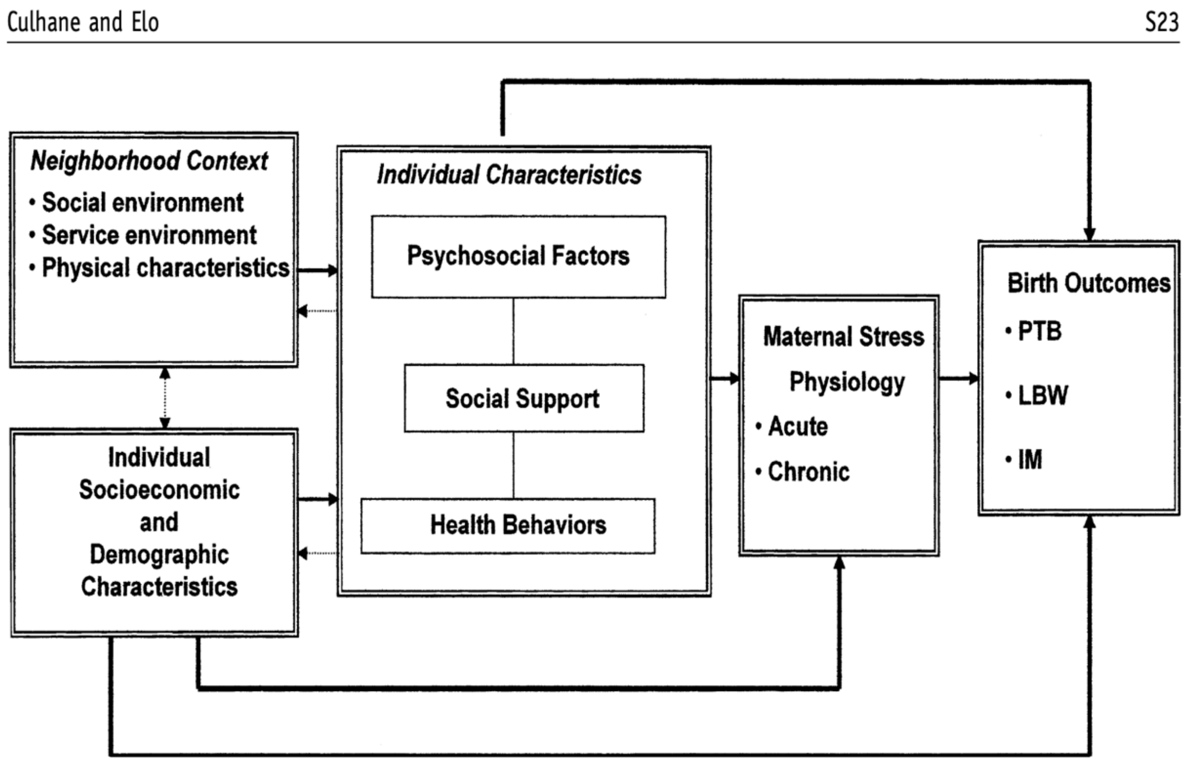


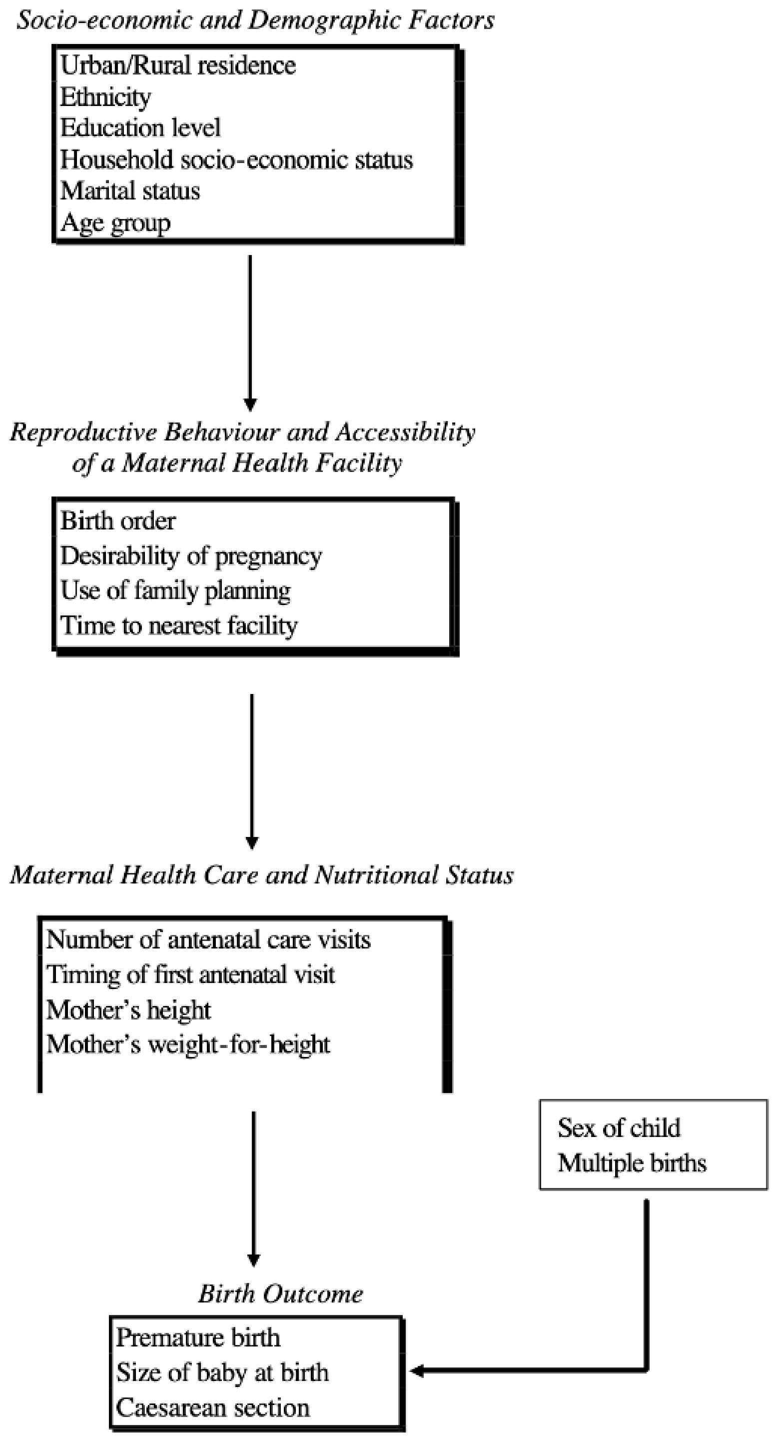
Figure Conceptual framework.

IM- Infant mortality

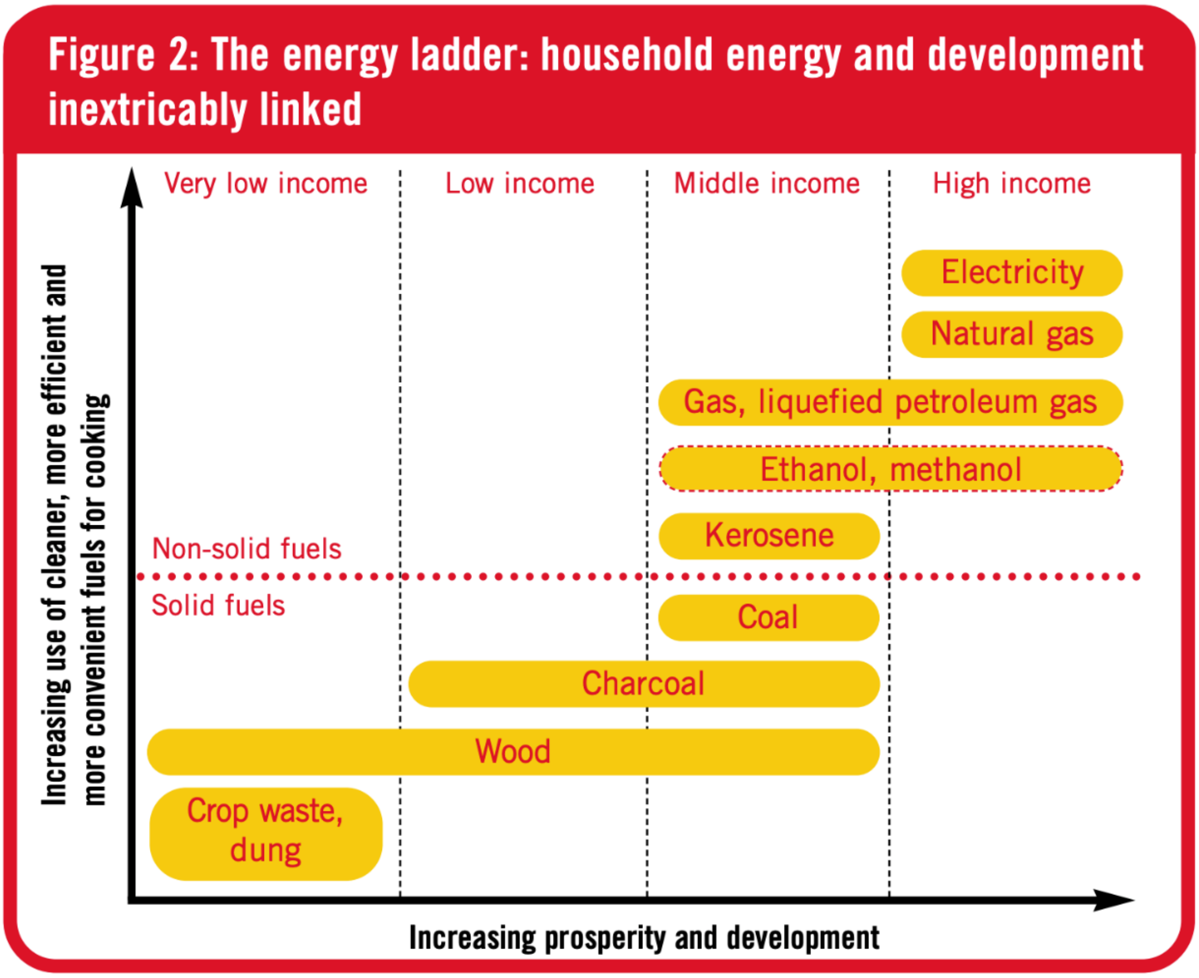
Appendix 6.

Conceptual framework of LBW risk factor determinants by Magadi et al.[33,32]

Framework for pathways of determinants of unfavourable birth outcomes



Appendix 7.
Energy ladder - WHO



https://www.who.int/airpollution/publications/fuelforlife.pdf?ua=1