Science of the Total Environment 774 (2021) 145717

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Maternal exposure to cooking smoke and risk of low birth weight in India

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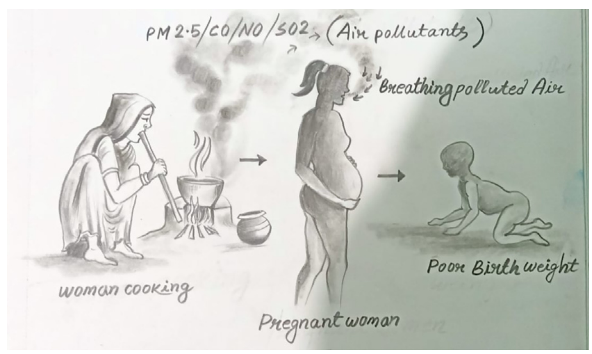
HIGHLIGHTS

- Association of cooking smoke and place of cooking with birth weight studied.
- Households using CCF had 80 g higher mean birth weight compared with UCF.
- UCF and cooking without separate kitchen had 3.5% higher LBW compared with households using CCF.
- Poor cooking practices significantly associated with risks of LBW.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 13 October 2020
Received in revised form 22 January 2021
Accepted 4 February 2021
Available online 9 February 2021

Editor: Lidia Morawska

Keywords:
Cooking fuels
Cooking practices
Exposure effects
Birth size
Household air pollution

ABSTRACT

Over half of the households in India are using unclean cooking fuels (UCF) and exposed to harmful pollutants that has adverse effects on weight of new born baby. Though studies examined the contextual determinants of birth weight, the association of cooking practices and kitchen location with low birth weight (LBW) is limited in India. This paper investigates the comprehensive effects of household air pollution (HAP) on LBW, mean birth weight (MBW) and birth size in India. Data from 93,721 full-term singleton births from the fourth round of National Family Health Survey, conducted during 2015–16 is used in the analyses. Binary logistic and linear regression methods were used to assess the effect of cooking practices on the outcome variables. Children born in households using clean cooking fuels (CCF) (2877 g, 95% CI: 2876–2877) had 80 g higher birth weight compared with UCF (2797 g, 95% CI: 2796–2798). Households using UCF and cooking without separate kitchen (2779 g, 95% CI:2778–2780) had 59 g and 98 g lower MBW as compared to the households using UCF and cooking in separate kitchen (2817 g, 95% CI:2816–2818) and CCF respectively. Significant associations of LBW observed with the place of cooking and cooking practices but no significant association found for cooking fuels. The HAP from poor cooking practices is associated with risks of LBW in India. Transition from unclean to clean fuels, provision of the separate kitchen should be encouraged to reduce the maternal exposure to HAP and improve birth outcomes.

1. Background

Universal access to improved cooking fuels is on global health and development agenda; the goal having first featured in the Millennium Development Goals (MDGs) and subsequently in the Sustainable Development Goals (SDGs) (Modi et al., 2005; UN, 2015). Goal 7 of the SDGs aims to ensure universal access to affordable, reliable, sustainable and modern energy (UN, 2015). Globally, around 4 billion people (more than half of the world's population) in 2018 lacked access to modern energy for cooking, with 2.75 billion of them using unclean cooking fuels (UCF) comprising wood, charcoal/coal, dung, and crop residues (ESMAP, 2020).

Exposure to smoke from the burning of UCF is a major source of household air pollution (HAP) in developing countries (HEI, 2020; Chowdhury et al., 2019), accounting for 2.3 million deaths (4.1% of all global deaths) and 91.5 million disability adjusted life years (DALYs)

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https://doi.org/10.1016/j.scitotenv.2021.145717

in 2019 (HEI, 2020). HAP is the leading cause of disease and premature mortality in low-income countries and accounts for 6% deaths, more than what is attributable to poor sanitation and lack of access to safe water (IHME, 2018). Lack of access to clean cooking fuels (CCF) costs more than $2.4 trillion each year (ESMAP, 2020). The health impact of HAP is far more than that of ambient air pollution. In spite of this, the health effects of HAP are not well understood (HEI, 2020; WHO, 2014a; Fullerton et al., 2008). HAP is a threat to women as they spend more time at home and are mainly responsible for cooking activities, which directly exposes them to harmful smoke (Dasgupta et al., 2006). A growing number of studies have identified the impact of HAP, caused by the use of UCF, on pregnancy outcomes, women's health, child health, nutritional status, and mortality (Bede-Ojimadu and Orisakwe, 2020; Islam et al., 2020; Lee et al., 2020; Junaid et al., 2018; Patelarou and Kelly, 2014; Kim et al., 2011; Fullerton et al., 2008).

1.1. Existing evidence on household air pollution and birth weight

Various studies performed to find the correlation between the detrimental effects of HAP on several pregnancy outcomes, which include stillbirths, preterm births, and LBW, in different geographical settings reveal a positive association between the two (Liu et al., 2018; Khan et al., 2017; Patelarou and Kelly, 2014; Wylie et al., 2014; Yucra et al., 2014; Amegah et al., 2014; Amegah et al., 2013; Kim et al., 2011; Pope et al., 2010). More evidently the studies indicate that continuous exposure to biomass smoke during pregnancy may lead to decrease in birth weight and also consequently increases the risk of LBW (Khan et al., 2017; Milanzi and Namacha, 2017; Jiang et al., 2015; Ahmed et al., 2015; Wylie et al., 2014; Amegah et al., 2013; Epstein et al., 2013; Sreeramareddy et al., 2011; Kim et al., 2011; Pope et al., 2010; Tielsch et al., 2009; Mishra et al., 2004). Amegah et al. (2014) carried out a systematic analysis to find out a 35% association of solid fuels with increased risk of LBW (EE-1.35, 95% CI: 1.23, 1.48) and also a reduction in birth weight by 86 g. Many other studies that carried out meta-analyses reports alike findings (Kim et al., 2011; Pope et al., 2010). Epstein et al. (2013) found that households using biomass fuels were significantly associated with increased odds of LBW (−110 g for coal, −107 g for kerosene, and -78 g for biomass). Women using solid fuels during pregnancy reportedly gave birth to lighter babies as compared to women using clean cooking fuels (Wylie et al., 2014; Sreeramareddy et al., 2011; Mishra et al., 2004). Pregnant women exposed to biomass are at a risk of 49% increase of LBW (Tielsch et al., 2009). A more than two-fold increase in LBW due to biomass has been reported by a birth cohort study in China (OR-2.51, 95% CI: 1.26, 5.01) (Jiang et al., 2015).

1.2. Low birth weight

Globally, more than 20 million infants are born with low birth weight (LBW), defined as birth weight < 2500 g, each year, with more than 91% being from developing countries – half of them from South Asia (48%) and one-fourth from sub-Saharan Africa (24%) (WHO, 2019; Blencowe et al., 2019). Improving birth weight is key to improving global health (Spong, 2016). LBW is an important public health concern and an important determinant of child and population health (Blencowe et al., 2019). Birth weight is also an important indicator of a child's vulnerability to the risks of various childhood morbidities, poor growth, and chances of survival (Aryastami et al., 2017; Rahman et al., 2016; Bernstein et al., 2000). Birth weight is positively associated with the physical and cognitive development of children (Gu et al., 2017; Ha et al., 2014). LBW has serious long-term consequences on the health and wellbeing of children, linked as it is with several diseases and morbidities, including chronic illness, obesity, diabetes, hypertension, etc. (Umer et al., 2020; Belbasis et al., 2016; Jornayvaz et al., 2016; Johnson and Schoeni, 2011; Hack et al., 2005; Curhan et al., 1996).

1.3. Area and need for the study

India, a signatory to both MDGs and SDGs, has committed to improve the lives and wellbeing of its 1350 million population (UN, 2019). Though huge efforts have been initiated by the national and state governments, only 44% of households have access to CCF – of them, 24% being in rural India and 81% in urban India (IIPS and ICF, 2017). About 41% of households use only wood for cooking, and over 97% use solid fuels in chullah (mud stove or earthen oven) or open fire despite decades of campaign and subsidies by the government on various schemes and programs related to clean fuels and technologies (Khandelwal et al., 2017; Manjula and Gopi, 2017; IIPS and ICF, 2017). Consequently, India accounts for the largest burden of HAP in the world (HEI, 2020; Pandey et al., 2020). HAP from the burning of UCF contributes to 30% of ambient $PM_{2.5}$ (Chowdhury et al., 2019), and exposure to HAP results in an estimated 0.61 million premature deaths every year in India, which is 6.5% of total deaths. HAP also contributes to 20.9 million DALYs or 4.5% of India's total DALYs (Pandey et al., 2020).

The NFHS-4 (2015–16) survey reported a higher prevalence of LBW (18%) in India compared with the global prevalence (15%) and the prevalence in developed countries (5%–7%) (World Health Organization, 2019; Blencowe et al., 2019; IIPS and ICF, 2017), describing it as a major public health issue. LBW is the second leading cause of infant mortality and morbidity in India. Despite this, there is limited research on its association with environmental correlates (Dandona et al., 2020). Previous studies have examined the contextual determinants of birth weight (Apte et al., 2019; Khan et al., 2020); however, only a few of them have examined the association of cooking fuels with birth weight in India and have used subjective measures for large missing cases of birth weight (Epstein et al., 2013; Sreeramareddy et al., 2011).

To date, the association of birth weight with cooking practices, particularly place of cooking, has not been studied well. Most of the previous studies have considered only cooking fuels as the surrogate measure of HAP, ignoring place of cooking (Khan et al., 2017; Jiang et al., 2015; Wylie et al., 2014; Amegah et al., 2014; Epstein et al., 2013; Sreeramareddy et al., 2011; Tielsch et al., 2009). Also, the role of potential confounders like environmental tobacco smoke and gestational period or duration of pregnancy has largely been ignored. Previous studies have also used wealth index as an explanatory variable that includes cooking fuels and electricity (Khan et al., 2017; Wylie et al., 2014; Epstein et al., 2013; Sreeramareddy et al., 2011; Tielsch et al., 2009). Failing to capture the heterogeneity of the Indian states, previous studies have been unable to give any evidence at the state level.

Thus, it is necessary to identify the role of cooking fuels and cooking practices as independent and combined risk factors of LBW across the states of India to formulate effective health policies and introduce preventive measures. Against this background, the present study attempts to fill the gap in the literature by exploring the association of type of cooking fuels and cooking practices with birth weight using data from the NFHS-4 (2015–16). Our analysis is based on the premise that mothers in households using UCF are exposed to cooking smoke during pregnancy.

2. Methods

2.1. Data

We used data from the fourth round of the National Family Health Survey (NFHS-4), conducted in 2015–16. The NFHS is a nationwide survey conducted with a representative sample of households throughout the country, under the aegis of the Ministry of Health and Family Welfare, Government of India, to provide high-quality data on population and health indicators for implementing national and state level policies. A uniform, multi-stage random sample design was adopted across the states. Households were selected by the two-stage probability proportional to size method in rural areas and the three-stage method in urban areas. A total of 601,509 households, 699,686 women (aged

15–49 years), and 103,525 men (aged 15–54 years) were successfully interviewed. The data provides information on fertility, mortality, maternal and child health, reproductive health, family planning and contraceptive use, HIV/AIDS, etc. (IIPS and ICF, 2017).

2.2. Study population

In this study, we used the household and kids data files, obtained from the household and the woman schedules respectively. The study population consisted of the most recent children born singleton in the last three years (from the interview date). We considered only singleton births due to the higher probability of LBW in the case of multiple births (Luke and Keith, 1992). We restricted our analysis to children born in the last three years because the information on birth size and birth weight was based on mother's recall; having a shorter recall time helped us reduce the bias. Furthermore, the study sample was restricted to full-term births, whose gestational period was nine or more months. So, our effective sample was 119,537 for birth size and 93,721 for birth weight.

2.3. Exposure

The exposure variables were cooking fuels[1] – categorized into clean cooking fuels (CCF) and unclean cooking fuels (UCF) – and place of cooking.[2] CCF included electricity, liquefied petroleum gas (LPG), biogas, and no food cooked in the house (N 7, 0.01%) while UCF included wood, agricultural by-products/ residues/wastes, straw/shrubs/grass, animal dung, kerosene, coal/lignite, charcoal, and other fuels. Place of cooking was categorized as: cooking in a separate kitchen (CISK), cooking without a separate kitchen (CWSK), and cooking outdoors, irrespective of type of cooking fuel. Furthermore, we combined the cooking fuels and the place of cooking variables into four categories (clean cooking fuels, unclean cooking fuels in a separate kitchen, unclean cooking fuels without a separate kitchen, and unclean cooking fuels outdoors) and referred to them as cooking practices. The purpose of doing so was to assess the independent and combined effects of the different components of HAP on birth weight.

2.4. Outcomes

We considered three outcome variables, namely, small birth size,[3] low birth weight (LBW), and mean birth weight (MBW) (in grams). In the woman's schedule, mothers were asked to classify the size of the baby at the time of birth and classified into five categories: very large, larger than average, average, smaller than average, and very small. We further categorized these to form binary variables, namely, greater than or equal to average size at birth (very large, larger than average, and average) and smaller than average size at birth (smaller than average and very small), corresponding to normal birth weight (2500 g or more) and low birth weight (less than 2500 g) respectively. The category of smaller than average size at birth was referred to as small birth size in the study. As mentioned above, we calculated small birth size (SBS) too as one of the outcome variables. This led us to capture the proxy measure of LBW for those children (25,816) whose birth weight information was not available, whether from health card or mother's recall (Appendix 1). Several previous studies have used size at birth as a proxy measure for birth weight (Nisha et al., 2019; Milanzi and Namacha, 2017; Ahmed et al., 2015; Islam, 2014; Lule et al., 2012; Sreeramareddy et al., 2011). LBW was defined as birth weight of less than 2500 g, while normal birth weight was defined as 2500 g or more birth weight, with a gestational age of nine or more months (Fig. 1).

Our rationale for taking three different outcome variables for the study was two-fold. The first was to help us understand the nuances of the effect of different components of HAP on birth weight in India. Second, earlier studies focused on either birth size or birth weight (from health cards or mother's recall) due to incompleteness of information. Since size at birth and birth weight from mother's recall are perception-based measurements, their use casts doubt on the robustness of the results. In addition, we considered birth size as an outcome variable to understand the association between HAP and birth weight with a bigger sample size for analysis. Therefore, our approach to understanding the association of the different components of HAP with three measures of birth weight would give robust results for an evidence-based policy.

2.5. Covariates

After an extensive review of the existing literature on HAP (Khan et al., 2017; Jiang et al., 2015; Wylie et al., 2014; Amegah et al., 2013; Epstein et al., 2013; Sreeramareddy et al., 2011; Mishra et al., 2004), several confounders were selected to study their association with birth weight. At the child level, the confounders selected were sex of child and birth order. At the maternal level, birth interval, mother's age at childbirth, mother's underweight, mother's anemia status, antenatal care visits during pregnancy, pregnancy intention, mother's tobacco use, mother's education, mother's social group, and environmental tobacco smoke were selected as the variables. Wealth index and place of residence were used as confounders at the household level. Since the wealth index[4] in the NFHS includes household access to electricity and cooking fuels, we computed a new wealth index excluding electricity and cooking fuels following a similar methodology (IIPS and ICF, 2017).

2.6. Statistical analyses

Descriptive statistics and bivariate analysis were conducted to ascertain the association between each exposure and outcome variable. Logistic and linear regression analyses were used to investigate the crude and adjusted association of different components of HAP with the measures of birth weight. In the logistic and linear regression analyses, SBS, LBW, and MBW were set as the dependent variables. All the three components of HAP were set as independent variables separately, and all the other factors mentioned above were set as confounders. In the first model, the main exposure variable was cooking fuels, whereas place of cooking and cooking practices were used as exposure variables in the second and third models. STATA 15.1 software was used for analysing the data.

[1] The question asked to the household head was: "What type of fuel does your household mainly use for cooking?" There were 12 answer options, including electricity, liquefied petroleum gas (LPG), biogas, no food cooked in the house wood, agricultural by-products/ residues/wastes, straw/shrubs/grass, animal dung, kerosene, coal/lignite, and charcoal and other fuels.

[2] The respondent was asked the question: "Is the cooking usually done in the house in a separate building or outdoors?" There were three answer options, namely, in the house, in a separate building, outdoors, and other. Follow-up questions were posed only to those households that answered that food was cooked in the house provided that they had a separate kitchen ("Do you have a separate room which is used as a kitchen?"—Yes/No). Separate kitchen referred to cooking in the house but in a dedicated kitchen or cooking in a separate building. This was termed cooking in a separate kitchen (CISK). In contrast, no separate kitchen implied cooking in the house but without a separate kitchen (CWSK) and outdoor cooking, irrespective of the type of cooking fuels used.

[3] The question on birth size and birth weight was as follows: "When (NAME) was born, was (he/she) very large, larger than average, average, smaller than average, or very small?" The follow-up question asked was: "Was (NAME) weighed at birth?" There were three answer options, namely, yes, no, and don't know. Further follow-up questions were posed only to those mothers that answered the question with a yes. Such mothers were asked: "How much did (NAME) weigh?" In case of mothers who had a health card, weight was recorded in kilograms, whereas in case of those who didn't possess a health card, birth weight was recorded according to mother's recall. The question on birth weight was asked at the time of the survey and the information recorded accordingly. Field investigators were trained to record the birth weight if a woman showed the health card – a card that notes the immunisation record of a child along with its weight at the time of birth. Such cards are issued by the health centres at the time of birth.

[4] The wealth index is a composite score of a diverse range of household assets such as land, housing conditions, household amenities and assets, and the presence of domestic servants. Details of the index can be found elsewhere (IIPS and ICF, 2015–16). Several studies have used wealth index as a proxy for economic status (Islam et al., 2020; Khan et al., 2017; Epstein et al., 2013; Sreeramareddy et al., 2011).

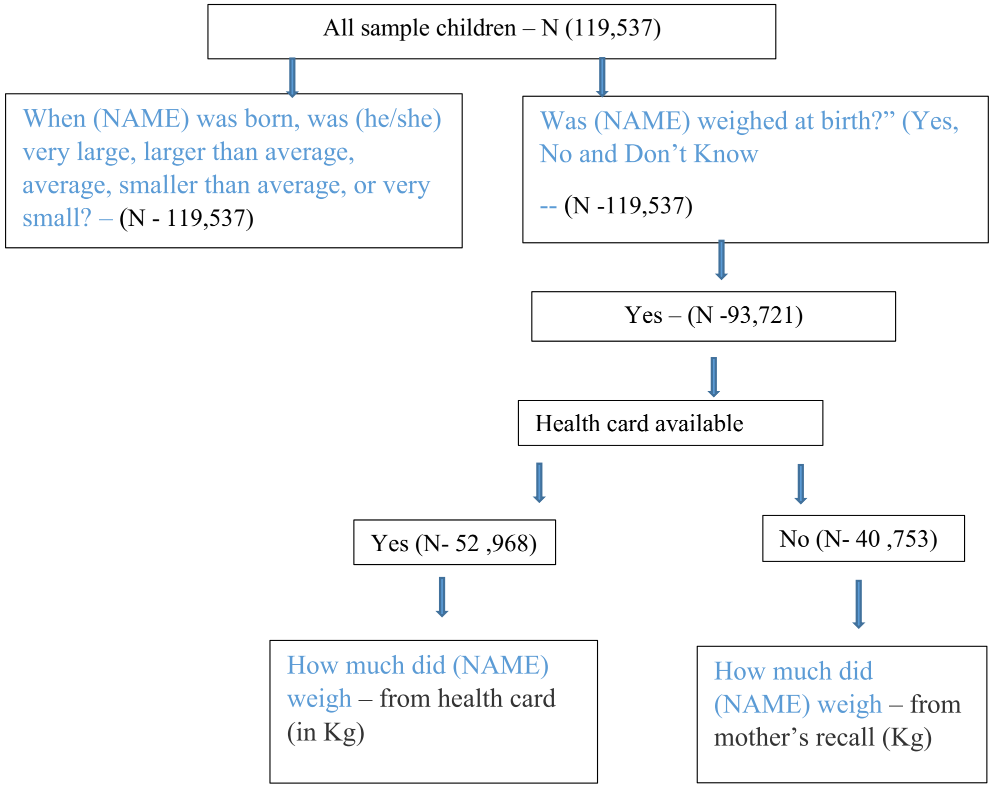


Fig. 1. Flow chart of the outcome variable.

3. Results

3.1. Prevalence of small birth size, low birth weight, and mean birth weight

Table 1 displays the state-wise variations in small birth size, low birth weight, and mean birth weight among the most recent full-term singleton births and household cooking practices in India. In India, 12% and 17% of births could be categorized as SBS and LBW respectively in 2015–16, with a difference of 5% observed at the national level. The highest prevalence (24%) of SBS was observed in the state of Tripura, followed by Arunachal Pradesh (21%) and Assam (20%). On the other hand, at 3%, the state of Sikkim reported the lowest prevalence of SBS in India, followed by Kerala (5%) and Telangana (6%). Delhi had the highest prevalence (23%) of LBW among the Indian states, where one in five children was born with LBW. It was followed by Uttarakhand (21%), Madhya Pradesh (21%), and Rajasthan (20%). Over 15% of babies were born with LBW in the states of Andhra Pradesh, Telangana, Gujarat, Maharashtra, Punjab, Haryana, Himachal Pradesh, Uttar Pradesh, and Odisha. The prevalence of LBW was higher by over 3% compared to SBS in 16 out of 30 states and by over 5% in the states of Andhra Pradesh, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Delhi, Rajasthan, Tamil Nadu, Uttarakhand, and Telangana. By contrast, the prevalence of SBS was higher compared to that of LBW by over 5% in the states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Nagaland, and Tripura.

The MBW of children also varied significantly across the states in India. The MBW was 2819 g, the highest being in the state of Nagaland (3266 g), followed by Mizoram (3223 g), Manipur (3174 g), and Arunachal Pradesh (3138 g). The state of Rajasthan (2713 g) had the lowest MBW, followed by Delhi (2734 g), Madhya Pradesh (2735 g), Uttarakhand (2738 g), and Punjab (2755 g).

3.2. Pattern of cooking practices

Only one in three Indian households were found to be using CCF, while 29%, 27% and 9% of households were using UCF in a separate kitchen, without a separate kitchen, and outdoors respectivelly. The variations in cooking practices were large across the states. The state of Delhi had the highest use of CCF (97%), followed by Tamil Nadu (71%), Telangana (67%), Mizoram (60%), and Punjab (60%). As many as 13 out of 30 states had above national average (65%) use of UCF. Over 80% households were using UCF in the states of Bihar (88%), Jharkhand (87%), Meghalaya (86%), Odisha (85%), Assam (83%), and Chhattisgarh (81%).

Over half of the households using UCF and cooking in a separate kitchen (CISK) were in the states of Meghalaya (75%), Assam (68%), Himachal Pradesh (65%), Tripura (56%), Nagaland (65%), and Chhattisgarh (50%). Interestingly, all these states have a low coverage of CCF and were found to be making a higher use of UCF and CISK. Among the four types of cooking practices, households using UCF and CWSK were the most exposed to harmful pollutants emitted from the use of UCF. Over 30% households were using UCF and CWSK in the states of Bihar (50%), Jharkhand (51%), Uttar Pradesh (45%), Madhya Pradesh (40%), and Mizoram (32%). Delhi had the lowest percentage (2%) of households using UCF and CWSK, followed by Kerala (2%), Sikkim (4%), Himachal Pradesh (5%), Tamil Nadu (7%), Karnataka (9%), Nagaland (8%), Andhra Pradesh (10%), and Meghalaya (10%). The use of CCF was high in the southern Indian states and low in central and eastern India. The state of Kerala, which has the highest human development index among all the Indian states, was found to have only half of the households using CCF, though the percentage of households using UCF and CWSK was only 2%. The states of Bihar, Jharkhand, Madhya Pradesh, Odisha, Rajasthan, Uttar Pradesh, and West Bengal had the poorest cooking practices; in these states, less than 30% and more than 25% of households were found to be using CCF and CWSK respectively.

3.3. Birth weight by primary cooking fuel types

Fig. 2 summarizes birth weight by type of cooking fuels in India. The analysis shows a clear pattern of LBW prevalence in relation to clean (electricity, biogas, and LPG) and other types of cooking fuels (coal, biomass, and kerosene). Households using electricity experienced the

Table 1
Percentage of small birth weight, low birth weight and mean birth weight among the most recent full-term singleton births and pattern of household's cooking practices across the states in India, 2015–16.
Data source - National Family Health Survey-4 (2015–16).

States/India	Small birth size[a] (%)	Low birth weight[b] (%)	Mean birth weight (g)	Cooking practices					Unweighted N[e]	Unweighted N[f]
				Clean cooking fuels[c]	Unclean cooking fuels[d]	Unclean cooking fuels and cooking in separate kitchen	Unclean cooking fuels and cooking without separate kitchen	Unclean cooking fuels and cooking in outdoor		
Andhra Pradesh	8.8	15.6	2834	58.2	41.8	9.9	10.1	21.8	1328	1283
Arunachal Pradesh	20.8	7.4	3138	40.9	59.1	33.3	25.6	0.2	2450	1330
Assam	20.4	14.0	2843	17.4	82.6	68.1	11.4	3.1	5407	4335
Bihar	15.3	13.1	2908	12.1	87.9	29.2	49.5	9.2	10,953	7216
Chhattisgarh	8.8	10.6	2846	19.5	80.5	50.3	28.3	2.0	4261	3731
Gujarat	13.6	18.3	2824	44.3	55.7	22.2	17.0	16.5	3462	3188
Haryana	9.1	19.3	2797	44.6	55.4	29.8	20.7	5.0	3606	3232
Himachal Pradesh	14.4	17.1	2794	27.1	72.9	65.1	4.7	3.1	1263	1052
Jammu and Kashmir	14.5	12.4	2854	48.5	51.5	34.9	10.8	5.8	4122	2902
Jharkhand	9.5	13.3	2850	12.8	87.2	30.3	51.1	5.9	5774	4213
Karnataka	7.3	14.6	2854	51.7	48.3	36.6	9.3	2.4	3324	3169
Kerala	5.2	10.3	2942	50.8	49.2	45.8	1.8	1.6	1165	1156
Madhya Pradesh	14.5	20.9	2735	25.1	74.9	32.0	39.6	3.3	11,461	9515
Maharashtra	9.7	18.0	2788	54.3	45.7	27.2	12.0	6.6	4427	4254
Manipur	13.6	6.9	3174	39.9	60.1	48.3	11.3	0.6	3006	2150
Meghalaya	17.4	11.3	2995	13.7	86.3	75.3	9.5	1.5	2250	1551
Mizoram	6.7	3.1	3223	60.1	39.9	6.4	32.4	1.2	2521	2272
Nagaland	15.8	5.6	3266	26.1	73.9	65.4	8.0	0.5	1824	752
Delhi	8.5	22.8	2734	97.0	3.0	0.9	1.5	0.5	706	633
Odisha	13.9	18.5	2773	15.1	85.0	39.4	27.5	18.1	5480	5172
Punjab	13.1	16.0	2755	60.3	39.7	22.8	13.0	3.9	2577	2492
Rajasthan	11.2	20.3	2713	25.9	74.1	28.4	26.1	19.7	7717	6369
Sikkim	2.6	6.2	3098	53.6	46.4	42.0	4.4	0.0	581	575
Tamil Nadu	9.1	14.7	2864	71.2	28.8	8.8	6.6	13.5	3948	3914
Tripura	23.7	14.7	2798	24.1	75.9	55.9	16.0	4.0	693	570
Uttar Pradesh	15.8	18.7	2825	27.0	73.0	20.7	44.7	7.6	17,054	9740
Uttarakhand	13.9	21.1	2738	42.8	57.2	33.3	17.0	6.9	2800	1914
West Bengal	12.0	14.7	2801	20.6	79.4	46.7	19.5	13.3	2642	2373
Telangana	6.0	16.6	2842	67.4	32.6	6.5	11.0	15.1	1085	1067
Union Territories[g]	7.8	18.4	2832	77.8	22.2	12.1	6.9	3.2	1650	1601
India	12.4	16.5	2819	35.0	65.0	28.9	26.8	9.3	119,537	93,721

[a] Mothers were asked to classify the 'size of the baby at the time of birth into the following five categories, namely very large, larger than average, average, smaller than average, or very small. We further categorized to form a binary variable as 'greater than or equal to average size' (very large, larger than average and average) and 'smaller than average' (smaller than average and very small) at birth corresponding to normal birth weight (weight 2500 g or more) and low birth weight (less than 2500 g) respectively.
[b] Low birth weight means children born less than 2500 g at the time of birth.
[c] Clean cooking fuels refers to electricity, LPG/gas, and biogas.
[d] Unclean cooking fuels refers to kerosene, coal/lignite, charcoal, wood, straw/shrubs/grass, agricultural crop and animal dung.
[e] N refers to sample size for small birth size and cooking practices.
[f] N refers to sample size for low birth weight and mean birth weight.
[g] Union Territories refers as the Andaman and Nicobar Islands, Chandigarh, Dadra and Nagar Haveli, Daman and Diu, Lakshadweep, Puducherry, Goa.

lowest prevalence of LBW (13%), while one in five (19%) children were born with LBW among households using kerosene. The lowest prevalence of SBS was reported among households using biogas (6%), followed by those using LPG (9%). The SBS prevalence was 12% for households using electricity, which was the highest among all clean fuels, while the highest prevalence (14%) in the case of UCF was reported among households using biomass. There was quite a significant difference in the prevalence of SBS and LBW by type of cooking fuels at the national level.

The MBW of the study population was 2819 g (95% CI: 2816–2823); significant differences were observed in MBW by fuel types. The MBW of the infants from households using kerosene was the lowest (2762 g, 95% CI:2729–2794), followed by those from households using biomass and coal. It was the highest among households using LPG (2856 g, 95% CI: 2851–2862).

3.4. Association between different components of household air pollution (cooking fuels, place of cooking, and cooking practices) with birth weight

The association between different components of household air pollution and three different measures of birth weight have been presented in Table 2. The prevalence of all three birth weight measures varied significantly by the different components of HAP (cooking fuels, place of cooking, and cooking practices) in India. There was a difference of 5% in the prevalence of SBS among households using CCF (9.4%, 95% CI: 9.1–9.6) and those using UCF (14.0%, 95% CI: 13.8–14.3). A significant difference was also observed by place of cooking, with households CISK experiencing an SBS prevalence of 10.9% (95% CI: 10.7–11.2) and households CWSK (14.5%, 95% CI- 14.1-14.8) observing a 4% higher SBS as against their counterparts. Similarly, by cooking practices, SBS varied greatly at the national level as households using UCF and CWSK had an SBS prevalence of 15.4% (95% CI-15.0-15.8), while those using UCF and CISK had an SBS prevalence of 13.1% (95% CI: 12.7–13.5).

LBW prevalence among households using CCF was 15.2% (95% CI:14.9–15.6) as against 17.4% (95% CI: 17.1–17.7) among households using UCF, 16.2% (95% CI:15.8–16.6) among households using unclean cooking fuels and cooking in a separate kitchen (UCF and CISK), and 18.7% (95% CI:18.1–19.2) among households using unclean cooking fuels and cooking without a separate kitchen (UCF and CWSK). Households using UCF had a 2.2% higher prevalence of LBW than those using CCF at the all-India level. Similarly, households that CWSK experienced a 3.2% higher prevalence of LBW than those who CISK. Furthermore,

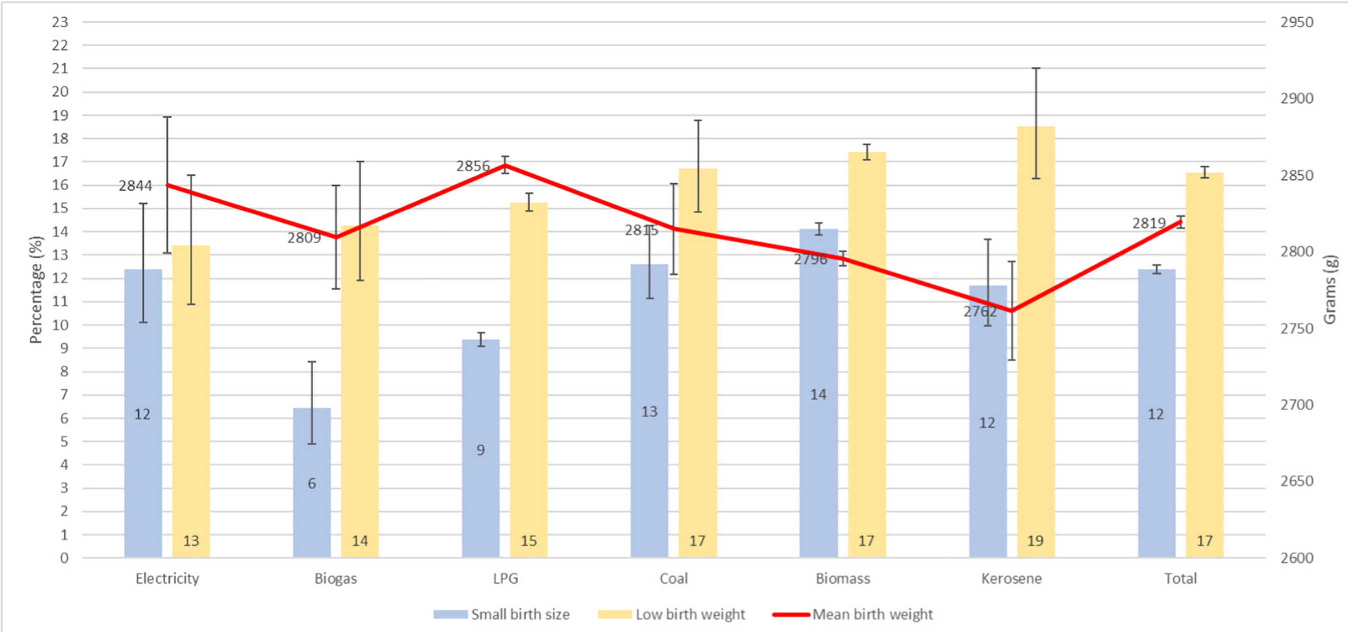


Fig. 2. Percentage of small birth size, low birth weight and mean birth weight among the most recent full-term singleton births by cooking fuel types in India, 2015–16.

households using UCF and CWSK had a 3.5% higher prevalence of LBW as against households using CCF.

Similar differences were observed in the prevalence of MBW by cooking practices. The lowest MBW of 2777 g (95% CI:2769–2785) was observed among households using UCF and CWSK compared with MBW of 2813 g (95% CI:2807–2820) and 2855 g (95% CI:2850–2861) among households using UCF and CISK and those using CCF respectively. The MBW was 80 g higher among households using CCF compared to those using UCF and 55 g higher among households CISK compared to those CWSK. Similarly, households using UCF and CWSK had 98 g and 59 g lower MBW compared to those CISK and using UCF and those using CCF respectively.

The state-wise variations in low birth weight by cooking fuels and cooking practices have been shown in Table 3. At the national level, we found a clear pattern of SBS and LBW prevalence by cooking fuels and cooking practices. Households using UCF and CWSK had the highest prevalence of SBS (15%) and LBW (19%), followed by those using UCF and those cooking outdoors (13% and 18% respectively). Households using CCF had the lowest prevalence of SBS (9%) and LBW (15%) as against all the other subcategories of cooking fuels and cooking practices, including households using UCF (14% and 17% respectively). There was a difference of 6% and 4% in SBS and LBW at the national level between households using CCF (9% and 15%) and those using UCF without a separate kitchen (15% and 19%) (UCF and CWSK). Similarly, households using UCF and CWSK had 2% and 3% higher prevalence of SBS and LBW (15% and 19%) compared to those using UCF and CISK (13% and 16%). The national pattern of the prevalence of both SBS and LBW with the cooking fuels and cooking practices was similar across the states. The highest prevalence of SBS and LBW was found in households using UCF and CWSK in the majority of the states. A high prevalence was also observed among households cooking outdoors. A difference of over 5% in SBS was observed between households using CCF and those using UCF in the states of Arunachal Pradesh, Assam, Gujarat, Madhya Pradesh, Manipur, Meghalaya, Mizoram, Nagaland,

Table 2
Percentage of small birth size, low birth weight and mean birth weight among the most recent full-term singleton births by the different components of household air pollution, 2015–16. Data source - National Family Health Survey-4 (2015–16).

Household air pollution	Small birth size			Low birth weight			Mean birth weight			Unweighted N[a]	Unweighted N[b]
	Percentage	95% Conf. Interval		Percentage	95% Conf. Interval		In grams	95% Conf. Interval			
Cooking fuels											
Clean cooking fuels	9.4	9.1	9.6	15.2	14.9	15.6	2855	2850	2861	36,110	32,789
Unclean cooking fuels	14.0	13.8	14.3	17.4	17.1	17.7	2795	2791	2800	83,427	60,932
Place of cooking											
Cooking in separate kitchen	10.9	10.7	11.2	15.2	14.9	15.5	2843	2838	2848	67,676	56,199
Cooking without separate kitchen	14.5	14.1	14.8	18.4	18.0	18.9	2786	2779	2792	42,753	30,491
Cooking in outdoor	13.0	12.4	13.7	18.3	17.5	19.2	2785	2773	2797	9108	7031
Cooking practices											
Clean cooking fuels	9.4	9.1	9.6	15.2	14.9	15.6	2855	2850	2861	36,110	32,789
Unclean cooking fuels and cooking in separate kitchen	13.1	12.7	13.5	16.2	15.8	16.6	2813	2807	2820	40,630	31,091
Unclean cooking fuels and cooking without separate kitchen	15.4	15.0	15.8	18.7	18.1	19.2	2777	2769	2785	33,863	22,961
Unclean cooking fuels and cooking in outdoor	13.1	12.4	13.7	18.2	17.4	19.0	2785	2773	2797	8934	6880
Total	12.4	12.2	12.6	16.5	16.3	16.8	2819	2816	2823	119,537	93,721

[a] N refers to sample size for small birth size.
[b] N refers to sample size for low birth weight and mean birth weight.

3
Percentage of small birth weight and low birth weight among the most recent full-term singleton births according to cooking practices across the states in India, 2015–16.
Data source - National Family Health Survey-4 (2015–16).

States/India	Small birth size					Low birth weight				
	Clean cooking fuels	Unclean cooking fuels	Unclean cooking fuels and cooking in separate kitchen	Unclean cooking fuels and cooking without separate kitchen	Unclean cooking fuels and cooking in outdoor	Clean cooking fuels	Unclean cooking fuels	Unclean cooking fuels and cooking in separate kitchen	Unclean cooking fuels and cooking without separate kitchen	Unclean cooking fuels and cooking in outdoor
Andhra Pradesh	7.6	10.4	10.3	16.0	7.8	13.7	18.5	20.3	22.4	16.0
Arunachal Pradesh	17.3	23.3	21.1	26.3	0.0	7.1	7.9	6.6	10.3	0.0
Assam	13.4	21.8	20.7	26.9	27.1	11.5	14.7	14.0	18.3	18.2
Bihar	12.3	15.7	14.9	16.3	14.8	11.0	13.5	13.2	13.9	12.6
Chhattisgarh	7.7	9.1	9.3	8.9	4.8	7.9	11.3	10.5	13.2	8.6
Gujarat	9.9	16.6	16.2	20.7	12.7	15.0	21.1	20.3	22.5	21.0
Haryana	7.7	10.2	8.4	11.8	14.7	18.3	20.2	17.4	24.6	20.6
Himachal Pradesh	13.6	14.8	14.3	16.4	21.9	17.7	16.9	16.8	7.3	33.2
Jammu and Kashmir	12.1	16.8	15.1	19.3	22.1	11.5	13.6	13.7	15.5	10.7
Jharkhand	5.7	10.0	8.4	10.4	14.8	10.7	13.8	14.5	13.3	14.5
Karnataka	6.6	8.0	7.4	9.9	10.4	15.5	13.7	13.9	12.8	12.6
Kerala	4.2	6.2	6.0	9.0	8.1	10.1	10.6	10.5	9.0	14.9
Madhya Pradesh	10.6	15.8	15.7	15.8	16.6	19.6	21.5	21.9	20.9	24.4
Maharashtra	8.5	11.1	9.3	14.6	12.3	17.4	18.7	18.8	19.7	16.8
Manipur	8.2	17.3	17.0	19.0	6.5	4.7	9.1	8.7	11.1	7.0
Meghalaya	7.3	19.0	19.6	14.4	15.7	9.0	11.8	11.8	12.4	8.4
Mizoram	4.2	10.4	9.2	11.0	1.4	2.7	3.8	4.0	3.9	1.4
Nagaland	11.5	17.3	18.1	11.1	5.2	5.2	5.9	5.9	5.2	10.0
Delhi	8.6	3.4	0.0	6.2	1.1	23.1	12.1	29.5	0.0	0.0
Odisha	8.5	14.9	15.2	15.4	13.5	10.0	20.0	18.2	22.2	20.8
Punjab	11.8	15.0	14.3	16.3	15.5	14.7	18.0	16.1	21.7	17.5
Rajasthan	8.5	12.2	10.6	14.3	11.6	17.1	21.6	18.5	24.1	22.7
Sikkim	2.6	2.5	2.7	0.0		5.7	6.8	7.3	1.8	0.0
Tamil Nadu	8.2	11.3	10.9	11.8	11.2	13.3	18.0	15.3	18.1	19.7
Tripura	14.6	26.6	23.9	39.5	12.8	13.8	15.1	15.3	17.0	7.1
Uttar Pradesh	14.4	16.3	15.4	16.4	18.4	17.2	19.5	17.4	20.6	19.6
Uttarakhand	10.0	16.8	15.7	18.9	17.5	18.9	23.7	24.0	21.7	26.3
West Bengal	9.1	12.7	11.9	15.1	12.2	11.6	15.6	15.1	18.7	12.7
Telangana	6.0	6.1	5.2	5.3	7.0	15.4	19.0	11.5	21.8	20.2
Union Territories[a]	7.5	8.8	8.3	8.9	10.4	16.9	23.9	26.8	23.5	13.4
India	9.4	14.0	13.1	15.4	13.1	15.2	17.4	16.2	18.7	18.2

[a] Union Territories refers as the Andaman and Nicobar Islands, Chandigarh, Dadra and Nagar Haveli, Daman and Diu, Lakshadweep, Puducherry, Goa.

Odisha, Tripura, and Uttarakhand. Likewise, a significant difference was seen in SBS between households CISK and those CWSK in the states of Andhra Pradesh, Arunachal Pradesh, Assam, Maharashtra, Delhi, and Tripura. In the case of LBW, over 5% higher prevalence was found in the states of Odisha, Gujarat, Andhra Pradesh, Uttarakhand, Tamil Nadu, and Rajasthan among households using UCF compared to those using CCF. Over 7% difference was observed between households using UCF and CWSK compared to those using CCF in the states of Odisha, Gujarat, Andhra Pradesh, Rajasthan, West Bengal, Punjab and Assam (Fig. 3). The prevalence of LBW was found to be higher by over 3% in households using UCF and CISK compared to those using CCF in the states of Andhra Pradesh, Gujarat, Jharkhand, Manipur, Delhi, Odisha, Uttarakhand, and Telangana.

The proportion of small birth size and low birth weight by cooking fuels and cooking practices according to the selected socio-demographic characteristics in India has been presented in Table 4. The bivariate analysis shows that households using UCF, those using UCF and CISK, and those using UCF and CWSK had a higher prevalence of SBS and LBW compared to households using CCF. There was a clear pattern of SBS and LBW gradient by cooking practices. Across the spectrum of cooking practices (except CCF) and by the background characteristics, a higher prevalence of both SBS and LBW was observed among those who had the following characteristics: exposed to environmental tobacco smoke, born as a female child, maternal age at childbirth less than 19 years, underweight and anemic mothers, mother made no antenatal care visits, born as unwanted children, mothers used tobacco, mother had no education, belonged to a scheduled tribe, and were from the poorest wealth quintile. Among households using CCF, there was a difference of 4–7% LBW prevalence between the poorest/poorer and the richest quintiles, while the difference was less than 1% among households using UCF and CWSK.

3.5. Effects of cooking fuels, place of cooking, and cooking practices on birth size, birth weight, and mean birth weight

Multivariate logistic and linear regression was used to assess the association between the components of HAP and the odds of SBS, LBW, and MBW (Table 5). Results show the probability of low birth weight by the three main exposure variables by applying the logistic and linear regression models. After controlling the covariates in model 1, the use of cooking fuels was found to be significantly associated with SBS (OR:1.08; 95% CI: 1.02–1.14) but not with LBW. LBW was significant in the unadjusted model, with odds of 1.24 (OR:1.24; 95% CI:1.19–1.29). The unadjusted model shows that SBS was significantly associated with the components of HAP, while the association was modest upon controlling for other covariates. For the place of cooking (model 2), we found that the odds of being LBW were higher among children from households CWSK (OR:1.11; 95% CI:1.04–1.19). In model 3, we estimated the adjusted effect of cooking fuels, place of cooking, and cooking practices on LBW. Children born in households using UCF and cooking outdoors had a negligibly higher risk of being born with LBW (OR: 1.08; 95% CI:1.00–1.17) than those born in households using CCF. The unadjusted odds show that households using UCF and CWSK (OR:1.34;95% CI:1.28–1.40) and those using UCF and CISK

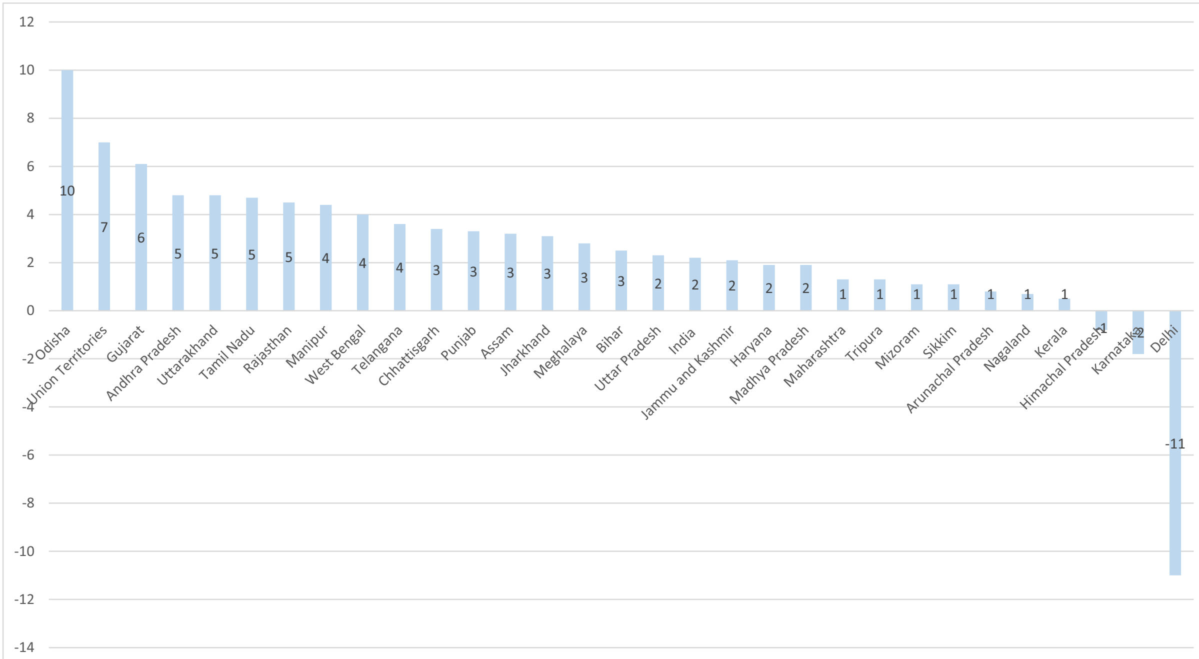


Fig. 3. Difference in prevalence of low birth weight (LBW) between clean cooking fuels (CCF) and unclean cooking fuels (UCF) across the states in India, 2015–16 [positive values shows higher LBW among UCF users].

(OR:1.12;95% CI:1.08–1.17) had a greater risk of being born with LBW as compared to the reference group in model 3.

After controlling the socio-demographic covariates, a significant difference in MBW was observed by different components of HAP. The results show that households using CCF (2877 g, 95% CI: 2876–2877) had 80 g higher MBW as against those using UCF (2797 g, 2796–2798). The difference was also observed in terms of place of cooking, with children born in households CWSK (2798 g, 95% CI: 2797–2799) being 55 g lighter compared to those born in households CISK (2852 g, 95% CI: 2851–2853). Furthermore, households using UCF and CWSK (2779 g, 95% CI:2778–2780) had 98 g and 38 g lower MBW compared to households using CCF (2877 g, 95% CI:2876–2877) and those using UCF and CISK (2817 g, 95% CI: 2816–2818).

4. Discussion

Using the nationally representative data from NFHS-4, this study examined the effects of the different components of household air pollution on birth weight across the states of India. To our knowledge, this is the first attempt to estimate the independent and combined effects of cooking fuels and place of cooking (HAP) on three different birth weight measures in India. Our results found a strong and significant association of UCF with birth weight. Independently, place of cooking was found to play a crucial role in birth weight. Using UCF, practicing CWSK, and using UCF and practicing CWSK increased the risk of low birth weight in the Indian setting. Households using UCF and CWSK had a 4% higher prevalence of LBW as compared to those using CCF. Households CISK had a 3% lower prevalence of LBW than households CWSK in India. Our linear regression result shows that households using CCF had 80 g higher mean birth weight compared to households using UCF, a result similar to that found in literature (Wylie et al., 2014; Epstein et al., 2013; Amegah et al., 2013; Pope et al., 2010; Mishra et al., 2004). Similarly, households using UCF and CWSK had 98 g lower mean birth weight as compared to those using CCF. Significant associations of birth weight were observed with place of cooking and cooking practices in the multivariate-adjusted model. Our findings with respect to the place of cooking are consistent with the findings of the previous studies (Islam et al., 2020; Deepthi et al., 2019; Khan et al., 2017). The low birth weight in Delhi may be largely attributable to high level of ambient air pollution and concentration of outdoor $PM_{2.5}$ (Xue et al., 2021).

In the adjusted model, the association between the low birth weight and cooking fuels was not significant. Similar results have been reported in India (Sreeramareddy et al., 2011) and other developing countries (Weber et al., 2020; Hussein et al., 2020; Liu et al., 2018; Khan et al., 2017; Jiang et al., 2015). One possible reason behind no significant association of cooking fuels and LBW is selection bias as there is evidence of a higher prevalence of miscarriage and stillbirth among households using UCF compared to those using CCF (Amegah et al., 2014; Patelarou and Kelly, 2014; Pope et al., 2010). This means that had pregnancies that ended in miscarriage or stillbirth been carried to the full term, there would have been a higher prevalence of LBW among households using UCF. It is also important to note that poor households are more likely to use UCF and that poverty is linked with poor health, including adverse pregnancy outcomes, through potential mediators such as poor nutritional status (Amegah et al., 2013). Further, the reporting of birth size and birth weight from mother's recall is perception based, which is prone to error, more so among the poor uneducated mother. Also, women from households using UCF are less likely to make four antenatal care visits, are more likely to have poor education, belong to the poorest wealth quintile and the traditionally disadvantaged groups, are more likely to use tobacco, be underweight and be anemic, and to have babies at an early age (Appendix 1). Therefore, any interpretation of our results on the association of cooking fuels with birth weight should consider the possibility of bias from unobserved characteristics.

Since HAP has an adverse impact on pregnancy outcomes, we carried out an extensive analysis of the different components of HAP and birth weight in India (Appendix 2). The association between different components of HAP and the risk of LBW after we dropped education (in model 1), wealth quintile (in model 2), and both education and wealth quintile (in model 3) gave an interesting insight. We checked the probability of LBW by the three main exposure variables by applying the logistic model with the same covariates. In all the three models, the use of cooking fuels was significantly associated with LBW, with OR:1.05 (95% CI:1.00–1.11), OR:1.09 (95% CI:1.04–1.15), and OR:1.18 (95% CI:1.12–1.24) in model 1, model 2, and model 3 respectively. Similarly, better results were observed for the other two exposure variables

Table 4
Percentage of small birth weight and low birth weight among the most recent full-term singleton births according to cooking practices and selected socio-demographic characteristics in India, 2015–16.
Data source - National Family Health Survey-4 (2015–16).

Socio-demographic characteristics	Small birth size					Low birth weight				
	Clean cooking fuels	Unclean cooking fuels	Unclean cooking fuels and cooking in separate kitchen	Unclean cooking fuels and cooking without separate kitchen	Unclean cooking fuels and cooking in outdoor	Clean cooking fuels	Unclean cooking fuels	Unclean cooking fuels and cooking in separate kitchen	Unclean cooking fuels and cooking without separate kitchen	Unclean cooking fuels and cooking in outdoor
Environmental tobacco smoke										
No	8.5	13.4	12.7	14.3	12.9	14.7	17.1	16.2	17.9	18.4
Yes	10.3	14.6	13.4	16.2	13.2	15.8	17.7	16.3	19.3	18.1
Sex of child										
Male	9.1	13.3	12.2	14.7	12.7	14.2	16.1	14.7	17.4	16.8
Female	9.6	14.9	14.1	16.2	13.5	16.4	19.0	17.9	20.1	19.8
Birth order of the child										
First	9.4	13.9	13.5	14.9	13.2	15.1	19.1	17.6	20.6	20.8
Second	8.2	13.1	12.0	15.0	11.6	15.1	16.4	15.6	18.0	15.3
Third	10.9	13.6	12.0	15.6	12.0	15.0	15.7	13.8	17.1	17.3
Four or more	13.7	16.2	15.9	16.2	16.9	17.2	17.6	16.2	18.0	20.2
Birth interval										
First births	9.4	13.9	13.5	14.9	13.2	15.1	19.1	17.6	20.6	20.8
0–24 months	9.8	14.5	13.4	16.3	12.0	15.4	17.6	16.0	18.5	19.5
25–36 months	9.7	14.2	13.0	15.3	14.4	15.8	16.1	15.2	17.5	15.1
36+ months	8.9	13.6	12.4	15.2	12.6	15.0	15.9	14.8	17.4	15.9
Mother's age at child's birth										
<19	11.7	14.7	13.7	16.8	13.0	17.7	19.6	17.4	22.1	20.7
20–24	9.3	13.6	12.8	14.9	12.5	15.1	17.0	16.2	17.8	17.5
25–30	8.4	13.7	12.5	15.1	13.4	14.4	16.8	15.4	18.0	18.0
30+	10.3	15.5	14.9	16.0	15.6	15.5	17.3	16.1	18.5	16.9
Mother underweight										
No	9.0	13.4	12.4	14.9	12.1	14.6	16.3	14.8	17.9	16.7
Yes	11.3	15.7	15.0	16.5	15.7	18.9	20.5	20.0	20.4	22.1
Mother's anemia status										
Not anemic	8.9	13.2	12.1	14.9	12.3	15.3	16.5	14.9	18.0	18.4
Mild	9.5	14.1	13.7	14.8	13.1	14.6	17.5	16.8	18.3	17.6
Moderate and severe	10.7	16.0	14.1	18.0	14.9	17.1	19.7	18.5	21.2	19.1
Antenatal care during pregnancy										
0	13.1	18.3	18.4	18.4	17.7	19.9	19.6	19.0	19.3	22.1
1–3′	11.1	14.2	13.8	14.6	14.3	17.0	17.7	16.7	18.1	19.5
4+	8.4	11.7	10.9	13.8	10.5	14.3	16.6	15.4	19.0	16.6
Missing	3.7	12.7	10.9	17.7	11.1	15.4	18.2	16.2	23.6	16.5
Pregnancy intention										
Then	9.2	13.7	12.8	15.0	12.8	15.1	17.4	16.2	18.7	18.2
Later	10.6	16.7	15.2	18.0	17.8	15.5	16.8	14.5	20.0	16.4
No more	12.6	17.6	17.0	19.1	14.3	18.3	18.3	18.3	17.5	21.0
Mother's tobacco use										
No	9.3	13.7	12.8	15.1	12.7	15.2	17.3	16.1	18.4	17.9
Yes	12.0	18.0	17.6	18.1	19.0	18.3	20.1	17.8	21.5	23.1
Mother's education										
No education	13.8	16.1	15.9	16.4	15.6	19.2	19.0	18.1	19.3	20.0
Primary	12.1	14.7	13.8	16.4	12.6	19.4	18.4	16.6	20.0	19.3
Secondary	9.1	12.2	11.7	13.6	11.1	15.8	16.5	15.8	17.6	16.8
Higher	7.3	10.9	9.9	13.1	11.1	11.6	13.7	12.4	15.8	15.9
Social groups										
Schedule tribe	7.5	15.8	14.2	17.8	14.4	15.9	19.7	17.5	20.8	24.1
Schedule caste	9.4	13.6	12.8	14.6	12.4	16.1	18.0	17.1	19.1	17.7
Other backward caste	9.4	13.8	12.7	15.3	12.8	14.9	17.0	15.9	17.9	18.0
Other[a]	9.5	13.7	13.2	14.5	14.1	15.1	16.0	15.2	17.7	15.7
Wealth quintile										
Poorest	13.1	16.6	16.4	16.6	16.9	17.6	18.9	17.8	19.4	19.8
Poorer	13.2	14.0	14.0	14.5	12.9	20.3	17.6	17.2	18.1	17.3
Middle	11.2	12.3	11.6	14.7	9.7	18.5	16.7	15.4	18.7	17.3
Richer	8.9	11.7	11.1	13.4	10.8	14.7	16.3	15.3	17.4	19.4
Richest	8.0	11.2	10.6	12.8	12.7	13.2	15.8	14.9	18.9	17.8

(continued on next page)

Table 4 (*continued*)

Socio-demographic characteristics	Small birth size					Low birth weight				
	Clean cooking fuels	Unclean cooking fuels	Unclean cooking fuels and cooking in separate kitchen	Unclean cooking fuels and cooking without separate kitchen	Unclean cooking fuels and cooking in outdoor	Clean cooking fuels	Unclean cooking fuels	Unclean cooking fuels and cooking in separate kitchen	Unclean cooking fuels and cooking without separate kitchen	Unclean cooking fuels and cooking in outdoor
Place of residence										
Urban	9.1	13.2	11.3	15.4	12.6	15.4	17.2	14.9	19.2	18.6
Rural	9.8	14.1	13.3	15.4	13.2	15.0	17.5	16.4	18.6	18.1
India	9.4	14.0	13.1	15.4	13.1	15.2	17.4	16.2	18.7	18.2

[a] Other caste includes other than ST/SC, other backward caste.

(place of cooking and cooking practices) compared to the results found in Table 5.

The existing scholarship on HAP shows that the level of pollutants or concentration depends on a host of factors, is result of a complex interaction between types of fuels used, behavioural factors, humidity, ambient air pollutants, cooking duration, availability of windows or chimney, ventilation, stoves etc. (Deepthi et al., 2019; Rupakheti et al., 2019; Fleming et al., 2018; Sidhu et al., 2017; Thompson et al., 2011; Clark et al., 2010). The incomplete combustion of UCF emits high levels of health-damaging pollutants such as $PM_{2.5}$ (particulate matter <2.5 in aerodynamic diameter), carbon monoxide (CO), and polycyclic aromatic hydrocarbons (PAHs) (Rupakheti et al., 2019; Bartington et al., 2017; WHO, 2014a; Bhargava et al., 2004). Fine particulate matter, or $PM_{2.5}$, can diffuse into the blood, causing inflammation, oxidative stress, and cell damage. PAHs damage the DNA and cause placental dysfunction. Exposure to carbon monoxide causes haemoglobin to bind to the carbon monoxide and form carboxyhaemoglobin. This can damage placental cells and affect the transportation of nutrients and oxygen to the foetus, resulting in LBW. The details of the biological mechanism of pollutants and birth weight can be found elsewhere (Jiang et al., 2015; Amegah et al., 2014). Therefore, future studies should explore this association by using air quality monitor for measuring personal level exposure to harmful pollutants during pregnancy and its effects on birth outcomes including birth weight.

Few policy relevant insights emerged from this study. First, our findings can better inform the policymakers to strengthen the polices on access to clean fuels – to reduce HAP and its adverse birth outcomes – and to meet the World Health Assembly nutrition targets and as well as the interconnected goals of the Sustainable Development Goals (UN, 2015; WHO, 2014b). It's important to note that birth weight is an indicator of population health and has long-term consequences on the health of the children. Therefore, reducing LBW will improve the health outcomes of the children. Second, it is crucial to address the challenges associated with indoor cooking, especially in rural areas, where 69% of India's population lives and where inefficient, polluting, traditional fuels are used for cooking. HAP is a particularly prominent public health concern in rural areas. While the majority of the people in rural areas of the world's poorest countries face the risk of exposure to cooking smoke, this

Table 5
The unadjusted and adjusted odd ratio of low birth weight and mean birth weight among the most recent full-term singleton births by different components of household air pollution in India, 2015–16.
Data source: National Family Health Survey-4 (2015–16).

Household air pollution	Small birth size						Low birth weight						Mean birth weight						Difference[a]
	COR	95% Conf. interval		AOR	95% Conf. interval		COR	95% Conf. interval		AOR	95% Conf. interval		COR	95% Conf. interval		Adjusted	95% Conf. interval		
Cooking fuels (Model 1)																			
Clean cooking fuels (Ref.)													2893	2893	2893	2877	2876	2877	
Unclean cooking fuels	**1.54**	1.48	1.60	**1.08**	1.02	1.14	**1.24**	1.19	1.29	1.03	0.97	1.08	2813	2813	2813	2797	2796	2798	80
Place of cooking (Model 2)																			
Cooking in separate kitchen (Ref.)													2864	2864	2864	2852	2851	2853	
Cooking without separate kitchen	**1.21**	1.17	1.26	1.03	0.99	1.08	**1.25**	1.20	1.29	**1.09**	1.04	1.14	2814	2814	2814	2798	2797	2799	55
Cooking in outdoor	**1.20**	1.13	1.28	**1.08**	1.01	1.15	**1.39**	1.30	1.48	**1.11**	1.04	1.19	2776	2776	2776	2773	2771	2775	79
Cooking practices (Model 3)																			
Clean cooking fuels (Ref.)													2892	2892	2892	2877	2876	2878	
Unclean cooking fuels and cooking in separate kitchen	**1.49**	1.43	1.56	**1.08**	1.02	1.14	**1.12**	1.08	1.17	1.01	0.95	1.06	2835	2835	2835	2817	2816	2818	59
Unclean cooking fuels and cooking without separate kitchen	**1.60**	1.53	1.67	**1.07**	1.00	1.14	**1.34**	1.28	1.40	1.04	0.98	1.11	2793	2793	2793	2779	2778	2780	98
Unclean cooking fuels and cooking in outdoor	**1.51**	1.41	1.62	**1.12**	1.04	1.21	**1.44**	1.35	1.54	**1.08**	1.00	1.17	2776	2775	2776	2772	2770	2774	104

COR refers to crude odd ratio.
AOR refers to adjusted odd ratio.
Model 1 - Environmental tobacco smoke, sex of the child, birth order of the child, mother age at child birth, mother underweight, mother anemia status, antenatal care during pregnancy, pregnancy intention, mother's tobacco use, mother's education, social groups, wealth quintiles and area of residence have been included in the model.
Model 2 - Environmental tobacco smoke, sex of the child, birth order of the child, mother age at child birth, mother underweight, mother anemia status, antenatal care during pregnancy, pregnancy intention, mother's tobacco use, mother's education, social groups, wealth quintiles and area of residence have been included in the model.
Model 3 - Environmental tobacco smoke, sex of the child, birth order of the child, mother age at child birth, mother underweight, mother anemia status, antenatal care during pregnancy, pregnancy intention, mother's tobacco use, mother's education, social groups, wealth quintiles and area of residence have been included in the model.
Bold mark shows coefficient significant at 5% ($P < 0.05$). L and U stands for lower and upper limit respectively with 95% Confidence Interval (CI).
[a] Difference in mean birth weight (adjusted) from clean cooking fuels.

problem is becoming common among poor urban dwellers. HAP in rural areas is far more damaging than ambient air pollution. It should also be noted that the impact of domestic fuel use goes beyond the impact on health and also affects the household economy, women's time and activities, gender roles and relations, safety and hygiene, as well as the local and global environment. Third, a special focus has to be given on the states with a higher level of use of UCF as well as CWSK. Finally, keeping the issues of HAP in mind, the government needs to focus on few key areas – awareness, behavioural change, poverty reduction policies, subsidies to the poor households, engagement of development stakeholders or NGOs, and community organization.

5. Strengths of the study

The strength of the present study is that we comprehensively evaluated the independent and combined effects of cooking fuels and cooking practices on three different measures of birth weight. We used a large sample data and gave estimates at the state level. We used several filters to draw meaningful results; these have been described as follows. First, the analysis was restricted to children born during three years before the survey date to minimize mother's recall bias regarding birth weight and size at birth. Second, in contrast to previous studies, we also took into account the gestation period of the child, considering only pregnancies with nine or more months of gestation. Third, we used three different outcome measures for birth weight namely, small birth size, low birth weight, and mean birth weight to draw a robust association between cooking smoke and birth weight. Fourth, we computed a new wealth index, excluding electricity and cooking fuels, to capture the economic gradient using a methodology similar to the one used in the NFHS, which earlier studies didn't do. We also considered important confounding factors like environmental tobacco smoke – an important component of HAP – mother's tobacco use, mother's nutritional status (underweight and anemia), etc. The combination of cooking fuels and place of cooking as cooking practices gave us a better understanding of the effects of HAP on birth weight. Lastly, the use of three different measures of birth weight to analyse their association with independent and combined components of HAP and a number of covariates allowed us to increase the precision in our estimates.

6. Limitations of the study

The results of this study need to be interpreted carefully. Below we discuss a few important points which may have affected our conclusions. First, we used cooking practices as the proxy measure of HAP. We didn't measure the actual exposure to pollution or the level of pollutants, but rather used it as a proxy measure. The existing scholarship on HAP shows that the level of pollutants depends on a host of factors such as cooking stoves, personal exposure, and availability of windows or chimney (Deepthi et al., 2019; Sidhu et al., 2017; Thompson et al., 2011; Clark et al., 2010). This is primarily due to lack of data. We didn't have information on ventilation in the place of cooking; ventilation may play an important role in the dispersion of smoke in the kitchen. Second, we were also not able to capture the fuel stacking behaviour of households or the use of mixed fuels as NFHS doesn't have any information on the use of mixed fuel. Third, we used a proxy measure for LBW for all the children since birth weight information was not available for as many as 25,816 children. Besides, birth weight (for low birth weight and mean birth weight) was recorded from mother's recall (perception based) and health card. Previous studies, though, have reported that the data collected in the Demographic and Health Survey (known as NFHS in India) on birth size can be used as an alternative of birth weight (Islam, 2014; Lule et al., 2012; Sreeramareddy et al., 2011). Fourth, we were unable to consider the levels of indoor pollution and its concentration and didn't have information on the duration exposure either. Although, we considered several important covariates, we did not capture confounding factors like ambient air pollution, birth season, maternal dietary habits, previous history of adverse birth outcomes, maternal comorbidity, etc. Finally, while we considered survey time use of cooking fuels, we assessed the association of the fuels with birth weight over a three-year period preceding the survey date. In other words, we used two different time responses. We suggest that the future studies use personal level exposure to harmful pollutants and the duration of such exposure during pregnancy and cooking activity to explore its effects on birth outcomes.

7. Conclusion

Our study explores the potential associations of the independent and combined effects of HAP with three measures of birth weight. Our findings suggest that poor cooking practices and exposure to HAP from the use of UCF are associated with the risk of poor birth weight in a developing country setting. The association with LBW appears to be stronger in households using UCF without a separate kitchen. Therefore, transition from unclean to clean fuels and provision of a separate kitchen should be encouraged to reduce the maternal exposure to HAP and improve birth outcomes. As there are large variations in the use of CCF fuels and in the association between cooking fuels and birth weight, there lies a big opportunity to reduce the exposure to HAP and improve birth weight by providing universal access to CCF, focusing on key areas like awareness, and offering subsidies to poor households. It's also important to address the issue of cooking smoke in rural areas, where 69% of India's population lives and fourth-fifths of the households use UCF. Therefore, there is a need to revise program interventions and give special focus to states with a higher use of UCF and practice of CWSK. This study has the potential to influence policies related to child and maternal health in developing countries. The results of this study support government initiatives like *Pradhan Mantri Ujjwala Yojana* (PMUY), the flagship programme for the provision of CCF that aims to provide subsidized LPG to 80 million poor households and reduce the adverse health impact of HAP. This policy commitment of the government is a much-needed step in the direction of sustainable and healthy development. The results of this study may be used as further evidence for the welfare of women and children across the developing world.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Availability of data and materials

The data can be downloaded from the website of the Demographic and Health Survey (DHS) (https://dhsprogram.com/Data/).

Ethical considerations

Our study base on secondary dataset, is available in public domain for research use. Hence, no ethical approval was required from any institutional review board.

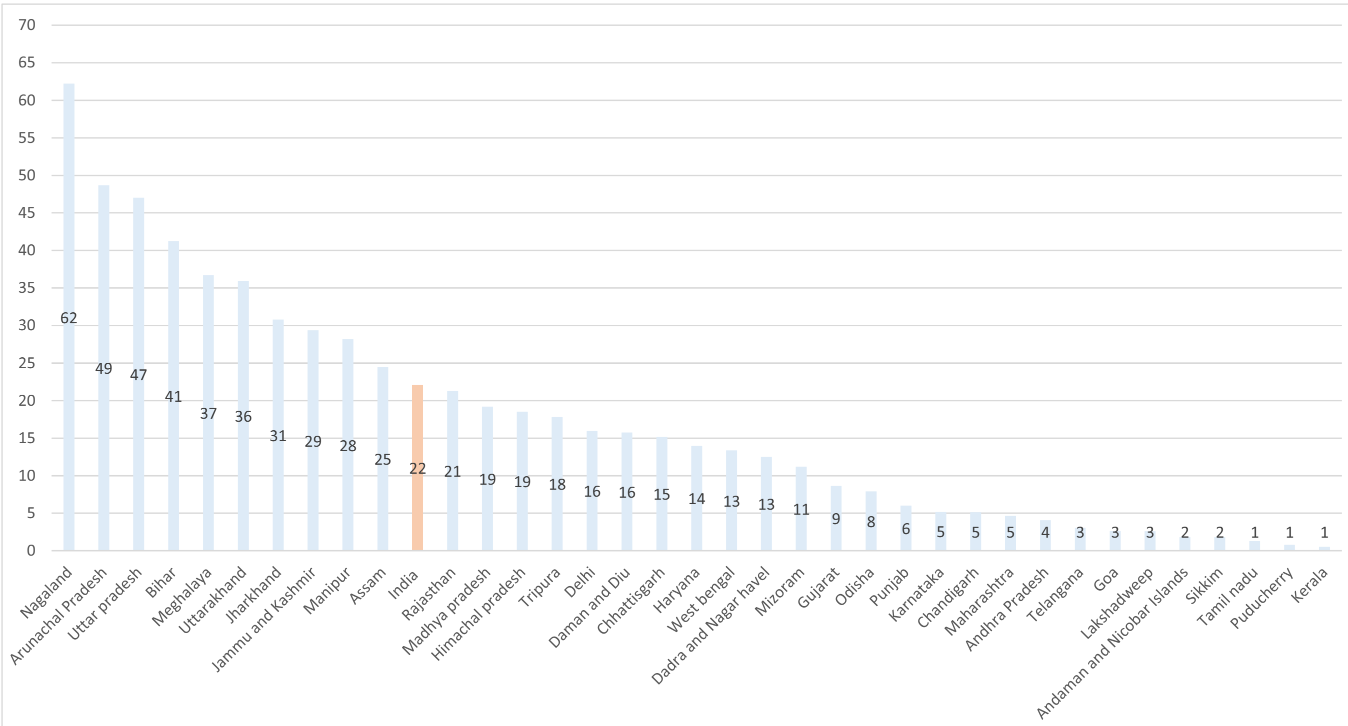
CRediT authorship contribution statement

Samarul Islam: Conceptualization, Methodology, Software, Data curation, Writing – original draft, Writing – review & editing, Validation. **Sanjay Kumar Mohanty:** Supervision, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no competing interests.

Appendix A



Appendix Fig. 1. Percentage of children born in the last 5 years by missing data on birth weight (birth weight not available either from health card or mother's recall) across the states in India, 2015–16

Appendix 1
The percentage of small birth size, low birth weight and mean birth weight among the most recent full-term singleton births and pattern of household's cooking practices by selected socio-demographic characteristics in India, 2015–16

Socio-demographic characteristics	Small birth size (%)	Low birth weight (%)	Mean birth weight (gm)	Cooking practices					Unweighted N[a]	Unweighted N[b]
				Clean cooking fuels	Unclean cooking fuels	Unclean cooking fuels and cooking in separate kitchen	Unclean cooking fuels and cooking without separate kitchen	Unclean cooking fuels and cooking in outdoor		
Environmental tobacco smoke										
No	11.5	16.1	2832	39.0	61.0	28.3	24.0	8.7	52,288	42,451
Yes	13.2	17.0	2807	31.2	68.8	29.5	29.4	9.9	67,249	51,270
Sex of child										
Male	11.8	15.3	2851	35.1	64.9	28.5	27.0	9.4	63,245	49,835
Female	13.0	18.0	2783	34.9	65.1	29.3	26.5	9.2	56,292	43,886
Birth order of the child										
First	12.0	17.3	2798	41.5	58.5	29.2	20.9	8.3	41,063	35,905
Second	11.1	15.8	2827	40.5	59.6	27.9	22.4	9.3	38,745	31,800
Third	12.9	15.5	2843	27.2	72.8	30.0	32.5	10.4	19,856	14,451
Four or more	15.8	17.6	2840	14.9	85.1	29.2	45.1	10.8	19,873	11,565
Birth interval										
First births	12.0	17.3	2798	41.5	58.5	29.2	20.9	8.3	41,063	35,905
0–24 months	13.2	16.8	2809	28.5	71.5	28.3	32.4	10.7	21,984	15,662
25–36 months	13.0	16.0	2829	27.6	72.4	29.3	32.8	10.4	23,845	17,141
36+ months	11.9	15.5	2852	36.4	63.6	28.5	26.2	8.9	32,645	25,013
Mother's age at child's birth										
<19	13.9	19.0	2765	26.6	73.4	34.5	27.8	11.1	16,029	13,078
20–24	12.1	16.3	2815	35.2	64.9	29.3	25.7	9.9	51,463	41,587
25–30	11.6	15.7	2849	40.0	60.0	26.5	25.5	8.0	37,141	28,807
30+	13.9	16.6	2840	31.8	68.2	26.0	33.9	8.3	14,904	10,249

Appendix 1 (*continued*)

Socio-demographic characteristics	Small birth size (%)	Low birth weight (%)	Mean birth weight (gm)	Cooking practices: Clean cooking fuels	Unclean cooking fuels	Unclean cooking fuels and cooking in separate kitchen	Unclean cooking fuels and cooking without separate kitchen	Unclean cooking fuels and cooking in outdoor	Unweighted N[a]	Unweighted N[b]
Mother underweight										
No	11.7	15.5	2843	39.0	61.0	27.6	24.7	8.8	93,155	73,566
Yes	14.8	20.1	2736	21.9	78.1	33.3	33.7	11.1	26,382	20,155
Mother's anemia status										
Not anemic	11.5	15.9	2831	39.2	60.8	28.1	24.0	8.7	53,348	42,425
Mild	12.6	16.4	2816	32.7	67.3	29.6	28.1	9.6	48,288	38,007
Moderate and severe	14.5	18.8	2793	28.8	71.2	29.3	31.4	10.5	17,901	13,289
Antenatal care during pregnancy										
0	17.5	19.7	2806	15.5	84.5	28.9	44.8	10.9	20,395	10,280
1–3′	13.5	17.5	2800	25.2	74.8	30.2	35.2	9.3	41,997	31,440
4+	10.2	15.5	2832	47.3	52.8	28.0	15.9	8.8	56,043	51,109
Missing	9.1	16.9	2813	40.1	59.9	33.4	15.8	10.8	1102	892
Pregnancy intention										
Then	12.1	16.5	2818	35.6	64.4	28.9	26.2	9.3	108,898	86,528
Later	14.8	16.3	2818	31.5	68.5	31.2	28.0	9.3	5320	3985
No more	16.4	18.3	2841	25.6	74.4	27.4	36.7	10.4	5319	3208
Mother's tobacco use										
No	12.1	16.4	2821	36.2	63.8	28.5	26.0	9.3	107,631	85,238
Yes	17.1	19.8	2777	14.1	86.0	35.5	40.1	10.4	11,906	8483
Mother's education										
No education	15.8	19.0	2774	11.7	88.3	28.9	46.6	12.8	34,532	21,063
Primary	14.2	18.6	2772	21.6	78.4	33.4	33.5	11.5	16,768	12,414
Secondary	10.9	16.2	2825	42.6	57.4	31.1	18.1	8.2	56,210	48,815
Higher	8.1	12.1	2916	76.2	23.8	14.4	6.2	3.2	12,027	11,429
Social groups										
Schedule tribe	14.7	19.0	2756	13.9	86.1	38.6	38.2	9.3	24,953	17,888
Schedule caste	12.4	17.4	2791	28.3	71.7	26.5	32.5	12.7	22,286	17,472
Other backward caste	12.2	16.2	2834	36.5	63.5	27.1	27.5	9.0	45,740	36,540
Other[c]	11.7	15.5	2843	47.8	52.3	30.0	15.3	7.0	26,558	21,821
Wealth quintile										
Poorest	16.5	18.9	2769	2.0	98.0	28.5	56.7	12.8	27,023	16,338
Poorer	13.9	17.9	2785	11.4	88.7	38.2	36.4	14.1	25,663	18,732
Middle	11.9	17.4	2808	33.7	66.3	34.4	21.1	10.9	23,822	19,601
Richer	10.0	15.4	2841	59.4	40.6	24.6	10.6	5.4	22,077	19,521
Richest	8.7	13.8	2882	77.1	22.9	17.1	3.6	2.3	20,952	19,529
Area of residence										
Urban	10.1	15.8	2835	75.6	24.4	10.2	10.1	4.1	28,596	25,234
Rural	13.3	16.9	2812	18.8	81.2	36.3	33.4	11.4	90,941	68,487
India	12.4	16.5	2819	35.0	65.0	28.9	26.8	9.3	119,537	93,721

Data source - National Family Health Survey-4 (2015–16).
[a] N refers to sample size for small birth size and cooking practices.
[b] N refers to sample size for low birth weight and mean birth weight.
[c] Other caste includes other than ST/SC, other backward caste.

Appendix 2
The adjusted odd ratio of low birth weight among the most recent full-term singleton births by different components of household air pollution in India, 2015–16

Household air pollution	Model 1 AOR	Model 1 95% Conf. Interval		Model 2 AOR	Model 2 95% Conf. Interval		Model 3 AOR	Model 3 95% Conf. Interval	
Cooking fuels (Model 1)									
Clean cooking fuels[a] (Ref.)									
Unclean cooking fuels[b]	**1.05**	1.00	1.11	**1.09**	1.04	1.15	**1.18**	1.12	1.24
Place of cooking (Model 2)									
Cooking in separate kitchen (Ref.)									
Cooking without separate kitchen	**1.10**	1.05	1.15	**1.14**	1.09	1.18	**1.19**	1.14	1.24
Cooking in outdoor	**1.13**	1.05	1.21	**1.15**	1.08	1.23	**1.21**	1.13	1.29
Cooking practices (Model 3)									
Clean cooking fuels (Ref.)									

(continued on next page)

Appendix 2 (*continued*)

Household air pollution	Model 1			Model 2			Model 3		
	AOR	95% Conf. Interval		AOR	95% Conf. Interval		AOR	95% Conf. Interval	
Unclean cooking fuels and cooking in separate kitchen	1.03	0.98	1.09	**1.06**	1.00	1.12	**1.13**	1.07	1.19
Unclean cooking fuels and cooking without separate kitchen	**1.07**	1.01	1.14	**1.13**	1.07	1.20	**1.24**	1.17	1.31
Unclean cooking fuels and cooking in outdoor	**1.11**	1.03	1.20	**1.16**	1.07	1.25	**1.25**	1.16	1.35

Data source - National Family Health Survey-4 (2015–16).
AOR refers to adjusted odd ratio.
Model 1 - Environmental tobacco smoke, sex of the child, birth order of the child, mother age at child birth, mother underweight, mother anemia status, antenatal care during pregnancy, pregnancy intention, mother's tobacco use, social groups, wealth quintiles and area of residence have been included in the model.
Model 2 - Environmental tobacco smoke, sex of the child, birth order of the child, mother age at child birth, mother underweight, mother anemia status, antenatal care during pregnancy, pregnancy intention, mother's tobacco use, mother's education, social groups, and area of residence have been included in the model.
Model 3 - Environmental tobacco smoke, sex of the child, birth order of the child, mother age at child birth, mother underweight, mother anemia status, antenatal care during pregnancy, pregnancy intention, mother's tobacco use, social groups, and area of residence have been included in the model.
Bold mark shows coefficient significant at 5% ($P < 0.05$). L and U stands for lower and upper limit respectively with 95% Confidence Interval (CI).
[a] Clean cooking fuels refers to electricity, LPG/gas, and biogas.
[b] Unclean cooking fuels refers to kerosene, coal/lignite, charcoal, wood, straw/shrubs/grass, agricultural crop and animal dung.

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