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Review

Household air pollution and stillbirths in India: Analysis of the DLHS-II National Survey

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ABSTRACT

Background: Several studies have linked biomass cooking fuel with adverse pregnancy outcomes such as preterm births, low birth weight and post-neonatal infant mortality, but very few have studied the associations with cooking fuel independent of other factors associated with stillbirths.
Method: We analyzed the data from 188,917 ever-married women aged 15–49 included in India's 2003–2004 District Level Household Survey-II to investigate the association between household use of cooking fuels (liquid petroleum gas/electricity, kerosene, biomass) and risk of stillbirth. Prevalence ratios (PRs) were obtained using Poisson regression with robust standard errors after controlling for several potentially confounding factors (socio-demographic and maternal health characteristics).
Results: Risk factors significantly associated with occurrence of stillbirth in the Poisson regression with robust standard errors model were: literacy status of the mother and father, lighting fuel and cooking fuel used, gravida status, history of previous abortion, whether the woman had an antenatal check up, age at last pregnancy >35 years, labor complications, bleeding complications, fetal and other complications, prematurity and home delivery. After controlling the effect of these factors, women who cook with firewood (PR 1.24; 95% CI: 1.08–1.41, $p=0.003$) or kerosene (PR 1.36; 95% CI: 1.10–1.67, $p=0.004$) were more likely to have experienced a stillbirth than those who cook with LPG/electricity. Kerosene lamp use was also associated with stillbirths compared to electric lighting (PR 1.15; 95% CI: 1.06–1.25, $p=0.001$). The population attributable risk of firewood as cooking fuel for stillbirths in India was 11% and 1% for kerosene cooking.
Conclusion: Biomass and kerosene cooking fuels are associated with stillbirth occurrence in this population sample. Assuming these associations are causal, about 12% of stillbirths in India could be prevented by providing access to cleaner cooking fuel.

1. Introduction

Worldwide, the focus of child health has remained on child survival, stillbirths remain mostly ignored (Froen et al., 2011). At least 2.65 million stillbirths were estimated globally in 2008. Ninety eight percent of them occur in low and middle-income countries (Cousens et al., 2011). However, only limited information is available on the risk factors associated with stillbirths in developing countries. Several studies have associated biomass cooking fuel with adverse pregnancy outcomes like preterm births, low birth weight and post-neonatal infant mortality but few studies have investigated associations between sources of household air pollution and stillbirths at the population level.

Biomass smoke contains a number of harmful air pollutants, including respirable particulate matter, carbon monoxide (CO), nitrogen oxides (NO_x), formaldehyde, benzene, 1,3 butadiene, polycyclic aromatic hydrocarbons, and many other toxic organic compounds (Bruce et al., 2000). Inefficient, unvented household stoves and *chulhas*[1] coupled with poor ventilation increase the indoor concentration of these pollutants manifold. There are possible mechanisms by which biomass smoke may cause adverse pregnancy outcome like stillbirths. CO undoubtedly plays a role but the role of other pollutants like particulate matter should not be overlooked.

Biomass smoke also contains the same pollutants as seen in tobacco smoke and ambient air pollution, which are established as risk factors for stillbirths. Thus the role of household biomass smoke

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[1] Earthen stoves.

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in the causation of stillbirths needs to be understood because most women in developing countries are exposed to biomass smoke over many hours a day, much more than they are exposed to tobacco smoke and ambient air pollution. This calls for good quality epidemiological studies in developing countries to test the hypothesis of association between biomass smoke and stillbirths. A meta-analysis, conducted by Pope et al., for looking at the association between cooking with biomass fuel and stillbirths found only 4 eligible studies. None of these studies looked comprehensively at all the major confounders for still births (Pope et al., 2010). A study by Mishra et al. in India controlled for socio-demographic characteristics of respondents, like age at birth, sex, body mass index, education, standard of living, religion, residence, iron supplements taken during pregnancy, etc. but did not take into account antenatal and maternal risk factors which can potentially confound the association (Mishra et al., 2005). The study from Pakistan by Siddique et al. in 2005 also ignored potential socio-demographic and maternal confounders except for the rural and urban setting (Siddiqui et al., 2005). Though the case-control study conducted by Mavalankar et al. looking at the risk factors for perinatal mortality considered both maternal and socio-demographic risk factors, the study was only able to enroll 25% of the stilbirths. This suggests potential for selection bias in the study (Mavalankar et al., 1991). The study by Tielsch et al. from South India also did not address all the maternal risk factors for stilbirths (Tielsch et al., 2009). Therefore, the present study was done to more precisely estimate the association between biomass smoke and stillbirths, while minimizing confounder bias by including risk factors like antenatal care visits, place of antenatal care, person doing antenatal care check-up and maternal factors like bleeding, hypertension, anemia, labor complications, fetal complications, previous abortion, premature labor, age at last pregnancy and gravid status, as well as adjusting for the effects of socio-demographic factors.

2. Methodology

2.1. Data

Primary data from the second District level Household Survey (DLHS-2) conducted in 2002–04 were utilized (IIPS, 2006). The survey was conducted in all the 593 districts of the country as per the 2001 census. It used a multi-stage stratified sampling design covering approximately 0.7 million households, representing all the districts of India. The details of sampling design, survey tools and data collection methods were provided in the survey report (IIPS, 2006). In each district, 40 primary sampling units were selected from both urban and rural areas with probability proportionate to size, as per 1991 census. The survey collected information using three questionnaires. The household questionnaire was used to list all the usual members who resided in the sampled household and also the residents who stayed there the previous night. The demographic details of the enlisted members such as age, sex, education, occupation, etc. were also collected. For households, information was collected on main source of drinking water, type of toilet facility, type of cooking fuel, source of lighting, religion and caste of the head of the household and household ownership of items, such as radio, television, vehicles, land holding, etc. This information was used for assessing the socio economic status of the family, for demographic information, such as age and education of the father and mother, and for information whether the women used biomass fuel. Another questionnaire was used to collect information from all currently married women in the sampled household who were aged 15–44 years. The information from the first two sections of the women's questionnaire was used for identifying the women who had a stillbirth resulting from their last pregnancy in the past 3 years, and the antenatal and natal care received by the women during pregnancy and delivery. The first section collected information on the age, education of the women, birth and death history of biological children, including stillbirths and abortions. The second section collected information on antenatal, natal and post natal care for the last pregnancy, if it had occurred in the 3 years preceding the date of survey. Prior permission was obtained from the International Institute of Population Sciences, Mumbai for analysis of DLHS-II data.

2.2. Health outcome

The outcome of the last pregnancy, whether it was a live birth or stillbirth, was considered as the dependent variable. The history of abortions was not considered for the present study as women might report induced abortions as spontaneous abortions if they had been done for sex-selective purposes.

2.3. Exposure assessment

Exposure to cooking fuel smoke was ascertained indirectly by the type of fuel used for cooking. The cooking fuel was coded as wood, kerosene, liquid petroleum gas (LPG)/electricity and 'others' in the dataset, where the category 'others' contained materials like animal dung, crop residues, coke/coal/charcoal, etc.

2.4. Covariates

The following socio-demographic and maternal factors were considered as covariates, as the association between household air pollution and stillbirths can be potentially confounded by them. Place of residence (urban, rural), literacy status (both mother and father), religion (Hindu, Muslim, Others), source of lighting (electricity, kerosene), standard of living index, antenatal care (ANC) received during pregnancy, complications during pregnancy such as bleeding, hypertension, anemia, labor complications, fetal complications, history of previous abortion or stillbirth, premature labor, age at last pregnancy and gravid status. A composite measure of standard of living index as a proxy for socio-economic status was calculated based on household amenities, such as source of drinking water, fuel for cooking, type of house, source of lighting, toilet facility and ownership of durable goods. The details of the scoring and classification into low, medium and high SES categories is given in the DLHS-2 national report (IIPS, 2006). The place of antenatal visit was considered to be a government facility if the mother had visited any of the government clinics or hospitals or health center (whether allopathic or Indian system of Medicine), irrespective of visits to private or any other type of clinic. The place of antenatal visit was considered to be a private facility if the check up was done only in clinics or hospitals run by private practitioners or organizations or non-governmental Organizations or trusts (whether allopathic or Indian system of Medicine). The person conducting the antenatal check-up was considered skilled if the provider was either a doctor or nurse or auxiliary nurse midwife or lady health visitor or any other health professional. Other people who conducted antenatal check-up, such as trained or untrained Dais or any other persons, were considered unskilled. Women were considered anemic if they had reported paleness during pregnancy. The women who reported either swelling of hands/feet or visual disturbances or convulsions during pregnancy were considered to be hypertensive. The category of 'bleeding complications' included women who reported bleeding either during pregnancy or during delivery. The labor complications category included women who reported to have either prolonged or obstructed labor. The women who reported abnormal position of the fetus or weak movements of the fetus were included in those who had fetal complications. The place of delivery was considered to be a government facility if it was any government hospital or clinic or dispensary or health center (whether allopathic or Indian System of Medicine). The delivery place was considered to be a private facility if delivery took place in any clinic or hospital run by private practitioners or organizations or non-governmental organizations or trust or places other than government facility or home. Though the person who conducted the delivery was considered initially for the analysis it was not included in the final analysis, as the data were missing for about 75,000 deliveries. The potential confounders mentioned above were included in the analysis.

2.5. Analysis

Stata 11 and SPSS 19 were used to conduct the statistical analysis. PRRs for association of socio-economic, demographic, environmental and maternal characteristics with stillbirths were estimated in univariate analysis. Chi square tests were used to test the statistical significance of associations. Multivariable analysis was done to find the 'independent' association between the type of cooking fuel used and stillbirth after controlling for potential confounders. For selecting the variables for multivariable analysis, we have first selected those variables which are directly related to the exposure i.e. type of fuel used and the source of lighting. Then, for selecting the other covariates from the list of potential confounders identified through literature review we examined two associations. (1) The association of the potential confounders with the exposure among controls and (2) the association of potential confounders with the outcome among unexposed. The multivariable analysis was first done using log binomial model and later by the Poisson model with robust standard errors as the log binomial model failed to converge for calculating adjusted PRRs (Barros et al., 2003). Any covariate which had a statistical association in both (1) and (2), indicated by a p value ≤ 0.2 was included in the multivariate model.

3. Results

A total of 197,010 respondents had either a stillbirth or live birth from their last pregnancy in the 3 years prior to the survey.

Table 1
Socio-demographic characteristic of the study population with prevalence ratio, for stillbirth among ever married women aged 15–49 years, India, 2002–4.

Characteristics	Categories	Number of respondents (%) N=1,88,917	Still births (%) N=3112	Live births (%) N=1,85, 805	Prevalence ratio (95% CI)	P value
Cooking fuel used	LPG–electricity	38362 (20.3)	439 (14.1)	37,923 (20.4)	1.00	
	Kerosene	6492 (3.4)	115 (3.7)	6377 (3.4)	1.55 (1.26–1.90)	<0.001
	Wood	121791 (64.5)	2056 (66.1)	119,735 (64.4)	1.48 (1.33–1.63)	<0.001
	Others	22272 (11.8)	502 (16.1)	21,770 (11.7)	1.97 (1.73–2.24)	<0.001
Type of residence	Urban	5299 (28.1)	770 (24.7)	52,229 (28.1)	1.00	
	Rural	1,35,918 (71.9)	2342 (75.3)	133,576 (71.9)	1.19 (1.09–1.29)	<0.001
Religion	Hindus	143236 (75.8)	2410 (77.4)	140,826 (75.8)	1.00	
	Muslims	24437 (12.9)	448 (14.4)	23,989 (12.9)	1.09 (0.99–1.20)	0.09
	Others	21244 (11.2)	254 (8.2)	20,990 (11.3)	0.71 (0.62–0.81)	<0.001
Caste	General	47553 (25.2)	721 (23.2)	46,832 (25.2)	1.00	
	SC/ST[a]	67214 (35.6)	1131 (36.3)	66,083 (35.6)	1.11 (1.01–1.22)	0.027
	OBC[b]	74150 (39.3)	1260 (40.5)	72,890 (39.2)	1.12(1.02–1.23)	0.013
Mother literacy	Yes	95639 (50.6)	1347 (43.3)	94,292 (50.7)	1.00	
	No	93278 (49.4)	1765 (56.7)	91,513 (49.3)	1.34 (1.25–1.44)	<0.001
Father literacy	Yes	137054 (72.5)	2061 (66.2)	134,993 (72.7)	1.00	
	No	51863 (27.5)	1051 (33.8)	50,812 (27.3)	1.35 (1.25–1.45)	<0.001
House type	*Pucca,Semipucca*[c]	114974 (60.9)	1776 (57.1)	113,198 (60.9)	1.00	
	Kaccha[d]	73943 (39.1)	1336 (42.9)	72,607 (39.1)	1.17 (1.09–1.25)	<0.001
Source of lighting	Electricity	114520 (60.6)	1605 (51.6)	112,915 (60.8)	1.00	
	Kerosene	72835 (38.6)	1481 (47.6)	71,354 (38.4)	1.45 (1.35–1.56)	<0.001
	Others	1562 (0.8)	26 (0.8)	1536 (0.8)	1.19 (0.80–1.74)	0.380
Standard of living index	High	36867 (19.5)	455 (14.6)	36,412 (19.6)	1.00	
	Low	96345 (51.0)	1802 (57.9)	94,543 (50.9)	1.52 (1.37–1.68)	<0.001
	Medium	55705 (28.5)	855 (27.5)	54,850 (29.5)	1.24 (1.11–1.39)	<0.001

[a] SC/ST: 'Scheduled castes/scheduled tribes', historically disadvantaged castes and tribes given express recognition in the Constitution of India.
[b] OBC: 'Other backward classes', castes other than SC/ST recognized in the Constitution of India as economically and socially backward and needing special upliftment efforts.
[c] *Pucca, Semipucca* house: A house made up of burnt bricks/stones/timber using cement.
[d] *Kaccha* house: A house made up of unburnt bricks/bamboos/mud/grass/thatch/loosely packed stones, etc.

Data from 188,917 respondents were included in the analysis after excluding those with missing values for key variables. The respondents who were excluded from analysis constituted <4% of the total respondents. There was no difference in the associations before and after excluding cases with missing variables.

3.1. Baseline characteristics of respondents

About 72% of the women respondents resided in rural areas. Three fourths of the respondents were Hindu. More than one third of the women lived in *kaccha*[2] houses—houses made of temporary materials. About half of the mothers (51%) and three fourths of the fathers (73%) were literate. Nearly half of the women belonged to a low socioeconomic group. About 61% of the households of the women had access to electricity. Sixty-five percent of the respondents used firewood as their cooking fuel, followed by liquid petroleum gas (20%). About 62% delivered their babies at home. Two thirds of women (66%) utilized ANC services. Nearly half of the respondents had delivery at a government facility. Out of the total 188,917 births, 3112 were stillbirths (1.7%).

3.2. Association between socio demographic and maternal risk factors and stillbirth

Associations between socio-demographic and maternal health characteristics of the respondents and outcome of pregnancy (stillbirth and live birth) are presented in Tables 1 and 2. Muslim religion and private hospitals as the place of delivery were not found to be significantly associated with the outcome of the pregnancy (i.e. live birth or stillbirth). The risk of still births stillbirths were significantly higher among women who used firewood for cooking as compared to those who use LPG (PR 1.48; 95% CI: 1.33–1.63, $p<0.001$). The risk of stillbirths were significantly raised among those who resided in rural areas, those who belong to scheduled castes or tribes or other backward classes, if either the mother or father were illiterate, who had a kaccha house, who used kerosene either for cooking or lighting purposes and those who had a medium or low standard of living index. The risk of stillbirth was also high among younger or older mothers, in the first pregnancy or for having more than two children, if the women did not go for antenatal check up or had a check up from an unskilled person, if the mother had previous history of stillbirth or abortion or had complications, such as anemia, hypertension, bleeding either during the antenatal period or during labor, obstructed or prolonged labor, premature labor, or the fetus had any abnormality.

3.3. Poisson regression with robust standard errors of the socio-demographic and maternal risk factors for stillbirths

The results of the final model of Poisson regression with robust standard errors, showing associations between type of fuel used for cooking and stillbirths after controlling for the potential confounders are given in Table 3. Type of cooking fuel used, lighting fuel used, literacy status of father and mother, age at last pregnancy, gravid status, complications during pregnancy and labor, fetal complications, ANC status, previous history of abortion, prematurity place of delivery, standard of living index, house type,

[2] A house made up of unburnt bricks/bamboos/mud/grass/thatch/loosely packed stones, etc.

Table 2
Maternal and pregnancy characteristics with prevalence ratio for stillbirth among ever married women aged 15–49 years, India, 2002–4.

Characteristics	Categories	Number of respondents (%)	Still births (%) $N=3112$	Live births (%) $N=185,805$	Prevalence ratio (95% CI)	*P* value
Age at last pregnancy	20–34	147433 (78.04)	2237 (71.9)	145,196 (78.1)	1.00	
	lowest—19	31339 (16.58)	633 (20.3)	30,706 (16.5)	1.33 (1.22–1.45)	<0.001
	35 and highest	10145 (5.37)	242 (7.8)	9903 (5.3)	1.57 (1.38–1.79)	<0.001
Gravida	2	82586 (43.72)	1169 (37.6)	81,417 (43.8)	1.00	
	1	46924 (24.84)	815(26.2)	46,109 (24.8)	1.23 (1.12–1.34)	<0.001
	3 and above	59407 (31.45)	1128 (36.2)	58,279 (31.4)	1.34 (1.24–1.45)	<0.001
History of previous abortion	No	166546 (88.16)	788 (25.3)	165,758(89.2)	1.00	
	Yes	22371 (11.84)	2324 (74.7)	20,047 (10.8)	21.96 (20.28–23.78)	<0.001
ANC check up	By skilled person	123286 (65.3)	1823 (58.6)	121,463 (65.4)	1.00	
	By unskilled person	729 (0.4)	20 (0.6)	709 (0.4)	1.86 (1.20–2.87)	0.005
	No ANC check-up	64902 (34.4)	1269 (40.8)	63633 (34.2)	1.32 (1.23-1.42)	<0.001
Anemia	No	165964 (87.85)	2576 (82.8)	163,388 (87.9)	1.00	
	Yes	22953 (12.15)	536 (17.2)	22,417 (12.1)	1.50 (1.37–1.65)	<0.001
Hypertension	No	140105 (74.16)	2093 (67.3)	138,012 (74.3)	1.00	
	Yes	48812 (25.84)	1019 (32.7)	47,793 (25.7)	1.40 (1.30–1.51)	<0.001
Bleeding	No	174008 (92.11)	2562 (82.3)	171,446 (92.3)	1.00	<0.001
	Yes	14909 (7.89)	550 (17.7)	14,359 (7.7)	2.51 (2.29–2.74)	
Labor complication	No	135373 (71.65)	1880 (60.4)	133,493 (71.8)	1.00	
	Yes	53544 (28.35)	1232 (39.6)	52,312 (28.2)	1.66 (1.54-1.78)	<0.001
Fetal complications	No	181237 (95.93)	2730 (87.7)	178,507 (96.1)	1.00	
	Yes	7680 (4.07)	382 (12.3)	7298 (3.9)	3.30 (2.97–3.67)	<0.001
Other complication	No	174020 (92.11)	2739 (88.0)	171,281 (92.2)	1.00	
	Yes	14897 (7.89)	373 (12.0)	14,524 (7.8)	1.59 (1.43–1.77)	<0.001
Premature labor	No	168423 (89.15)	2424 (77.9)	165,999 (89.3)	1.00	
	Yes	20494 (10.85)	688 (22.1)	19,806 (10.7)	2.33 (2.15–2.54)	<0.001
Place delivery	Government	36629 (19.38)	682 (21.9)	35,947 (19.3)	1.00	
	Private	35250 (18.65)	690 (22.2)	34,560 (18.6)	1.05 (0.95–1.17)	0.349
	Home	117038 (61.95)	1740 (55.9)	115,298 (62.1)	0.80 (0.73–0.87)	<0.001

type of residence, religion and caste were considered in the final multivariate analysis model. Type of fuel used for cooking, with wood (Adjusted PR 1.24; 95% CI 1.08–1.41) and kerosene (Adjusted PR 1.36; 95% CI 1.10–1.67) were found to be significantly associated with stillbirth, after adjusting for potential confounders. Kerosene used as a source of lighting was also significantly associated with stillbirth among women after controlling for confounders (Adjusted PR 1.15; 95% CI 1.06–1.25).

4. Discussion

Women who cook with biomass fuels like wood and kerosene were found to be at approximately 20–40% higher risk of delivering a stillbirth than those using cleaner fuels (LPG/electricity). The stillbirth rate was significantly higher among illiterate parents (either mother or father), women having their pregnancy after 35 years of age, primigravida and multigravida (3 or more) births, women with bleeding complications during pregnancy, prematurity of the fetus, fetal complications, and among women who didnot have an antenatal check-up, who had a previous history of abortion, and who delivered in a government hospital. One might expect the stillbirth rate to be higher among those who delivered at home. However, the stillbirth rate was found to be higher in the hospitals in this study. Because most of the uncomplicated deliveries occur at home whereas complicated ones, for which chances of survival are lower, are usually referred to hospitals. Anemia and hypertension were not found to be significantly associated with stillbirths. Since anemia status was ascertained by reporting of paleness, and hypertension during pregnancy was indicated by pedal edema, convulsions or blurring of vision during pregnancy, these non-specific measures are likely to have led to random misclassification of exposure, with a resultant bias towards the null.

The main strength of the current study was that it addressed the maternal risk factors for stillbirths along with socio-demographic risk factors. Another major strength of this study was that the results were based on a large sample size of 3112 stillbirths and 185,505 live births, which had occurred among a representative sample taken from all districts of India.

However there are certain limitations similar to those found in the study by Mishra et al. which analyzed NFHS-II data for exploring the association between cooking fuel smoke and stillbirths (Mishra et al., 2005). Erroneous reporting of early neonatal deaths as stillbirths can result in non differential misclassification of stillbirths, which can bias the results towards the null value. Certain characteristics of women may have changed over the course of the reported pregnancy. For example women might have shifted from biomass fuel to cleaner fuels or vice-versa. As the chances of shifting from use of biomass fuel to cleaner fuels are higher than the reverse shift, if any such bias would have occurred, it would pull the prevalence ratio towards the null. On that basis, our results would underestimate the true magnitude of associations. This study also did not consider the effects of maternal smoking. However, as the prevalence of active smoking among women aged 15–49 years was only 1.73%, the maternal smoking is unlikely to be confounding our results.

The results of the study are consistent with the study by Mishra et al. which showed a significant association between household fuel and stillbirths (Mishra et al., 2005) (OR=1.44, 95% CI=1.04–1.97). Siddique et al. from Pakistan also reported a

Table 3
Adjusted[a] Poisson regression with robust standard errors of the socio-demographic and maternal risk factors for stillbirths among ever married women aged 15–49 years.

Outcome of pregnancy	Poisson regression with robust standard errors	
	Prevalence ratio (95% CI)	*P* value
Type of cooking fuel used		
LPG/electricity	1.00	
Kerosene	1.36 (1.10–1.67)	0.004
Wood	1.24 (1.08–1.41)	0.003
Others	1.23 (1.05–1.44)	0.010
Illiterate Mother	1.13(1.04–1.23)	0.005
Illiterate Father	1.14(1.06–1.23)	0.001
Lighting fuel used		
Electricity	1.00	
Kerosene	1.15 (1.06–1.25)	0.001
Others	1.13 (0.8–1.61)	0.520
Age at last pregnancy		
20–34	1.00	
< 19	0.93 (0.85–1.01)	0.065
> 35	1.45 (1.26–1.65)	< 0.001
Gravida		
2 or 3	1.00	
1	3.49 (3.18–3.82)	< 0.001
> 3	0.53 (0.48–0.58)	< 0.001
History of previous abortion or stillbirth	37.84 (34.13–41.98)	< 0.001
ANC check-up		
By skilled person	1.00	
By unskilled person	2.08 (1.43–3.05)	< 0.001
No ANC check-up	1.53 (1.41–1.66)	< 0.001
Anemia	0.97 (0.89–1.07)	0.544
Hypertension	0.96 (0.89–1.03)	0.278
Labor complications	1.05 (0.99–1.13)	0.124
Bleeding complications	1.57 (1.44–1.71)	< 0.001
Fetal complications	1.90 (1.73–2.09)	< 0.001
Other complications	1.13 (1.03–1.24)	0.012
Prematurity	1.56 (1.44–1.69)	< 0.001
Place of delivery		
Government	1.00	
Private	0.96 (0.87–1.05)	0.360
Home	0.75 (0.68–0.82)	< 0.001
Standard of living index		
High	1.00	
Medium	1.06 (0.94–1.21)	0.337
Low	1.09 (0.94–1.27)	0.262
House type		
Pucca, Semipucca	1.00	
Kaccha	1.03 (0.95–1.11)	0.536
Type of residence		
Urban	1.00	
Rural	1.04 (0.95–1.13)	0.417
Religion		
Hindus	1.11 (1.003–1.22)	0.043
Muslims	0.99 (0.88–1.13)	0.982
Others		
Caste		
General	1.01 (0.92–1.10)	
SC/ST	1.10 (1.01–1.21)	0.778
OBC		0.045

[a] Adjusted for all the factors mentioned in the table.

nearly 2-fold greater risk of stillbirths among pregnant women exposed to biomass smoke (Siddiqui et al., 2005) (OR=1.9, 95% CI=1.10–3.20). Another Indian study, by Mavalankar et al., also demonstrated a significant association (OR=1.5, 95% CI=1.0–2.1) (Mavalankar et al., 1991). A fixed-effect meta-analysis by Pope et al. (I^2=0%) found that IAP was associated with increased risk of stillbirth (OR=1.51, 95% CI: 1.23–1.85) (Pope et al., 2010). The present study possibly provided a more accurate estimate of risk than the previous studies due to the large sample size and adjustment of maternal risk factors which were not fully addressed in the previous study designs.

Providing some biologic plausibility for our results, there are several studies establishing associations between sources of household air pollution and other adverse pregnancy outcomes, such as low birth weight and perinatal mortality (Boy et al., 2002; Mavalankar et al., 1991; Mishra et al., 2004; Pope et al., 2010). Even studies linking smoking, ETS and ambient air pollution with adverse pregnancy outcomes strengthen the plausibility of the results of the present study (Chen et al., 2002; Gouveia et al., 2004; Sram et al., 2005; Windham et al., 1999, 2000; Wisborg et al., 2001).

The significant association between biomass burning and stillbirths is consistent with the high amounts of CO contained in biomass smoke (Pokhrel et al., 2010). Exposure to high levels of carbon monoxide, which binds to hemoglobin to form carboxy-hemoglobin, reduces the capacity of the blood to carry oxygen to body tissues. Carbon monoxide crosses the placental barrier, and hemoglobin in fetal blood has 10 times more affinity for binding carbon monoxide than adults hemoglobin (Ritz and Yu, 1999). Furthermore, fetal elimination of carbon monoxide is slower than in the mother (Hill et al., 1977). Thus, a developing fetus can be deprived of adequate oxygen, leading to intrauterine growth retardation and risk of LBW and stillbirth. The unexpected associations with kerosene cooking and lighting, which do not produce such high levels of CO, may argue for some other toxicological.

Another key issue is whether biomass fuel users really did have higher exposure to pollutants, particularly to CO, and whether the level of exposure they experienced was sufficient to impair fetal growth. Although the present study does not have direct measures of the exposure levels, there is substantial evidence from other studies, which shows that in many parts of the developing world the peak indoor concentration of PM10 often exceeds 2000 $\mu g/m^3$ (Regalado et al., 2006). The upper (Interim Target—I) annual particulate matter levels set in the WHO guidelines for air quality are 70 $\mu g/m^3$ for PM_{10} and 35 $\mu g/m^3$ for $PM_{2.5}$, which are exceeded in nearly all homes burning biomass (WHO, 2006). The results for kerosene cooking and lighting add to the growing evidence that kerosene should not be considered a "clean" (Lam et al., 2012; Pokhrel et al., 2010).

4.1. Attributable risks of household fuel use

More than 65% of households in India rely primarily on biomass fuels (wood, crop residues, and dung) for cooking and heating purposes. Exposure of very large numbers of pregnant women to high levels of CO and other noxious pollutants, over many hours each day, with increased relative risk (1.24 for firewood in this study) translates into substantial population attributable risk (11%) for stillbirths. The PAR for kerosene is 1% (PRR 1.36) as it is used by only 3% of households for cooking.

5. Conclusions

This study finds that use of biomass fuel and kerosene for cooking were associated with stillbirths, independent of maternal, ante-natal and natal risk factors.

5.1. Recommendations

Biomass smoke is a strongly associated risk factor for ARI in children, COPD, lung cancer, ischemic heart disease and TB in women, blindness, cataract, asthma, other adverse pregnancy outcomes like low birth weight, prematurity and early infant death. Around 400–550 thousand premature deaths can be attributed annually to use of biomass fuels in India, which is 4–6% of national burden of disease in India (Smith, 2000).

Use of firewood as cooking fuel not only harms health, but it also generates greenhouse gases that affect climate (Venkataraman et al., 2010). Moreover it also increases pressure on deforestation which badly damages the ecosystem and requires women and children to spend many hours collecting fuel in some parts of the country.

Due to the aforementioned reasons, the use of clean fuels and stoves should be promoted through crucial policy changes. There is growing evidence, including this study, however, that kerosene is not a healthy alternative for either cooking or lighting and continuing subsidies of kerosene may not be the best national policy from a health standpoint. LPG has also been historically subsidized in India but it is largely used by the advantaged groups in the urban sector. The LPG subsidy limited to below-poverty-level (BPL) families is a positive step in this regard. States like Andhra Pradesh and recently Delhi have already experimented with this innovative idea. The government of India has also announced a free LPG connection for all BPL families. Such policy level decisions will encourage use of cleaner fuels, like LPG, and thereby help improve the health of the population.

5.2. Future research implications

The extent of evidence relating household air pollution to stillbirths is llimited, as it is largely based on observational studies (Barros et al., 2010). Thus, future studies of interventions like clean stoves, fuels, and ventilation and behavior modifications to reduce exposure must be carried out to investigate associations with pregnancy and neonatal outcomes. There is also a need to directly measure the exposure of women to cooking fuel smoke in a household at a large scale using new inexpensive techniques and equipment rather than indirectly assessing the exposure status simply by the type of fuel. Kerosene, which used to be considered as a relatively clean fuel, has been associated with health outcomes such as tuberculosis, cataract, and stillbirths, and needs to be studied regarding the chemical composition of emissions and plausible causative mechanisms for affecting health.

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