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Cooking smoke and tobacco smoke as risk factors for stillbirth

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Abstract
Smoke from biomass combustion produces some of the same pollutants found in tobacco smoke and ambient air, yet only one study to date has linked cooking with biomass fuels to increased risk of stillbirth. The mechanisms by which biomass smoke may cause stillbirth are through exposure to CO and particulates in biomass smoke. Using information on 19,189 ever-married women aged 40 – 49 included in India's 1998 – 99 National Family Health Survey, we examined the association between household use of biomass fuels (wood, dung, and crop residues), tobacco smoke (both active and passive), and risk of stillbirth. Data were analyzed using binary and multinomial logistic regression after controlling for several potentially confounding factors. Results indicate that, with other factors controlled, women who cook with biomass fuels are significantly more likely to have experienced a stillbirth than those who cook with cleaner fuels (OR = 1.44; 95% CI: 1.04, 1.97). Women who cook with biofuels are twice as likely to have experienced two or more stillbirths as those who cook with cleaner fuels (RRR = 2.01; 95% CI: 1.11, 3.62). The adjusted effect of active tobacco smoking is also positive (OR = 1.23) but not statistically significant. No effect of passive smoking was found, nor was there evidence of any modifying effects of tobacco smoking.

Keywords: *Indoor air pollution, biomass smoke, tobacco smoking, women, adverse pregnancy outcome, stillbirth, India*

Introduction

Biomass smoke exposure has been associated with a host of respiratory diseases, but little is known about its effects on pregnancy outcomes. Apparently only one study to date has linked cooking with biomass fuels during pregnancy to stillbirths (Mavalankar et al. 1991), and only two recent studies, one in Zimbabwe and another in rural Guatemala, have linked it to reduced birth weight (Mishra et al. 2004; Boy et al. 2002). In a case-control study of 451 stillbirths and 1465 controls in western India, Mavalankar et al. (1991) observed a significantly higher risk of stillbirth among women using wood fuels for cooking than among women using cleaner cooking fuels (OR = 1.5; 95% CI: 1.0 – 2.1). This study was the first to report an association between biofuel use and stillbirth in a human population, although the

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association was only marginally significant at the 5% level. Other studies in India have associated risk of stillbirth with maternal age (age group 20 – 29 has the lowest risk) (Khandait et al. 2000); first order birth and absence of antenatal care (Kumar & Singhi 1992); and tobacco use (Gupta & Ray 2003), among other factors (Bhargava et al. 1991). In this study, we have analyzed data from a recent national household survey in India to examine the relationship between biomass smoke and risk of stillbirth.

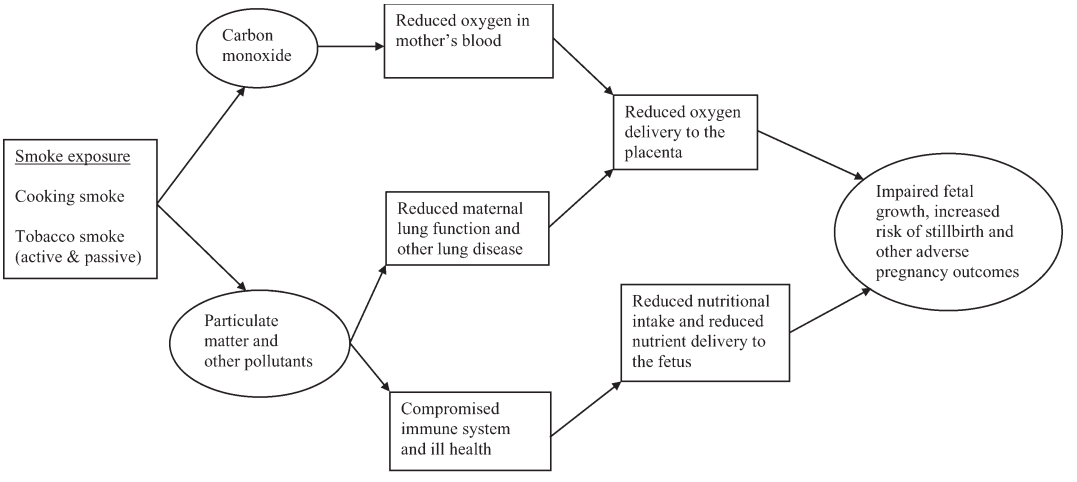
Like tobacco, smoke from biomass combustion produces a large number of health-damaging air pollutants, including respirable particulate matter, carbon monoxide (CO), nitrogen oxides (NO_x), formaldehyde, benzene, 1,3 butadiene, polycyclic aromatic hydrocarbons (such as benzo[a]pyrene), and many other toxic organic compounds (Bruce et al. 2000). In developing countries, where large proportions of households rely on biomass fuels for cooking and space heating, concentrations of these air pollutants tend to be highest indoors. The fuels are typically burned in simple, inefficient, and mostly unvented household cookstoves, which, combined with poor ventilation, generate large volumes of smoke indoors. In such settings, daily average and peak exposures to air pollutants often far exceed levels recommended by the World Health Organization (Bruce et al. 2000; WHO 1997). Exposure levels are usually much higher among women, who tend to do most of the cooking (Behera et al. 1988).

Studies in India, mostly in biomass-fuel-using rural homes, have measured kitchen area particulate matter concentrations of 4000 – 21000 $\mu g/m^3$ and 2 – 5 h daily exposures of 3600 – 6800 $\mu g/m^3$ during cooking (reviewed in Smith et al. 2000a). A recent study using time-activity data from 412 rural homes in south India estimated a 24-h average exposure of 573 $\mu g/m^3$ in solid-fuel-using households, compared with 80 $\mu g/m^3$ in households using gas for cooking (Balakrishnan et al. 2004). Another study in western India measured indoor CO levels of 156 mg/m^3 when cooking with wood and 144 mg/m^3 when cooking with dung, compared with 14 mg/m^3 when cooking with gas (Patel & Raiyani 1995). A number of respiratory and other health effects in children and adults have been attributed to such high exposures, leading to estimates of hundreds of thousands of premature deaths annually in India from household use of solid fuels for cooking (Smith et al. 2004; Smith 2000). To date, however, the evidence linking such exposures to adverse pregnancy outcomes has not been sufficient to be included in such published risk assessments.

The mechanisms by which exposure to biomass smoke may cause adverse pregnancy outcomes are only partly understood. The primary mechanism is believed to be through exposure to CO in biomass smoke (see Figure 1) (Smith et al. 2000a; Hass 1992). As in the case of tobacco smoke, biomass combustion in simple, poorly-vented cookstoves produce large volumes of CO, which binds to hemoglobin and forms carboxyhemoglobin. This reduces the capacity of the blood to carry oxygen to body tissues. A developing fetus, deprived of adequate oxygen, suffers intrauterine growth retardation and increased risk of perinatal mortality.

Levels of CO in homes using biomass fuels are sometimes high enough to result in carboxyhemoglobin levels comparable to those in smokers (Behera et al. 1988; Dary et al. 1981). Exposure to CO has been associated with retarded fetal development and adverse pregnancy outcomes, including perinatal mortality and reduced birth weight (Garvey & Longo 1978; Longo 1977; Astrup et al. 1972).

Particulate matter and other pollutants (e.g., polycyclic aromatic hydrocarbons) in biomass smoke can also increase the risk of an adverse pregnancy outcome by reducing mother's lung function and increasing the risk of maternal chronic and acute respiratory disease, which also reduces oxygen delivery to the fetus. Maternal lung function and lung disease during pregnancy have been associated with intrauterine growth retardation, preterm delivery, and reduced birth weight (Edenborough et al. 1995; Schatz et al. 1990).



Source: Revised from Hass (1992) and Smith et al. (2000a).

Figure 1. How exposure to cooking smoke and tobacco smoke might cause stillbirth.

Numerous studies have linked maternal tobacco smoking to fetal growth retardation and adverse pregnancy outcomes, including premature delivery, perinatal mortality, and reduced birth weight (USDHHS 2001; Wisborg et al. 2001; Kukla et al. 2001). Exposure to passive tobacco smoke has also been linked to adverse pregnancy outcomes (USDHHS 2004; Windham et al. 2000; Windham et al. 1999). Although there are differences – in nicotine content, for example – the incomplete combustion products thought to be responsible for most of the adverse health effects of tobacco smoke are also found in smoke from other forms of biomass combustion, such as wood or dung. The concentrations found in the typical household cooking situation in India, however, are often much higher than those found in passive smoking studies, although much lower than those found in active smoking studies (Smith 1987).

In recent years, an increasing number of studies have found an association between adverse pregnancy outcomes, including intrauterine growth retardation and reduced birth weight, and maternal exposure to outdoor air pollution at levels of pollution substantially lower than found in biomass-burning households (Chen et al. 2002; Maisonet et al. 2001; Ha et al. 2001; Bobak & Leon 1999; Ritz & Yu 1999; Xu et al. 1995).

Given that smoke from biomass combustion for cooking and heating produces many of the same pollutants found in tobacco smoke and ambient air, there is good reason to expect a relationship between biomass smoke exposure and adverse pregnancy outcomes.

Material and methods

Data

Data are from India's second National Family Health Survey (NFHS-2) conducted in 1998 – 99. NFHS-2 collected demographic, socioeconomic, and health information from a nationally representative probability sample of 92,486 households. All states of India are represented in the sample, covering more than 99% of the country's population. The sample is a multi-stage cluster sample with an overall household response rate of 98% and

an overall woman response rate of 96%. Details of sample design and survey instruments, including sampling frame, sample implementation, and the survey questionnaires, are provided in the basic survey report for all India (IIPS and ORC Macro 2000). The analysis here is based on 19,189 ever-married women aged 40–49 with complete birth histories.

Human subjects informed consent

The analysis presented in this paper is based on secondary analysis of existing survey data with all identifying information removed. The survey obtained informed consent from each respondent before asking questions.

Response variables

The survey collected complete birth histories from all ever-married women aged 15–49, including whether the woman experienced any stillbirths (Q#220). Stillbirth is defined as the delivery of a dead baby after the 28th week of pregnancy. Separate questions were asked about induced abortion and spontaneous abortion (i.e., miscarriage or delivery of a dead baby before 28 weeks). In order to minimize recall lapse, women were asked about stillbirths separately for each birth interval (including open birth intervals at both ends). From this information, we constructed two response variables – woman ever had a stillbirth (yes, no) and number of stillbirths (none, one, two or more). Only women aged 40–49 years are included in this study because most women in India complete childbearing before age 40. In NFHS-2, less than 2% of all births occurred to women aged 40 and older.

Explanatory variables

Exposure to cooking smoke is ascertained indirectly by type of fuel used for cooking or heating. Measurements in India show that the emissions of pollutants from household stoves vary along the 'energy ladder', with solid fuels producing substantially more pollution per meal cooked than liquid or gaseous fuels (Smith et al. 2000b). Fuel type has also been shown in India to be a good predictor of indoor pollution levels in households (Mehta 2002). The NFHS-2 used a ten-fold classification of cooking fuel – wood, crop residues, dung cakes, coal/coke/lignite, charcoal, kerosene, electricity, liquid petroleum gas, biogas, and a residual category of other fuels. The question was, 'What type of fuel does your household mainly use for cooking?' (Q#37), which was followed by the above list of fuels. The survey also included a second question, 'What other types of fuel does your household commonly use for cooking or heating?' (Q#38), with the same ten-fold classification of fuels. This second question was a multiple response question, meaning a respondent could choose more than one fuel. We use information from these questions to group households into three categories representing the extent of exposure to cooking smoke – high exposure group (households using only biomass fuels: wood, dung, or crop residues), low exposure group (households using only cleaner fuels: electricity, liquid petroleum gas, biogas, or kerosene), and medium exposure group (a mix of biomass fuels and cleaner fuels or coal/coke/lignite/charcoal). This three-category classification of fuels is the principal predictor variable.

The survey also collected information on tobacco smoking (both current and lifetime) for each household member (Q#s24–26). For all persons in a sampled household, the household respondent was asked, 'Does anyone listed smoke?' For current nonsmokers,

the survey asked, 'Has any (other) person listed ever smoked regularly?' The information from these two questions is used to ascertain exposure to tobacco smoke – active smoking (woman currently smokes or has smoked regularly in the past), passive smoking or environmental tobacco smoke (ETS) exposure (one or more other persons in the household smoke currently), no smoking (the woman has never smoked regularly and no other person in the household smokes currently). All forms of tobacco smoking are included, encompassing the use of both commercial and non-commercial tobacco.

Because the effects of exposure to cooking smoke, as well as tobacco smoke, on the risk of stillbirth are likely to be confounded with the effects of other risk factors, it is necessary to statistically control, or adjust, for such factors. Other risk factors and potential confounders included in the analysis are woman's anemia status (not anemic, mildly anemic, moderately to severely anemic), body mass index (<18.5, $18.5-24.9$, $\geqslant 25.0\,kg/m^2$), education (illiterate, $<$ middle school complete, middle complete or higher), religion of household head (Hindu, Muslim, other), caste/tribe status of household head (scheduled caste or scheduled tribe, other backward class, other), house type (*pucca*, semi-*pucca*, *kachha* – see Table I for explanation), availability of a separate kitchen (yes, no), household crowding (<3 persons per room, $\geqslant 3$ persons per room), household standard of living (low, medium, high), residence (urban, rural), and geographic region (north, central-west, east-northeast, south). We also included interaction terms between biomass fuel use and active and passive tobacco smoking to test if exposure to tobacco smoke modifies the effect of cooking smoke and *vice versa*, but the interaction effects were not statistically significant and did not alter the independent effects of cooking smoke and tobacco smoke. In the final analysis, these interaction terms were not included. See Table I for more details on definitions of variables.

Analysis

Effects of cooking smoke and tobacco smoke (both active and passive) on the likelihood of having a stillbirth were estimated using binary logistic regression models. A number of alternative regression models were estimated to assess the relative significance of different potentially confounding factors included in the analysis. To examine the effects of cooking smoke and tobacco smoke on the likelihood of multiple stillbirths in a woman's lifetime, we also estimated several multinomial logistic regression models. Because exposure to cooking smoke and tobacco smoke as well as access to health care differ considerably by urban/rural residence, the analyses were carried out separately for urban and rural areas. Because the effects of cooking smoke and tobacco smoke do not differ much by urban/rural residence, however, we present results only for India as a whole, controlling for urban/rural residence and other factors.

In the survey, certain states and certain categories of households were over-sampled and non-response rates varied from one geographical area to another. In all our analyses, weights are used to restore the representativeness of the sample (IIPS and ORC Macro 2000). Results from binary logistic regression are presented in the form of odds ratios (OR) and results from multinomial logistic regression are presented as relative risk ratios (RRR) with 95% confidence intervals (95% CI). The estimation of confidence intervals takes into account design effects due to clustering at the level of the primary sampling unit. Clustering at the household level is not a serious problem because only 1% of households with at least one ever-married woman aged 40 – 49 years have two or more such women in the household. The binary and multinomial logistic regression models were estimated using the STATA statistical software package (Stata Corporation 2003).

Results

Characteristics of women

A majority (53%) of ever-married women aged 40–49 cook with high pollution biomass fuels, and another 27% use biomass fuels in combination with cleaner cooking fuels (Table I). Few women (5%) smoke tobacco or have ever smoked tobacco regularly in the past. Forty-two percent live in households where someone else smokes. One in two are anemic, about

Table I. Percent distribution of ever-married women aged 40–49 by selected characteristics, India 1998–99.

Characteristic	Urban	Rural	Total
Cooking smoke[1]			
Biomass fuels	12.1	71.0	53.2
Fuel mix	31.2	25.9	27.5
Cleaner fuels	56.6	3.2	19.3
Tobacco smoke[2]			
Active	1.4	6.0	4.6
Passive	34.2	46.0	42.4
No smoking	64.4	48.0	53.0
Anemia[3]			
None	54.5	47.4	49.5
Mild	32.8	36.8	35.6
Moderate/severe	12.7	15.9	14.9
Body mass index (kg/m^2)			
<18.5	14.6	37.5	30.7
18.5–24.9	49.4	51.8	51.1
$\geqslant 25.0$	35.9	10.6	18.2
Education			
Illiterate	37.1	75.5	64.0
Literate, <middle complete	24.1	17.0	19.1
Middle complete or higher	38.7	7.6	16.9
Religion			
Hindu	77.3	84.2	82.1
Muslim	14.0	10.1	11.3
Other[4]	8.7	5.7	6.6
Caste/tribe[5]			
Scheduled caste/scheduled tribe	16.7	27.9	24.5
Other backward class	28.9	36.0	33.9
Other	54.4	36.0	41.6
House type[6]			
Pucca	70.7	23.5	37.7
Semi-*pucca*	21.4	38.7	33.5
Kachha	7.8	37.9	28.8
Separate kitchen			
Yes	72.6	52.7	58.7
No	27.4	47.3	41.3
Crowding			
<3 persons per room	72.0	62.7	65.5
$\geqslant 3$ persons per room	28.0	37.3	34.5
Standard of living[7]			
Low	10.6	47.4	36.4
Medium	43.6	41.7	42.3
High	45.8	10.8	21.3

(*Continued*)

Table I. (*Continued*)

Characteristic	Urban	Rural	Total
Region[8]			
North	21.5	21.7	21.7
Central-west	34.3	23.2	26.5
East-northeast	15.9	28.2	24.5
South	28.3	26.9	27.4
Number of children[9]	5,571	12,996	18,567

[1]Biomass fuels: wood, animal dung, or crop residues; fuel mix: mix of biomass fuels and cleaner fuels, or coal/coke/lignite/charcoal; cleaner fuels: electricity, liquid petroleum gas, biogas, or kerosene. [2]Active: woman currently smokes or has smoked regularly in the past; passive: one or more other persons in the household smoke currently; no smoking: woman has never smoked regularly and no other person in the household smokes currently. [3]Mild anemia: blood hemoglobin level 10.0 – 10.9 grams/deciletre for pregnant women and 10.0 – 11.9 g/dl for nonpregnant women; moderate anemia: 7.0 – 9.9 g/dl; severe anemia: <7.0 g/dl. [4]Sikh, Buddhist, Christian, Jain, Jewish, Zorastrian, etc. [5]Scheduled castes (SC), scheduled tribes (ST), and other backward classes are those castes and tribes designated by the Government of India as socially and economically backward and in need of protection from social injustice and exploitation. [6]*Kachha* houses are made from mud, thatch, or other low-quality materials. *Pucca* houses are made from high-quality materials (such as bricks, tiles, cement, and concrete) throughout, including roof, walls, and floor. Semi-*pucca* houses are made from partly low-quality materials and partly high-quality materials. [7]Standard of living index (SLI) is calculated by adding the scores assigned to the durable goods in the household as following: 4 for a car or tractor; 3 each for a moped/scooter/motorcycle, telephone, refrigerator, or color television; 2 each for a bicycle, electric fan, radio/transistor, sewing machine, black and white television, water pump, bullock cart, or thresher; and 1 each for a mattress, pressure cooker, chair, cot/bed, table, or clock/watch. Index scores range from 0 – 5 for low SLI, 6 – 15 for medium SLI, 16 – 42 for high SLI. [8]North: Jammu & Kashmir, Himachal Pradesh, Haryana, Punjab, Delhi, Uttar Pradesh; Central-west: Maharashtra, Gujarat, Madhya Pradesh, Rajasthan; East-northeast: Bihar, West Bengal, Orissa, Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura; South: Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Goa. [9]Number of children varies slightly for individual variables depending on the number of missing values.

one-third are underweight, and more than three-fifths are illiterate. Four-fifths are Hindu, one-fourth belong to a scheduled caste or scheduled tribe, and another one-third belong to a backward caste. About two-thirds live in *kachha* or semi-*pucca* houses, two-fifths live in houses without a separate kitchen, and one-third live in houses with more than three persons per room. Thirty-seven percent belong to households with a low standard of living, and more than two-thirds live in rural areas. There are considerable urban-rural differences in these characteristics, with rural women being more likely than urban women to cook with biomass fuels, smoke tobacco, be undernourished, be illiterate, belong to a scheduled caste, scheduled tribe, or other backward class, live in a *kachha* or semi-*pucca* house, not have a separate kitchen, live in a crowded household, and live in a household with a low standard of living.

Prevalence of stillbirths

Overall, 7% of ever-married women aged 40 – 49 reported having a stillbirth in their lifetime. This proportion is considerably higher in rural areas (8%) than in urban areas (5%) (Table II). Women cooking with biomass fuels are twice as likely (9%) to have experienced a stillbirth as those using cleaner fuels (4%). As expected, active tobacco smoking is strongly associated with the experience of stillbirth, and passive smoking weakly so.

Anemic women and underweight women are considerably more likely to have experienced a stillbirth. On the other hand, more educated women, those living in *pucca* houses, and women in households with a higher standard of living are less likely to have experienced a stillbirth than

Table II. Proportion of ever-married women aged 40–49 having experienced a stillbirth by selected characteristics, India 1998–99.

Characteristic	Urban	Rural	Total
India	5.4	8.1	7.3
Cooking smoke			
Biomass fuels	8.6	8.8	8.8
Fuel mix	6.3	6.6	6.5
Cleaner fuels	4.3	5.0	4.4
Tobacco smoke			
Active	10.6	10.2	10.2
Passive	6.1	8.4	7.9
No smoking	5.0	7.6	6.7
Anemia			
None	4.9	7.3	6.5
Mild	6.5	8.6	8.0
Moderate/severe	5.7	9.4	8.4
Body mass index (kg/m^2)			
< 18.5	5.8	8.9	8.5
18.5–24.9	6.0	7.5	7.0
$\geqslant 25.0$	4.9	8.1	6.2
Education			
Illiterate	6.9	8.8	8.5
Literate, < middle complete	5.8	6.2	6.1
Middle complete or higher	3.8	6.0	4.5
Religion			
Hindu	5.3	7.7	7.0
Muslim	7.2	11.6	9.9
Other	4.4	7.8	6.4
Caste/tribe			
Scheduled caste/scheduled tribe	5.7	9.2	8.5
Other backward class	5.9	7.6	7.2
Other	5.1	7.8	6.7
House type			
Pucca	4.9	6.5	5.6
Semi-*pucca*	7.0	9.0	8.6
Kachha	6.4	8.3	8.2
Separate kitchen			
Yes	5.4	7.4	6.7
No	5.6	9.0	8.3
Crowding			
< 3 persons per room	5.1	8.0	7.0
$\geqslant 3$ persons per room	6.5	8.4	7.9
Standard of living			
Low	8.5	8.7	8.7
Medium	5.7	7.9	7.2
High	4.5	6.8	5.3
Region			
North	6.5	9.6	8.7
Central-west	4.4	6.6	5.8
East-northeast	5.0	8.8	8.1
South	6.1	7.6	7.1
Number of children	5,571	12,996	18,567

For variable definitions, see Table I.

other women. Muslim women are much more likely to have experienced a stillbirth than non-Muslim women. By geographic region, the prevalence of stillbirth is lowest in the central-west region.

Effects of cooking smoke

Table III shows the estimated effects of cooking smoke, tobacco smoke, and selected demographic and socioeconomic variables on the risk of stillbirth among ever-married women aged 40–49 in alternative models. Model 1 in the table shows that the unadjusted odds of a stillbirth are more than two times higher among women living in households using biomass fuels than among those living in households using cleaner fuels (OR = 2.11; 95% CI: 1.74, 2.57). Women living in households using a mix of biomass fuels and cleaner fuels or coal/coke/lignite or charcoal are also at a considerably higher risk of having experienced a stillbirth (OR = 1.52; 95% CI: 1.23, 1.89). Controlling for exposure to tobacco smoke (in Model 3) reduces the effect of biomass fuel use on the risk of stillbirth slightly (OR = 2.03; 95% CI: 1.66, 2.48). The effect of biomass fuel use is further reduced when the effects of woman's nutritional status, socioeconomic status, and household conditions are additionally controlled (OR = 1.60 in Model 4 and OR = 1.54 in Model 5). The effect is reduced even more in the full model (Model 6), when the effects of urban/rural residence and geographic region are also controlled, but it remains large and statistically significant (OR = 1.44; 95% CI: 1.05, 1.97).

Figure 2 shows the unadjusted and adjusted effects of cooking smoke and active tobacco smoke on number of stillbirths (none, one, two or more). Both the unadjusted and adjusted effects are estimated using multinomial logistic regression. The adjusted effects control for all the variables included in Model 6 in Table III. Figure 2 shows that the relative risk of experiencing two or more stillbirths is four times greater among women using biomass cooking fuels than among those using cleaner fuels. Even when tobacco smoking and the other 12 factors are controlled, the relative risk of two or more stillbirths is two times greater among biomass-fuel-using women (RRR = 2.01; 95% CI: 1.11, 3.62) than among cleaner-fuel-using women.

Effects of tobacco smoke

Women who currently smoke tobacco or have ever smoked regularly in the past are significantly more likely to have had a stillbirth (OR = 1.60; 95% CI: 1.23, 2.08) than those who have never smoked and do not live in a household with other smokers (Model 2 in Table III). This effect is reduced considerably when the effect of cooking smoke is controlled (OR = 1.34; 95% CI: 1.03, 1.75), and it is reduced further to statistical non significance when the effects of the 12 other variables are additionally controlled in Model 6 (OR = 1.23; 95% CI: 0.92, 1.64). In Figure 2, women who smoke tobacco or regularly smoked tobacco in the past also have a higher relative risk of two or more stillbirths (RRR = 1.36), but this effect is also not statistically significant (95% CI: 0.87, 1.57). Passive tobacco smoking also does not have any significant effect on the risk of stillbirth when cooking smoke and the other factors included in Table III are controlled.

Effects of other risk factors

The discussion of the adjusted effects of the control variables focuses on the full model (Model 6) in Table III. As expected, with cooking smoke, tobacco smoke, and other variables

Table III. Unadjusted and adjusted effects (odds ratios) of cooking smoke, tobacco smoke, and other factors on the risk of stillbirth, alternative models, India 1998–99.

Characteristic	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Cooking smoke						
Biomass fuels	2.11***		2.03***	1.60***	1.54**	1.44*
Fuel mix	1.52***		1.49***	1.27	1.25	1.19
Cleaner fuels†	–		–	–	–	–
Tobacco smoke						
Active		1.60***	1.34*	1.28	1.28	1.23
Passive		1.19**	1.09	1.07	1.08	1.05
No smoking†		–	–	–	–	–
Anemia						
None†				–	–	–
Mild				1.21*	1.21*	1.21*
Moderate/severe				1.21	1.20	1.20
Body mass index (kg/m^2)						
<18.5				1.05	1.05	1.05
18.5–24.9†				–	–	–
$\geqslant 25.0$				1.14	1.14	1.13
Education						
Illiterate†				–	–	–
Literate, < middle complete				0.80*	0.80*	0.82*
Middle complete or higher				0.70**	0.70**	0.70**
Religion						
Hindu†				–	–	–
Muslim				1.49***	1.51***	1.46***
Other				1.01	1.01	0.97
Caste/tribe						
Scheduled caste/scheduled tribe				1.10	1.10	1.13
Other backward class				1.00	1.00	1.00
Other†				–	–	–
House type						
Pucca					0.91	0.90
Semi-*pucca*					1.12	1.13
Kachha †					–	–
Separate kitchen						
Yes					0.98	1.00
No†					–	–
Crowding						
< 3 persons per room†					–	–
$\geqslant 3$ persons per room					0.93	0.95
Standard of living						
Low†					–	–
Medium					0.96	0.94
High					1.08	1.03
Residence						
Urban						0.99
Rural†						–
Region						
North						1.21
Central-west						0.77*
East-northeast						0.98
South†						–
Number of children	19,090	19,164	19,066	16,876	16,802	16,802

For variable definitions, see Table I. †Reference category. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

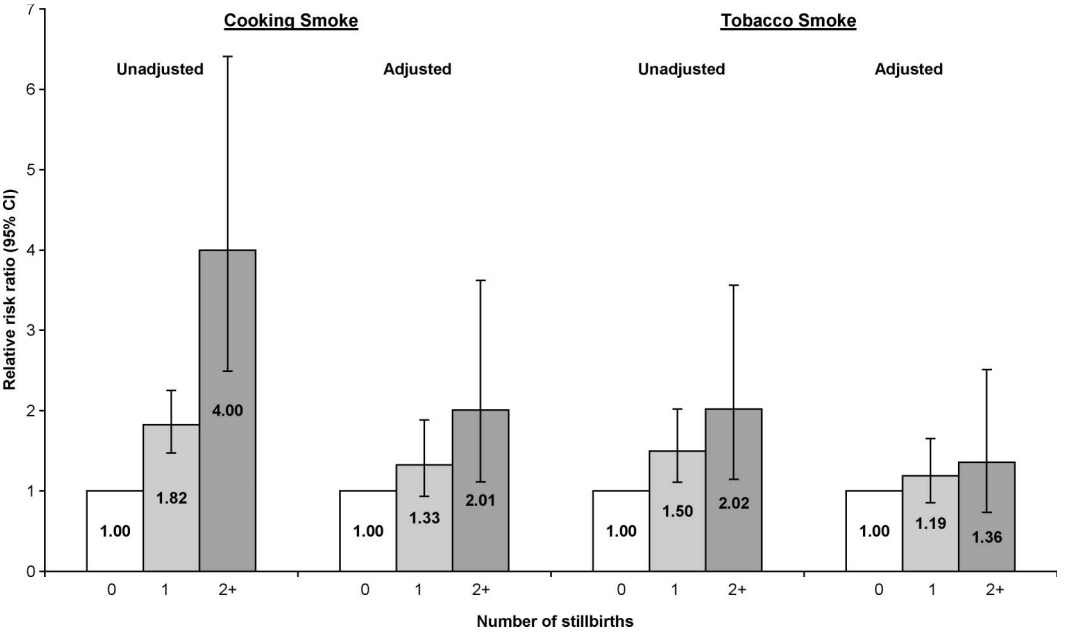


Figure 2. Unadjusted and adjusted effects of cooking smoke (biomass fuels relative to cleaner fuels) and tobacco smoke (active smoking relative to no smoking) on the relative risk of 0, 1, and 2+ stillbirths (risk relative to no stillbirth), India 1998–99.

controlled, anemic women are significantly more likely to have had a stillbirth. Also as expected, the risk of stillbirth declines as education increases. Muslim women are significantly more likely than other women to have experienced a stillbirth. The risk of stillbirth is highest in the north region and lowest in the central-west region. None of the other control variables has any significant effect on the risk of stillbirth. Urban and rural women are about equally likely to have experienced a stillbirth. In separate analyses for urban and rural, the effect of cooking smoke does not vary by urban/rural residence (results not shown).

Discussion

Results indicate that ever-married women aged 40–49 who cook with wood, dung, or crop residues are significantly more likely to have experienced a stillbirth than those who cook with electricity, LPG, biogas, or kerosene (OR = 1.44; 95% CI: 1.04, 1.97), independent of active and passive tobacco smoking, nutritional status, education, household living standard, and other factors. Results also indicate that women who cook with biomass fuels are twice as likely to have had two or more stillbirths as women who cook with cleaner fuels (RRR = 2.01; 95% CI: 1.11, 3.62), which is evidence for a dose-response effect. These results are consistent with the earlier Indian study linking wood fuels to increased risk of stillbirth (Mavalankar et al. 1991), and they provide further evidence that cooking with high-pollution unprocessed biomass fuels increases the risk of adverse pregnancy outcomes.

The effect of active tobacco smoking on the risk of stillbirth is also positive (OR = 1.23) but not statistically significant after other variables (including type of cooking fuel) are statistically controlled. We also tested for interactions between the effects of cooking smoke and tobacco smoke, but find no evidence of modifying effects of exposure to tobacco smoke.

Several limitations should be kept in mind when considering the findings of this study: One is that exposure to cooking smoke was ascertained indirectly from type of fuel used for cooking, rather than by direct measurement of household air pollution. Another is that the analysis correlates woman's lifetime experience of stillbirths with woman's characteristics at the time of the survey. This is a problem to the extent that some characteristics of a woman may have changed over the years. For example, an unknown fraction of the women shifted from biomass fuels to cleaner fuels during their lifetime. Our estimated effects are underestimated to the extent that this occurred.

Another problem is that some women may not recall their experience of stillbirth, although care was taken in NFHS-2 to minimize such recall lapse by asking about adverse pregnancy outcomes in each birth interval. To the extent that such recall lapse is greater among poorer, biomass-fuel-using women, our measured effects are again likely to be underestimated. On the other hand, some women may erroneously report an early neonatal death as a stillbirth. Our estimated effects may be overestimated to the extent that this bias is more prevalent among biomass-fuel-using women. Given the considerable emphasis on recording all live births accurately in the survey, however, bias due to these recall errors is probably small.

Although our analysis accounts for a large number of potential confounders and effect modifiers, it is also possible that our measured effects are partly due to variables that we were not able to include in the analysis; e.g., antenatal care, which is correlated with both household fuel use and risk of stillbirth. (The survey collected information on antenatal care for live births but not for stillbirths.) Moreover, we were unable to control for exposure to cooking oil fumes, which has been associated with adverse health effects (Wu et al. 2004) and may have modified the effects of exposure to cooking smoke to some degree.

The implication of these various limitations is that our research needs to be followed up with carefully designed studies with better measures of smoke exposure and clinical measures of pregnancy outcomes. Such research is important because large proportions of households in India and other developing countries rely on biomass fuels for household energy, and because adverse pregnancy outcomes are a serious health problem in these countries.

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