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Does biofuel smoke contribute to anaemia and stunting in early childhood?

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Background Reliance on biomass fuels for cooking and heating exposes many women and young children in developing countries to high levels of air pollution indoors. Exposure to biomass smoke has been linked to reduced birth weight, acute respiratory infections, and childhood mortality. This study examines the association between household use of biofuels (wood, dung, and crop residues) for cooking and heating and prevalence of anaemia and stunting in children.

Methods Data are from a 1998–99 national family health survey in India, which measured height, weight, and blood haemoglobin of 29 768 children aged 0–35 months in 92 486 households. Multinomial logistic regression is used to estimate the effects of biofuel use on prevalence of anaemia and stunting, controlling for exposure to tobacco smoke, recent episodes of illness, maternal education and nutrition, and other potentially confounding factors.

Results Analysis shows that prevalence of moderate-to-severe anaemia was significantly higher among children in households using biofuels than among children in households using cleaner fuels (RRR = 1.58; 95% CI: 1.28, 1.94), independent of other factors. Prevalence of severe stunting was also significantly higher among children in biofuel-using households (RRR = 1.84; 95% CI: 1.44, 2.36). Thirty-one per cent of moderate-to-severe anaemia and 37% of severe stunting among children aged 6–35 months in India may be attributable to exposure to biofuel smoke. Effects on mild anaemia and moderate stunting were smaller, but positive and statistically significant. Effects of exposure to tobacco smoke on anaemia and stunting were small and not significant.

Conclusions The study provides a first evidence of the strong association between biofuel use and risks of anaemia and stunting in children, suggesting that exposure to biofuel smoke may contribute to chronic nutritional deficiencies in young children.

Keywords Air pollution, anaemia, biomass, child, indoor, smoke, stunting

Introduction

Reliance on biomass fuels for cooking and heating exposes many women and young children in developing countries to high levels of air pollution indoors. Biofuel smoke exposure has been linked to reduced birth weight and to acute respiratory infections (ARI) and mortality in early childhood, but little is known about its effects on the nutritional status and physical growth of children. This study investigates the association between household use of unprocessed biofuels for cooking and heating and prevalence of anaemia and stunting in children in India, using data from a large, nationally representative household survey conducted in 1998–99.

According to the survey, almost half of children under three years of age (48%) suffered from moderate-to-severe levels of anaemia, and a similar proportion (46%) were stunted.[1] Chronic childhood undernutrition, which can result in stunting, is a known source of ill health and death.[2,3] According to a recent comparative risk assessment by the World Health Organization, undernutrition is estimated to be, by far, the largest contributor to the global burden of disease.[4] Widespread childhood anaemia is also a major problem because it can result in impaired cognitive performance, behavioural and motor

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development, coordination, language development, and scholastic achievement, as well as increased susceptibility to a host of childhood diseases.[5–7]

Biofuels are at the low end of the energy ladder in terms of combustion efficiency and cleanliness.[8] Smoke from biomass combustion produces a large number of health-damaging air pollutants including respirable particulate matter, carbon monoxide (CO), nitrogen oxides, formaldehyde, benzene, 1,3 butadiene, polycyclic aromatic hydrocarbons (such as benzo-[a]pyrene), and many other toxic organic compounds. In developing countries, large proportions of households rely on biofuels for cooking and space heating. The fuels are typically burned in simple, inefficient, and mostly unvented household cookstoves, which, when combined with poor ventilation, generate large volumes of smoke indoors.[9] Moreover, these cookstoves are typically used for several hours each day at times when people are present, resulting in much higher exposure to indoor air pollutants than from outdoor sources.[10]

In such settings, daily average and peak exposures to air pollutants often far exceed safe levels recommended by the World Health Organization.[11] A comparison of typical levels of CO, PM_{10}, and $PM_{2.5}$ in developing-country homes using biofuels with the United States Environmental Protection Agency's standards for 24 h average levels concluded that indoor concentrations of these pollutants in biofuel-using developing-country homes usually exceed the guideline levels by several-fold.[9] Exposure is usually much greater among women, who tend to do most of the cooking,[12] and among young children who tend to stay indoors and who are often carried on their mother's back or lap while she cooks.[13]

Studies in India, mostly in biofuel-using rural homes, have measured kitchen area particulate matter concentrations of 4000–21 000 $\mu g/m^3$ and 2–5 h daily exposures of 3600–6800 $\mu g/m^3$ during cooking.[14] 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.[15] Another study in western India measured indoor CO levels of 156 mg/m^3 for cooking with wood and 144 mg/m^3 for cooking with dung, compared with 14 mg/m^3 for cooking with gas.[16] Such high exposures have been linked to adverse pregnancy outcomes, ARI among children, and chronic bronchitis and lung cancer among women, leading to estimates of hundreds of thousands of premature deaths annually in India.[17,18] Although there has been speculation about a link between biofuel smoke and anaemia and stunting, we are aware of no empirical studies on this topic.

The Indian survey measured height, weight, and blood haemoglobin levels of children below three years of age and their mothers. The survey also collected information on cooking and heating fuels, fuel mix, and tobacco smoking for all persons included in the survey. Such data are relatively rare in developing-country settings and provide a unique opportunity to explore the relationship between exposure to biofuel smoke and prevalence of anaemia and stunting in children.

The mechanisms by which biofuel smoke may contribute to anaemia and stunting are uncertain. Biofuel smoke contains large quantities of CO, which binds with haemoglobin (necessary for transporting oxygen to body tissues), forms carboxyhaemoglobin, and reduces the quantity of haemoglobin in the blood, thereby causing anaemia. Levels of CO in homes using biomass fuels are sometimes high enough to result in carboxyhaemoglobin levels comparable to those in smokers.[12,19] Smoke exposure can also contribute to stunting by causing not only anaemia but also reduced birth weight,[20,21] ARI,[22,23] and other childhood diseases.

Materials 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 >99% of the country's population. The sample is a multi-stage cluster sample with an overall household response rate of 98%. Ninety-six per cent of eligible women were interviewed and 88% were tested for anaemia. Details of sample design, including sampling frame and sample implementation, are provided in the basic survey report for all India.[1] The analysis here is based on 29 768 children aged 0–35 months living in the sample households.

Response variables

To assess the physical growth of children, measurements of weight and height/length were obtained for children born in the three years preceding the survey. Weight was measured using a solar-powered digital scale with an accuracy of $\pm$100 g, and height was measured using an adjustable wooden measuring board, especially designed to provide accurate measurements (to the nearest 0.1 cm) in a field situation. Using these data, a child was defined as stunted if his or her height-for-age *Z*-score was more than two standard deviation (SD) units below the median of an international reference population recommended by the World Health Organization.[24,25] We use a three-category variable for stunting in the analysis: not stunted ($Z \geqslant -2$ SD), moderately stunted (-3 SD $\leqslant Z < -2$ SD), severely stunted ($Z < -3$ SD).

To assess the anaemia status of children and their mothers, blood haemoglobin levels were measured using the portable HemoCue system. The system uses a drop of blood from a finger prick (or heel prick for infants below six months), which is drawn into a cuvette and then inserted into a portable, battery-operated instrument to obtain a digital reading on haemoglobin concentration. The haemoglobin measurements were adjusted for altitude. Children were categorized as not anaemic ($\geqslant$11.0 g/dl), mildly anaemic (10.0–10.9 g/dl), moderately anaemic (7.0–9.9 g/dl), or severely anaemic (<7.0 g/dl). Because the proportion of severely anaemic children is small (5%) in the sample, we use a three-category response variable for anaemia—no anaemia, mild anaemia, moderate/severe anaemia.

Predictor variables

Exposure to biofuel smoke is ascertained indirectly by type of fuel used for cooking or heating. The survey used a 10-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?' followed by the above list of fuels. The survey also included a second multiple-response question, 'What other types of fuel does your household commonly use for cooking or heating?' with the same 10-fold classification of fuels. Using this information, households were grouped into three categories representing extent of exposure to biofuel smoke—high exposure group (only biofuels: wood, crop residues, or dung cakes), low exposure group (only cleaner fuels: electricity, liquid petroleum gas, biogas, or kerosene), and medium exposure group (a mix of biofuels 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. The survey asked the household respondent, 'Does anyone listed smoke?' Children living in households where one or more persons smoked tobacco were categorized as having exposure to tobacco smoke.

Because the effects of biofuel smoke, as well as tobacco smoke, on the prevalence of anaemia and stunting are likely to be confounded with other factors, it is necessary to statistically control, or adjust, for such factors. Factors, identified in previous research as covariates of childhood nutritional status, include child's age (0–5, 6–11, 12–23, 24–35 months), sex (boy, girl), birth order (1, 2, 3, 4+), iron supplementation during pregnancy, ARI in the preceding two weeks, diarrhoea in the preceding two weeks, malaria in the preceding three months; mother's age at childbirth (13–24, 25–34, 35–49 years), body mass index (BMI) (<18.5, 18.5–25.0, $\geqslant 25.0$ kg/m^2), anaemia status (none, mild, moderate/severe), education (illiterate, below middle complete, middle complete or higher); religion of household head (Hindu, Muslim, other), caste/tribe (scheduled-caste or scheduled-tribe, other backward class, other); house type (*pucca*, semi-*pucca*, *kachha*), separate kitchen availability, household crowding (<3 persons/room, 3+ persons/room), household living standard (low, medium, high); residence (urban, rural); and region of residence (north, central-west, east-northeast, south). (See footnotes to Tables 1 and 2 for more details on definitions of variables.)

Analysis

We use multinomial logistic regression to estimate relative risks of suffering from anaemia (none, mild, moderate/severe) and stunting (none, moderate, severe) among children from households using only biofuels and households using a mix of biofuels and cleaner fuels relative to children from households using only cleaner fuels, after controlling for exposure to tobacco smoke and other potentially confounding factors. We also included interaction terms between biofuel use and tobacco smoke to test whether exposure to tobacco smoke modifies the effect of exposure to biofuel smoke and vice versa, but this effect was not significant and did not alter the independent effects of biofuel smoke and tobacco smoke. In the final analysis, this interaction term was not included. Because blood haemoglobin levels and stunting in very young children (below six months) mostly reflect anaemia and nutritional status of mothers, multivariate analyses of effects of exposure to biofuel smoke were limited to children aged 6–35 months. A number of alternative regression models were estimated using different combinations of the 20 potentially confounding variables mentioned above.

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 our analysis, weights are used to restore the representativeness of the sample.[1] Results are presented in the form of relative risk ratios (RRR) with significance levels and 95% confidence intervals (CI). The estimation of confidence intervals adjusts for clustering at the level of the primary sampling unit. In the case of mothers who had more than one child during the 3 year period, we restrict the analysis to the last birth in order to avoid any clustering at the mother level. Multinomial logistic regression models are estimated using the STATA statistical software package.[26]

Human subjects' informed consent

The analysis is based on secondary analysis of existing survey data with all identifying information removed. The survey was approved by the ethical review boards of the implementing agencies and the Indian government. Participation in the survey was totally voluntary. The survey obtained informed consent from each respondent (in this case, mothers of children included in the analysis) before asking questions, and separately before obtaining height, weight, and blood haemoglobin measurements. The haemoglobin test result was explained to the mother, and for anaemic children, the mother was advised to seek medical treatment. For severely anaemic children, consent for medical referral was obtained from the mother, and where mothers consented, a list of severely anaemic children was provided to the local health provider for follow-up.

Results

Characteristics of children

About two-thirds (64%) of the children live in households using only biofuels for cooking and heating, another 24% live in household using a mix of biofuels and cleaner fuels or coal/coke/lignite/charcoal (Table 1). The proportion using biofuels is much greater in rural areas (78%) than in urban areas (17%). On the other hand, only 2% of rural households exclusively use cleaner fuels, compared with 47% of urban households. One in two children live in households where at least one adult smokes tobacco regularly. This proportion is greater in rural areas than in urban areas. Children are distributed more or less evenly by age. Fifty-two per cent are boys and 48% are girls. Thirty per cent of children are birth order four or higher. The proportion of higher-order births is much greater in rural areas than in urban areas, consistent with higher fertility in rural areas. Also as expected, mothers of rural children are considerably less likely to have received iron supplementation during pregnancy (52%) than mothers of urban children (76%). One in five children suffered from an ARI in the two weeks preceding the survey, and a similar proportion suffered from diarrhoea in the same period. Four

Table 1 Sample distribution of children aged 0–35 months by fuel type and other selected characteristics, and by urban/rural residence, India 1998–99

Characteristics	Urban (%)	Rural (%)	Total (%)
Biofuel smoke[a]			
Biomass fuels	17	78	64
Fuel mix	36	20	24
Cleaner fuel	47	2	12
Environmental tobacco smoke (ETS)[b]			
Yes	41	54	51
No	59	46	49
Age of child (months)			
0–5	15	17	16
6–11	17	16	16
12–23	34	34	34
24–35	34	33	34
Sex of child			
Boy	52	52	52
Girl	48	48	48
Birth order			
1	34	25	27
2	30	24	26
3	16	18	18
4+	21	32	30
Iron supplements during pregnancy			
Yes	76	52	57
No	24	48	43
Suffered from ARI[c] in past 2 weeks			
Yes	16	21	20
No	84	79	80
Suffered from diarrhoea in past 2 weeks			
Yes	19	19	19
No	81	81	81
Suffered from malaria in past 3 months			
Yes	2	4	4
No	98	96	96
Mother's age at childbirth (years)			
13–24	59	61	61
25–34	38	34	35
35–49	4	5	5
Mother's body mass index (kg/m^2)			
<18.5	32	42	40
18.5–25.0	57	55	56
⩾25.0	11	2	4
Mother's anaemia status[d]			
None	51	42	44
Mild	34	38	37
Moderate/severe	15	20	19
Mother's education			
Illiterate	36	67	60
Literate, below middle complete	20	17	17
Middle complete or higher	44	16	22
Religion			
Hindu	71	81	79
Muslim	23	14	16
Other[e]	7	5	5
Caste/tribe[f]			
Scheduled caste/scheduled tribe	21	33	31
Other backward class	30	33	32
Other	49	34	37
House type[g]			
Pucca	61	16	26
Semi-*pucca*	28	40	37
Kachha	11	44	37
Separate kitchen			
Yes	59	41	45
No	41	59	55
Crowding			
<3 persons per room	50	43	45
⩾3 persons per room	50	57	55
Standard of living[h]			
Low	18	55	47
Medium	51	37	40
High	31	8	13
Residence			
Urban	100	0	22
Rural	0	100	78
Geographic region[i]			
North	24	28	27
Central and west	37	26	29
East and northeast	14	30	26
South	24	16	18
Number of children[j]	6482	22 599	29 081

[a] Biomass fuels: wood, animal dung, or crop residues; fuel mix: mix of biomass fuels and cleaner fuels, or coal/coke/lignite/charcoal; cleaner fuel: kerosene, petroleum gas, biogas, or electricity.

[b] Child lives in a household where one or more persons currently smoke.

[c] ARI is defined as coughing accompanied by short, rapid breathing.

[d] Mild anaemia: blood haemoglobin level 10.0–10.9 g/dl for pregnant women and 10.0–11.9 g/dl for non-pregnant women; moderate anaemia: blood haemoglobin level 7.0–9.9 g/dl; and severe anaemia: blood haemoglobin level < 7.0 g/dl.

[e] Sikh, Buddhist, Christian, Jain, Jewish, Zorastrian, etc.

[f] 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.

[g] *Kachha* houses are made from mud, thatch, or 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.

[h] 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 0–5 for low SLI, 6–15 for medium SLI, 16–42 for high SLI.

[i] North: Jammu & Kashmir, Himachal Pradesh, Haryana, Punjab, Delhi, Uttar Pradesh; Central and west: Maharashtra, Gujarat, Madhya Pradesh, Rajasthan; east and northeast: Bihar, West Bengal, Orissa, Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura; south: Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Goa.

[j] Number of children varies slightly for individual variables depending on the number of missing values.

Table 2 Prevalence of anaemia and stunting in children aged 0–35 months by fuel type and other selected characteristics, India 1998–99

Characteristics	Anaemia[a] (%) Mild	Anaemia[a] (%) Moderate/severe	Stunting[b] (%) Moderate	Stunting[b] (%) Severe
India	23	48	23	23
Biofuel smoke				
Biomass fuels	23	51	24	29
Fuel mix	23	46	22	17
Cleaner fuel	24	39	19	10
Environmental tobacco smoke (ETS)				
Yes	23	49	23	26
No	24	47	22	21
Age of child (months)				
0–5	24	33	12	5
6–11	27	44	20	11
12–23	22	55	28	30
24–35	22	49	24	32
Sex of child				
Boy	23	50	22	22
Girl	24	46	23	25
Birth order				
1	24	45	22	18
2	24	46	22	20
3	21	51	24	25
4+	23	51	23	31
Iron supplements during pregnancy				
Yes	23	46	22	18
No	23	51	23	31
Suffered from ARI in past 2 weeks				
Yes	24	52	24	24
No	23	47	22	23
Suffered from diarrhoea in past 2 weeks				
Yes	24	50	24	25
No	23	48	22	23
Suffered from malaria in past 3 months				
Yes	23	51	24	28
No	23	48	23	23
Mother's age at childbirth (years)				
13–24	23	48	24	23
25–34	23	47	21	24
35–49	24	48	19	29
Mother's body mass index (kg/m^2)				
<18.5	23	54	25	26
18.5–25.0	24	45	22	22
⩾25.0	24	38	15	12
Mother's anaemia status				
None	24	42	22	21
Mild	24	50	23	23
Moderate/severe	22	59	22	28
Mother's education				
Illiterate	22	53	24	30
Literate, below middle complete	25	47	23	19
Middle complete or higher	25	38	19	11
Religion				
Hindu	23	49	23	24
Muslim	25	46	23	25
Other	21	45	20	14
Caste/tribe				
Scheduled caste/ scheduled tribe	22	54	24	28
Other backward class	24	46	22	23
Other	24	45	22	19
House type				
Pucca	23	42	20	15
Semi-*pucca*	23	49	24	25
Kachha	23	51	23	29
Separate kitchen				
Yes	24	45	21	19
No	23	51	24	28
Crowding				
<3 persons per room	24	45	21	20
⩾3 persons per room	23	51	24	26
Standard of living				
Low	23	52	24	30
Medium	24	46	22	21
High	23	40	18	11
Residence				
Urban	24	44	20	16
Rural	23	49	23	26
Region				
North	21	50	24	28
Central and West	23	51	24	23
East and Northeast	27	48	22	26
South	22	43	21	14
Number of children		21 381		21 660

For variable definitions, see footnotes to Table 1.

[a] Childhood anaemia is defined as a blood haemoglobin level < 11.0 g/dl. Mild anaemia: blood haemoglobin level 10.0–10.9 g/dl; moderate anaemia: blood haemoglobin level 7.0–9.9 g/dl; and severe anaemia: blood haemoglobin level < 7.0 g/dl.

[b] Stunting is a measure of linear growth retardation in children. A child whose height-for-age is more than two standard deviation units below the median of the International Reference Population is defined as stunted.

per cent of children suffered from an episode of malaria in the preceding three months. Three-fifths were born to young mothers aged 13–24, and a similar proportion have illiterate mothers. Forty per cent have undernourished mothers (BMI < 18.5 kg/m^2), and 56% have anaemic mothers (19% with moderate-to-severe anaemia). Twenty-one per cent belong to non-Hindu households and 31% belong to a scheduled-caste or scheduled-tribe household. Thirty-seven per cent live in *kachha* (poor quality) houses, 55% live in houses without a separate kitchen, and 55% live in crowded households with three or more persons per room. Forty-seven per cent live in low-standard-of-living households and only 13% live in high-standard-of-living households. About four-fifths (78%) live in

Table 3 Unadjusted and adjusted effects of biofuel smoke, ETS, and other risk factors on anaemia prevalence in children aged 6–35 months in alternative models, India 1998–99

	Model 1		Model 2		Model 3		Model 4		Model 5	
Characteristics	Mild	Moderate/ severe	Mild	Moderate/ severe	Mild	Moderate/ severe	Mild	Moderate/ severe	Mild	Moderate/ severe
Biofuel smoke										
Biomass fuels	1.56***	2.18***	1.57***	2.14***	1.52***	2.04***	1.43***	1.88***	1.25	1.58***
Fuel mix	1.24*	1.53***	1.24*	1.51***	1.22*	1.48***	1.19*	1.44***	1.13	1.36***
Cleaner fuel†	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Environmental tobacco smoke (ETS)										
Yes			0.98	1.08	0.98	1.08	0.97	1.07	0.95	1.03
No†			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Age of child (months)										
6–11†					1.00	1.00	1.00	1.00	1.00	1.00
12–23					1.05	1.59***	1.06	1.61***	1.07	1.61***
24–35					0.80**	1.07	0.81**	1.08	0.79**	1.07
Sex of child										
Boy†					1.00	1.00	1.00	1.00	1.00	1.00
Girl					1.03	0.88**	1.03	0.88**	1.04	0.86**
Birth order										
1†					1.00	1.00	1.00	1.00	1.00	1.00
2					1.12	1.15*	1.13	1.15*	1.13	1.15*
3					1.07	1.37***	1.06	1.35***	1.02	1.24**
4+					1.20**	1.33***	1.17*	1.28***	1.09	1.14
Iron supplements during pregnancy										
Yes							0.86*	0.81***	0.95	0.92
No†							1.00	1.00	1.00	1.00
Suffered from ARI in past 2 weeks										
Yes							1.20**	1.26***	1.16*	1.23***
No†							1.00	1.00	1.00	1.00
Suffered from diarrhoea in past 2 weeks										
Yes							1.03	1.08	1.02	1.03
No†							1.00	1.00	1.00	1.00
Suffered from malaria in past 3 months										
Yes							1.20	1.15	1.07	0.94
No†							1.00	1.00	1.00	1.00
Mother's age at childbirth (years)										
13–24†									1.00	1.00
25–34									0.93	0.91
35–49									1.07	1.01
Mother's body mass index (kg/m^2)										
<18.5									1.17**	1.46***
18.5–25.5†									1.00	1.00
⩾25.0									0.98	1.03
Mother's anaemia status										
None†									1.00	1.00
Mild									1.30***	1.58***
Moderate/severe									1.97***	2.98***
Mother's education										
Illiterate†									1.00	1.00
Literate, below middle complete									1.01	0.93
Middle complete or higher									0.89	0.66***
Religion										
Hindu†									1.00	1.00
Muslim									1.06	0.89
Other									0.86	0.87

Table 3 continued

Characteristics	Model 1 Mild	Model 1 Moderate/ severe	Model 2 Mild	Model 2 Moderate/ severe	Model 3 Mild	Model 3 Moderate/ severe	Model 4 Mild	Model 4 Moderate/ severe	Model 5 Mild	Model 5 Moderate/ severe
Caste/tribe										
Scheduled caste/ scheduled tribe									1.00	1.14
Other backward class									0.91	0.91
Other†									1.00	1.00
House type										
Pucca									0.95	0.90
Semi-*pucca*									1.03	1.03
Kachha†									1.00	1.00
Separate kitchen										
Yes									0.92	0.95
No†									1.00	1.00
Crowding										
<3 persons per room†									1.00	1.00
⩾3 persons per room									1.05	1.06
Standard of living										
Low†									1.00	1.00
Medium									0.95	0.96
High									0.98	1.09
Residence										
Urban									1.11	1.22*
Rural†									1.00	1.00
Region										
North									1.13	1.43***
Central and west									1.38***	1.52***
East and northeast									1.48***	1.19*
South†									1.00	1.00
Number of children		16 557		16 557		16 557		16 488		16 187

For variable definitions, see footnotes to Tables 1 and 2.
*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.
†Reference category.

rural areas. By geographic region, 18% of the children are from the south, and the proportions in the other regions range from 26 to 29%.

Prevalence of childhood anaemia and stunting

Overall, 71% of the children in our sample are anaemic—23% are mildly anaemic and 48% are moderately-to-severely anaemic (Table 2). Children living in households using only biofuels are much more likely to be moderately-to-severely anaemic (51%) than those living in households using only cleaner fuels. The prevalence of moderate-to-severe anaemia is noticeably higher among children of undernourished, anaemic, and less-educated mothers. It is also higher among children in scheduled-caste and scheduled-tribe households and in poorer households. Prevalence of mild anaemia does not vary much by fuel type or by any of the other characteristics.

Forty-six per cent of the children are stunted—23% moderately stunted and 23% severely stunted. Prevalence of both moderate and severe stunting is much higher among children living in households using only biofuels than among children living in households using only cleaner fuels. Children in biofuel-using households are about three times as likely to be severely stunted as those in cleaner-fuel-using households. The proportion severely stunted is higher among children living in households where at least one person smokes tobacco, and it increases with age and birth order of child. Iron supplementation during pregnancy is strongly negatively associated with severe stunting. Children of less-educated, undernourished, and anaemic mothers are more likely to be severely stunted than other children, as are children from poorer and scheduled-caste and scheduled-tribe households. Children living in urban areas and those in the south region are less likely to be severely stunted. Associations of moderate stunting with these characteristics tend to be similar but weaker.

Effects of biofuel smoke on anaemia

Table 3 shows unadjusted and adjusted effects of biofuel smoke exposure on prevalence of anaemia among children

Table 4 Unadjusted and adjusted effects of biofuel smoke, ETS, and other risk factors on stunting prevalence in children aged 6–35 months in alternative models, India 1998–99

Characteristics	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
	Moderate	Severe	Moderate	Severe	Moderate	Severe	Moderate	Severe	Moderate	Severe	Moderate	Severe
Biofuel smoke												
Biomass fuels	2.16***	5.12***	2.15***	4.81***	2.08***	4.42***	1.93***	3.65***	1.25*	1.90***	1.24	1.84***
Fuel mix	1.41***	1.96***	1.40***	1.89***	1.37***	1.78***	1.34***	1.69***	1.08	1.26*	1.07	1.21
Cleaner fuel†	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Environmental tobacco smoke (ETS)												
Yes			1.03	1.27***	1.03	1.26***	1.02	1.22***	0.95	1.11	0.94	1.09
No†			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Age of child (months)												
6–11†					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
12–23					2.38***	4.85***	2.42***	5.04***	2.52***	5.28***	2.39***	4.95***
24–35					1.96***	5.15***	2.00***	5.37***	2.08***	5.76***	2.04***	5.67***
Sex of child												
Boy†					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Girl					1.07	1.16**	1.07	1.15**	1.07	1.13*	1.08	1.15**
Birth order												
1†					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2					1.04	1.11	1.03	1.08	1.06	1.12	1.02	1.11
3					1.33***	1.55***	1.31***	1.46***	1.23**	1.32***	1.14	1.26**
4+					1.37***	2.06***	1.30***	1.80***	1.15	1.56***	1.11	1.56***
Child’s anaemia status												
No anaemia†											1.00	1.00
Mild											1.10	1.14
Moderate/severe											1.44***	1.65***
Iron supplements during pregnancy												
Yes							0.79***	0.53***	0.93	0.70***	0.92	0.70***
No†							1.00	1.00	1.00	1.00	1.00	1.00
Suffered from ARI in past 2 weeks												
Yes							1.08	1.07	1.06	1.00	1.03	0.98
No†							1.00	1.00	1.00	1.00	1.00	1.00
Suffered from diarrhoea in past 2 weeks												
Yes							1.16*	1.27***	1.10	1.17*	1.10	1.17*
No†							1.00	1.00	1.00	1.00	1.00	1.00
Suffered from malaria in past 3 months												
Yes							1.04	1.09	0.92	0.93	0.92	0.95
No†							1.00	1.00	1.00	1.00	1.00	1.00
Mother’s age at childbirth (years)												
13–24†									1.00	1.00	1.00	1.00
25–34									0.86*	0.79***	0.87*	0.78***
35–49									0.69**	0.79	0.70*	0.77*
Mother’s body mass index (kg/m^2)												
<18.5									1.10	1.08	1.10	1.07
18.5–25.5†									1.00	1.00	1.00	1.00
⩾25.0									0.86	0.87	0.86	0.81
Mother’s anaemia status												
None†									1.00	1.00	1.00	1.00
Mild									1.11	1.15*	1.07	1.11
Moderate/severe									1.17*	1.45***	1.08	1.30***
Mother’s education												
Illiterate†									1.00	1.00	1.00	1.00
Literate, below middle complete									0.80**	0.66***	0.81**	0.66***
Middle complete or higher									0.70***	0.48***	0.70***	0.50***

Table 4 continued

Characteristics	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
	Moderate	Severe	Moderate	Severe	Moderate	Severe	Moderate	Severe	Moderate	Severe	Moderate	Severe
Biofuel smoke												
Religion												
Hindu[†]									1.00	1.00	1.00	1.00
Muslim									1.17	1.23*	1.13	1.22*
Other									0.76*	0.72**	0.77*	0.72**
Caste/tribe												
Scheduled caste/scheduled tribe									1.23**	1.39***	1.21**	1.38***
Other backward class									1.11	1.36***	1.10	1.37***
Other[†]									1.00	1.00	1.00	1.00
House type												
Pucca									1.05	0.91	1.07	0.90
Semi-*pucca*									1.08	1.02	1.08	1.01
Kachha[†]									1.00	1.00	1.00	1.00
Separate kitchen												
Yes									0.95	0.93	0.96	0.94
No[†]									1.00	1.00	1.00	1.00
Crowding												
<3 persons per room[†]									1.00	1.00	1.00	1.00
⩾3 persons per room									1.17**	1.11	1.18**	1.10***
Standard of living												
Low[†]									1.00	1.00	1.00	1.00
Medium									0.84**	0.80***	0.87	0.80***
High									0.65***	0.56***	0.65***	0.54***
Residence												
Urban									0.97	1.06	0.98	1.08
Rural[†]									1.00	1.00	1.00	1.00
Region												
North									1.73***	2.97***	1.70***	2.98***
Central and west									1.44***	2.14***	1.40***	2.08***
East and northeast									1.18*	1.80***	1.22*	1.78***
South[†]									1.00	1.00	1.00	1.00
Number of children		16 646		16 646		16 646		16 579		15 741		14 980

For variable definitions, see footnotes to Tables 1 and 2.
*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.
[†]Reference category.

aged 6–35 months. Effects are measured by relative risk ratios (RRRs) calculated from the fitted multinomial logistic regressions underlying each of the five models. 'Unadjusted' means that effects are estimated without controlling for other variables. Control variables are introduced by adding them to the set of predictor variables. In the unadjusted case (Model 1), biofuel smoke is the only predictor variable.

The unadjusted relative risk of moderate-to-severe anaemia (relative to no anaemia) is much greater among children in households using only biofuels than among children in households using only cleaner fuels (RRR = 2.18; 95% CI: 1.90, 2.52). The unadjusted relative risk of moderate-to-severe anaemia is also significantly greater among children in households using a mix of biofuels and cleaner fuels than among children in households using only cleaner fuels (RRR = 1.53; 95% CI: 1.31, 1.58). Progressively adding control variables in Models 2–5 reduces the RRRs, but even when all 20 control variables are included in Model 5, the relative risk of moderate-to-severe anaemia remains significantly higher among children living in households using only biofuels (RRR = 1.58; 95% CI: 1.28, 1.94) and among children living in households using a mix of biofuels and cleaner fuels (RRR = 1.36; 95% CI: 1.13, 1.63) than among children living in households using only cleaner fuels. These adjusted effects suggest that 31% of moderate-to-severe anaemia in children aged 6–35 months may be attributable to biofuel smoke exposure (27% in children in households using only biofuels and 8% in children in households using a mix of biofuels and cleaner fuels). The adjusted effects of biofuel smoke on mild anaemia are smaller but in the same direction.

With biofuel smoke controlled, exposure to tobacco smoke does not have a significant effect on the risk of anaemia in any

Table 5 Adjusted effects of biofuel smoke on the prevalence of anaemia and stunting in children aged 6–35 months by sex and by urban/rural residence, India 1998–99

	Anaemia							
	Boy		Girl		Urban		Rural	
Characteristics	Mild	Moderate/Severe	Mild	Moderate/Severe	Mild	Moderate/Severe	Mild	Moderate/Severe
Biofuel smoke								
Biomass fuels	1.11	1.51**	1.46*	1.65***	1.57*	1.66**	1.15	1.65**
Fuel mix	1.01	1.36**	1.30*	1.37*	1.13	1.27	1.07	1.41*
Cleaner fuel†	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Number of children		8701		7486		4460		11 727
	Stunting							
	Boy		Girl		Urban		Rural	
Characteristics	Moderate	Severe	Moderate	Severe	Moderate	Severe	Moderate	Severe
Biofuel smoke								
Biomass fuels	1.16	1.86***	1.35	1.84**	1.20	1.67**	1.28	2.36***
Fuel mix	1.07	1.21	1.09	1.22	1.13	1.13	1.07	1.55
Cleaner fuel†	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Number of children		8049		6931		4216		10 764

Adjusted effects are based on full models in Tables 3 and 4 run separately for boys and girls and for urban and rural areas. For variable definitions, see footnotes to Tables 1 and 2.

$^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$.

†Reference category.

of Models 2–5. The adjusted relative risk of anaemia is much greater among children of undernourished and anaemic mothers (Model 5). The adjusted relative risk of moderate-to-severe anaemia is about three times greater among children of mothers with moderate-to-severe anaemia than among children of mothers with no anaemia. Children of mothers with middle complete or higher education have a significantly lower relative risk of moderate-to-severe anaemia than children of illiterate mothers. The relative risk of anaemia is significantly higher among children who suffered from ARI in the preceding two weeks, but this may be due to reverse causation inasmuch as anaemic children are more likely to have suffered from ARI. Child's age, sex, birth order, urban residence, and region also have significant effects on the relative risk of moderate-to-severe anaemia.

Effects of biofuel smoke on stunting

The unadjusted relative risk of severe stunting is much higher among children in households using only biofuels than among children in households using only cleaner fuels (RRR = 5.12; 95% CI: 4.30, 6.11) (Table 4). The unadjusted relative risk of severe stunting is also significantly higher among children in households using a mix of biofuels and cleaner fuels than among children in households using only cleaner fuels (RRR = 1.96; 95% CI: 1.62, 2.38). Progressively adding controls in Models 2–5 reduces the RRRs, but even when all 20 control variables are included in Model 5, the relative risk of severe stunting is significantly higher among children living in households using only biofuels (RRR = 1.90; 95% CI: 1.49, 2.42) and among children living in households using a mix of biofuels and cleaner fuels (RRR = 1.26; 95% CI: 1.00, 1.58) than among children living in households using only cleaner fuels. Additionally controlling for child's anaemia status reduces these effects, but only slightly (Model 6). These adjusted effects suggest that 37% of severe stunting in children aged 6–35 months may be attributable to biofuel smoke exposure (35% in children in households using only biofuels and 5% in children in households using a mix of biofuels and cleaner fuels). The adjusted effects of biofuel smoke on moderate stunting are smaller but in the same direction.

With the effects of biofuel smoke and other factors controlled, exposure to tobacco smoke does not have any significant effect on the risks of moderate or severe stunting. The adjusted relative risk of severe stunting is much greater among older and higher-birth-order children (Model 6). The relative risks of moderate and severe stunting are significantly greater among children with moderate-to-severe anaemia than among non-anaemic children. Children born to mothers who received iron supplementation during pregnancy have a significantly lower relative risk of severe stunting than children of mothers who did not receive such supplementation. The relative risk of severe stunting is significantly higher among children who suffered from diarrhoea in the preceding two weeks than those who did not. Children of younger, less-educated, and anaemic mothers have a significantly higher relative risk of severe stunting than other children. Unexpectedly, mother's BMI does not have any significant adjusted effects on stunting in their children. On the other hand, children living in richer, less-crowded, non-Hindu/non-Muslim, upper-caste/class households and children in the southern region have significantly lower adjusted relative risks of severe stunting than other children.

The adjusted effects of biofuel use on anaemia and stunting were similar in magnitude and direction when the above analyses were repeated for boys and girls separately and for urban and rural areas separately (as shown in Table 5).

Discussion

Household use of unprocessed biofuels for cooking and heating exposes many women and young children in developing countries to high levels of toxic air pollutants indoors. Anaemia and stunting among young children are serious problems in India. About one in two children under three years of age suffer from moderate-to-severe anaemia and a similar proportion from moderate-to-severe stunting.

Our analysis shows that exposure to biofuel smoke is significantly associated with prevalence of anaemia and stunting in young children, independent of exposure to tobacco smoke, child's age, sex, recent episodes of illness, maternal education and nutritional status, household living standard, and other factors. Children in households using a mix of biofuels and cleaner fuels also have a significantly higher prevalence of anaemia and stunting than children in households using only cleaner fuels. The results hold when the analysis is done separately for boys and girls and separately for urban and rural areas. These results suggest that household use of biofuels for cooking and heating may contribute to the risks of anaemia and stunting in young children, independently of other factors. Given heavy reliance on biofuels in India and significantly higher risks of anaemia and stunting in children living in households using biofuels, our analysis indicates that 31% of moderate-to-severe anaemia and 37% of severe stunting among children aged 6–35 months may be attributable to biofuel smoke exposure.

With effects of biofuel smoke and other factors controlled, the effects of exposure to tobacco smoke on anaemia and stunting are small and not statistically significant. Moreover, tests for interaction between the effects of biofuel smoke and tobacco smoke indicated no modifying effects.

The analysis confirmed a strong positive relationship between mother's anaemia and child's anaemia. With other factors controlled, the relative risk of moderate-to-severe anaemia was about three times greater among children of mothers with moderate-to-severe anaemia than among children of mothers with no anaemia. The study also confirmed a strong positive association between anaemia and stunting in children.

Several measurement constraints should be kept in mind when considering the findings of this study. There is a possibility of some selection in the sample due to anaemia- and stunting-related mortality. To the extent that children living in poorer biofuel-using households are more likely to die from anaemia and stunting, our estimated effects of biofuel smoke may be downwardly biased. Given high prevalence of anaemia and stunting and a relatively small mortality, however, the impact of this bias on our estimated effects is likely to be small.

Our estimated effects are also likely to be underestimated to the extent that the effects of biofuel smoke on anaemia and stunting are cumulative and to the extent that some households shifted from biofuels to cleaner fuels in recent years. The survey did not collect any information on history of fuel use in the household or on past episodes of ARI and other biofuel-smoke-related illness that would allow us to assess the magnitude of this bias. Although the symptomatic definition of ARI used in the survey was intended to measure acute lower respiratory infections (ALRI) in children, considerable acute upper respiratory infections (AURI) are probably included in the reported prevalence and some ALRI was probably missed.[27]

Another limitation is our inability to control directly for extent of use of medical services. This limitation is mitigated, however, by controls for several socioeconomic characteristics that are correlated with access to and use of medical services. Although our analysis has included a wide range of possible confounding variables, there is always potential for some residual confounding.

Anaemia and stunting were measured adequately in the survey, but smoke exposure was ascertained indirectly from type of fuel used for cooking and heating. This imperfect measurement also tends to bias downward our estimates of the effects of biofuel smoke on anaemia and stunting. However, measurements in India and other developing countries show that the emission of pollutants from household stoves directly varies along the 'energy ladder', with unprocessed solid fuels producing substantially more pollution per meal cooked than liquid or gaseous fuels.[28] Fuel type has also been shown to be a good predictor of indoor pollution levels in households.[29]

Despite these various limitations, our study has value due to its large nationally representative sample of children with measured levels of blood haemoglobin and anthropometry. The consistency in the size and direction of our estimated effects suggests a causal relationship between biofuel smoke exposure and both anaemia and stunting. Similar effects observed separately in boys and girls and separately in urban and rural areas further strengthen this conclusion. Moreover, increasing size of estimated effects with extent of exposure to biofuel smoke (from the low exposure group using only cleaner fuels to the medium exposure group using a mix of cleaner fuels and biofuels to the high exposure group using only biofuels) suggests a possible dose–response relationship. To validate this relationship, our research needs to be followed by carefully designed epidemiological studies, with direct measures of smoke exposure and a careful assessment of past history of fuel use and subsequent morbidity. Such research is important in view of the high prevalence of anaemia and stunting and the high proportion of households in India, as well as other developing countries that rely on biofuels for cooking and heating.

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KEY MESSAGES

- Household use of unprocessed biofuels (wood, dung, crop residues) exposes many women and young children in developing countries to high levels of toxic air pollutants indoors.
- In India, two in three children under three years of age live in a household relying entirely on biofuels for cooking and heating, and about one in two children suffer from moderate-to-severe anaemia and a similar proportion suffer from moderate-to-severe stunting.
- Children in households using biofuels are much more likely to suffer from anaemia and stunting than those in households using cleaner fuels (electricity, liquid, or gaseous fuels). Thirty-one per cent of moderate-to-severe anaemia and 37% of severe stunting among children aged 6–35 months in India may be attributable to biofuel smoke.
- Exposure to smoke from biofuels may contribute to chronic nutritional deficiencies in young children.
- Governments in developing countries need to promote widespread use of cleaner fuels, provide improved cookstoves, and inform people about health risks of indoor smoke from biofuel combustion.

References

1 International Institute for Population Sciences (IIPS) and ORC Macro. National Family Health Survey (NFHS-2), 1998–99: India. Mumbai: International Institute for Population Sciences, 2000.

2 Pelletier DL. Malnutrition, morbidity and child mortality in developing countries. In: United Nations (eds). *Too Young to Die: Genes or Gender?* New York: Department of Economic and Social Affairs, Population Division, United Nations, 1998, pp. 109–32.

3 Rice AL, Sacco L, Hyder A *et al*. Malnutrition as an underlying cause of childhood deaths associated with infectious diseases in developing countries. *Bull World Health Organ* 2000;**78:**1207–21.

4 World Health Organization (WHO). World Health Report 2002: *Reducing Risks, Promoting Healthy Life*. Geneva: World Health Organization, 2002.

5 Seshadri S. Nutritional anaemia in South Asia. In: Gillespie S (ed.). *Malnutrition in South Asia: A Regional Profile*. Kathmandu: Regional Office for South Asia, UNICEF, 1997, pp. 109–32.

6 Stoltzfus RJ. Iron-deficiency anaemia: reexamining the nature and magnitude of the public health problem. Summary: implications for research and programs. *J Nutr* 2001;**131:**697S–701S.

7 World Health Organization (WHO). *Focusing on Anaemia: Towards an Integrated Approach for Effective Anaemia Control. Joint statement by the World Health Organization and the United Nations Children's Fund*. Geneva: World Health Organization, 2004.

8 Smith KR, Liu Y. Indoor air pollution in developing countries. In: Samet JM (ed.). *Epidemiology of Lung Cancer*, New York, NY: Marcel Dekker, Inc., 1994, pp. 154–63.

9 Bruce N, Perez-Padilla R, Albalak R. Indoor air pollution in developing countries: a major environmental and public health challenge. *Bull World Health Organ* 2000;**78:**1080–92.

10 Smith KR. Indoor air pollution in developing countries: recommendations for research. *Indoor Air* 2002;**12:**1–7.

11 World Health Organization (WHO). *Health and Environment for Sustainable Development: Five Years After the Earth Summit*. Geneva: World Health Organization, 1997.

12 Behera D, Dash S, Malik SK. Blood carboxyhaemoglobin levels following acute exposure to smoke of biomass fuel. *India J Med Res* 1988;**88:**522–42.

13 Albalak R, Frisancho AR, Keeler GJ. Domestic biomass fuel combustion and chronic bronchitis in two rural Bolivian villages. *Thorax* 1999;**54:**1004–8.

14 Smith KR, Samet JM, Romieu I *et al*. Indoor air pollution in developing countries and acute lower respiratory infections in children. *Thorax* 2000;**55:**518–32.

15 Balakrishnan K, Sambandam S, Ramaswamy P *et al*. Exposure assessment for respirable particulates associated with household fuel use in rural districts of Andhra Pradesh, India. *J Expo Anal Environ Epidemiol* 2004;**14:**S14–S25.

16 Patel TS, Raiyani CV. Indoor air quality: problems and perspectives. In: Shukla PR (ed.). *Energy Strategies and Green House Gas Mitigation*. New Delhi: Allied Publishers, 1995.

17 Smith KR, Mehta S, Maeusezahl-Feuz M. Indoor smoke from household solid fuels. In: Ezzati M, Lopez AD, Rodgers A, Murray CJL (eds). *Comparative Quantification of Health Risks: Global and Regional Burden of Diseases Attributable to Selected Major Risk Factors*, Vol. 2. Geneva: World Health Organization, 2004, pp. 1437–95.

18 Smith KR. National burden of disease in India from indoor air pollution. *Proc Natl Acad Sci USA* 2000;**97:**13286–93.

19 Dary O, Pineda O, Belizan JM. Carbon monoxide contamination in dwellings in poor rural areas of Guatemala. *Bull Environ Contam Toxicol* 1981;**26:**24–30.

20 Mishra V, Dai X, Smith KR *et al*. Maternal exposure to biomass smoke and reduced birth weight in Zimbabwe. *Ann Epidemiol* 2004;**14:**740–47.

21 Boy E, Bruce N, Delgado H. Birth weight and exposure to kitchen wood smoke during pregnancy in rural Guatemala. *Environ Health Perspect* 2002;**110:**109–14.

22 Mishra V. Indoor air pollution from biomass combustion and acute respiratory illness in preschool age children in Zimbabwe. *Int J Epidemiol* 2003;**32:**847–53.

23 Ezzati M, Kammen D. Indoor air pollution from biomass combustion and acute respiratory infections in Kenya: an exposure-response study. *Lancet* 2001; **358:**619–24. *Erratum in Lancet* 2001;**358:**1104.

24 Dibley MJ, Goldsby JB, Staehling NW *et al*. Development of normalized curves for the international growth reference: historical and technical considerations. *Am J Clin Nutr* 1987;**46:**736–48.

25 Dibley MJ, Staehling N, Neiburg P *et al*. Interpretation of z-score anthropometric indicators derived from the international growth reference. *Am J Clin Nutr* 1987;**46:**749–62.

[26] Stata Corporation. *Stata/SE 8.2 for Windows, Release 8.02*. College Station, TX: Stata Corporation, 2003.

[27] Mishra V, Smith KR, Retherford RD. Effects of cooking smoke and environmental tobacco smoke on acute respiratory infections in young indian children. *Pop Environ* 2005;**26:**375–96.

[28] Smith KR, Zhang J, Uma R *et al*. Greenhouse implications of household fuels: an analysis for India. *Annu Rev Energy Environ* 2000;**25:**741–63.

[29] Mehta S. *Characterizing exposures to indoor air pollution from household solid fuel use in India*. *PhD Dissertation,* Berkeley, CA: University of California, 2002.