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Robert D. Retherford

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

Vinod Mishra[1,2] and Robert D. Retherford[2]

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Institutional affiliations: [1]ORC Macro, Calverton, MD; [2]East-West Center, Honolulu, HI

Corresponding author: Vinod Mishra, Demographic and Health Research Division, ORC Macro,11785 Beltsville Drive, Suite 300, Calverton, MD 20705. Phone: 301-572-0220, Fax: 301-572-0999, Email: vinod.mishra@orcmacro.com

ABSTRACT

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 anemia and stunting in children.

Methods: Data are from a 1998–99 national family health survey in India, which measured height, weight, and blood hemoglobin 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 anemia and stunting, controlling for ETS, recent episodes of illness, maternal education and nutrition, and other potentially confounding factors.

Results: Analysis shows that prevalence of moderate-to-severe anemia 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). Effects on mild anemia and moderate stunting were smaller, but positive and statistically significant. Effects of ETS on anemia and stunting were small and not significant.

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

KEY WORDS: air pollution, anemia, biomass, child, indoor, smoke, stunting

ABBREVIATIONS:

ARI	Acute respirator infection
BMI	Body mass smoke
CI	Confidence interval
CO	Carbon monoxide
ETS	Environmental tobacco smoke
NFHS	National Family Health Survey
$PM_{2.5}$	Particulate matter less than 2.5 micrometers in diameter
PM_{10}	Particulate matter less than 10 micrometers in diameter
RRR	Relative risk ratio

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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 anemia 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 percent) suffered from moderate-to-severe levels of anemia, and a similar proportion (46 percent) 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 anemia is also a major problem because it can result in impaired cognitive performance, behavioral and motor 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-hour 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 4,000–21,000 $\mu g/m^3$ and 2–5-hour daily exposures of 3,600–6,800 $\mu g/m^3$ during cooking (14). A recent study using time-activity data from 412 rural homes in south India estimated a 24-hour 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 anemia and stunting, we are aware of no empirical studies on this topic.

The Indian survey measured height, weight, and blood hemoglobin 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 anemia and stunting in children.

The mechanisms by which biofuel smoke may contribute to anemia and stunting are only partially understood. Biofuel smoke contains large quantities of CO, which binds with hemoglobin (necessary for transporting oxygen to body tissues), forms carboxyhemoglobin, and reduces the quantity of hemoglobin in the blood, thereby causing anemia. Smoke exposure can also contribute to stunting by causing not only anemia but also reduced birth weight (19, 20), ARI (21, 22), and other childhood diseases.

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 percent of country's population. The sample is a multi-stage cluster sample with an overall response rate of 98 percent. 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 under 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 ±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 (s.d.) units below the median of an international reference population (23, 24). We use a three-category variable for stunting in the analysis: not stunted ($Z \geq -2$ s.d.), moderately stunted (-3 s.d.$\leq Z < -2$ s.d.), severely stunted ($Z < -3$ s.d.).

To assess the anemia status of children and their mothers, blood hemoglobin 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 hemoglobin concentration. The hemoglobin measurements were adjusted for altitude. Children were categorized as not anemic (≥11.0 g/dl), mildly anemic (10.0–10.9 g/dl), moderately anemic (7.0–9.9 g/dl), or severely anemic (<7.0 g/dl). Because the proportion of severely anemic children is small (5 percent) in the sample, we use a three-category response variable for anemia—no anemia, mild anemia, moderate/severe anemia.

Predictor variables

Exposure to biofuel smoke is ascertained indirectly by type of fuel used for cooking or heating. The survey 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?” 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 ten-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 ETS.

Because the effects of biofuel smoke, as well as ETS, on the prevalence of anemia 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, diarrhea 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, ≥25.0 kg/m2), anemia 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 anemia (none, mild, moderate/severe) and stunting (none, moderate, severe) among children from households using only biofuels and household using a mix of biofuels and cleaner fuels relative to children from households using only cleaner fuels, after controlling for ETS and other potentially confounding factors. We also included interaction terms between biofuel use and ETS to test if 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 ETS. In the final analysis, this interaction term was not included. Since blood hemoglobin levels and stunting in vary young children (below six months) are not likely to be associated with exposure to biofuel smoke, multivariate analyses were limited to children age 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 percent confidence intervals. 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 (25).

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 hemoglobin measurements. The hemoglobin test result was explained to the mother, and for anemic children, the mother was advised to seek medical treatment. For severely anemic children, consent for medical referral was obtained from the mother, and where mothers consented, a list of severely anemic children was provided to the local health provider for follow-up.

RESULTS

Characteristics of children

About two-thirds (64 percent) of the children live in households using only biofuels for cooking and heating, another 24 percent 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 percent) than in urban areas (17 percent). On the other hand, only two percent of rural households exclusively use cleaner fuels, compared with 47 percent of urban households. One in two children live in households where at least one adult smokes tobacco regularly. This proportion is greater in rural area than in urban areas. Children are distributed more or less evenly by age. Fifty-two percent are boys and 48 percent are girls. Thirty percent 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 percent) than mothers of urban children (76 percent). One in five children suffered from an acute respiratory infection in the two weeks preceding the survey, and a similar proportion suffered from diarrhea in the same period. Four percent 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 percent have undernourished mothers (BMI<18.5 kg/m^2), and 56 percent have anemic mothers (19 percent with moderate-to-severe anemia). Twenty-one percent belong to non-Hindu households and 31 percent belong to a scheduled-caste or scheduled-tribe household. Thirty-seven percent live in *kachha* (poor quality) houses, 55 percent live in houses without a separate kitchen, and another 55 percent live in crowded households with three or more persons per room. Forty-seven percent live in low-standard-of-living households and only 13 percent live in high-standard-of-living households. About four-fifths (78 percent) live in rural areas. By geographic region, 18 percent of the children are from the South, and the proportions in the other regions range from 26 percent to 29 percent.

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

Characteristic	Urban	Rural	Total
Biofuel smoke[*]			
Biomass fuels	17	78	64
Fuel mix	36	20	24
Cleaner fuel	47	2	12
Environmental tobacco smoke (ETS)[†]			
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[‡] in past 2 weeks			
Yes	16	21	20
No	84	79	80
Suffered from diarrhea 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

Continued…

Table 1-*Continued*			
Characteristic	Urban	Rural	Total
Mother's anemia status[§]			
None	51	42	44
Mild	34	38	37
Moderate/severe	15	20	19
Mother's education			
Illiterate	36	67	60
Literate, <middle complete	20	17	17
Middle complete or higher	44	16	22
Religion			
Hindu	71	81	79
Muslim	23	14	16
Other[#]	7	5	5
Caste/tribe[**]			
Scheduled caste/scheduled tribe	21	33	31
Other backward class	30	33	32
Other	49	34	37
House type[††]			
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[‡‡]			
Low	18	55	47
Medium	51	37	40
High	31	8	13
Residence			
Urban	100	0	22
Rural	0	100	78
Geographic region[§§]			
North	24	28	27
Central and West	37	26	29
East and Northeast	14	30	26
South	24	16	18
Number of children[##]	6,482	22,599	29,081

Continued…

Table 1-*Continued*

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

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

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

[§] Mild anemia: blood hemoglobin level 10.0-10.9 g/dl for pregnant women and 10.0-11.9 g/dl for nonpregnant women; moderate anemia: blood hemoglobin level 7.0-9.9 g/dl; and severe anemia: blood hemoglobin level <7.0 g/dl.

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

[**] 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.

[††] *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.

[‡‡] 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.

[§§] 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.

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

Prevalence of childhood anemia and stunting

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

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

	Anemia*		Stunting†	
Characteristic	Mild	Moderate/ severe	Moderate	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 diarrhea 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

Continued…

Table 2-*Continued*				
	Anemia*		Stunting†	
Characteristic	Mild	Moderate/ severe	Moderate	Severe
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 anemia 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, <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

Continued…

Table 2-*Continued*				
	Anemia[*]		Stunting†	
Characteristic	Mild	Moderate/ severe	Moderate	Severe
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	

[*] Childhood anemia is defined as a blood hemoglobin level of less than 11.0 g/dl. Mild anemia: blood hemoglobin level 10.0-10.9 g/dl; moderate anemia: blood hemoglobin level 7.0-9.9 g/dl; and severe anemia: blood hemoglobin level <7.0 g/dl.
[†] 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.
Note: For definitions of other variables, see footnotes to table 1.

Forty-six percent of the children are stunted—23 percent moderately stunted and 23 percent severely stunted. Prevalence of both moderate and severe stunting is much higher among children living in households using 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 anemic 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 anemia

Table 3 shows unadjusted and adjusted effects of biofuel smoke exposure on prevalence of anemia among children 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 anemia (relative to no anemia) is much greater among children in households using only biofuels than among children in households using only cleaner fuels (RRR=2.18; 95 percent confidence interval: 1.90, 2.52). The unadjusted relative risk of moderate-to-severe anemia 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 percent confidence interval: 1.31, 1.58). 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 moderate-to-severe anemia remains significantly higher among children living in households using only biofuels (RRR=1.58; 95 percent confidence interval: 1.28, 1.94) and among children living in households using a mix of biofuels and cleaner fuels (RRR=1.36; 95 percent confidence interval: 1.13, 1.63) than among children living in households using only cleaner fuels. The adjusted effects of biofuel smoke on mild anemia are smaller but in the same direction.

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

	Model 1		Model 2		Model 3		Model 4		Model 5	
Characteristic	Mild	Mod/ severe	Mild	Mod/ severe	Mild	Mod/ severe	Mild	Mod/ severe	Mild	Mod/ 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 diarrhea in past 2 weeks										
Yes							1.03	1.08	1.02	1.03
No†							1.00	1.00	1.00	1.00

Continued…

Table 3-*Continued*

Characteristic	Model 1 Mild	Model 1 Mod/ severe	Model 2 Mild	Model 2 Mod/ severe	Model 3 Mild	Model 3 Mod/ severe	Model 4 Mild	Model 4 Mod/ severe	Model 5 Mild	Model 5 Mod/ severe
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 anemia 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, <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
Caste/tribe										
Scheduled caste/scheduled tribe									1.00	1.14
Other backward class									0.91	0.91
Other†									1.00	1.00

Continued…

Table 3-*Continued*

	Model 1		Model 2		Model 3		Model 4		Model 5	
Characteristic	Mild	Mod / severe	Mild	Mod/ severe	Mild	Mod/ severe	Mild	Mod/ severe	Mild	Mod/ severe
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	

* p<.05, ** p<.01, *** p<.001
†Reference category
Note: For variable definitions, see footnotes to tables 1 and 2.

With biofuel smoke controlled, ETS does not have a significant effect on the risk of anemia in any of Models 2–5. The adjusted relative risk of anemia is much greater among children of undernourished and anemic mothers (Model 5). The adjusted relative risk of moderate-to-severe anemia is about three-times greater among children of mothers with moderate-to-severe anemia than among children of mothers with no anemia. Children of mothers with middle complete or higher education have a significantly lower relative risk of moderate-to-severe anemia than children of illiterate mothers. The relative risk of anemia is significantly higher among children who suffered from ARI in the preceding two weeks, but this may be due to reverse causation inasmuch as anemic 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 anemia.

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 percent confidence interval: 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 percent confidence interval: 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 percent confidence interval: 1.49, 2.42) and among children living in households using a mix of biofuels and cleaner fuels (RRR=1.26; 95 percent confidence interval: 1.00, 1.58) than among children living in households using only cleaner fuels. Additionally controlling for child's anemia status reduces these effects, but only slightly (Model 6). The adjusted effects of biofuel smoke on moderate stunting are smaller but in the same direction.

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

	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
Characteristic	Mod	Severe	Mod	Severe	Mod	Severe	Mod	Severe	Mod	Severe	Mod	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 anemia status												
No anemia†											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

Continued…

Table 4-*Continued*

Characteristic	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
	Mod	Severe	Mod	Severe	Mod	Severe	Mod	Severe	Mod	Severe	Mod	Severe
Suffered from diarrhea 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 anemia 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, <middle complete									0.80**	0.66***	0.81**	0.66***
Middle complete or higher									0.70***	0.48***	0.70***	0.50***
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

Continued…

Table 4-*Continued*

Characteristic	Model 1 Mod	Model 1 Severe	Model 2 Mod	Model 2 Severe	Model 3 Mod	Model 3 Severe	Model 4 Mod	Model 4 Severe	Model 5 Mod	Model 5 Severe	Model 6 Mod	Model 6 Severe
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	

* p<.05, ** p<.01, *** p<.001

[†]Reference category

Note: For variable definitions, see footnotes to tables 1 and 2.

With the effects of biofuel smoke and other factors controlled, ETS 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 anemia than among non-anemic 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 diarrhea in the preceding two weeks than those who did not. Children of younger, less-educated, and anemic 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 south region have significantly lower adjusted relative risks of severe stunting than other children.

The adjusted effects of biofuel use on anemia and stunting are 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).

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

	ANEMIA							
	Boy		Girl		Urban		Rural	
Characteristic	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	8,701		7,486		4,460		11,727	

	STUNTING							
	Boy		Girl		Urban		Rural	
Characteristic	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	8,049		6,931		4,216		10,764	

* p<.05, ** p<.01, *** p<.001

†Reference category

Note: 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.

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. Anemia 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 anemia and a similar proportion from moderately-to-severe stunting.

Our analysis shows that exposure to biofuel smoke is significantly associated with prevalence of anemia and stunting in young children, independent of ETS, 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 anemia and stunting than children in households using only cleaner fuels. These results suggest that household use of biofuels for cooking and heating may contribute to the risks of anemia and stunting in young children, independently of other factors.

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

The analysis confirmed a strong positive relationship between mother's anemia and child's anemia. With other factors controlled, the relative risk of moderate-to-severe anemia was about three times greater among children of mothers with moderate-to-severe anemia than among children of mothers with no anemia. The study also confirmed a strong positive association between anemia 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 anemia- and stunting-related mortality. To the extent that children living in poorer biofuel-using households are more likely to die from anemia and stunting, our estimated effects of biofuel smoke may be downwardly biased. Given high prevalence of anemia and stunting and a relatively small number of deaths in the sample, 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 anemia 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.

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.

Anemia 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 anemia 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 (26). Fuel type has also been shown to be a good predictor of indoor pollution levels in households (27).

Despite these various limitations, the consistency of both the size and direction of our estimated effects suggest a possible causal relationship between biofuel smoke and both anemia and stunting. 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 illness. Such research is important in view of the high prevalence of anemia 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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