Effect of Indoor Air Pollution from Biomass Combustion on Prevalence of Asthma in the Elderly

Vinod Mishra

East-West Center, Honolulu, Hawaii, USA

In this study I examined the effect of cooking smoke on the reported prevalence of asthma among elderly men and women (≥ 60 years old). The analysis is based on 38,595 elderly persons included in India's second National Family Health Survey conducted in 1998–1999. Effects of exposure to cooking smoke, ascertained by type of fuel used for cooking (biomass fuels, cleaner fuels, or a mix of biomass and cleaner fuels), on the reported prevalence of asthma were estimated using logistic regression. Because the effects of cooking smoke are likely to be confounded with effects of age, tobacco smoking, education, living standard, and other such factors, the analysis was carried out after statistically controlling for such factors. Results indicate that elderly men and women living in households using biomass fuels have a significantly higher prevalence of asthma than do those living in households using cleaner fuels [odds ratio (OR) = 1.59; 95% confidence interval (95% CI), 1.30–1.94], even after controlling for the effects of a number of potentially confounding factors. Active tobacco smoking was also associated with higher asthma prevalence in the elderly, but not environmental tobacco smoke. Availability of a separate kitchen in the house and a higher living standard of the household were associated with lower asthma prevalence. The adjusted effect of cooking smoke on asthma was greater among women (OR = 1.83; 95% CI, 1.32–2.53) than among men (OR = 1.46; 95% CI, 1.14–1.88). The findings have important program and policy implications for countries such as India, where large proportions of the population rely on polluting biomass fuels for cooking and space heating. More epidemiologic research with better measures of smoke exposure and clinical measures of asthma is needed to validate the findings. *Key words:* asthma, biomass fuels, cooking smoke, elderly, indoor air pollution, respiratory health, tobacco smoking. *Environ Health Perspect* 111:71–77 (2003). [Online 3 December 2002] doi:10.1289/ehp.5559 available via *http://dx.doi.org/*

Increasing prevalence of asthma in both developed and developing countries has been a major public health challenge for more than two decades (Anderson 1997; Platts-Mills and Woodfolk 1997; World Resources Institute 1998). Asthma is a chronic respiratory disease characterized by sudden attacks of labored breathing, chest tightness, and coughing. It is a complex multifactorial disease with both genetic and environmental components. A rapid increase in asthma in recent years cannot be ascribed to changes in genetic (heritable) factors; the focus of interventions for the increased prevalence of asthma, therefore, should be on environmental factors.

A number of studies have suggested that ambient air pollution can trigger asthma attacks (Bjorksten 1999; Koren and Utell 1997). Exposure to several specific air pollutants, such as respirable particulate matter [≤ 10 µm in aerodynamic diameter (PM_{10})], carbon monoxide (CO), ozone (O_3), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2), has been associated with increased asthma symptoms (Baldi et al. 1999; Bates 1995; Castellsague et al. 1995; de Diego Damia et al. 1999; Greer et al. 1993; Hajat et al. 1999; Koren 1995; Zhang et al. 1999). In indoor environments, home bioallergens such as dust mites, molds, cockroach parts, and animal dander (Dales et al. 1991; Lewis et al. 2002; Litonjua et al. 1997; Rosenstreich et al. 1997; Thorn et al. 2001; Togias et al. 1997; Weiss et al. 1993), and household cleaning agents, pesticides, and mosquito coil smoke (Azizi and Henry 1991; Azizi et al. 1995; Weiss et al. 1993) have been linked to increased risk of developing asthma. A number of lifestyle-related factors, such as outdoor activity and exercise, have also been associated with modifying asthma (Platts-Mills and Woodfolk 1997).

Numerous studies have suggested that exposure to tobacco smoke can increase the risk of developing asthma (Azizi and Henry 1991; Azizi et al. 1995; Flodin et al. 1995; Martinez et al. 1992; Strachan and Cook 1998; Thorn et al. 2001). According to one estimate, children have about twice the risk of developing asthma if one or both parents smoke (NHLBI 1995). Several studies have found that exposure to tobacco smoke can increase the frequency and severity of attacks in asthmatics (Althuis et al. 1999; Beeh et al. 2001; Eisner et al. 1998; Siroux et al. 2000), but some fail to link tobacco smoking to onset of asthma in adults (Ben-Noun 1999; Siroux et al. 2000; Vesterinen et al. 1988).

Much of the research on factors affecting asthma has been in urban areas of developed countries. In many homes in developing countries, however, a major source of exposure to indoor air pollutants is cooking smoke, when people rely on unprocessed biomass fuels such as wood, crop residues, and dung cakes for cooking and space heating. According to some estimates, more than half of the world's population still relies on unprocessed biomass fuels for cooking and heating (Bruce et al. 2000). In the developing countries of South Asia and sub-Saharan Africa, this proportion is as high as 80% or more (Holdren and Smith 2000). These fuels are typically burned indoors in simple household cookstoves, such as a pit, three pieces of brick, or a U-shaped construction made from mud, which burn these fuels inefficiently and are often not vented with flues or hoods to take the pollutants to the outside. Even when the cookstoves are vented to the outside, combustion of unprocessed solid fuels produces enough pollution to significantly affect local "neighborhood" pollution levels, with implications for total exposures (Smith 2002).

Under these conditions, high volumes of a number of health-damaging airborne pollutants, including PM_{10}, CO, NO_x, SO_x (more from coal), formaldehyde, and dozens of toxic polycyclic aromatic hydrocarbons (e.g., benzo[*a*]pyrene) and other organic matter, are generated indoors. Because cookstoves are usually used for several hours each day at times when people are present indoors, their exposure effectiveness is high; that is, the percentage of their emissions that reach people's breathing zones is much higher than for outdoor sources. The individual peak and mean exposures experienced in such settings are

Address correspondence to V. Mishra, Population and Health Studies, East-West Center, 1601 East-West Rd, Honolulu, HI 96848-1601 USA. Telephone: (808) 944-7452. Fax: (808) 944-7490. E-mail: mishra@hawaii.edu

I thank G. Yamashita for assistance in preparing data files, S. Dai for assistance with bibliographic search and preparation of tables, and R. Retherford, K. Smith, and three anonymous reviewers for comments on an earlier draft of the manuscript. A shorter version of this article was presented at the Indoor Air 2002 conference in Monterey, California, USA, 30 June–5 July 2002.

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

This research was supported by a grant from the Hewlett Foundation (2001-6265).

Received 26 February 2002; accepted 17 June 2002.

often much greater than the safe levels recommended by the World Health Organization (WHO 1997). Bruce et al. (2000) compared typical levels of CO, PM_{10}, and $PM_{2.5}$ in homes in developing countries that use biomass fuels, with the U.S. Environmental Protection Agency's standards for 24-hr average and concluded that indoor concentrations of these pollutants in homes that use biomass fuels usually exceed the guideline levels by several-fold. The poorest and most vulnerable populations in developing countries are most exposed to indoor air pollution from biomass combustion for cooking and heating. Exposure levels are usually much higher among women who tend to do most of the cooking (Behera et al. 1988) and among young children who are often held on their mother's back or lap during cooking times (Albalak 1997). The elderly and the disabled also tend to stay indoors and therefore have higher exposure levels.

High exposures to air pollutants in biomass smoke have been associated with a host of respiratory diseases, including acute respiratory infections (Armstrong and Campbell 1991; Collings et al. 1990; Smith et al. 2000), chronic bronchitis (Albalak et al. 1999; Bruce et al. 1998; Pandey 1984), and tuberculosis (Mishra et al. 1999; Perez-Padilla et al. 2001). But the evidence on the effect of cooking smoke on asthma is mixed (Bruce et al. 2000), even though it contains some of the same pollutants that are found in ambient air pollution or tobacco smoke, both of which have been associated with asthma. Anecdotal association of asthma with cooking smoke is common, but few epidemiologic studies seem to have been done (Smith 2002). Of the limited research that does exist on this subject, some studies have found a positive association between cooking smoke and asthma (Mohammed et al. 1995; Pistelly 1997; Thorn et al. 2001; Xu et al. 1996), whereas others found no relationship (Azizi et al. 1995; Maier et al. 1997; Noorhassim et al. 1995; Qureshi 1994) or found a protective effect (Volkmer et al. 1995; von Mutius et al. 1996).

The mechanisms by which cooking smoke might influence asthma are not well understood. Air pollutants commonly found in biomass smoke have been associated with compromised pulmonary immune defense mechanisms in both animals and humans (Chang et al. 1990; Fujii et al. 2001; Green et al. 1977; Hardin et al. 1992; Kong et al. 1994; Mukae et al. 2001; Schnizlein et al. 1982; Tan et al. 2000; Taszakowski and Dwornicki 1992; van Eeden et al. 2001; Wang and Hu 1992; Zelikoff 1994). It is plausible that exposure to cooking smoke can impair pulmonary defense mechanisms and increase the risk of developing asthma or increase the frequency and severity of attacks in asthmatic people.

In this article I examine the effect of cooking smoke on the prevalence of asthma among the elderly in a developing country—India—using data from a nationally representative sample.

Materials and Methods

Data. Data are from India's second National Family Health Survey (NFHS-2) conducted in 1998–1999. NFHS-2 collected demographic, socioeconomic, and health information from a nationally representative probability sample of 92,486 households. All states of India are represented in the sample, covering more than 99% of the country's population. The sample is a multistage cluster sample with an overall response rate of 98%. Details of sample design, including sampling frame and sample implementation, are provided in the basic survey report for all India (IIPS and ORC Macro 2000). The analysis here is based on 38,595 persons 60 or more years old living in the sample households.

Response variable. The survey asked several questions relating to the current health status of household members, including whether each member suffered from asthma. The question was (referring to the listing of persons in the household) "Does anyone listed suffer from asthma?" The household head or other knowledgeable adult in the household reported for each household member. The survey was conducted using an interviewer-administered questionnaire in the native language of the respondent using a local, commonly understood term for asthma. A total of 18 languages were used in the survey. No effort was made to clinically test for the disease.

It is important to recognize that reported asthma is not as accurate as clinical measures of asthma. Because the disease carries a stigma, reported prevalence of asthma may be underestimated because of intentional concealment or lack of knowledge, especially for children and young adults. For the elderly, however, there is not much stigma attached to the disease and it is not considered contagious like tuberculosis, so underreporting due to intentional concealment should not be a major problem. There is also a possibility of overreporting because some other disease conditions with similar symptoms, such as chronic bronchitis or chronic obstructive pulmonary disease, may be reported as asthma.

In India, where clinical data on asthma are mostly unavailable or very weak, this reported prevalence of asthma from a representative national sample provides a unique opportunity to examine the factors associated with asthma prevalence among the elderly. In our analysis, this reported prevalence of asthma is the response variable.

Predictor variables. Exposure to cooking smoke is ascertained indirectly by type of fuel used for cooking or heating. The survey used a 10-item 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 question, "What other types of fuel does your household commonly use for cooking or heating?" with the same 10-item classification of fuels. This second question was a multiple response question, meaning a respondent could choose more than one fuel. We used information from these questions to group households into three categories representing the extent of exposure to cooking smoke—high-exposure group (households using only biomass fuels: wood, crop residues, or dung cakes), low-exposure group (households using only cleaner fuels: kerosene, petroleum gas, biogas, or electricity), and medium-exposure group (a mix of biomass fuels and cleaner fuels or coal/coke/lignite/charcoal). This three-category classification of fuels is the principal predictor variable.

The survey also collected information on tobacco smoking (both current and lifetime) for each household member. For all persons in the sampled households, the NFHS-2 asked "Does anyone listed smoke?" For current nonsmokers, the survey asked "Has any (other) person listed ever smoked regularly?" The information from these two questions was used to ascertain exposure to tobacco smoke—active smoking (person currently smokes or has smoked regularly in the past), passive smoking (one or more other persons in the household smoke currently), no smoking (the person has never smoked regularly and no other person in the household smokes currently).

Because the effects of exposure to cooking smoke as well as tobacco smoke on the prevalence of asthma are likely to be confounded with the effects of other risk factors, it is necessary to statistically control, or adjust, for such factors. Control variables included in this study were age, sex, marital status, education, religion of household head, caste/tribe of household head, house type, availability of a separate kitchen in the house, crowding in the household, living standard of the household, urban/rural residence, and geographic region. For definition of variables, see Table 1.

Analysis. Because our response variable—prevalence of asthma—is dichotomous, we use logistic regression to estimate the effects of cooking smoke (from biomass fuel use relative to cleaner fuel use) and tobacco smoke (both active and passive) on asthma prevalence with the other 12 demographic and socioeconomic variables mentioned above as controls. Because of large sex differentials in the exposure to cooking smoke and tobacco smoke, the analysis is also carried out separately for men and women. Results are presented in the form of odds ratios (ORs) with 95% confidence intervals (95% CI). The estimation of confidence intervals takes into account design effects due to clustering at the level of the primary sampling unit. The logistic regression models were estimated using the STATA statistical software package (Stata Corporation 2001).

Before carrying out the multivariate models, we tested for the possibility of multicollinearity between the predictor variables. In the correlation matrix of predictor variables, all pairwise Pearson correlation coefficients are < 0.5, suggesting that multicollinearity is not a problem. In the survey, certain states and certain categories of households were oversampled. In all our analysis, weights are used to restore the representativeness of the sample (IIPS and ORC Macro 2000).

Results

Profile of the elderly. According to the NFHS-2, about 8% of India's population is ≥ 60 years old (IIPS and ORC Macro 2000). Table 1 shows the distribution of elderly people by selected background characteristics. Fifty-nine percent of the elderly live in households using biomass fuels (wood, dung cakes, or crop residues), 15% live in households using cleaner fuels (kerosene, liquid petroleum gas, biogas, or electricity), and the remaining 26% live in households that use a mix of biomass fuels and cleaner fuels or coal/coke/lignite or charcoal. Forty-seven percent of elderly men and 6% of elderly women currently smoke tobacco or have smoked regularly in the past. Another 10% of men and 36% of elderly women live in households where someone else smokes.

The proportion of elderly declines by age, as expected. Sixty-two percent are currently married (81% of men and 41% of women). About two-thirds are illiterate, and only 12% have middle school or higher education. The proportion illiterate is much higher for women than for men (82% and 50%, respectively), as expected. Distribution by religion and caste/tribe resembles that in the total population, with a little more than four out of five elderly belonging to Hindu religion and one out of four belonging to a scheduled caste or scheduled tribe. About one-third live in *pucca* (higher-quality) houses, about one-half live in houses without a separate kitchen, and more than one-third live in houses with three or more persons per room. Two of five live in households with a low standard of living, and one of five lives in a household with a high standard of living. Three of four live in rural areas, and one of two lives in the central and east region.

Prevalence of asthma among the elderly. Asthma is a serious problem among the elderly in India. According to the NFHS-2, one of every 10 people ≥ 60 years old suffers from asthma (IIPS and ORC Macro 2000). Table 2 shows that the prevalence of asthma is higher among elderly men than among elderly women and higher in rural areas than in urban areas. By type of cooking fuel, elderly living in households using biomass

Table 1. Variable definitions and distribution of elderly (≥ 60 years old) by selected characteristics, India, 1998–1999.

Characteristic	Male	Female	Total
Cooking smoke[a]			
Biomass fuels	59.6	57.6	58.7
Fuel mix	25.8	27.0	26.4
Cleaner fuel	14.6	15.4	14.9
Tobacco smoke			
Active smoking	46.8	6.0	27.4
Passive smoking	9.7	36.3	22.4
No smoking	43.5	57.7	50.2
Age			
60–64	35.7	38.9	37.2
65–69	24.5	25.7	25.0
70–74	21.0	17.7	19.4
≥ 75	18.8	17.7	18.3
Marital status			
Currently married	81.3	40.6	62.0
Not married	18.7	59.4	38.0
Education			
Illiterate	49.8	82.3	65.3
Literate, < middle completed	31.5	13.6	23.0
Middle completed or higher	18.7	4.0	11.7
Religion			
Hindu	82.5	82.7	82.6
Muslim	10.7	10.6	10.7
Other[b]	6.8	6.7	6.8
Caste/tribe[c]			
Scheduled caste/scheduled tribe	26.5	25.4	26.0
Other	73.5	74.6	74.0
House type[d]			
Pucca	31.6	33.3	32.4
Semi-*pucca*	36.2	35.7	36.0
Kachha	32.1	31.0	31.6
Separate kitchen			
Yes	55.0	55.7	55.3
No	45.0	44.3	44.7
Crowding			
< 3 persons per room	63.7	64.2	63.9
≥ 3 persons per room	36.3	35.8	36.1
Standard of living[e]			
Low	40.6	42.3	41.4
Medium	39.7	37.8	38.8
High	19.8	20.0	19.9
Residence			
Urban	23.3	25.2	24.2
Rural	76.7	74.9	75.8
Region[f]			
North and Northeast	4.1	3.6	3.9
Central and East	52.8	49.5	51.2
West	18.7	20.6	19.6
South	24.3	26.3	25.3
Number of elderly[g]	20,418	18,177	38,595

[a] Biomass fuels: wood, dung, or crop residues; fuel mix: mix of biomass and cleaner fuels or coal/coke/lignite; cleaner fuel: kerosene, petroleum gas, biogas, or electricity. [b]Sikh, Buddhist, Christian, Jain, Jewish, Zorastrian. [c]Castes and tribes identified by the Government of India as socially and economically backward and needing protection from social injustice and exploitation. [d]*Pucca* houses are made from high-quality materials (bricks, tiles, cement, and concrete) throughout, including roof, walls, and floor; *kachha* houses are made from mud, thatch, or other low-quality materials. Semi-*pucca* houses are made from a combination. [e]Standard of living index 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; 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, to 16–42 for high SLI. [f]North and northeast: Jammu, Kashmir, Himachal Pradesh, Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura; central and east: Haryana, Punjab, Delhi, Uttar Pradesh, Madhya Pradesh, Bihar, West Bengal, Orissa; west: Maharashtra, Goa, Gujarat, Rajasthan; south: Andhra Pradesh, Karnataka, Kerala, Tamil Nadu. [g]Number of elderly varies slightly for individual variables depending on the number of missing values.

fuels are about two times more likely to suffer from asthma (11.9%) than are those living in households using cleaner fuels (6.6%). Elderly who smoke (or have ever smoked regularly in the past) are also much more likely to suffer from asthma than are those who have never smoked. Elderly with middle school or more education are less likely to suffer from asthma than are those with less or no education. The prevalence of asthma is considerably lower among the elderly living in households with a separate kitchen and among elderly living in households with a high standard of living. The prevalence is also somewhat lower among elderly living in *pucca* houses and among those living in houses with fewer than three persons per room. The prevalence does not vary much by other characteristics. Differentials in the prevalence of asthma by sex are similar to those discussed above for both men and women combined.

Table 2. Reported prevalence of asthma among the elderly (≥ 60 years old) by selected characteristics, India, 1998–1999.

Characteristic	Male	Female	Total
Cooking smoke			
Biomass fuels	13.9	9.7	11.9
Fuel mix	10.1	7.9	9.0
Cleaner fuel	7.7	5.5	6.6
Tobacco smoke			
Active smoking	14.4	14.6	14.4
Passive smoking	12.2	8.5	9.4
No smoking	9.4	7.9	8.6
Age			
60–64	9.5	7.5	8.5
65–69	12.2	8.1	10.2
70–74	14.5	9.6	12.4
≥ 75	14.0	10.5	12.4
Marital status			
Currently married	11.8	8.1	10.6
Not married	13.3	8.9	10.0
Education			
Illiterate	13.7	8.8	10.8
Literate, < middle completed	12.1	8.0	10.9
Middle completed or higher	7.5	6.3	7.3
Religion			
Hindu	12.1	8.5	10.4
Muslim	13.2	9.5	11.4
Other	9.9	8.5	9.2
Caste/tribe			
Scheduled caste/tribe	13.0	9.1	11.2
Other	11.4	8.3	10.0
House type			
Pucca	9.9	7.8	8.9
Semi-*pucca*	12.8	8.4	10.8
Kachha	13.2	9.5	11.5
Separate kitchen			
Yes	10.4	7.6	9.1
No	14.0	9.8	12.0
Crowding			
< 3 persons per room	11.6	8.2	10.0
≥ 3 persons per room	12.8	9.1	11.1
Standard of living			
Low	14.2	10.2	12.2
Medium	12.2	7.8	10.1
High	7.4	6.5	7.0
Residence			
Urban	9.6	7.0	8.3
Rural	12.8	9.1	11.0
Region			
North and Northeast	10.3	8.4	9.5
Central and East	12.1	8.6	10.5
West	12.6	9.9	11.3
South	11.7	7.5	9.6
Number of elderly[a]	20,414	18,168	38,582

[a]Number of elderly varies slightly for individual variables depending on the number of missing values. For variable definitions, see Table 1.

Effects of cooking smoke on asthma. Table 3 shows the estimated effects of cooking smoke, tobacco smoke, and selected demographic and socioeconomic variables on the prevalence of asthma among the elderly (> 60 years old) in alternative models. Model 1 in Table 3 shows that unadjusted odds of suffering from asthma are almost two times higher among the elderly living in households using biomass fuels for cooking than among those living in households using cleaner fuels for cooking (OR = 1.92; 95% CI, 1.67–2.19). Elderly living in households using a mix of biomass fuels and cleaner fuels or coal/coke/lignite or charcoal are also at a considerably higher risk of suffering from asthma (OR = 1.40; 95% CI, 1.21–1.62). Controlling for exposure to tobacco smoke (in Model 3) reduces the effect of biomass fuel use on asthma prevalence slightly (OR = 1.75; 95% CI, 1.53–2.01). The effect of biomass fuel use remains virtually unchanged when the two demographic variables—age and sex—are additionally controlled in Model 4. Even when the 10 socioeconomic control variables are included in Model 5, cooking with biomass fuels still has a large and statistically significant effect (OR = 1.59; 95% CI, 1.30–1.94) on the prevalence of asthma among the elderly. In the full model (Model 5), the elderly living in households using a mix of biomass and cleaner fuels or coal/coke/lignite or charcoal also have a significantly higher risk of suffering from asthma compared with those living in households that use cleaner fuels (OR = 1.24; 95% CI, 1.04–1.49).

Effects of tobacco smoke on asthma. Elderly men and women who currently smoke tobacco or have ever smoked regularly in the past are at a considerably higher risk of suffering from asthma (OR = 1.79; 95% CI, 1.63–1.96) than do those who have never smoked and do not live in a household with other smokers (Model 2, Table 3). This effect is reduced somewhat when the effect of cooking smoke is controlled (OR = 1.66; 95% CI, 1.51–1.82) and reduced further when respondent's age and sex are additionally controlled (OR = 1.54; 95% CI, 1.39–1.71). In the full model (Model 5), when the effects of cooking fuel type and the 12 other variables are controlled, the odds of suffering from asthma are 1.55 (95% CI, 1.39–1.73) times higher among the elderly who are current smokers or have ever smoked regularly than among those who have never smoked tobacco regularly and do not live in a household with other smokers. Passive smoking does not seem to have any significant effect on the risk of asthma among the elderly. Elderly men and women who have never smoked tobacco regularly but who live in households where other household members smoke are about as likely to suffer from asthma as those who never smoked who live in households where no one else smokes (OR = 1.09; 95% CI, 0.97–1.22).

Effects of the control variables on asthma. The discussion of the adjusted effects of the control variables focuses on the full model (Model 5) in Table 3. With other variables controlled, age has a positive effect on the prevalence of asthma and women have a considerably lower prevalence of asthma than do men. Effects of both age and sex are statistically significant. Elderly men and women with middle school or higher education have significantly lower prevalence of asthma than do those with less or no education. As expected, elderly living in households with a separate kitchen have a significantly lower prevalence of asthma than do those living in households without a separate kitchen. Also as expected, household living standard has a significant negative effect on asthma prevalence among the elderly. However, contrary to the expectation, elderly living in higher-quality (*pucca*) housing have a significantly higher risk of asthma do than those living in *kachha* (lower-quality) houses. Crowding within the house also has a negative effect on the prevalence of asthma, but the effect of crowding is not significant statistically.

With other variables controlled, the prevalence of asthma among the elderly does not vary significantly by urban/rural residence. Marital status of the elderly at the time of the survey, religion, and membership in a scheduled caste or scheduled tribe also do not have significant effects on asthma prevalence in the elderly. By geographic region, elderly in the western region have significantly higher prevalence of asthma than do those in other regions.

Sex differences in effects. Because women tend to do the cooking and are much more exposed than are men to cooking smoke, because men are much more likely than are women to smoke tobacco, and because there are sex differences in nutritional status, susceptibility to disease, and access to treatment and care, the effects of cooking smoke on asthma are likely to vary by sex. To examine this, we repeated the above analysis separately for men and women. Only adjusted effects in full models are presented in Table 4.

The adjusted effect of exposure to cooking smoke (biomass fuel use relative to cleaner fuel use) on the prevalence of asthma is large and statistically significant for both elderly men and women. The adjusted effect is larger for women (OR = 1.83; 95% CI, 1.32–2.53) than for men (OR = 1.46; 95% CI, 1.14–1.88). Elderly women in households using a mix of biomass and cleaner fuels also have significantly higher asthma prevalence than do those in households using only cleaner fuels (OR = 1.48; 95% CI, 1.12–1.97), but this adjusted effect of fuel mix for elderly men is small and not significant statistically (OR = 1.12; 95% CI, 0.89–1.41). The adjusted effects of active tobacco smoking (ever smoked tobacco regularly) on asthma are also large and statistically significant for both men and women. Again, the effect is larger for women (OR = 1.89; 95% CI, 1.49–2.39) than for men (OR = 1.50; 95% CI, 1.33–1.69). Adjusted effects of passive smoking (others in the household smoke) are much smaller for both men and women and statistically not significant.

With the effects of cooking smoke, tobacco smoke, and other variables controlled, only age, household living standard, and geographic region have significant effects on asthma prevalence for both men and women. Availability of a separate kitchen has a significant negative effect on asthma prevalence in men, but this effect is relatively small and not statistically significant for women. Education has a significant negative effect for men, but for women the relationship is reversed and the effect is not statistically significant. Both elderly men and women in *pucca* houses have higher prevalence of asthma than do those living in *kachha* houses, but these effects are also not significant. Effects of all other control variables are small and not significant statistically.

Discussion

Results from this study suggest that exposure to cooking smoke is strongly associated with the prevalence of asthma among elderly men and women, independent of exposure to tobacco smoke, age, education, living standard, and other factors. Active tobacco smoking also has substantial effects, but passive smoking tends not to have any significant effect. Effects of both cooking smoke and tobacco smoke are greater for women than for men.

The finding that the effect of cooking smoke is greater for women than for men is consistent with expectation, because women are more exposed than men to cooking smoke. However, given the relatively low status of women in India, asthma may be less likely to be reported for women than for men, especially in households that use biomass fuels for cooking. For this reason, the sex differential in the effect of cooking smoke on asthma may be greater than indicated by our analysis. A larger effect of tobacco smoking in women than in men may reflect greater vulnerability of women because of their compromised respiratory system from cooking smoke, poorer nutritional status, and less access to treatment and care compared with men. A larger negative effect of availability of a separate kitchen for men than for women is consistent with expectation because availability of a separate kitchen in the household is more likely to reduce cooking smoke exposures in men than in women, who do much of the cooking.

To the extent that the effect of cooking smoke on asthma is cumulative over time, previous shifts from biomass fuels to cleaner fuels tend to downwardly bias our estimates of the effect. Our estimated effect is also downwardly biased to the extent that asthma is more likely to be underreported for persons from households that use biomass fuels. On the other hand, our estimated effect may be upwardly biased to the extent households that use biomass fuels are more likely to report some other disease condition with similar symptoms as asthma. To the extent that this happens, our results represent the association of biomass combustion with chronic respiratory

Table 3. Unadjusted and adjusted effects (OR, 95% CI) of cooking smoke, tobacco smoke, and other factors on asthma among the elderly (≥ 60 years old), India 1998–1999.

Characteristic	Model 1	Model 2	Model 3	Model 4	Model 5
Cooking smoke					
Biomass fuels	1.92 (1.67, 2.19)		1.75 (1.53, 2.01)	1.77 (1.54, 2.34)	1.59 (1.30, 1.94)
Fuel mix	1.40 (1.21, 1.62)		1.32 (1.14, 1.53)	1.32 (1.14, 1.53)	1.24 (1.04, 1.49)
Cleaner fuel[a]	—		—	—	—
Tobacco smoke					
Active smoking		1.79 (1.63, 1.96)	1.66 (1.51, 1.82)	1.54 (1.39, 1.71)	1.55 (1.39, 1.73)
Passive smoking		1.10 (0.99, 1.22)	1.03 (0.93, 1.15)	1.08 (0.97, 1.20)	1.09 (0.97, 1.22)
No smoking[a]		—	—	—	—
Age					
60–64[a]				—	—
65–69				1.25 (1.12, 1.38)	1.22 (1.10, 1.36)
70–74				1.53 (1.37, 1.71)	1.52 (1.35, 1.70)
≥ 75				1.54 (1.37, 1.73)	1.51 (1.33, 1.71)
Sex					
Male[a]				—	—
Female				0.83 (0.75, 0.91)	0.80 (0.71, 0.89)
Marital status					
Currently married					0.94 (0.85, 1.04)
Not married[a]					—
Education					
Illiterate[a]					—
Literate, < middle completed					1.03 (0.92, 1.16)
Middle completed or higher					0.83 (0.70, 0.98)
Religion					
Hindu[a]					—
Muslim					0.97 (0.82, 1.15)
Other					1.02 (0.84, 1.22)
Caste/tribe					
Scheduled caste/scheduled tribe					0.96 (0.87, 1.63)
Other[a]					—
House type					
Pucca					1.17 (1.03, 1.34)
Semi-*pucca*					1.03 (0.93, 1.15)
Kachha[a]					—
Separate kitchen					
Yes					0.83 (0.75, 0.92)
No[a]					—
Crowding					
< 3 persons per room[a]					—
≥ 3 persons per room					0.93 (0.85, 1.03)
Standard of living					
Low[a]					—
Medium					0.89 (0.80, 0.98)
High					0.75 (0.63, 0.88)
Residence					
Urban					1.05 (0.91, 1.20)
Rural[a]					—
Region					
North and Northeast					0.99 (0.83, 1.19)
Central and East					1.04 (0.92, 1.19)
West					1.37 (1.18, 1.59)
South[a]					—
Number of elderly	38,389	38,549	38,297	38,297	36,520

For variable definitions, see Table 1.
[a]Reference category.

disorders in elderly Indians, including asthma. In cases where asthma might have been confused with some other chronic respiratory disorder, it is not possible from our data to separate the effect on asthma from the effect on some other condition with similar symptoms. Moreover, we are not able to control directly for extent of use of medical services in connection with asthma, although our set of control variables includes several measures of socioeconomic status, which is correlated with access to and use of medical services. Well-designed epidemiologic studies with better measures of smoke exposure and clinical measures of asthma are needed to validate the findings of this study and to better understand the pathogenesis of asthma.

The findings from this study have important policy and program implications, including the need for public information campaigns designed to inform people about the risks of exposure to cooking smoke and, where shifts to cleaner fuels are not feasible, programs to promote improved cookstoves designed to reduce exposure to smoke by means of improved combustion and improved venting. For such programs to be effective, local needs and community participation should be given high priority. Programs to reduce exposure to tobacco smoke should be promoted, in addition to strengthening asthma prevention and treatment programs.

Table 4. Adjusted effects (OR, 95% CI) of cooking smoke, tobacco smoke, and other factors on asthma among the elderly (≥ 60 years old) by sex, India, 1998–1999.

Characteristic	Male	Female
Cooking smoke		
Biomass fuels	1.46 (1.14, 1.88)	1.83 (1.32, 2.53)
Fuel mix	1.12 (0.89, 1.41)	1.48 (1.12, 1.97)
Cleaner fuel[a]	—	—
Tobacco smoke		
Active smoking	1.50 (1.33, 1.69)	1.89 (1.49, 2.39)
Passive smoking	1.20 (0.99, 1.46)	1.05 (0.91, 1.21)
No smoking[a]	—	—
Age		
60–64[a]	—	—
65–69	1.35 (1.17, 1.57)	1.06 (0.90, 1.26)
70–74	1.68 (1.44, 1.93)	1.32 (1.09, 1.60)
≥ 75	1.57 (1.34, 1.85)	1.42 (1.18, 1.71)
Marital status		
Currently married	0.90 (0.78, 1.03)	0.97 (0.84, 1.12)
Not married[a]	—	—
Education		
Illiterate[a]	—	—
Literate, < middle completed	0.99 (0.87, 1.12)	1.17 (0.92, 1.45)
Middle completed or higher	0.77 (0.64, 0.93)	1.18 (0.78, 1.77)
Religion		
Hindu[a]	—	—
Muslim	0.94 (0.76, 1.15)	1.03 (0.80, 1.32)
Other	0.97 (0.77, 1.20)	1.05 (0.81, 1.38)
Caste/tribe		
Scheduled caste/scheduled tribe	0.96 (0.84, 1.09)	0.96 (0.82, 1.12)
Other[a]	—	—
House type		
Pucca	1.16 (0.97, 1.38)	1.20 (0.99, 1.46)
Semi-*pucca*	1.05 (0.92, 1.20)	1.02 (0.86, 1.21)
Kachha[a]	—	—
Separate kitchen		
Yes	0.81 (0.72, 0.93)	0.86 (0.75, 1.00)
No[a]	—	—
Crowding		
< 3 persons per room[a]	—	—
≥ 3 persons per room	0.91 (0.81, 1.02)	0.97 (0.83, 1.12)
Standard of living		
Low[a]	—	—
Medium	0.95 (0.84, 1.08)	0.79 (0.67, 0.92)
High	0.72 (0.58, 0.89)	0.76 (0.59, 0.98)
Residence		
Urban	1.09 (0.91, 1.30)	1.00 (0.80, 1.23)
Rural[a]	—	—
Region		
North and Northeast	0.86 (0.69, 1.09)	1.19 (0.91, 1.54)
Central and East	0.98 (0.83, 1.15)	1.14 (0.95, 1.37)
West	1.25 (1.04, 1.50)	1.56 (1.26, 1.92)
South[a]	—	—
Number of elderly	19,329	17,191

For variable definitions see Table 1.
[a]Reference category.

References

Albalak R. 1997. Cultural Practices and Exposure to Particulate Pollution from Indoor Biomass Cooking: Effects on Respiratory Health and Nutritional Status among the Aymara Indians of the Bolivian Highlands [PhD Thesis]. Ann Arbor, MI: University of Michigan.

Albalak R, Frisancho AR, Keeler GJ. 1999. Domestic biomass fuel combustion and chronic bronchitis in two rural Bolivian villages. Thorax 54:1004–1008.

Althuis MD, Sexton M, Prybylski D. 1999. Cigarette smoking and asthma symptom severity among adult asthmatics. J Asthma 36:257–264.

Anderson HR. 1997. Air pollution and trends in asthma. Ciba Found Symp 206:190–202, 203–207.

Armstrong JR, Campbell H. 1991. Indoor air pollution exposure and lower respiratory infections in young Gambian children. Int J Epidemiol 20:424–429.

Azizi BH, Henry RL. 1991. The effects of indoor environmental factors on respiratory illness in primary school children in Kuala Lumpur. Int J Epidemiol 20:144–150.

Azizi BH, Zulkifli HI, Kasim S. 1995. Indoor air pollution and asthma in hospitalized children in a tropical environment. J Asthma 32:413–418.

Baldi I, Tessier JF, Kauffmann F, Jacqmin-Gadda H, Nejjari C, Salamon R. 1999. Prevalence of asthma and mean levels of air pollution: results from the French PAARC survey. Eur Respir J 14:132–138.

Bates DV. 1995. Observations on asthma. Environ Health Perspect 103(suppl 6):243–247.

Beeh KM, Micke P, Ksoll M, Buhl R. 2001. Cigarette smoking, but not sensitization to *Alternaria*, is associated with severe asthma in urban patients. J Asthma 38:41–49.

Behera D, Dash S, Malik SK. 1988. Blood carboxyhaemoglobin levels following acute exposure to smoke of biomass fuel. India J Med Res 88:522–542.

Ben-Noun L. 1999. Is there a relationship between smoking and asthma in adults? J Int Med Res 27:15–21.

Bjorksten B. 1999. The environmental influence on childhood asthma. Allergy 54:17–23.

Bruce N, Neufeld L, Boy E, West C. 1998. Indoor biofuel air pollution and respiratory health: the role of confounding factors among women in highland Guatemala. Int J Epidemiol 27:454–458.

Bruce N, Perez-Padilla R, Albalak R. 2000. Indoor air pollution in developing countries: a major environmental and public health challenge. Bull WHO 78:1080–1092.

Castellsague J, Sunyer J, Saez M, Anto JM. 1995. Short-term association between air pollution and emergency room visits for asthma in Barcelona. Thorax 50:1051–1056.

Chang JC, Distler SG, Kaplan AM. 1990. Tobacco smoke suppresses T cells but not antigen-presenting cells in the lung-associated lymph nodes. Toxicol Appl Pharmacol 102:514–523.

Collings DA, Sithole SD, Martin KS. 1990. Indoor woodsmoke pollution causing lower respiratory disease in children. Trop Doct 20:151–155.

Dales RE, Burnett R, Zwanenburg H. 1991. Adverse health effects among adults exposed to home dampness and molds. Am Rev Respir Dis 143:505–509.

de Diego Damia A, Leon Fabregas M, Perpina Tordera M, Compte Torrero L. 1999. Effects of air pollution and weather conditions on asthma exacerbation. Respiration 66:52–58.

Eisner MD, Yelin EH, Henke J, Shiboski SC, Blanc PD. 1998. Environmental tobacco smoke and adult asthma. The impact of changing exposure status on health outcomes. Am J Respir Crit Care Med 158:170–175.

Flodin U, Jonsson P, Ziegler J, Axelson O. 1995. An epidemiologic study of bronchial asthma and smoking. Epidemiology 6:503–505.

Fujii T, Hayashi S, Hogg JC, Vincent R, Van Eeden SF. 2001. Particulate matter induces cytokine expression in human bronchial epithelial cells. Am J Respir Cell Mol Biol 25:265–271.

Green GM, Jakab GJ, Low RB, Davis GS. 1977. Defense mechanisms of the respiratory membrane. Am Rev Respir Dis 115:479–514.

Greer JR, Abbey DE, Burchette RJ. 1993. Asthma related to occupational and ambient air pollutants in nonsmokers. J Occup Med 35:909–915.

Hajat S, Haines A, Goubet SA, Atkinson RW, Anderson HR. 1999. Association of air pollution with daily GP consultations for asthma and other lower respiratory conditions in London. Thorax 54:597–605.

Hardin JA, Hinoshita F, Sherr DH. 1992. Mechanisms by which benzo[*a*]pyrene, an environmental carcinogen, suppresses B cell lymphopoiesis. Toxicol Appl Pharmacol 117:155–164.

Holdren JP, Smith KR. 2000. Energy, the environment, and health. In: The World Energy Assessment: Energy and the Challenge of Sustainability (Goldemberg J, ed). New York: United National Development Programme, 61–110.

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

Kong LY, Luster MI, Dixon D, O'Grady J, Rosenthal GJ. 1994. Inhibition of lung immunity after intratracheal instillation of benzo(*a*)pyrene. Am J Respir Crit Care Med 150:1123–1129.

Koren HS. 1995. Associations between criteria air pollutants and asthma. Environ Health Perspect 103(suppl 6):235–242.

Koren HS, Utell MJ. 1997. Asthma and the environment. Environ Health Perspect 105:534–537.

Lewis SA, Weiss ST, Platts-Mills TA, Burge H, Gold DR. 2002. The role of indoor allergen sensitization and exposure in causing morbidity in women with asthma. Am J Respir Crit Care Med 165:961–966.

Litonjua AA, Sparrow D, Weiss ST, O'Connor GT, Long AA, Ohman JL Jr. 1997. Sensitization to cat allergen is associated with asthma in older men and predicts new-onset airway hyperresponsiveness: The Normative Aging Study. Am J Respir Crit Care Med 156:23–27.

Maier WC, Arrighi HM, Morray B, Llewellyn C, Redding GJ. 1997. Indoor risk factors for asthma wheezing among Seattle school children. Environ Health Perspect 105:208–214.

Martinez FD, Cline M, Burrows B. 1992. Increased incidence of asthma in children of smoking mothers. Pediatrics 89:21–26.

Mishra VK, Retherford RD, Smith KR. 1999. Biomass cooking fuels and prevalence of tuberculosis in India. Int J Infect Dis 3:119–129.

Mohammed N, Ng'ang'a L, Odhiambo J, Nyamwaya J, Menzies R. 1995. Home environment and asthma in Kenyan school children: a case-control study. Thorax 50:74–78.

Mukae H, Vincent R, Quinlan K, English D, Hards J, Hogg JC, et al. 2001. The effect of repeated exposure to particulate air pollution (PM_{10}) on the bone marrow. Am J Respir Crit Care Med 163:201–209.

NHLBI. 1995. Global Initiative for Asthma: Global Srategy for Asthma Management and Prevention [workshop report]. Bethesda, MD:National Health Heart, Lung, and Blood Institute.

Noorhassim I, Rampal KG, Hashim JH. 1995. The relationship between prevalence of asthma and environmental factors in rural households. Med J Malaysia 50:263–267.

Pandey MR. 1984. Domestic smoke pollution and chronic bronchitis in a rural community of the hill region of Nepal. Thorax 39:337–339.

Perez-Padilla R, Perez-Guzman C, Baez-Saldana R, Torres-Cruz A. 2001. Cooking with biomass stoves and tuberculosis: a case-control study. Int J Tuberc Lung Dis 5:1–7.

Pistelly R. 1997. Wood smoke and asthma: a controversial issue. Am J Respir Crit Care Med 155:A941.

Platts-Mills TAE, Woodfolk J. 1997. Rise in asthma cases. Science 278:1001.

Qureshi K. 1994. Domestic smoke pollution and prevalence of chronic bronchitis/asthma in a rural area of Kashmir. Indian J Chest Dis Allied Sci 36:61–72.

Rosenstreich DL, Eggleston P, Kattan M, Baker D, Slavin RG, Gergen P, et al. 1997. The role of cockroach allergy and exposure to cockroach allergen in causing morbidity among inner-city children with asthma. N Engl J Med 336: 1356–1363.

Schnizlein CT, Bice DE, Mitchell CE, Hahn FF. 1982. Effects on rat lung immunity by acute lung exposure to benzo(*a*)pyrene. Arch Environ Health 37:201–206.

Siroux V, Pin I, Oryszczyn MP, Le Moual N, Kauffmann F. 2000. Relationships of active smoking to asthma and asthma severity in the EGEA study. Epidemiological Study on the Genetics and Environment of Asthma. Eur Respir J 15:470–477.

Smith KR. 2002. Indoor air pollution in developing countries: recommendations for research. Int J Indoor Environ Health 12:1–7.

Smith KR, Samet JM, Romieu I, Bruce N. 2000. Indoor air pollution in developing countries and acute lower respiratory infections in children. Thorax 55:518–532.

Stata Corporation. 2001. Stata Reference Manual. Release 7. College Station, TX: Stata Press.

Strachan DP, Cook DG. 1998. Parental smoking and childhood asthma: longitudinal and case-control studies. Thorax 53:204–212.

Tan WC, Qiu D, Liam BL, Ng TP, Lee SH, van Eeden SF, et al. 2000. The human bone marrow response to acute air pollution caused by forest fires. Am J Respir Crit Care Med 161:1213–1217.

Taszakowski W, Dwornicki J. 1992. Effect of environmental factors on the defense system of the respiratory tract [Abstract in English]. Pol Tyg Lek 47:763–765.

Thorn J, Brisman J, Toren K. 2001. Adult-onset asthma is associated with self-reported mold or environmental tobacco smoke exposures in the home. Allergy 56:287–292.

Togias A, Horowitz E, Joyner D, Guydon L, Malveaux F. 1997. Evaluating the factors that relate to asthma severity in adolescents. Int Arch Allergy Immunol 113:87–95.

van Eeden SF, Tan WC, Suwa T, Mukae H, Terashima T, Fujii T, et al. 2001. Cytokines involved in the systemic inflammatory response induced by exposure to particulate matter air pollutants (PM_{10}). Am J Respir Crit Care Med 164:826–830.

Vesterinen E, Kaprio J, Koskenvuo M. 1988. Prospective study of asthma in relation to smoking habits among 14,729 adults. Thorax 43:534–539.

Volkmer RE, Ruffin RE, Wigg NR, Davies N. 1995. The prevalence of respiratory symptoms in South Australian preschool children. II. Factors associated with indoor air quality. J Paediatr Child Health 31:116–120.

von Mutius E, Illi S, Nicolai T, Martinez FD. 1996. Relation of indoor heating with asthma, allergic sensitization, and bronchial responsiveness: survey of children in south Bavaria. Br Med J 312:1448–1450.

Wang J, Hu SM. 1992. The effects of kitchen air pollution on animals immune function [Abstract in English]. Chung Hua Yu Fang I Hsueh Tsa Chih 26:86–88.

Weiss KB, Gergen PJ, Wagener DK. 1993. Breathing better or wheezing worse? The changing epidemiology of asthma morbidity and mortality. Annu Rev Public Health 14:493–494.

WHO. 1997. Health and Environment for Sustainable Development: Five Years after the Earth Summit. Geneva: World Health Organization.

World Resources Institute. 1998. World Resources 1998–99: A Guide to the Global Environment. Oxford: Oxford University Press.

Xu X, Niu T, Christiani DC, Weiss ST, Chen C, Zhou Y, et al. 1996. Occupational and environmental risk factors for asthma in rural communities in China. Int J Occup Environ Health 2:172–176.

Zelikoff JT. 1994. Woodsmoke emissions: effects on host pulmonary immune defense. CIAR Curr November, 1–3.

Zhang J, Qian Z, Kong L, Zhou L, Yan L, Chapman RS. 1999. Effects of air pollution on respiratory health of adults in three Chinese cities. Arch Environ Health 54:373–381.