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What Do We Know About Health Effects of Smoke from Solid Fuel Combustion?

Vinod Mishra

Vinod Mishra is a Fellow in Population and Health Studies at the East-West Center in Honolulu.

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Address correspondence to: Dr. Vinod Mishra, Population and Health Studies, East-West Center, 1601 East-West Road, Honolulu, HI 96848-1601, USA; Tel: (1-808) 944-7452; Fax: (1-808) 944-7490; Email: MishraV@EastWestCenter.org.

***Title*: What do we know about health effects of smoke from solid fuel combustion?**

Author: Vinod Mishra, PhD, MPH

Address for correspondence:

Vinod Mishra
Population and Health Studies
East-West Center
1601 East-West Road
Honolulu, HI 96848–1601
USA
Phone: 808–944–7452
Fax: 808–944–7490
Email: MishraV@EastWestCenter.Org

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ABSTRACT

Household use of unprocessed solid fuels (wood, dung, crop residues/grasses, and coal) for cooking and heating exposes large proportions of people in developing countries to high levels of toxic air pollutants indoors. Indoor smoke contains some of the same pollutants found in tobacco smoke and in ambient air, which have been linked with serious health consequences. There is growing evidence that exposure to indoor smoke can cause serious respiratory and other adverse health effects, but the quantity and quality of scientific literature vary considerably by type of health outcome. There is compelling evidence linking indoor smoke to acute respiratory infections in children and chronic obstructive pulmonary disease (COPD) or chronic bronchitis in women. But, the evidence linking indoor smoke to asthma, tuberculosis, lung cancer, and adverse pregnancy outcomes is limited and sometimes conflicting; and evidence linking indoor smoke to cataract and blindness, otitis media, lung fibrosis, and cardiovascular disease is weak or nonexistent. Many of the studies use indirect measures of smoke exposure and reported measures of health outcomes, do not adequately account for confounding and interactions, and few address gender aspects of smoke exposure and its health effects. Differences in gender roles result in differential exposures to indoor smoke among males and females; and gender differences in nutritional status, treatment, and care result in differential effects of these exposures. Moreover, there are biological and genetic differences between males and females that mediate the effects of smoke exposure on health. There is need to improve both the quality and quantity of research in this area, using better study designs, direct measures of smoke exposure, and clinical measures of health outcomes. To reduce exposures to indoor smoke, there is need to promote widespread use of cleaner fuels, provide improved cookstoves, and inform people about potential health risks, especially to women and young children.

Key words: indoor air pollution, smoke, biomass, gender, health, developing countries

INTRODUCTION

Indoor air pollution from combustion of solid fuels for cooking and space heating has been identified as one of the ten most important risk factors in global burden of disease (measured as disability adjusted life years [DALY]). It accounts for an estimated 2.7 percent of the global disease burden and some 1.6 million premature deaths annually. In poor developing countries, indoor smoke from solid fuels ranks fourth, behind only under-nutrition, unsafe sex, and unsafe water/sanitation/hygiene, accounting for an estimated 3.7 percent of the disease burden. In comparison, the much-publicized ambient air pollution accounts for less than one percent of the global disease burden (WHO, 2002). Despite its large health effects, indoor air pollution from household use of unprocessed biomass (wood, animal dung, crop residues, and grasses) and coal has not received much attention.

According to some estimates, more than half of the world's population rely on unprocessed solid 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 percent or more (Holdren & 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 respirable particulate matter (PM_{10} and $PM_{2.5}$)[1], carbon monoxide (CO), nitrogen oxides (NOx), sulfur oxides (SOx) (more from coal), formaldehyde, benzene, 1,3 butadiene, polycyclic aromatic hydrocarbons (such as benzo[a]pyrene), and many other toxic organic compounds, are generated indoors (Smith, 1987). Even endocrine-disrupting compounds have been identified in biomass smoke (Wu, Wang, Zhao & You, 2002). Since cookstoves are usually used for several hours each day at times when people are present indoors, their exposure effectiveness tends to be high, i.e., the percentage of their emissions that reach people's breathing zones tends to be much higher than for outdoor sources. The individual peak and mean exposures experienced in such settings are often much greater than the safe levels recommended by the World Health Organization (WHO, 1997a). Bruce et al., (2000) compare typical levels of CO, PM_{10}, and $PM_{2.5}$ in developing-country homes using biomass fuels with the United States Environmental Protection Agency's (USEPA) standards for 24-hour average and conclude that indoor concentrations of these pollutants in biomass-fuel-using developing-country homes usually exceed the USEPA guideline levels by several times. The poorest and most vulnerable populations in developing countries are most exposed to indoor air pollution from combustion of solid fuels for cooking and heating. Exposure levels are usually much higher among women who tend to do most of the cooking and spend more time indoors than men (Behera, Dash, & Malik, 1988; Parikh, Smith, & Laxmi, 1999), and among young children who are often carried on their mother's back or lap while

[1] PM_{10} and $PM_{2.5}$ refer to particulate matter with an aerodynamic diameter of ≤10 micrometer (μm) and ≤2.5 μm, respectively.

cooking (Albalak, 1997). The elderly and the disabled also tend to stay indoors and therefore have higher exposure levels.

This paper reviews current understanding of health effects of indoor air pollution from combustion of solid fuels for cooking and heating, and discusses gender aspects of these effects.

HOW CAN SMOKE FROM SOLID FUELS CAUSE ILL HEALTH?

The mechanisms by which smoke from solid fuel combustion causes ill health are only partially understood. Studies have shown that exposure to biomass smoke is associated with compromised pulmonary immune defense mechanisms in both animals and humans (Zelikoff, 1994; Thomas & Zelikoff, 1999; Wang & Hu, 1992; Green, Jakab, Low, & Davis, 1977; Taszakowski & Dwornicki, 1992). Moreover, smoke from tobacco, which is also biomass, has been shown to cause depressed immune system responses (Johnson, Houchens, Kluwe, Craig, & Fisher, 1990; Chang, Distler, & Kaplan, 1990; Sopori, Cherian, Chilukuri, & Shopp, 1989; Hersey, Prendergast, & Edwards, 1983; Jacob, Stelzer, & Wallace, 1980). Of the specific pollutants in smoke from burning solid fuels, exposure to respirable particulate matter has been shown to induce a systemic inflammatory response involving stimulation of the bone marrow, which can contribute to cardiorespiratory morbidity (Tan, Qiu, Liam, Ng, Lee, van Eeden, et al., 2000; Mukae, Vincent, Quinlan, English, Hards, Hogg, et al., 2001; van Eeden, Tan, Suwa, Mukae, Terashima, Fujii, et al., 2001; Fujii, Hayashi, Hogg, Vincent, & van Eeden, 2001). Other evidence indicates that exposure to polycyclic aromatic hydrocarbons—especially benzo[a]pyrene, which is found in large quantities in biomass smoke—can cause immune suppression and can increase the risk of infection and disease (Kong, Luster, Dixon, O'Grady, & Rosenthal, 1994; Hardin, Hinoshita, & Sherr, 1992; Schnizlein, Bice, Mitchell, & Hahn, 1982). Benzo[a]pyrene, a known carcinogen, also can increase the risk of lung and other types of cancers.

Acute exposures to oxides of nitrogen and sulfur, commonly found in biomass and coal smoke, have been associated with increased bronchial reactivity and susceptibility to bacterial and viral infections (Samet & Utell, 1990; Samet & Spengler, 1991). Carbon monoxide in smoke combines with hemoglobin to form carboxyhemoglobin, which reduces the oxygen-carrying capacity of the blood and can contribute to anemia and adverse pregnancy outcomes, including miscarriage, stillbirth, low birth weight, and early infant mortality (Windham, Eaton, & Hopkins, 1999a; Ritz & Yu, 1999; Boy, Bruce, & Delgado, 2002). Moreover, extended exposure to biomass smoke has been shown to cause oxidative damage to the eye lens and can cause cataract (Taylor, Jacques, & Epstein, 1995; Shalini, Luthra, Srinivas, Rao, Basti, Reddy, et al., 1994; Rao, Qin, Robison, & Zigler, 1995). Also, both tobacco smoke and ambient air pollution have been linked with lung cancer, hypertension, and heart disease. Smoke from household use of solid fuels for cooking and heating, which has some of the same pollutants, is likely to have similar effects.

HEALTH EFFECTS OF SMOKE FROM SOLID FUEL COMBUSTION

There is a growing body of evidence that exposure to smoke from burning biomass fuels and coal is linked to ill health and a number of specific diseases that are widespread in many developing countries. Both the exposure to smoke and health effects of such exposure depend on not only social, behavioral, and environmental factors, but also on genetic and other biological factors. Exposure to indoor smoke from cooking and heating has been linked to a host of respiratory diseases, including acute respiratory infections, chronic bronchitis, asthma, and tuberculosis. It has also been linked to lung cancer, adverse pregnancy outcomes, cataract, and blindness. Moreover, there is reason to expect an association with heart disease. In the following, the paper reviews current status of our understanding of these effects, with special emphasis on sex differentials in the effects.

Acute respiratory infections in children

ARI is a disease category that includes severe respiratory infections from a range of viruses and bacteria with similar symptoms and risk factors. ARI is a leading cause of childhood illness and death worldwide, accounting for an estimated 6.5 percent of the global burden of disease. More than three million children under age five die from ARI every year, mostly in developing countries.

More than two-dozen studies have examined the effects of cooking smoke on ARI in children. Several of them show that young children living in homes that burn biomass fuels have two to three times the risk of developing serious respiratory infections than children who are not exposed. Most studies conducted among preschool age children have observed a positive association between exposure to biomass smoke and ARI (Mishra, 2003a; Ezzati & Kammen, 2001; Robin, Less, Winget, Steinhoff, Moulton, Santosham, et al., 1996; Armstrong & Campbell, 1991; Collings, Sithole, & Martin, 1990; Pandey, Boleji, Smith, & Wafula, 1989; Kossove, 1982), but others have failed to find a relationship (Aldous, Holberg, Wright, Martinez, & Taussig, 1996; Samet, Lambert, Skipper, Cushing, Hunt, & Young, 1993). Some studies of school-age children also failed to find a relationship between biomass smoke and ARI (Azizi & Henry, 1991; Tuthill, 1984; Anderson, 1978).

Most studies of cooking smoke and ARI in children do not examine the effects separately for boys and girls. A study of children under age 3 in India, based on a national household survey, noted that both the prevalence of ARI and the effect of cooking smoke on ARI were greater among boys than among girls (Mishra & Retherford, 1997). The authors concluded this in part to the fact that, due to strong preference for sons and discrimination against daughters, mothers in India are more likely to carry young boys than girls or keep them in the kitchen area while cooking. The finding from the Indian study on gender differential in the effect of cooking smoke on ARI is opposite to the finding from a Gambian study, which found a significant association between cooking smoke and ARI in girls, but not in boys (Armstrong & Campbell, 1991). However, given that in the Gambian case girls were more likely to be carried on their mothers' back and in India boys were more likely to be carried or kept around kitchen area, the results from the two studies are not necessarily inconsistent.

Environmental tobacco smoke (ETS) is a known risk factor for middle ear infections (Strachan & cook, 1998a). There is some evidence, mostly from developed countries, of an association between cooking smoke and middle ear infection (otitis media) in children, which often results from upper respiratory infections (Daigler, Markello, & Cummings, 1991). Wood burning stoves and open fires in developed countries have been associated with otitis media (Daigler et al., 1991).

A comprehensive review of studies on indoor air pollution and acute respiratory infections in children can be found in Smith, Samet, Romieu, & Bruce (2000).

Chronic obstructive pulmonary disease

Tobacco smoking is a known risk factor for chronic bronchitis, emphysema, and chronic obstructive pulmonary disease. Yet, high levels of chronic lung disease are reported among non-smoking women in many developing countries, implicating indoor air pollution from cooking with solid fuels. There is strong evidence from laboratory studies that wood smoke exposure causes broncho-constriction, emphysema, bronchiolitis, and lung fibrosis (Hsu, Lai, & Kou, 1998; Lal, Dutta, Vachhrajani, Gupta, & Srivastava, 1993). A number of studies have reported an association between biomass smoke and chronic bronchitis and chronic obstructive pulmonary disease (Albalak, Keeler, Frisancho, & Haber, 1999; Bruce, Neufeld, Boy, & West, 1998; Perez-Padilla, Regalado, Vedal, Pare, Chapela, Sansores, et al., 1996; Dennis, Maldonado, Norman, Baena, & Martinez, 1996; Sandoval, Salas, Martinez-Guerra, Gomez, Martinez, Portales, et al., 1993; Dhar & Pathania, 1991; Behera & Jindal, 1991; Pandey, Basnyat, & Neupane, 1988; Malik, 1985; Pandey, 1984; Padmavati & Arora, 1976). In studies in South Asia, the prevalence of chronic bronchitis was found to be similar in men and women (Pandey, 1984; Padmavati & Arora, 1976), or higher among women than among men (Norboo, Yahya, Bruce, Heady, & Ball, 1991; Qureshi, 1994), despite the fact that women are much less likely to smoke tobacco than men in this region. Moreover, chronic bronchitis tends to start at a younger age for women than for men, again implicating cooking smoke.

Asthma

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. Asthma has been on the rise in many parts of the world (WRI, 1998; Platts-Mills & Woodfolk, 1997). A rapid increase in the prevalence of asthma in recent years cannot be ascribed to changes in genetic (heritable) factors; the focus, therefore, should be on environmental factors.

A number of studies have suggested that ambient air pollution can trigger asthma attacks (Bjorksten, 1999; Koren & Utell, 1997). Exposure to several specific air pollutants, such as PM_{10}, CO, ozone (O_3), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2), all of which except O_3 are commonly found in cooking smoke, have been associated with increased asthma symptoms (Baldi, Tessier, Kauffmann, Jacqmin-Gadda, Nejjari, & Salamon, 1999; Bates, 1995; Castellsague, Sunyer, Saez, & Anto, 1995; de Deigo, Leon, Perpina, & Compte, 1999; Greer, Abbey, & Burchette, 1993; Hajat, Haines, Goubet, Atkinson, & Anderson, 1999; Koren, 1995; Zhang, Qian, Kong, Zhou, Yan, & Chapman, 1999). Also, numerous studies have suggested that exposure to tobacco smoke (both active and passive) can increase the risk of developing asthma (Azizi & Henry, 1991; Azizi, Zulkifli, & Kasim, 1995; Flodin, Jonsson, Ziegler, & Axelson, 1995; Martinez, Cline, & Burrows, 1992; Strachan & Cook, 1998b; Thorn, Brisman, & Toren, 2001). According to one estimate, children have about twice the risk of developing asthma if one or both parents smoke (NHLBI, 1995). Several studies find that exposure to tobacco smoke can increase the frequency and severity of attacks in asthmatics (Althuis, Sexton, & Prybylski, 1999; Beeh, Micke, Ksoll, & Buhl, 2001; Eisner, Yelin, Henke, Shiboski, & Blanc, 1998; Siroux, Pin, Oryszczyn, Le Moual, & Kauffmann, 2000), but some fail to link tobacco smoking to onset of asthma in adults (Ben-Noun, 1999; Siroux et al., 2000; Vesterinen, Kaprio, & Koskenvuo, 1988).

The evidence on the effect of smoke from solid fuels on asthma is mixed (Bruce, Perez-Padilla, & Albalak, 2000), even though it has some of the same pollutants that are found in ambient air pollution or tobacco smoke, both of which have been associated with the disease. Anecdotal association of asthma with cooking smoke is common, but few epidemiological studies seem to have been done (Smith, 2002). Of the limited research that does exist on this subject, some studies find a positive association between cooking smoke and asthma (Mishra, 2003b; Thorn et al., 2001; Mohammed, Ng'ang'a, Odhiambo, Nyamwaya, & Menzies, 1995; Pistelly, 1997; Xu, Niu, Christiani, Weiss, Chen, Zhou, et al., 1996), while others fail to find any relationship (Maier, Arrighi, Morray, Llewellyn, & Redding, 1997; Azizi et al., 1995; Noorhassim, Rampal, &

Hashim, 1995; Qureshi, 1994) or find a protective effect (von Mutius, Illi, Nicolai, & Martinez, 1996; Volkmer, Ruffin, Wigg, & Davies, 1995).

A recent study of self-reported asthma among elderly in India observed a strong association between cooking smoke from biomass fuel use and asthma. The study also found a strong effect of active smoking on asthma, but not passive smoking. Consistent with the expectation, the effect of cooking smoke on asthma was considerably greater among women than among men (Mishra, 2003b).

Tuberculosis

Tuberculosis, which kills about 2 million people each year worldwide, is resurgent. Tuberculosis is an airborne contagious disease that is transmitted by coughing, sneezing, or even talking. Once a person becomes infected, any condition that weakens the immune system can trigger the development of active tuberculosis. Exposure to cooking smoke can increase the risk of tuberculosis by reducing resistance to initial infection or by promoting the development of active tuberculosis in already-infected persons. As indicated earlier, extended exposure to the pollutants contained in biomass smoke can weaken the immune system, impair the lungs, and make them more susceptible to infection and disease. Cooking smoke also tends to increase coughing, which contributes to the spread of tuberculosis infection.

Empirical research linking cooking smoke and tuberculosis is very limited. A study of more than 200,000 Indian adults observed that people living in households that use biomass fuels for cooking are 2.6 time more likely to suffer from active tuberculosis than those living in households using cleaner cooking fuels, after statistically adjusting for age, education, household crowding, and a number of other potentially confounding factors (Mishra, Retherford, & Smith, 1999b). The effect of biomass fuel use on tuberculosis was considerably greater for women than for men, as expected. However, despite higher exposure to cooking smoke among women, the prevalence of tuberculosis was much higher among men, most likely because men are much more likely than women to come in contact with people who suffer from active tuberculosis and because men in India smoke more than women. Another study, designed to test the India finding, found a similar effect of biomass fuel use on active tuberculosis from a hospital based case-control study in Mexico (Perez-Padilla, Perez-Guzman, Baez-Saldana, & Torres-Cruz, 2001).

Cataract and blindness

Blindness is another important public health problem in many developing countries. Long-term exposure to cooking smoke probably contributes to impaired vision and blindness mainly through oxidative damage to the eye lens and severe eye irritation, leading to cataract and other disorders. Worldwide, the most important direct cause of complete blindness is cataract, a progressive condition in which the lens of the eye becomes increasingly opaque. In India, for example, cataract accounts for more than 80 percent of complete blindness. Another direct cause of blindness, conjunctivitis, may also be aggravated by long-term exposure to cooking smoke. Trachoma, which also can cause blindness, can be contracted when irritation from exposure to smoke causes people to rub their eyes frequently.

Anecdotal association between eye problems and cooking smoke is common, but epidemiological studies of this association are very limited. There exist a few laboratory studies that have linked cataract to wood smoke (Shalini et al., 1994; Rao et al., 1995). A case-control study of patients at a New Delhi ophthalmic clinic showed that, after controlling for several physiological, behavioral, environmental, and biochemical factors, use of wood and dung for cooking was significantly associated with cortical, nuclear, and mixed types of cataract (Mohan, Sperduto, Angra, Milton, Mathur, & Underwood, 1989). Another recent study based on data from a large national household survey in India found that women cooking with biomass fuels were considerably more likely to suffer from both partial and complete blindness than those cooking with cleaner fuels (Mishra, Retherford, & Smith, 1999c).

Adverse pregnancy outcomes

Smoke from combustion of solid fuels in simple, poorly vented cookstoves produces large volumes of carbon monoxide, which binds to hemoglobin and forms carboxyhemoglobin. This reduces oxygen carrying capacity of blood to body tissues. A developing fetus, deprived of adequate oxygen, suffers intrauterine growth retardation and subsequent reduced birth weight. Particulate matter and other pollutants in biomass smoke may also increase the risk of adverse pregnancy outcome by reducing mother's lung function and increasing the risk of maternal lung disease, and in turn reducing oxygen delivery to the fetus (Boy et al., 2002).

A number of studies have linked exposure to both active and passive tobacco smoke to fetal growth and adverse pregnancy outcomes, including reduced birth weight (Windham, Hopkins, Fenster, & Swan, 2000; Windham et al., 1999a; Windham, Von Behren, Waller, & Fenster, 1999b; Walsh, 1994; Windham, Swan, & Fenster, 1992; Mathai, Vijayasri, Babu, & Yeyaseelan, 1992; Rubin, Krasilnikoff, Leventhal, Weile, & Berget, 1986; Martin & Bracken 1986). In recent years, an increasing number of studies have found an association between maternal exposure to ambient air pollution and fetal growth and various adverse pregnancy outcomes at levels of pollution substantially lower than found in solid fuel-burning homes (Ritz, Yu, Fruin, Chapa, Shaw, & Harris, 2002; Ritz & Yu 1999; Ha, Hong, Lee, Woo, Schwartz, & Christiani, 2001; Maisonet, Bush, Correa, & Jaakkola, 2001; Wang, Ding, Ryan, & Xu, 1997; Bobak & Leon, 1999; Bobak, 2000; Rogers, Thompson, Addy, Mckeown, Cowen, & Decoufle, 2000; Chen, Yang, Jennison, Goodrich, & Omaye, 2002; Maroziene & Grazuleviciene, 2002; Xu, Kjellstorm, Xu, Lin, & Daqlan, 1995; Sram, Binkova, Rossner, Rubes, Topinka, & Dejmek, 1999; Pereira, Loomis, Conceicão, Braga, Arcas, Kishi, et al., 1998; Woodruff, Grillo, & Schoendorf, 1997; Loomis, Castillejos, Gold, Mcdonnell, & Borja-Aburto, 1999; Lipfert, Zhang, & Wyzga, 2000; Perera, Jedrychowshi, Rauh, & Whyatt, 1999).

Despite strong and growing evidence from tobacco smoke and ambient air pollution, little is known about the effects of cooking smoke exposure on pregnancy outcomes. A recent study of newborn children in rural Guatemala reported that babies born to mothers using wood fuels were 63 gm lighter, on average, than those born to mothers using gas or electricity (Boy et al., 2002). Another study based data from a recent national household survey in Zimbabwe observed that babies born to mothers using biomass fuels (wood, dung, or straw) were 133 gm lighter, on average, than those born to mothers using electricity or biogas/LPG, after controlling for a number of potential confounders (Mishra, Dai, Smith, & Mika, [unpublished manuscript]). There is only one study to date to have reported an association between cooking with biomass fuels during pregnancy and stillbirths (Mavlankar, Trivedi, & Gray, 1991).

Cancer

Tobacco smoke is known to be the single largest risk factor for lung cancer in developed countries. Biomass smoke contains several mutagenic and carcinogenic compounds, such as polycyclic aromatic hydrocarbons, formaldehyde, and other organic matter, yet there is little epidemiological evidence connecting biomass smoke to lung cancer (Smith 2002). However, a large majority of women with lung cancer in several developing countries are found to be non-smokers (Gao, 1996; Medina, 1996; Gupta, 1998), suggesting that cooking smoke might play a role. There is also some evidence to implicate biomass smoke in oral, nasopharyngeal and laryngeal cancers (Pintos, Franco, Kowalski, Oliveira, & Curado, 1998; Franco, Kowalski, Oloveira, Curado, Pereira, Silva, et al., 1989; Clifford, 1972), although the evidence is not conclusive (Yu, Ho, Henderson, & Armstrong, 1985).

There is more consistent evidence linking smoke from household use of coal to lung cancer. Several studies in China have reported an association between household use of open coal stoves for cooking and lung cancer among non-smoking women (Mumford, 1995; Xu et al., 1995).

GENDER DIFFERENCES IN SMOKE EXPOSURE AND HEALTH EFFECTS

Gender differentials in exposure to indoor smoke and health impacts of such exposure are influenced not only by social and behavioral factors, but also biological and environmental factors. This section reviews how some these factors affect gender roles and activity patterns of males and females that determine their exposure levels and health impacts.

Women are the primary collectors and users of biomass fuels, fodder, water, and other natural resources for household consumption in most poor, rural homes in developing countries. Due to their roles in these subsistence activities and closer proximity to the environment, women bear a disproportionate burden of deteriorating environmental conditions, including deforestation and loss of common property resources (Cecelski, 1995; United Nations, 1995; Agarwal, 1986, 1995). In many poor countries in South Asia and Africa women and girls spend several hours each day fetching fuelwood or animal dung for cooking and space heating (United Nations, 1995; WEC, 1999). Because biofuels are very inefficient source of energy, women need to collect large quantities of these fuels and need to carry them long distances. Women’s role as primary collectors, carriers, and users of biofuels also has implications for their school attendance, childcare, and health.

Women usually work more hours than men in most countries, and unpaid household work dominates women's time. In South Asia, women work anywhere from about 7 to 21 hours per week more than men. Cooking accounts for a large share of women's household work, and compared with men, women contribute 75 percent or more to cooking activities in most countries. According to a study in 21 countries (mostly developed), the average time women spend cooking declined from about 90 minutes per day in 1961 to about 60 minutes per day in 1992. During the same period, the average time that men spend cooking increased slightly from about 15 minutes per day to about 20 minutes per day, indicating that the gender gap in time spent on cooking may be narrowing somewhat (United Nations, 1995).

A recent Time Use Survey in six Indian states found that women spend about 15 hours per week cooking food, compared to only about 30 minutes per week by men (GOI, 2000). In a study in the Himalayan foothills in India, men spent little time in the kitchen area and considerably more time outdoors and away from the village than women. Consequently, women had much higher levels of exposure to total suspended particulate matter (TSP) and CO than men (Saksena, Prasad, Pal, & Joshi, 1992). Another study of exposure to particulates from cooking with biomass fuels in two Bolivian highland villages also recorded that men spend relatively less time in the kitchen area, but there was little difference in the time spent indoors or outdoors by gender. Although, women recorded higher levels of daily exposure to particulate matter (PM_{10}) in each village and in each season, the differences between men and women were not large (Albalak et al., 1999).

Sources of exposure to air pollutants depend on gender roles. As mentioned earlier, because women do much of the cooking and spend more time indoors than men, they tend to have much higher levels of exposure to air pollutants, and for longer periods of time. However, men may also have substantial exposures to smoke from solid fuel combustion from other sources, such as brick-making, charcoal-making, and sugar-making activities in rural areas, sitting around open fires and household heating during the winter, as well as indoor cooking. Also, because men spend more time outdoors and at work places, they tend to be more exposed to ambient air pollution, secondary tobacco smoke, and employment-related air pollutants than women. Men are also more likely to come in contact with people infected with diseases. It is, however, also important to recognize that women are not a homogeneous group and there are considerable class-gender differences in both gender roles and their implications. Moreover, much of women's work goes beyond the household sector and involves agriculture, manufacturing, and services (Cecelski, 1995, 2000; Agarwal, 1995; Parikh, 1995, 1996). Therefore, women are exposed not only to a disproportionate share of indoor air pollution but also other employment-related pollutants.

Young children are often carried by mothers or kept in the kitchen area during cooking, exposing them to high levels of smoke (Collings et al., 1990; Albalak, 1997). In some parts of the world (for example, in Gambia), young girls are more likely to be carried or kept on mother's back or lap during cooking than young boys (Armstrong & Campbell, 1991), but in other areas where son preference is strong (for example, in South Asia), boys may be more likely than girls to be carried or kept in the kitchen area where mothers are cooking. In countries with strong discrimination against females, such discriminatory practices may actually benefit girls and result in greater smoke exposure to boys.

In many developing countries where sons are preferred over daughters and where the status of women is lower, health problems are less likely to be reported for women and girls. This may lead to an impression that the problem is less serious among women than it actually is. This differential under reporting for women is more likely to occur among less educated women and among women living in households using high pollution solid fuels. Not only the health problems in women and girls are less likely to be reported but also reported later when their problems reach more acute status. And, when sick, women and girls are less likely to receive proper medical attention, which may aggravate their condition and lead to more permanent damage or higher mortality. Such discrimination against women and girls is likely to be greater among high-pollution solid-fuel-using households than among cleaner-fuel-using households.

Effects of cooking smoke interact with gender roles and other sources of air pollution, prevalence of various diseases in the population, and overall health and nutritional status of the population. For instance, women in rural areas of South Africa have been found to suffer from a form of silicosis, named "Hut Lung", apparently caused by the interaction of cookfire smoke and the dust generated by daily grinding of maize (Grobbelaar & Batsman, 1991). Altitude is another factor that is known to increase the effect of CO exposures, found in large quantities in biomass smoke.

Men generally smoke more than women (WHO, 1997b). Tobacco smoking may aggravate the effects of cooking smoke and vice versa. However, effects of cooking smoke are confounded by the effects of tobacco smoke only to the extent that use of solid fuels is correlated with tobacco smoking. Even though women smoke much less than men, they are found to have lower lung functions than men in many parts of the world (Byerley, Weitz, & Richards, 1992). The most obvious reason for this is believed to be the differential exposure to cooksmoke (Smith, 1996).

Climatic conditions such as altitude, frequency and magnitude of rainfall, wind patterns, and temperature all play a role in determining how much time people spend cooking, what kinds of fuels people use, how much time is spent indoors, whether people cook indoors or outdoors, how much ventilation is needed in the house, how much space heating is required, what kinds of building material are used, and what kinds of occupations men and women engage in. It is also important to know men's and women's activity patterns and cooking habits within households. For example, do women spend all their time in the kitchen area during cooking or go in and out of the area to check on food?

Biological and genetic differences between males and females also play important role in determining health impacts of indoor smoke exposure. There is evidence to suggest that in early years of life biological and genetic factors are favorable to female children than male children in relation to most infectious diseases (Waldron, 1998; Tabutin & Willems, 1998). To the extent that this occurs, effects of cooking smoke exposure may be greater in boys than in girls. Also, there is evidence that men's and women's bodies respond differently to different pollutants. For example, CO is a pollutant of particular concern to women. CO binds to hemoglobin and forms carboxyhemoglobin, which reduces oxygen carrying capacity of blood to body tissues and can result in adverse pregnancy outcomes (Boy et al., 2002; Smith, 1996). Women generally have less hemoglobin in reserve than men and they naturally produce more CO internally during pregnancy (Linderholm & Lundstrom, 1969; Longo, 1977). So, women not only have higher levels of exposure to CO from indoor smoke, but also likely to have greater negative impact of such exposure than men.

Effects of indoor smoke are also likely to be stronger among females than among males because females in poor developing-country homes tend to be more malnourished than males. However, since there is little six-disaggregated analysis of effects of indoor air pollution on health and much of this research does not account for nutritional status, it is not clear if poor nutritional status necessarily leads to greater health impacts of smoke exposure. In the case of childhood malnutrition, the general assumption and evidence that young girls are discriminated against boys in quality, quantity, and timeliness in feeding, in schooling, in clothing, and in treatment and care when sick is not reflected in the empirical evidence on gender differentials in nutritional status of boys and girls (Marcoux, 2002; Mishra, Lahiri, & Luther, 1999a; Sommerfelt & Arnold, 1998). It is possible that such discrimination against girls is not across the board, and depends on family size and sex composition of previous living children (Mishra, Roy, & Retherford, [unpublished manuscript]; Muhuri & Preston, 1991; Das Gupta, 1987).

There are few studies that address these various gender aspects of health effects of indoor air pollution. Few differentiate exposure to indoor air pollution by sex and still fewer that examine the effects in two sexes separately. Even though most studies focus on women and their young children, gender issues are mentioned only peripherally. Most studies start with the assumption that women have higher exposures and greater health impacts than men. Men are generally not included in the study of indoor air pollution. Indoor air pollution studies on children often include both boys and girls, but do not study the exposures and effects separately. Moreover, exposure is usually measured using proxy variables such as type of cooking fuel used in the household, which does not allow sex-disaggregation of exposure data.

Cumulative exposures over extended periods, as they occur in the case of women cooking with solid fuels several hours per day over many years, are likely to cause greater health damage. Knowledge of the history of fuel switching and current mix of fuel use are important in determining the extent of such cumulative exposures. But, little is known about these cumulative exposures or their health impacts. We do not know if the effects of smoke exposure on health are linear. In other words, we do not know what the shape of the exposure-response curve is for specific pollutants and health outcomes and what the thresholds are, if any. It is possible that if the indoor air pollution levels are high beyond a critical level then one may not find a sex differential in the effect, even if women are more exposed.

CONCLUSIONS AND RECOMMENDATIONS

A review of evidence on health effects of indoor air pollution indicates that household use of unprocessed solid fuels for cooking and space heating has significant impact on human health. However, the quantity and quality of scientific literature on the health effects of smoke vary considerably by type of health outcome. There is compelling evidence linking smoke from biomass and coal use for cooking to acute respiratory infections in children and chronic bronchitis in women. Also, there is limited evidence linking indoor smoke and asthma, tuberculosis, lung cancer, and adverse pregnancy outcomes. But the evidence on cataract and blindness, otitis media, lung fibrosis, and cardiovascular disease is weak or nonexistent.

Although thousands of large and rigorous studies have measured how cigarette smoking affects health worldwide and a relatively large and growing number of studies have linked ambient air pollution to various health outcomes, only a few dozen studies have measured how cooking smoke affects health. There is need to strengthen both the quantity and quality of evidence linking indoor air pollution from solid fuel burning and various health outcomes, especially for health conditions with weak or no evidence. This can be accomplished by measuring exposure levels more directly; by including clinical measures of disease outcomes; and by adequately accounting for social, behavioral, and environmental confounding factors. In these efforts, there is need to use more powerful study designs, such as a randomized intervention trial currently underway in upland Guatemala to study effects of improved stoves on acute respiratory infections in young children.

Because indoor air pollution from cooking and heating is often worst in poor, remote, rural areas, it tends to receive less attention than more visible ambient air pollution in cities and other proximate health problems that catch public attention. Moreover, only a small fraction of biomass fuels are purchased through formal markets. Instead, people—mainly women and girls—gather fuelwood and other biomass in the countryside. Their energy-supply efforts do not show up on accounting ledgers or as commercial transactions. Thus use of biomass fuels is not adequately measured in national and international data collection efforts (Smith, 2002).

An examination of gender aspects of indoor air pollution and health reveals that differences in gender roles result in differential exposures to indoor air pollution among males and females. Moreover, gender differentials in nutritional status, treatment, and care result in differential effects of these exposures on health. Also, there are biological differences between males and females that mediate the effects of indoor air pollution on health. Yet, there are very few studies that address gender aspects of indoor air pollution and its health impacts, and still fewer that empirically examine these gender differentials. Most studies assume that women have greater exposure than men, and do not include men or even discuss how sex and gender roles determine differential exposure levels and impacts.

There is need to collect sex-disaggregated data on smoke exposure and health outcomes. Information on men's and women's activity patterns, cooking habits, and time spent in various microenvironments, and information on gender differentials in access to and utilization of health care services is needed to better understand how sex and gender roles mediate the effects of indoor air pollution on health. There is also need to determine exposure-response relationships and threshold levels for effects of specific pollutants on health outcomes separately for males and females. Detailed data on fuel-mix, fuel-switching, and cumulative exposures should be collected.

The scientific evidence available to date, although not conclusive for several health outcomes, clearly indicates that health hazards from indoor air pollution are a major public health problem that needs immediate attention. Millions of people could be healthier if they had less exposure to cooking smoke. Actions to reduce exposure include (i) promoting use of cleaner fuels, (ii) providing more efficient and better-ventilated cookstoves, and (iii) educating people about the risks of exposure to cooking smoke (Mishra, Retherford, & Smith, 2002).

Widespread adoption of cleaner fuels probably would do most to reduce indoor air pollution, but poor households that currently rely on solid fuels are unlikely to be able to afford cleaner fuels any time soon. And because few poor people can afford to use cleaner fuels, markets have yet to develop to supply them, so many rural communities lack access to improved cookstoves and cleaner sources of energy. In the long run, rising levels of development will reduce indoor air pollution from cooking smoke as households gradually shift to cleaner fuels. The international health community and government public health officials have an obligation, however, not to wait for the long run.

Inexpensive but highly efficient cookstoves have to be an important part of an effective short-run strategy. A major shift to cleaner and more energy-efficient cookstoves in poor, rural households in developing countries could substantially reduce the burden of ill health. The most successful cookstove program has been in China, where some 200 million improved stoves have been introduced in recent decades. The Chinese program demonstrates that a concerted action program can achieve remarkable results.

Additionally, there is need for public information campaigns designed to inform people about the health risks of exposure to cooking smoke. In designing and implementing policies and intervention programs, such as the improved cookstove program, special attention should be given to the local community needs and the needs of women, who do most of the cooking. Communities should be educated about adverse health effects of indoor air pollution and about differential exposures and health impact among males and females.

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