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Indoor Air Pollution

ENERGY AND HEALTH FOR THE POOR

In India, approximately 86 per cent of rural households and 24 per cent of urban households rely on solid biomass fuels for their cooking needs. These fuels used in traditional stoves, in households often with little ventilation, emit smoke containing significant quantities of harmful pollutants in the immediate proximity of people leading to serious health consequences. It is estimated that up to 444,000 premature deaths in children under 5 years, 34,000 cases of chronic respiratory disease in women under 45 years and 800 cases of lung cancer are attributable to exposure to Indoor Air Pollution (IAP) due to use of solid fuels by households.

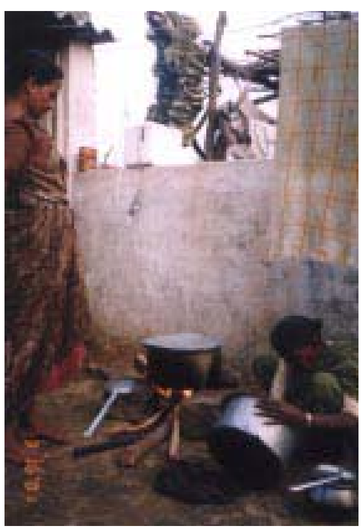
While health risks drive policy concerns, these are often difficult and costly to estimate. Information on population exposure to IAP is a useful proxy for health risks, and hence guide and facilitate mitigation actions. Better information on patterns of exposure and its determinants would assist in designing more effective interventions and strategies.

As part of World Bank's study on Household Energy, Air Pollution and Health in India, a pilot exercise was conducted in rural Andhra Pradesh to collect quantitative evidence on the levels of exposure to IAP and key factors influencing these levels. This issue of the newsletter presents the results of this study designed by the Center for Occupational and Environmental Health, University of California, Berkeley (USA), and undertaken in partnership with Sri Ramachandra Medical College in Chennai and the Institute of Health Systems in Hyderabad (India).

Exposure to Smoke from Cooking Fuels: Evidence from Andhra Pradesh

An exposure assessment study was piloted in three districts of Andhra Pradesh (AP), a state in Southern India with a warm climate all year around, which does not require heating. The study included three major components:

- Household-level surveys to obtain data on various household characteristics and behavioral factors, with focus on secondary indicators of IAP, such as the distribution of fuel use, stove type and ventilation conditions.
- Field monitoring to collect data on daily average concentrations of respirable suspended particulate matter (RSPM) in the micro-environments of the same households and household surveys to collect 24-hour activity patterns of household members to estimate exposure (RSPM is defined in the study as particles with a median aerodynamic diameter of 4 microns). Exposure to RSPM — a measure combining the number of people, the concentration of RSPM, and the amount of time spent breathing it — is one of the best indicators of health risks due to IAP.
- Finally, a statistical analysis to examine relationships between secondary household indicators of IAP and indoor RSPM concentrations.



Source: Sri Ramachandra Medical College and Research Institute, Chennai

Field monitoring of respirable particulate matter being conducted in an outdoor kitchen in Andhra Pradesh (India) as part of the Exposure Assessment Study

Table 1: Health Impact of Exposure to Biomass Fuel Smoke

Table 1 shows relative risk estimates for health outcomes associated with exposure to smoke from household fuel use based on a review of IAP studies. For example, children under five years of age exposed to indoor air pollution from solid fuel use have a two to three times greater risk of developing lower respiratory infections compared to unexposed children. There is strong evidence to support an association between solid fuel use and acute lower respiratory infections (ALRI), chronic obstructive pulmonary disease (COPD), and lung cancer (for coal only). Although there is epidemiological evidence to suggest an association with blindness (from cataract), asthma, and tuberculosis, more carefully controlled studies are needed to confirm these associations. Associations with adverse pregnancy outcomes (including low birth weight and still-birth) and ischaemic heart disease need further exploration for exposures from solid fuel use.

Table- 1: Health Effects of Exposure to Smoke from Solid Fuel Use: Plausible Ranges of Relative Risk in Households Using Solid Fuels Households

Health Outcome	*Population Affected*	Relative Risk		Evidence
		Low	High	
Acute Lower Respiratory Infections (ALRI)	<5 years	2.0	3.0	Strong
Asthma	Females >15 years	1.4	2.5	Intermediate/ moderate
Blindness (cataracts)	Females >15 years	1.3	1.6	Intermediate/ moderate
Chronic Obstructive Pulmonary Disease (COPD)	Females >15 years	2.0	4.0	Strong
Lung Cancer (coal only)	Females >15 years	3.0	5.0	Strong
Tuberculosis	Females >15 years	1.5	3.0	Intermediate/ moderate

Source: The above table is adapted from Smith KR and Mehta S. 2000. "The burden of disease from indoor air pollution in developing countries. comparison of estimates." Paper presented at the USAID/ WHO Global Technical Consultation on the Health Impacts of Indoor Air Pollution and Household Energy in Developing Countries.

Note: A relative risk of 1 indicates that the risk is the same in the exposed and unexposed groups, i.e. there is no increased risk associated with exposure.

Study Design

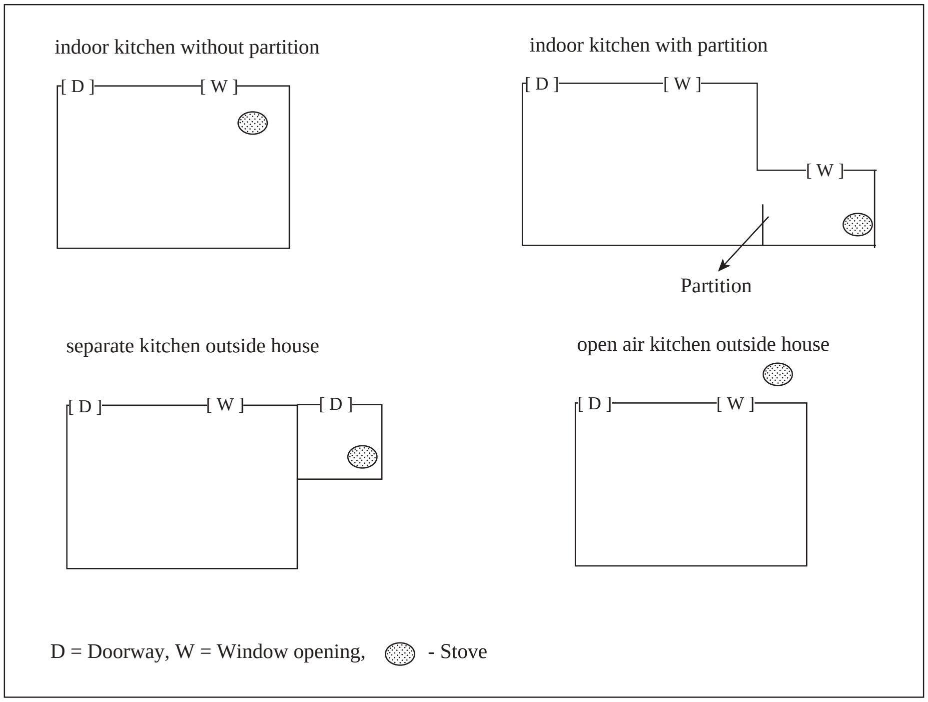
The exposure assessment study involved the design of a household questionnaire to collect data on household, fuel and other characteristics relevant to IAP exposure. Reviews of national and state level surveys served as a basis for designing the questionnaire. Primary data collection was undertaken for two categories of information:

- Information from households that parallels the information already collected by demographic surveys, including the Census and the National Family Health Survey (NFHS).
- Information on household characteristics that are not well-characterised in existing demographic surveys but could be incorporated into future surveys if found to be predictive of IAP levels, such as kitchen type the presence of cooking exhaust, number of open doorways, and information on the type and quantity of fuel consumed.

Selection of Study Households

The households were selected from three districts — Nizamabad, Warangal, and Rangareddy of Telangana region of Andhra Pradesh. Since the main objective of this exercise was to investigate which household parameters affect exposure, household selection was done purposively, using a cluster sampling method to ensure that a variety of kitchen types and cooking fuel types are present within each cluster of households. The cluster-sampling scheme aimed at obtaining approximately 150 households in each district by selection of mandals (group of villages; smallest administrative unit in a district) as first stage sampling unit (5 from each district), habitations as second stage sampling unit (1 from each mandal) and households as third stage sampling unit (up to 30 from each habitation). Only mandals having a higher percentage of clean fuel use (i.e., >2 per cent) were considered and selected using the probability proportionate to size

Figure-1: Sketch of kitchen types in sample households



criteria. (Roughly, 10 per cent of the study households used clean fuels). Within each selected mandal, habitations having populations above 2,000 were considered and one habitation was randomly selected. Finally, within a habitation, a cluster of households was selected to include a similar number of households in the five categories described below: four categories of solid fuel users with four different kitchen types (see Figure 1) and one category of clean fuel users.

The sampling protocol for selecting a cluster of households that satisfied the desired criteria above, involved visiting every fourth household starting from the center of a habitation. In the end, 420 households were covered by both the household survey and monitoring, including:

Solid fuel users, i.e. households using wood, dung, and a combination of dung and wood:

1. Kitchen inside the home without a partition (113 households)
2. Separate kitchen inside the home (108 households)
3. Separate indoor kitchen outside the home (96 households)
4. Outdoor kitchen (i.e., open air cooking) (95 households)
5. Clean fuel users, i.e., households using kerosene, liquefied petroleum gas (LPG) and biogas (45 households).

Cooking with clean fuels is negligible in rural areas, so even with a purposive sampling, the number of clean fuel users came out much smaller than in other categories.

Measuring IAP Concentrations

In summary, the data collection framework for measuring RSPM concentrations and estimating exposure consisted of:

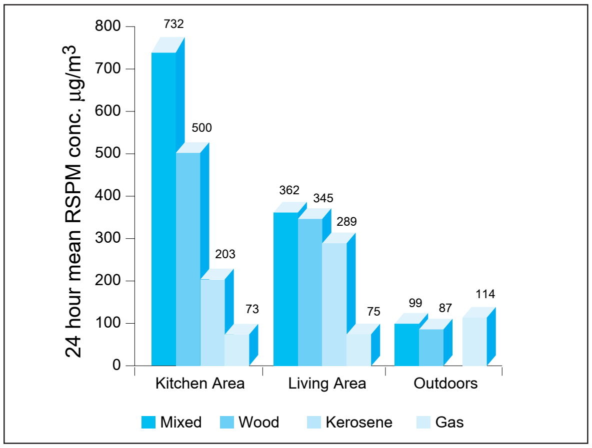
- 24-hour average concentrations of RSPM in kitchen and living areas for all study households;
- In addition, 10 per cent of households were monitored using a real-time monitoring instrument (PDRAM) to determine concentrations during cooking and non-cooking windows;
- 24-hour outdoor area concentrations for about 20 per cent of the households
- A detailed questionnaire was administered to each household to collect time-activity information as well as information on some other variables likely to influence concentrations (e.g., smoking habits and the use of insect coils).

Findings of the Study

Impact of Fuel Type on RSPM Levels

Depending on the type of primary cooking fuel, households were grouped in mixed solid fuel users (97 households in the sample using wood and dung, or dung, with small amounts of kerosene to start the fire but too small to affect overall emissions over a whole burn cycle or day), wood users (270 households), kerosene users (11 households) and gas users (34 households using LPG or biogas). Households using mixed fuels have the highest RSPM concentrations, followed by wood, kerosene and gas, illustrating the "energy ladder" sequence observed in other settings (Figure 2). Mean 24-hour kitchen concentrations in solid fuel using households were 2.5 (wood users) to 3.5 (mixed fuel users) times higher than that in kerosene households, while in kerosene using households it is also about three times higher than that in LPG using households. Households using kerosene were found to be ambiguous in terms of fuel use because many of these households frequently switch to wood for cooking, while report kerosene as their primary fuel on the basis of larger expenditure on kerosene in the household budget than on traditional biomass fuels.

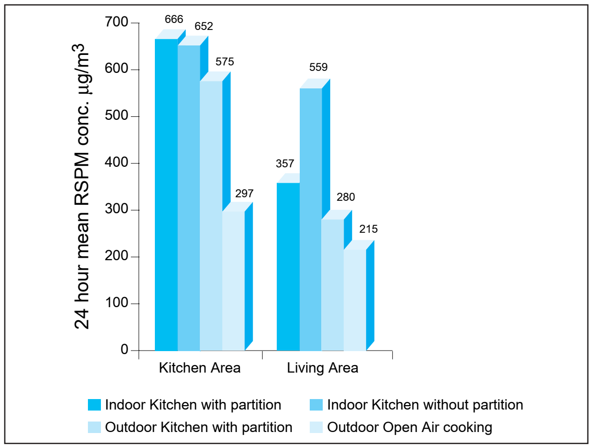
Figure 2: Mean 24-hour RSPM concentration for different fuels and house areas in rural AP



Effect of Kitchen Configuration on RSPM Levels in Solid Fuel Households

In kitchen areas, no significant difference in concentrations was observed between households having indoor kitchens with partitions and those without partitions (666 $\mu g/m^3$ versus 652 $\mu g/m^3$). Inferring from Figure 3, average kitchen area concentrations are significantly higher in indoor kitchens compared to outdoor kitchens with or without partitions (659 $\mu g/m^3$ versus 436 $\mu g/m^3$). Still, even in outdoor cooking, concentrations levels are substantial both in the kitchen and living areas (297 $\mu g/m^3$ and 215 $\mu g/m^3$), and well above the health guidelines for outdoor air quality. (24-hour Indian average standard for PM10 — airborne particulate matter less than 10 microns — in rural outdoors is 100 $\mu g/m^3$, and RSPM was found to be approximately 60 per cent of PM10 in the households monitored).

Figure 3. Kitchen and living area RSPM concentrations for different kitchen configurations in solid fuel[a] households in rural AP



a –Solid fuel households include wood and mixed fuel users

Average living area concentrations were the highest in households having kitchens without partitions (559 $\mu g/m^3$), followed by kitchens with partitions (357 $\mu g/m^3$), separate kitchens outside (280 $\mu g/m^3$) and outdoor open air kitchens (215 $\mu g/m^3$). Living area concentrations in households using outdoor kitchens were much lower than those with indoor kitchens (215 $\mu g/m^3$ versus 458 $\mu g/m^3$) but about similar to households with a separate kitchen (215 $\mu g/m^3$ versus 280 $\mu g/m^3$). These results indicate that dispersion can considerably affect adjacent living area concentrations during outdoor cooking.

In households using gas, concentrations did not vary across kitchen types.

Fuel Quantity and Ventilation Effects

A regression analysis showed that both kitchen and living area concentrations increased with greater consumption of fuel amongst solid fuel users. Living room concentrations were also influenced more by number of windows and additional rooms, while kitchen area concentrations were not, indicating the role of dispersion in reducing area concentrations. This indicates that more specialised improvements in kitchen ventilation, such as possibly stove hoods to vent out exhaust, are needed to have an impact. Concentrations were also not correlated with the number of people being cooked for; nor with total cooking duration. Concentrations were not significantly influenced by use of kerosene lamps, incense coils or mosquito coils; or by presence of smokers in the house.

Exploring Determinants of IAP Concentrations

Based on data collected from household surveys and RSPM monitoring, the study examined the relationships between kitchen / living area concentrations and household characteristics based on statistical modeling. Variables significantly associated with kitchen and living area concentrations were included in the modeling process to explore whether and how certain household characteristics can be used to predict household exposure levels.

The following variables were significantly correlated with both kitchen and living area concentrations:

- Type of cooking fuel (mixed, wood, kerosene, gas)
- Type of kitchen (4 types, as described earlier)
- Separate kitchen (outside the living area or not)
- Kitchen ventilation (poor, moderate, good)
- Wall type (pucca, semi-pucca, kachha)
- Floor type (pucca, semi-pucca, kachha)
- Housing type (pucca, semi-pucca, kachha)
- Stove type (traditional, improved, kerosene, gas)

Linear regression models that were used to predict continuous outcome variables for kitchen and living-area concentrations did not yield sufficient information for explaining great variability in the kitchen and living-area concentrations, especially within the wood and mixed fuel categories. Subsequently, modeling was conducted for binary concentration categories (high and low concentration households) using logistic regression, and classification and regression trees (CART) techniques.

After trying a number of modeling approaches and specifications, the following observations were drawn:

- Three variables — fuel type, kitchen type, and kitchen ventilation — were found to be good predictors of kitchen and living-area concentrations in high concentration households.. Fuel type is the best predictor of high concentrations, but not a good predictor of low concentrations. This is due to the wide range of concentrations within fuel categories. In general, low concentrations appear to be more difficult to predict than high concentrations

- Kitchen type is a good predictor of kitchen concentrations; indoor kitchens are much more likely to have high concentrations than outdoor kitchens. For living-area concentrations, knowing the specific type of kitchen is less important than knowing whether or not the kitchen is separate from the living area.

- Households with good kitchen ventilation are less likely to have high concentrations — in both kitchen and living areas — than households with moderate or poor ventilation. Kitchen type and kitchen ventilation are equally good predictors of household concentrations. Each of these variables is unable to better predict household concentrations above and beyond the other variable. This suggests that it may not be necessary to collect information on both kitchen type and kitchen ventilation.

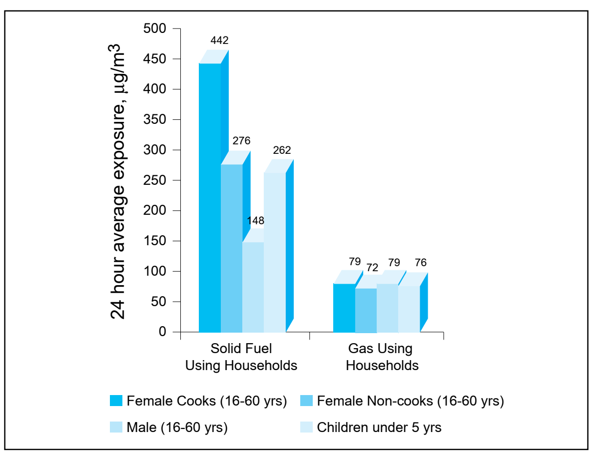
Gender Differences in Exposure

The study estimated exposure to IAP by combining concentrations measurement data with time activity patterns. As shown in Figure 4, among solid fuel users, mean 24-hour average exposure concentrations for women cooks in the age group 16-60 years is one and a half times greater than that of women non-cooks (442 $\mu g/m^3$ vs. 276 $\mu g/m^3$), and three time greater than that of men in the same age group (442 $\mu g/m^3$ vs. 148 $\mu g/m^3$). The exposures of cooks are not significantly different across indoor kitchen types but are higher than outdoor kitchens.

Among non-cooks in solid fuel using households, women in the age groups of 61-80 years experience the highest exposures followed by women in the age group of 16-60 years, while men in the age groups of 16-60 years experience the lowest exposures. This is presumably because older women are most likely to remain indoors leaving the younger women to be involved in assisting the cooks, while men are most likely to have outdoor jobs that lowers their exposures. Young children (2-5 years) are the only group in solid fuel using households for which female and male exposures are similar.

There is no difference in exposure among household members in gas using households .

Figure 4: Exposure of different household members: solid fuel versus gas households in rural AP



The field monitoring team of the Exposure Assessment Study is explaining the monitoring procedure in an outdoor kitchen setting to village people in rural Andhra Pradesh (India)

- The study strengthens the evidence that cooking with clean fuels reduces exposure substantially and, further, makes it equally low for all household members, including for women-cooks who suffer much more than others in solid fuel using households. At the same time, the study finding that indoor concentrations are well correlated with the quantity of solid fuel used indicates that the adoption of clean fuels will lead to a tangible reduction in exposure only if these fuels meet a substantial portion of cooking needs and biomass consumption is reduced considerably. It is known that in the reality of rural life, complete or substantial switching to clean fuels is seldom, and people continue to rely on biomass fuels. This highlights the need for multiple interventions to reduce exposure to IAP ranging from alteration in housing design to provision of cleaner fuels and better stoves that vent smoke outside the house.

Looking to the Future

The following key observations and conclusions emerge from the AP exposure assessment study:

- This study provides, for the first time, quantitative information on 24-hour concentrations and exposures to respirable particulate matter, for a wide cross-section of rural homes using a variety of household fuels and under various exposure conditions. There is a need, however, to exercise caution in the extrapolation of the study results as the findings are based on a sample from only three districts of a single agro-climatic zone of one state in southern India, wherein socio-cultural, housing and climatic conditions in this region are likely to differ from other parts of the country. Further, monitoring was carried out only in summer months, which is not reflective of the time-activity pattern of household members and the nature of biomass fuel used for all seasons. This points to the need to collect quantitative data on a regional basis to increase the level of confidence in the findings emerging from this study.

- While women-cooks suffer from far greater exposure in solid fuel using households, the exposure level could be significant for residents of the house other than the cook. An important finding for policy concern is that even for households that cook outdoors, the 24-hour concentrations and exposures could be significant both in the cooking place and indoors, well above levels considered acceptable by air quality guidelines. This challenges the conventional wisdom, and a frequent excuse to ignore the problem, that cooking outdoors — as the majority of poor households do — prevents the health risks from fuel smoke.

- While exploratory in nature, the effort at modeling indoor air pollution concentrations provided valuable insight to the key determinants of exposures — fuel type, kitchen type, and/or kitchen ventilation. Remarkably, access to clean fuels and ventilation in IAP-related health issues seems to be analogous to access to clean water and sanitation in water-related health issues.

- Future studies of this kind could address the high intra-household variability in the behavioral aspects of family cooking, e.g., in ways a stove has been operated on a particular day. Multiple-day measurements could be taken in future studies to smooth out this variability. The resulting multi-day mean concentrations levels would, presumably, be better suited to be predicted by parameters that do not change daily, such as fuel type and house structure.

- The findings of this study, if validated with other data and refined models, could also influence the design of large-scale survey instruments, such as the Census or National Sample Survey, by introducing questions on the key determinants of exposure, namely kitchen type and/or ventilation, in addition to the fuel type already used by these surveys, with a view to facilitating classification of population sub-groups into exposure sub-categories.

Health Benefits of IAP Mitigation Strategies: Strengthening the Evidence

Recent studies on household energy and indoor air pollution issues have significantly contributed to a better understanding of the impact of interventions on exposure and health benefits. A brief summary of selected studies is presented below.

Improved stoves and lung cancer risk reduction: evidence from China

Stove improvements reduce exposure to indoor air pollution and thereby decrease the risk of lung cancer among farmers in rural China, suggests one recent study published in the Journal of the National Cancer Institute.

Traditionally, household cooking and heating in China commonly involved burning of coal in unvented indoor stoves. Such unvented burning produces very high indoor concentrations of airborne particulate matter, benzopyrene and other organic compounds. These pollutants are risk factors for lung cancer and other respiratory diseases. In this retrospective cohort study of 21,232 farmers followed from 1976 to 1992 in Xuanwei, China, the incidence of lung cancer among 17,184 farmers who switched from unvented firepits or stoves to stoves with chimneys was compared with the incidence of lung cancer among 4,048 farmers who continued to use unvented firepits or stoves. Tobacco smoking and frequency of cooking were similar in both groups. The authors found that levels of indoor air pollution created by vented burning were less than 35 per cent of levels created by unvented burning. Average concentrations of PM10 decreased from 2080 $\mu g/m^3$ before stove improvement to 710 $\mu g/m^3$ after improvement. Further, after adjusting for factors such as tobacco smoking and duration of cooking, changing from unvented to vented stoves was associated with a 41 per cent reduction in lung cancer risk in men, and a 46 per cent reduction in lung cancer risk in women. The findings of the study provide strong encouragement for stove improvements and other measures to reduce indoor air pollution from household fuel burning.

(Q. Lan, R. Chapman, D. Schreinemachers, L. Tian and X. He. Household Stove Improvement and Risk of Lung Cancer in Xuanwei, China, Journal of The National Cancer Institute, Vol. 94, No. 11, 826-835, June 5, 2002)

IAP and acute respiratory infections in Kenya – an exposure response study

A recent field study examined the details of personal exposure and the exposure-response relationship for indoor air pollution and acute respiratory infection (ARI) in children and adults in rural Kenya. The study took place at Mpala Ranch in Laikipia District, Central Kenya, where cattle herding and domestic labour are the main occupations. Stoves used by the households were unvented and used firewood or charcoal (and kerosene in 3-4 houses).

By monitoring both the health and exposure to indoor smoke over a three-year period, the researchers have characterised the 'exposure-response' relationship between indoor air pollution from biomass smoke and the rates of acute upper and lower respiratory infections. This, first of its kind, characterisation of the health effects of indoor smoke over a wide range of exposure levels shows that:

- The average daily exposure concentration of children under the age of 5 to PM10 is approximately 1,500 $\mu g/m^3$ and that of adult women approximately 5,000 $\mu g/m^3$. By comparison, the latest National Ambient Air Quality Standards of the US Environmental Protection Agency required the daily average concentration of PM10 (particulates below 10 microns in diameter) to be below 150 $\mu g/m^3$ (annual average below 50 $\mu g/m^3$).
- Young and adult women who regularly participate in cooking activities have exposure levels that are two to four times higher than men. They are also in average twice as likely as men to be diagnosed with a case of acute respiratory infection (ARI). Children exposed to high levels of indoor air pollution are in average diagnosed with ARI in approximately 20 per cent of weekly examinations and the more severe Acute Lower Respiratory Infection (ALRI) in 6-8 per cent of weekly examinations.
- With the best-estimate of the exposure-response relationship and controlling for a number of important confounding factors, the study found that ARI and ALRI are increasing functions of average daily exposure to PM10, but the increase may flatten for exposures above approximately 1,000-2,000 $\mu g/m^3$.

- Simple, locally manufactured improved-efficiency stoves can reduce exposure to indoor smoke by approximately 40 per cent and cleaner fuels (such as charcoal) by approximately 90 per cent compared to traditional wood-burning stove. If this reduction in exposure is maintained, the incidence of lower respiratory infections among children, the most important health effect from exposure to indoor smoke will be reduced by an estimated 20-45 per cent.
- While these first results, which are subject to uncertainty due to both statistical factors and difficulties in measurement of exposure and health, should be confirmed in future studies, they provide an important bridge to understanding the exposure and health effects associated with this important risk factor. The results demonstrate the potential extensive health benefits of efforts to develop and promote improved stoves and cleaner fuels among the poor households in the developing world still relying on traditional biomass.

(Ezzati, M. and D. M. Kammen (2002) "Evaluating the Health Benefits of Transitions in Household Energy Technology in Kenya" Energy Policy, 30(10), 815-826

Ezzati, M. and D. M. Kammen (2001) "Indoor Air Pollution from Biomass Combustion as a Risk Factor for Acute Respiratory Infections in Kenya: An Exposure-Response Study" Lancet, 358(9282), 619-624 (erratum 358(9287))

Ezzati, M., H. Saleh, and D. M. Kammen (2000) "The Contributions of Emissions and Spatial Microenvironments to Exposure to Indoor Air Pollution from Biomass Combustion in Kenya" Environmental Health Perspectives, 108(9), 833-839)

A combination of interventions: Kenya experience

International Technology Development Group (ITDG) experience over the past ten years in Kenya has shown that an effective program to reduce IAP and ensure better health and cleaner homes, requires a combination of improvements in cooking and housing depending on the needs and preferences of the household members, especially women-cooks. More efficient stoves alone cannot reduce IAP to levels that could be considered safe. Poor Kenyan households in rural areas use firewood as the primary source of fuel in inefficient cooking devices ranging from three stone fires to metal charcoal stoves that consume large amounts of fuel and pre-dispose users to harmful emissions. To reduce indoor air pollution levels in these houses, participatory approaches were used to develop a package of interventions together with local communities that were durable, affordable and accessible. These included changes to kitchens, improved cooking stoves, smoke hoods, and the provision of windows and eaves. Monitoring of the reductions in particulate matter and carbon monoxide (CO) to assess the impact of the interventions revealed that smoke hoods were most effective in reducing concentrations of both pollutants, by 75 per cent and 78 per cent, respectively. Windows did not result in any significant changes in kitchen pollutant concentrations. While eaves space reduced particulate levels by 60 per cent, it cut CO levels only by 28 per cent. Improved stoves brought down particulate matter and CO levels by 54 per cent and 42 per cent, respectively.

(J. Nyaga, Lessons from Kenya's Household Energy Activities, Presentation at the Regional Workshop on Household Energy, Air Pollution and Health, New Delhi, May 9-10, 2002)

Feedback

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