Measuring Indoor Air Pollution and Lung Functioning in Indian Field Settings

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ABSTRACT

Research on indoor air pollution (IAP) is finally catching up with the size of the health risks posed by this environmental hazard. Unfortunately, most studies use fuel and kitchen variables as proxy measures of IAP exposure and self-reports as the only indicator of respiratory illness. On the other hand, household research using physical measures of IAP or lung functioning have been limited to small, geographically focused designs. This paper reports results from a pilot study of 617 households in four geographically dispersed states of India that integrates physical and questionnaire measures in ways that are cost effective and can be scaled up for larger studies. Portable spirometers and new compact IAP monitors were successfully used in combination with a detailed household survey. Results are reported for these instruments, compared with other physical and questionnaire measures, and tested for significant interrelationships.

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Research on indoor air pollution (IAP) is finally catching up with the size of the health risks posed by this environmental hazard (Smith 1993). Almost half the world's households cook with solid fuels (wood, dung, agricultural wastes) that emit high levels of particulates, carbon monoxide, and other pollutants. Confined within often poorly ventilated households, this household smoke results in particulate (PM_{10}) concentration levels of between 200 and 5000 $\mu g/m^3$ (and up to 50,000 $\mu g/m^3$ in the immediate vicinity of the fire) compared with EPA guidelines of 150 $\mu g/m^3$ for maximum daily concentrations (Ezzati and Kammen 2002).

In high mortality developing countries, the risk attributable to this indoor air pollution accounts for 3.6% to 3.7% of disability-adjusted life years (DALYs), fourth in importance below underweight, unsafe sex, and polluted drinking water and poor sanitation (WHO 2002). Annually, IAP accounts for between 1.5 and 2 million deaths. Most of the DALY impact is from acute respiratory infections (ARI), the leading killer of children (Bruce, Perez-Padilla, and Albalak 2000; Smith, Samet, Romieu, and Bruce 2000). IAP has also been linked to chronic obstructive pulmonary disease; lung, nasopharyngeal, and laryngeal cancers; asthma; tuberculosis (Mishra, Retherford, and Smith 1999a); perinatal conditions and low birth weight (Boy, Bruce, and Delgado 2002; Torres 2002); and eye diseases such as cataracts and blindness (Mishra, Retherford, and Smith 1999b). Ezzati and Kammen (2001) find increased rates of respiratory infections over two years among Kenyan children and adults as a function of continuously measured PM_{10} exposure.

Unfortunately, most studies use fuel and kitchen variables as proxy measures of IAP exposure and self-reports as the only indicator of respiratory illness. For example, DHS data for 4426 Guatemalan children reveal that separate kitchen facilities and IAP exposure predict child mortality, even after controlling for household wealth and mother's education (Torres 2002). A similar analysis of ARI symptoms also showed some evidence of IAP effects ($p=.07$). Equivalent data for a sample of 59,770 Indian children also showed child mortality effects of biomass fuels after controls for household wealth and mother's education (Hughes and Dunleavy 2000).

Except for a handful of studies, IAP consequences for mortality or ARI have been evaluated without physical measurements of pollution or lung functioning. Instead, most research has relied on questionnaire measures of fuel sources and respiratory problems. This reliance on proxy rather than physical measures may have reduced the strength of the relationships yet uncovered.

On the other hand, household research using physical measures of IAP or lung functioning have been limited to small, geographically focused designs. Since many factors of interest, such as housing construction vary far more across regions than within a single village, these designs limit their utility. At the same time, large surveys designed by social scientists have not been able to incorporate intensive physical measurements required by environmental scientists due to cost constraints.

This paper reports results from a pilot study of 617 households in four geographically dispersed states of India. Both urban and rural samples are included from each state. Given its cultural and socio-economic heterogeneity, India is an ideal country for such a study. The project has developed methodologies that can integrate physical and questionnaire measures in ways that are cost effective and yet fill a potential gap in the literature. Both environmental and social science approaches are incorporated to study the full range of environmental and social variation across different regions.

Proximate determinants. IAP concentrations in the household are primarily a function of the type of fuel used, the amount of ventilation, and how thoroughly the kitchen is separated from the rest of the house (Larson and Rosen 2002, World Bank 2002). Regression analyses of eight separate factors in a sample of almost 400 Andhra Pradesh households identified these three as the primary determinants of 24 hour particulate concentrations. Each of these is linked to the economic and social status of the household so that the most disadvantaged tend to be exposed to the most intense pollution. Individuals' exposure to household pollution is determined by the time spent inside the house, especially in close proximity to the stove (Ezzati, Saleh, and Kammen 2000). These behavioral patterns put women and children especially at risk of IAP. One of the strengths of the survey component of this study is a broad array of measures of gender and economic stratification of Indian households.

Social structure. While it is well recognized that exposure to indoor air pollution is socially structured, little research has explored its demographic determinants in much depth (what Larson and Rosen, 2002, analyze as the household-level demand for IAP interventions). Poverty, of course, is assumed to limit household access to cleaner cooking fuels such as liquid petroleum gas (LPG). But the causal connections between poverty and IAP are more complex than the simple linear relationship often assumed. The poorest families often must cook outdoors, a "disadvantage" which actually protects them from the worst levels of IAP experienced by somewhat wealthier households (World Bank 2002). Moreover, it is not just the household's own economic status that determines availability of clean fuels but also the regional economic levels that can sustain sufficient local markets or government programs for clean fuel distribution. Thus, even rich households in backward areas may have great difficulty obtaining a regular supply of clean fuels. Much of the substantial urban-rural differences observed in IAP can be attributed to this variability in local supply of different fuel sources.

Research has also not yet distinguished between a household's economic and social status in the community. In India, for example, high caste households, whatever their economic position, would be especially reluctant to cook outdoors because of their need to protect women from the gaze of strangers. Similar caste restrictions encourage separation of kitchen facilities into separate spaces (and thus more gender-segregated IAP exposures). Not only kitchen arrangements but fuel type itself is now recognized to have broad status implications. Thus, in Mexico for instance, it was found that household shifts to cleaner LPG stoves were usually accompanied by a wider set of household changes, including for instance housing expansion, new utensils, and cooking appliances (Sheinbaum, Martínez, and Rodríguez 1996). Beneficiaries of government subsidized LPG distribution in India noted that "the use of LPG was inviting envy from non-beneficiaries" (World Bank 2002: 70). Especially in rural villages where neighbors easily monitor household status, fuel and kitchen arrangements which determine exposure to IAP are likely to follow social status as much as purely financial considerations. As Smith (2002) notes, "The factors leading to adoption of any device operating at the household level extend well beyond the technical and economic to the social, cultural, and perceptual."

Gender has also been well recognized as a crucial social dimension sorting out who is exposed to IAP. Ezzati and Kammen (2001) show that the gender effect on ARI in rural Kenya is mediated through the extent of exposure to IAP, in particular through the amount of time spent cooking. But again, beyond noting that women do most of the cooking around the world and are therefore more exposed to IAP, research has not yet incorporated any of the complexities of gender stratification into the analysis. Thus, the extent of women's confinement to the household is a socially structured characteristic that varies widely across cultures and even across households within a cultural pattern.

Women are the main beneficiaries of a transition to cleaner fuels not only because of better health, but also because of eliminating the drudgery of fuel collection and the cleaning of soot from kitchen utensils. In fact, it is these convenience advantages of LPG that are most often cited by women in developing countries, not the health benefits (World Bank 2002: 70). But if the lessening of housework drudgery is to play a role in household decision making, women must have a voice in those decisions. Ezzati and Kammen (2002) note that there is little systematic evidence of what factors motivate households to adopt different stove, fuel, or kitchen types. The degree to which women influence household financial decision making may play a crucial role in those choices.

We suspect that the relative neglect of demographic determinants of IAP and lung functioning can be explained by the still nascent character of this literature. Public health concerns of establishing the exposure-response relationship have naturally taken priority; broader social structural determinants still appear to be "at the most distal level" and so, perhaps, less urgent for attention (Ezzati and Kammen 2002). The restricted geographic scope of much IAP research has also limited the demographic variation that could be analyzed. Many studies have investigated only a small rural area (e.g., Ezzati and Kammen 2001), urban neighborhood (e.g., D'Souza 1997) or at most a region within a larger country (e.g., World Bank 2002). Inter-village heterogeneity is limited by these constraints, but it is precisely these village differences that most reveal larger social structural patterns. Thus the excellent work on IAP monitoring in the Indian states of Tamil Nadu (Balakrishnan 2000, Parikh and Laxmi 2000) or Andhra Pradesh (World Bank 2002) still looks at only a handful of districts and all of them in South India where gender inequalities tend to be muted relative to the North.

Before demographic factors can be fully incorporated into environmental research, it is necessary to develop research practices that include bio-markers of health status, physical measures of environmental pollution, survey measures of social structure, and sampling designs across a wide range of geographic and social settings. Such research is inherently multi-disciplinary and must build on teams of investigators with a broad range of methodological expertise. The current paper reports preliminary results from an especially promising investigation that combined all these elements.

RESEARCH DESIGN AND METHODS

Data and Sample

The study sampled households in four geographically and culturally diverse states (Uttaranchal in the Northern hills, Madhya Pradesh in the Hindi heartland, West Bengal in the East, and Tamil Nadu in the South). Approximately 25 households were studied in each of four villages and two urban neighborhoods from two districts in each state.

Research teams visited each household on at least four occasions. The first contact was a brief interview for a village or neighborhood census that recorded fuel (and water) sources to establish the sampling frame. Once sampled, households were generally visited next by a pair of survey interviewers who completed two household interviews generally lasting between one and one and a half hours each. After interviewing, environmental teams arrived, often on the next day, and installed air pollution monitors and sampled water from household storage containers. The IAP monitors remained in the house for a day. During the installation or retrieval visits, often during both, the environmental teams administered lung functioning tests to selected household members. After retrieval of the IAP monitors, households were again interviewed about fuel use and IAP exposure during the previous day using modified time diary methods. At this time, further health and respiratory illness questionnaires were also administered.

While initially we were concerned about the feasibility of this ambitious data collection design, most of our anxieties about the technical problems we would encounter proved to be unfounded or resolvable. The portable lung functioning devices performed very well although short battery life was a persistent problem. An extra battery or two would allow for greater flexibility. Respondents were quite accommodating to these strange requests and usually interpreted the multiple repetitions required to obtain two or three valid readings as a kind of game. Even elderly respondents (who were a special concern because of their longer exposures to IAP) were usually able to provide valid data.

Similarly, the new IAP monitors were easily installed and retrieved. As hoped, their use is a great operational advance over the older cyclone monitors used in a subsample of the households for comparison purposes. Even locally hired personnel were easily trained to handle this equipment. Downloading of data to laptop computers and calibrating each monitor for two hours in a sealed environment were daily tasks that were eventually routinized although often requiring work late into each night.

Social, rather than technical, problems proved to be the biggest obstacle in this design. As one might expect, respondent fatigue became an issue, especially in urban households. This was sometimes exacerbated by insufficient explanations from the first interview teams to visit the household. Indeed, the complex co-ordination required between the survey and environmental teams was the principal logistical and organizational difficulty faced throughout the study. These two teams, employed by different organizations, had understandable differences in training and past education. These background differences also meant quite different levels of logistical support and compensation to the two teams. Nevertheless the research plan required careful co-ordination between the two teams based on a tight time schedule. The survey team was responsible for the village census, the environmental team used that census to draw a stratified sample (in order to insure a range of fuel and water sources), the survey teams then conducted interviews in those sampled houses, and were followed as soon as possible by the environmental teams to install equipment and complete their own questionnaires. While co-ordination difficulties were eventually resolved in each state, this was a learning experience for all the research teams.

Lung capacity measures. New portable spirometers for measuring lung capacity provided many advantages over the older spirometry equipment used in earlier studies. Three spirometers were acquired and used by our Indian collaborators. These spirometers could be taken directly into respondents' households instead of requiring all tests to be performed in a central location. Originally we were concerned about the difficulty of administering these tests in rural Indian field settings, but field experience proved these concerns were largely unfounded. Respondents treated the tests as an interesting diversion, and we were usually able to achieve satisfactory readings for all tested respondents. Even most of the sample of elderly respondents had little difficulty in completing the tests. In some households, we also collected the simpler peak flow meter data for comparison purposes.

Indoor air pollution measures. IAP measures focused on continuous 24-hour monitoring of respirable particulate matter (PM_{10}) in all selected households. Up to three micro-environments were measured (kitchen, living area, and, for each village or urban neighborhood, outdoor ambient levels). The principal measures were taken by the new UCB monitors. In approximately one fifth of the households the older cyclone instruments were also installed for comparison with the new monitors. CO monitors were also used in most households.

The new air pollution monitors (UCBs) were developed by the Berkeley team and offer many advantages over the older cyclone instruments. They provide far more detailed data (continuous levels over a 24 hour period rather than a single cumulative total); the data are recorded directly on electronic chips and the measurements are probably more reliable because they do not require extremely sensitive weighing scales; the new monitors are easier to install in households and do not require as highly skilled technicians; they are more compact and transportable; and, perhaps best of all, they are less expensive. We experienced some difficulties in processing these monitors through Indian customs and have thus learned how to avoid these delays.

ANALYSES

Fieldwork (see attached photographs) and data entry have been completed for all households. Data cleaning and merging of files is currently proceeding. We propose to have the following analyses available for the PAA meetings:

- statewise distributions for two basic lung functioning measures from the spirometry tests: PEF, peak expiratory flow and FEV1, forced expiratory volume in 1 second;
- comparisons of the spirometry results with self reports of lung functioning;
- comparisons of the spirometry results with results from the subsample who also use the peak flow meter;
- statewise distributions for indoor air pollution from the UCB monitors: maximum levels and 24 hour averages;
- comparisons of the UCB results with the CO meters and the results from the subsample where the cyclone measures were also collected;
- comparisons of UCB results by fuel source and kitchen type;
- relationships between spirometry and IAP measures, separately for cooks and other household members.

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