Supplementary material for Smith (2000) *Proc. Natl. Acad. Sci. USA* **97** (24), 13286–13293.

PM_{10} Concentrations

The distribution of annual PM_{10} (particles less than 10 microns in diameter) concentrations in Indian cities does not even overlap with that for U.S. cities as shown in Figs. 3 (1) and 4.[1] Where total suspended particles (TSP) have been measured (SPM in Indian terminology), conversion to PM_{10} has been done using a factor of 0.55. Note, however, that data from urban monitoring stations are only available for about 30% of the Indian urban population and that concentrations in smaller unmonitored cities may be less on average. Coverage of indoor concentrations is poor and in nearly all cases focuses TSP. Fig. 5 shows the distribution of available studies (3) assuming that TSP is about 75% PM_{10}, which is what has been found in biomass-burning households (4). Where needed, a conservative factor of 0.20 has been used convert measurements made solely during cooking periods to 24-hour means. The population-weighted mean of the available studies would seem to be 700-800 $\mu g/m^3$, but more measurements are needed to determine representative national and regional distributions.

Major Evidence Used: Acute Lower Respiratory Infections (ALRI) and Chronic Obstructive Pulmonary Disease (COPD)

This "bottom-up" approach that starts from the actual disease pattern in India and attempts to determine the proportion attributable to indoor exposure for the particular diseases known to be related to air pollution and for which specific studies have been done. The risks due to air pollution of each of the diseases known to be important in India are evaluated one by one using studies from developing-country households using solid fuel. Both mortality and morbidity estimates can be derived in this fashion and thus the overall burden of lost healthy life years can be determined. Although information is not available for all combinations of diseases and age groups, those for which impacts can be determined, when summed, represent another estimate of national impacts. A sample calculation is given in Box 1 below.

Box 1: Calculation of Population Attributable Fraction

[1] This figure based on U.S. EPA data (2).

Taking, for illustration, an odds ratio of 2 for ARI incidence from smoke and a population of 1 million rural children under 5, 75% of whom are exposed to biomass smoke, the following calculation shows how the number attributable to ARI is determined (5):

>Annual ARI deaths (assumed to be directly proportional to incidence for all ARI risk factors) = 9400/million (6)
>Base mortality rate = 9400/(0.25+(0.75*2)) = 5371/million
>Exposed mortality rate = 5371 * 2 = 10742/million
>Number from smoke = (9400/million - 5371/million) * 1.0 million = 4029
>Or, 4029/9400 = 42.9% is attributable to smoke exposure

The most important impacts seem to be ALRI in young children and COPD in adult women. The odds ratios used in the national burden of disease (NBD) calculations for these two effects are based on a growing body of research. The most relevant epidemiological literature for these two effects is elaborated in supplemental Tables 3 and 4 with Tables 5 and 6 summarizing the results. All these tables contain only studies that were designed to allow for quantitative estimates of odds ratios using disease endpoints defined in a rigorous manner. A wide range of additional studies examining non-specific symptoms, such as cough, wheeze, and lowered lung function, are not included in the tables, although a few are cited in the captions and notes.

Table 3: Biomass fuel use and ALRI in children under 5 in developing countries and the United States (3) (7). This list is confined to quantitative studies that have used internationally standardized criteria for diagnosing ALRI. There are additional studies that have noted a relationship with various respiratory symptoms, including cough, runny nose, noisy respiration, and sore throat. See, for example, the study in Lucknow, India, (8).

Study (ref.)	Design	Case Definition	Exposure	Confounding Adjusted	Comments	OR (95% CI)
Rural South Africa (1980) Natal	Case Control 0-12 mo. 132 cases 18 controls	Outpatients Cases: Wheezing, bronchiolitis & ALRI. Clinical + X-ray Controls: Non-resp problems	Asked: "Does the child stay in the smoke?" Prevalence = 33%	Routine data collection: -number of sibs -economic status Examined, not adjusted	Only 63% of 123 X-rayed had pneumonic changes. Control group was small. Exposure assessment was vague.	4.8 (1.7, 13.6)
Rural Nepal (1984-85) Kathmandu Valley	Cohort 0-23 mo. 780 (study 1) 455 (study 11)	Fortnightly home visits: ARI grades 1-1V (Goroka) Breathlessness	Asked mothers for average hours per day the child near fireplace. In Study 1, same team asked about exposure & ARI > possible bias 77% exposed over 1 hour	Since homes were 'homogeneous,' confounding not taken into account	Dose response relationship found Exposure assessment not validated	2.2(1.6, 3.0)
Rural Gambia (1987-88) Basse	Cohort 0-11 mo. 280	Weekly surveillance Mother's history of "difficulty with breathing" over subsequent 3 month period	Reported carriage of child on the mother's back Prevalence = 37%	Adjusted for -birth interval -parental ETS -crowding -socioeconomic score -nutritional indicators --vaccination status -no of health center visits -ethnic group -maternal education -other	Father's ETS only other significant factor. Cautious about interpretation, ability to deal with confounding , and to establish causation where exposure and incidence high	2.8 (1.3, 6.1)
Urban,	Case-control	Three hospitals:	Interview with mother:	None, but success of	No data available re charcoal	9.9 (1.8,

Study (ref.)	Design	Case Definition	Exposure	Confounding Adjusted	Comments	OR (95% CI)
Argentina (1984-87) Buenos Aires (9)	0-59 mo. Cases:516 in-patients; 153 out-patients Controls: 669	Cases: ALRI within previous 12 days Controls: well-baby clinic or vaccination, matched by age, sex, nutritional status, socioeconomic level, date of visit, and residence.	Household heating by charcoal; heating with any fuel; bottled gas for cooking	matching verified. Multivariate analysis "currently underway"	heating in out-patient households. Chimney smoke nearby found to be associated (OR=2.5-2.7) with ARLI in both kinds of patients. ETS not significant for either.	31.4) for charcoal heat for in-patients. 1.6 (1.3,2.0) for any heating fuel in in-patients. 2.2 (1.2,3.9) for gas cooking in out-patients
Rural Zimbabwe (?) Marondera	Case control 0-35 mo. 244 cases 500 controls	Hospital: Cases: Hosp ALRI, clinical and X-ray Controls: Local well-baby clinic	(a) Questionnaire on cooking/exposure to woodsmoke (b) COHb (all) (c) TSP (2 hr. during cooking): 20 ALRI and 20 AURI cases 73% exposed to open fire	Questionnaire: -maternal ETS -overcrowding -housing conditions -school age sibs -paternal occupation not adjusted	Confounding: only difference was number of school age sibs, but not adjusted. COHb not different between ALRI and AURI. TSP means: - ALRI (n=18) 1915 $\mu g/m^3$ -AURI (n=15) 546 $\mu g/m^3$	2.2 (1.4, 3.3)
Rural Gambia (?) Upper River Division	Cohort 0-59 mo. 500 (approx.)	Weekly home visits: ALRI Clinical and X-ray	Questionnaire: Carriage on mother's back while cooking	Questionnaire: -parental ETS -crowding -socioeconomic index -number of siblings -sharing bedroom -vitamin A intake -no. of wives -no. of clinic visits Adjusted in MLR	Boy/girl difference could be due to greater exposure. Report carriage on back quite a distinct behavior so should define the two groups fairly clearly with low level of misclassification	Approach (i) (All episodes) M: 0.5 (0.2, 1.2) F: 1.9 (1.0, 3.9) Approach (ii) (1st episode) M: 0.5(0.2, 1.3) F: 6.0 (1.1,

Study (ref.)	Design	Case Definition	Exposure	Confounding Adjusted	Comments	OR (95% CI)
						34.2)
Urban Nigeria (1985-86) Ibadan (10)	Case control n = 103+103 0-59 mo.	Cases: Hospitalized for ALRI (croup, bronchiolitis, pneumonia, empyema thoracis) based on clinical, x-ray, and biolab workup Controls: Infant Welfare Clinic, age and sex matched, no resp. dis.	Interview Type of cooking fuel used at home (wood, kerosene, gas)	None	Age, nutritional status, ETS, crowding, and location of cooking area also not significant.	n.s.
-same-	Case fatality n= 103 0-59 mo.	Cases: Death in hospital among ALRI patients (see above)	Interview Type of cooking fuel used at home (79 = kerosene, gas=5, wood=16, other=3)	None	Overall case fatality rate = 7.8%. 5 of 8 deaths were from wood-burning homes; one additional death had partial exposure to woodsmoke. Poor nutrition (1.8x), low income (1.5x), low maternal literacy (2.1x) were more frequent in wood-burning homes. ETS rates were similar. Yet, paternal income, maternal education, household crowding, ETS not related to case fatality rate.	12.2 ($p<0.0005$) For those exposed to woodsmoke compared to those exposed to kerosene and gas
Rural Tanzania (1986-87)	Case-control Cases: ALRI deaths = 154	Cases: Verbal autopsy certified by physician of all deaths in period	Household interview; -Child sleeps in room where cooking is done -Cook with wood	Village, age, questionnaire respondent, maternal education, parity,	About 95% of all groups cook with wood. No tendency to be different distances from road. Perhaps confusion of ALRI with	All deaths: 2.8 (1.8, 4.3) for sleeping in room with

Study (ref.)	Design	Case Definition	Exposure	Confounding Adjusted	Comments	OR (95% CI)
Bagamoyo District (11)	Other deaths = 456 Controls = 1160 0-59 mo.	Controls: Multistage sampling (40 of 76 villages). Children with ALRI were excluded.		water source, child eating habit, whether mother alone decides treatment.	other diseases (e.g., measles) . Water not from tap had OR = 11.9 (5.5, 25.7). Models with all deaths, pneumonia deaths, and non-pneumonia deaths all had same significant risk factors. No difference in source of treatment by location where child sleeps. Maternal education, religion, crowding, and ETS, not significant	cooking. 4.3 for pneumonia only. 2.4 for other deaths
Rural Gambia Upper River Division (12)	Case-control Cases: 129 ALRI deaths Controls: 144 other deaths 270 live controls 0-23 mo.	Cases: Verbal autopsy confirmed by 2 of 3 physicians Controls: Matched by age, sex, ethnic group, season of death, and geographic area	Indoor air pollution index based on location and type of stove, carrying of child while cooking, and parental ETS (details not provided)	Cases vrs. Live controls: Adjusted for significant factors in univariate analysis: socioeconomic score, crowding, parental ETS, and nutrition indicators plus maternal education. No significant factors for Cases vrs. Dead controls.	Only other significant risk factor remaining after multiple conditional logistic regression was whether child ever visited welfare clinic OR = 0.14 (0.06,0.36) Misclassification of ALRI deaths (e.g., confusion with malaria) is possible reason for lack of significant difference between Cases and Dead controls .	5.2 (1.7,15.9) for Cases vrs. Live controls
Urban Brazil (1990) Porto Alegre	Case control 0-23 mo. 510 cases 510 controls	Cases: ALRI admitted to hospital, clinical and X-ray Controls: Age matched, neighborhood	Trained field worker interview: -Any source of indoor smoke (open fires, woodstoves, fireplaces) -usually in kitchen while cooking	Interview: -cigarettes smoked -housing quality -other children in hh -income/education -day center attendance -history of resp illness -(other) Hierarchical	Only 6% of children exposed to indoor smoke. Urban population with relatively good access to health care. Not representative of other settings in developing countries	Indoor smoke: 1.1 (0.61, 1.98) Usually in the kitchen: 0.97 (0.75, 1,26)

Study (ref.)	Design	Case Definition	Exposure	Confounding Adjusted	Comments	OR (95% CI)
				model/MLR		
Urban and Rural India (1991) South Kerala-Trivandrum	Case control 2-60 mo. 400 total	Hospital: Cases: Admitted for severe/v severe ARI (WHO definition) Controls: Outpatients with non severe ARI	History taken, including -type of stove, with 'smokeless' category -outdoor pollution	History: -smokers in house -number of siblings -house characteristics -socioeconomic conditions -education -birth wt. etc. Adjusted in MLR	This is a study of the risk factors for increased severity, as the controls have ARI (non-severe). On MLR, only age, sharing a bedroom, and immunization were significant. Exposure assessment was vague and invalidated.	'Smokeless" stove: 0.82 (0.46, 1.43).
Rural Gambia (1989-1991) Upper River Division (13)	Prospective Case-control n=80+159 0-59 mo.	Attending clinic Cases: if high resp. rate, transported to Medical Research Council where physician diagnosed pneumonia after lab tests and x-ray Controls: selected randomly from neighborhood of cases, matched by age	Household questionnaire: Mother carries child while cooking	Adjusted for mother's income, ETS, child's weight slope, recent illness, and significant illness in last six months.	No effect of bednets, crowding, wealth, parental education, paternal occupation, age of weaning, and nutritional status. ETS OR = 3.0 (1.1, 8.1). Etiologic (preventive) fraction for eliminating maternal carriage while cooking = 39%; for eliminating ETS in house = 31%. May be reverse causality, i.e., sick children being more likely to be carried.	2.5 (1.0, 6.6)
Navaho reservation* (1988) Tuba City AZ	Case control 0-24 mo. n = 58+58	Hospital: Cases: ALRI, bronchiolitis, pneumonia clinical and X-ray Controls: Age-sex matched, well child clinic	Interview: Primary energy source for heating and cooking	Family history of asthma, Recent resp. dis. exposure, Dirt floor, Presence of running water.	Wood burning stoves with chimneys but exposure levels not validated. Recent resp. dis. exposure only other factor remaining significant OR=1.4 after multivariate analysis. Humidifiers, ETS, pets, crowding, and house type not	4.8 (1.7, 12.9)

Study (ref.)	Design	Case Definition	Exposure	Confounding Adjusted	Comments	OR (95% CI)
					significant.	
Navaho reservation* (1993) Fort Defiance, AZ	Case-control 1-24 mo. n= 45+45	Hospital: Cases: ALRI, bronchiolitis, pneumonia Controls: Age-sex matched, sought care not for other conditions	Interview: cook with wood Measured 15-h PM10 levels (5 PM - 8 AM)	Interview -# children/hh -running water -electricity -difficulty of transport to clinic -ETS -house type	No variation of PM10 levels with ETS, type of home, etc. Type of cooking/heating only explained 10% of variance. Median PM10 levels for cases: 24 ug/m3, for controls, 22 ug/m3. No effect for coal use or wood for heating, but sample sizes small	Cook with wood 5.0 (0.6,43) PM> 65 ug/m3 7.0 (0.9,57)

* Other U.S. studies have just looked at the relationship of wood burning with respiratory symptoms, e.g. Honicky et al. (14); Butterfield et al. (15); and Browning et al. (16.)

Table 4: Biomass fuels and COPD in women. Note: This list is confined to quantitative studies that have used internationally standardized criteria for diagnosing COPD. There are others that have noted relationships with various respiratory symptoms, many including low lung function in India (17-23); Mozambique (24); Mexico: (25); and Solomon Islands:(26).

Study (ref.)	Design	Case Definition	Exposure	Confounding Adjusted	Comments	OR (95% CI)
Hill Region Nepal (27, 28)	Cross-sectional 1451 women, 1375 men	UKMRC questionnaire on chronic bronchitis	Self-reported hours per day near the fire	Age and sex adjustments only. Separate analyses done for smokers, ex-smokers, and non-smokers	Crude prevalences high: 19% women, similar to me in spite of higher smoking rate among men (83% vrs 63%); Dose-response effect significant (ORs compared to 0-1 h/d): Smokers/ex-smokers: 1-2 h/d: 1.9; 2-4 h/d: 3.7; 4+ h/d: 4.9 Non-smokers: 1-2 h/d: - ; 1-2 h/d: 2.5; 4+ h/d: 2.8 Cor pulmonale has high prevalence (1.4%). 67% of CB cases showed obstructive airway pattern	All women: 1-2 h/d: 1.4 2-4 h/d: 3.3 4+ h/d: 4.3
Urban and Rural Chandigarh, India (29, 30)	Cross-sectional; 2180 women > 20 y; 66 cases	UKMRC questionnaire and peak flow measurement	Reported cook fuel: LPG, kerosene, coal, biomass	No account made for smoking, but few women smoke. No difference in age or height among four groups	Peak expiratory flow significantly low only in cases using biomass fuels. (Odds ratios not reported by author, but calculated here from data in paper)	Biomass/LPG & kero: 3.6 (1.9-6.7); Biomass/Coal & kero: 2.0 (0.95-4.1)

Study (ref.)	Design	Case Definition	Exposure	Confounding Adjusted	Comments	OR (95% CI)
Urban/ Plains/ Mountains, Nepal (31)	Cross-sectional 316/287/346 Mean age: 41/38/36	UKMRC questionnaire on chronic bronchitis	Self-reported current hours per day near the fire.	Age and sex adjustments only. Separate analyses done for smokers, ex-smokers, and non-smokers	Crude prevalences: 11%/14%/28% Dose-response significant: Urban/Plains (ORs compared to 0-1 h/d) Smokers/ex-smokers: 2-4 h/d: 1.3/1.6; 4+ h/d: 2.0/2.0 Non-smokers: 2-4 h/d: -/1.6; 4+ h/d: 1.3/5.8 Mountain: everyone exposed, some more than 12 h/d; prevalence for 8+ h/d: Smokers: 47%; non-smokers: 27% Cor pulmonale has similar trends in all regions, but sample is small	All women: 2-4 h/d: 1.2/1.6 4+ h/d: 1.7/2.3
Saudi Arabia (32)	Case-control 27 cases, 38 controls, visiting hospital, 56,55 y mean ages	Clinically determined COPD. Exclusion criteria: unstable condition, history of atopic disease, IgE, TB, etc.	Interviewed as to number of years exposed to open cooking fires using biomass, or modern fuels. Low lung cancer rates in Saudi women tend to confirm reported low smoking rate	No multivariate analysis, but controls and cases did not differ in age, place of residence, smoking status, use of incense, ETS, occupational exposure	No significant effect found in men (23 cases, 33 controls), nearly all of whom were smokers or ex-smokers (100% of cases, 73% of controls). Although selection bias not completely ruled out, very low male/female ratio of cases (0.7) in spite of low female smoking rate.	For ever having used open fire: 3.3; For using open fire for 20+ years: 12.7

Study (ref.)	Design	Case Definition	Exposure	Confounding Adjusted	Comments	OR (95% CI)
Bogota, Columbia (33, 34) [7, 8]	Case-control, 104 cases, 107 controls, visiting 3 hospitals serving poor populations, women only	Clinically determined chronic bronchitis (CB)/ obstructive airway disease; cases of CB only were not included	Exposure history to household fuel back to infancy taken by interview; subsample cross-checked f or current fuel use found 3 of 40 to be miss-labeled.	Multivariate analysis corrected for age, hospital, smoking, occupational exposure, marital status, education, ETS	Population attributable risk for woodsmoke found to be 50%; dose-response as years of exposure to woodsmoke found to be significant. Protective effect of "gasoline" (probably white gas or kerosene) found in crude model, but not after adjustment for confounders	Adjusted: 3.9 (1.7-9.1)
Mexico City, Mexico (35)	Case-control; 127 cases; 83 TB controls; 100 interstitial lung disease; 97 ear/nose/ throat (ENT); 95 healthy; women over 40	Clinically determined Chronic bronchitis (CB); chronic airways obstruct (CAO), and both together separately evaluated	Type of stove and fuel, number of years, hours per day, degree of kitchen ventilation	Multivariate analysis adjusted for age, smoking, region of origin, income, education, place of residence	Dose response with number of hour-years (hours per day times years of cooking with wood) significant for CB and all control groups except TB as well as all groups together; and significant for CB/CAO with ENT, healthy, and all control groups together.	Odds ratios: for highest exposure group (>200 hour-years) = CB 15 (5.6-40); CB/CAO 75 (18-306); for 100-200 h-y = 9.3, 10.3

Study (ref.)	Design	Case Definition	Exposure	Confounding Adjusted	Comments	OR (95% CI)
Lucknow, India (36)	Cross-sectional 543 rural; 164 urban; ages 16-60; male and female	UKMRC and ATS questionnaires; clinical exam, x-ray	Type of fuel; wood and dung classified as dirty; coal, kero, and LPG as clean; current use.	No multivariate analysis, but corrected for age and sex	Lack of correction for socio-economic factors may be critical because of urban/rural mix. Effect of dirty fuel also found for TB (OR=2.5). Population attributable fraction of dirty fuel for all resp disease (mainly COLD, TB, ARI) put at 71%. (For smoking: 64%; keeping large animal: 9.5%)	All ages and both sexes: 7.9 (2.8-21.8)
Highland Bolivia (37)	Cross-sectional; 2 villages, n=214 over 20 years	UKMRC questionnaire	Outdoor cooking in one village, indoor in other. Time-activity questionnaire. PM_{10} in 12 houses	Adjustment for age and sex; similar socio-economic status, access to health care, and physical conditions. Smokers excluded.	No difference between men and women. Chronic bronchitis prevalence = 22% and 13% in the 2 villages.	OR = 2.5 (1.3-5.0) for indoor cooking.

Table 5. Summary of ALRI studies in children under 5 years and indoor biomass fuel use for cooking. Details and additional studies in ref. 3. Only studies with standardized diagnostic criteria for ALRI and sufficient information to calculate odds ratios are included here. Odds ratios are significant at least to 95%.

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9 Case-control Studies: South Africa (38), Zimbabwe (39), *Nigeria (10), Tanzania (11), Gambia (12) (13), *Brazil (40), *India (41), Argentina (9)

6 adjusted for confounders; *n* = 4311; Odds Ratios = 2.2-9.9

*Results not significant (Nigeria: no risk factors found to be significant; Brazil: only 6% of children used biomass; India: exposure determined by stove type, which has been shown to be a poor predictor)

3 Cohort Studies: Nepal (42), Gambia (43) (44)

2 adjusted for confounders; *n* = 910; Odds Ratios = 2.2-6.0

1 Case-fatality Study: Nigeria (10)

Hospitalized patients; *n* = 103 Odds Ratio = 8.2

2 in USA (Navaho reservation) with metal woodstoves (45, 46)*

Case-control; *n* = 206 Adjusted for confounders Odds Ratios = 4.8

*Significant only at 92.5%, but just 10% difference in measured PM_{10} levels between exposed and un-exposed.

Such studies do not always find consistent effects, however (47) (48).

Table 6. Summary of studies of household biomass cookfuel use and chronic obstructive lung disease (COPD) in women. For details and additional studies see (49). Here only studies are included with validated procedures for determining COPD status and sufficient information to calculate odds ratios. Reported odds ratios are significant at least to 95%.

3 Case-control studies: Saudi Arabia (32); Columbia (34); Mexico (35)	
2 adjusted for confounders; *n* = 498; 2 showed exposure-response with years of cooking	Odds Ratios = 3.3 - 15
5 Cross-sectional studies: Nepal (28) (31); India (30, 36); Bolivia (37)	
All partly adjusted; *n* = 5528 2 showed exposure-response with years of cooking	Odds Ratios = 1.4 - 7.9

Background Disease Burden in India

Although not consistent in every particular with other estimates of Indian health conditions, the India dataset from the Global Burden of Disease (GBD) studies (6) is used here for attributable burden calculations. Unlike any other available databases, the GBD has the considerable advantages of being coherent and internally consistent, i.e., the deaths and illness for all diseases, broken down by age and sex, add to the know totals in each category. In addition, the criteria used to determine disease categories, cause of death, duration of disease, etc. have been consistently applied across diseases and age-groups in all major global regions, thus facilitating comparisons.

Shown in Table 7 is the national burden of disease (NBD) in India in the form of a list of those disease categories causing at least 1% of the NBD or at least 1% of all deaths. Although commonly used, number of deaths is not a very informative indicator of ill-health. Better is some measure of the loss of healthy life entailed by injury, disease, and premature death. From the GBD, I use the disability-adjusted life year (DALY), which is one such measure becoming common in international comparisons (6). The DALY basically indicates the amount of healthy life expectancy lost because of a disease or risk factor, including both mortality and morbidity. Note that the first four categories mostly (87%) affect children less than five years, who as a result bear the largest overall ill-health burden of any age group.

Table 7. Indian National Burden of Disease: Disease categories accounting for at least 1% of lost DALYs or 1% of deaths. Also showing percent of burden in children under 5 and overall female/male ratio (6).

Disease Category	DALYs %	Deaths %	DALYs in <5yr olds[†]	Female / Male[‡]
-ARI	12	13	80	1.13
-Diarrhea	10	9.8	85	1.1
-Perinatal	8.8	7.0	100	1.04
-Child Cluster	6.4	5.4	83	1.0
-TB	4.6	8.0	6.5	0.58
-Malnutrition	4.2	1.3	52	1.2
-Depression	3.6	0.02	0	1.49
-Heart (ischaemic)	3.5	13	~0	0.81
-Falls	3.5	0.5	39	0.62
-Congenital	2.9	1.8	90	1.02
-Maternal	2.6	1.2	0	xxx
-Cancer	2.5	5.3	2.7	1.15
-Road Accidents	2.1	1.9	14	0.4
-STD/HIV	1.9	0.7	19	1.87
-Fires*	1.9	1.3	14	2.54
-Stroke	1.5	4.8	5.3	0.99
-Tropical Cluster*	1.1	0.4	5.5	0.45
-Eye*	1.1	~0	0.3	1.03
-Cirrhosis*	1	1.6	4.7	0.46
-COPD	1	1.5	5.9	0.79
-Suicide	1	1.1	0	0.99
-Diabetes*	0.8	1.1	6.2	1.05
Total	78	80	45[§]	1.02[§]

DALY= Disability-Adjusted Life Year; ARI= Acute Respiratory Infections; STD= Sexually Transmitted Diseases; COPD= Chronic Obstructive Pulmonary Disease

*Not on the global list of 1% diseases. On the global list, but not on India's, are malaria, war, violence, alcohol (direct effects), and drowning.

[†]Children under 5 are 14% of the national population;

[‡]Ratio of DALYs lost at all ages;

[§]For total national burden.

Weaknesses and Implications for Further Research

Although a major improvement over application of the pollutant-based method using developed-country data, the approach presented here has important remaining weaknesses:

1. All the epidemiological studies relied upon for the estimates here have been observational, i.e., they examined the health conditions of populations with existing differences in exposure patterns. Such studies are always subject to potential bias from confounders, i.e., some third factor may be responsible for the effect. For example, because both solid fuel use and poor nutrition are a consequence of being poor, it may be that poor health in solid-fuel-using households is mainly attributable to poor nutrition, lack of education, or other factors associated with poverty. Most of the epidemiological studies reviewed above attempted to check and/or adjust for confounders, but it is never possible to be sure that all potential confounders have been adequately accounted (49).

   In epidemiology, the "gold standard" for arguing causality is the prospective randomized double-blind intervention, where the researchers randomly allocate the exposure-reducing treatment within a population and follow the resulting difference in health conditions between the intervention group and the controls. Done well, it is thought that such a study design essentially eliminates the possibility that some unknown confounders have been operating.

   It might be noted, however, that all epidemiological studies of air pollution, including those in developed-country urban settings, have been observational. Apparently, no randomized studies have ever been done. Even so, society has been able to derive risks and set standards in spite of not reaching the "gold standard," which is required for drug trials, for example. Given careful accounting for confounders in sufficient numbers of studies by different investigators in different settings and backed by other evidence, such as animal tests and plausible physiological mechanisms, observational data by themselves are often adequate for establishing causality in practical terms.

   Randomized trials would at best be difficult and in practical terms are impossible for many air pollution endpoints. It is not feasible to impose a treatment and wait for 25 years to detect a difference in lung cancer rates, for example. Furthermore, it is difficult to imagine how one would randomize cities or parts of cities with regard to some intervention related to outdoor air pollution.

   In this respect, household air pollution in developing countries offers a research opportunity not available in developed countries, i.e., to conduct randomized trials in ways that could provide large exposure differences between intervention and control groups.

Improved fuels, stoves, or ventilation could be randomly allocated at the household level, thus providing an opportunity to move air pollution epidemiology toward the "gold standard."[2] Not only do such study designs have scientific advantages, they have important policy merits because they reveal much more convincingly how much health improvement can be achieved by a particular intervention. Endpoints that would seem most appropriate for such trials are ARI, low birth weight, perinatal effects, and, perhaps, TB and asthma.

2. Essentially all the studies relied on here focused only on morbidity, e.g., they monitored the difference in incidence or prevalence of ARI, COPD, or TB between exposed and un-exposed populations. Much of the overall burden from these diseases, however, is due to mortality, which was not measured directly, but was estimated by using morbidity as an indicator. We assumed, for illustration, that a case of ARI attributed to air pollution in children under 5 years in India carries the same mortality risk as the average case of ARI from all causes, i.e., that the case fatality rate for air-pollution-induced ARI is no different from the average. This may well be a conservative assumption, however, for the one relevant study (10) indicates that the case-fatality rate may be much higher in smoke-exposed infants. Clearly, however, more work of this kind is needed to pin down this relationship for all the major health outcomes.

   The availability of information on fuel use from the fuel use databases and on exposure-response relationships from the literature mandated use of a simple binary variable for exposure, i.e., exposed or not to smoke from household solid fuels. In reality of course, there is a continuum of exposures from high to low and the binary indicators used are only imperfect indicators.[3] For example, households using solid fuels have different ventilation conditions, different family behavior patterns, different solid fuel characteristics (biomass/coal type, moisture, contaminant content, etc.), different distances from neighbors using smoky fuels, and may use different mixtures of solid and other fuels over the year even if relying principally on one or the other. Consequently, there is undoubtedly a substantial amount of "nondifferential misclassification bias (NMB)," meaning that some households classified as exposed actually had low exposures and vice versa. Because it dilutes the real differences in health effects, the most likely result of NMB is an underestimate of the risks and thus an underestimate of the NBD (51).

   NMB could be reduced by a number of means. Some are relatively easy. For example, more detailed fuel use questions could be asked at each household to determine whether a mixture of fuels is used, what kinds of solid fuels are used, the condition of stoves, degree of ventilation, etc. To reduce NMB to a minimum, however, it would be important to actually measure exposures in the households participating in a epidemiological study. Done with care, such efforts could also lead to better understanding of the

[2] It would difficult, however, to meet the further requirement of the "gold standard" that the studies be double-blind, i.e., that neither householders nor researchers knew which households were receiving the intervention and which not (controls).
[3] For example, see (4) and (50).

actual shape of the exposure-response relationship over a wide range of exposures.[4] They might also be able to distinguish whether measures of mean or peak exposures best reflect risk.

To go from better risk estimates to better estimates of the burden will require better national estimates of exposure as well. For this purpose, additional household fuel questions have been added to the 1991 Indian Census questionnaire to determine fuel quality and the use of mixtures. If buttressed with random stratified measurements of pollution levels in different settings or validated household exposure models, such information could greatly improve NBD estimates. Similar surveys are needed in other parts of the world.

3. Although by broad comparison with what is known in developed countries, there is need for further study of all the health outcomes noted above, perhaps the most egregious gaps exist for TB and heart disease. TB is the chief outcome of AIDS in developing countries, and because of the alarming rise in HIV rates, TB is expected to continue to grow rapidly in India and elsewhere (52). It would be quite valuable to know how much this burden might be blunted by household environmental improvements.

   Heart disease is one of the main outcomes of smoking and of air pollution exposures in developed countries, but no studies have been done of the risks from indoor air pollution in developing countries. The background rate is expected to rise in India as incomes rise and thus it is becoming increasingly important to know the incremental burden from air pollution (both indoor and outdoor).

   In addition, perinatal conditions represent a significant fraction of the NBD in India and other developing countries [7.3% for all developing countries, 18% of the burden in developing-country children under 5 (6)]. Because of their relatively acute nature compared to COPD or heart disease, for example, these disease conditions would not be difficult to study and could be done so using the more powerful randomized intervention design.

4. Attributable risk calculations are usually done with the assumption that all other risks remain constant (53). Thus, a number of separate attributable risks calculated for a population can add up to more than the actual total burden of disease. What this means is that the risks and the diseases they produce are not completely independent. In the case of indoor air pollution, for example, some of the resulting IHD may have been induced or exacerbated by COPD. As a result, the disease-by-disease method has the

[4] Developing-country settings offer not only the opportunity to study higher exposure levels than now exist in developed countries, but also to explore larger ranges within the same population, because typical exposure distributions overlap with the upper end of those in developed countries.

potential of some double counting.

5. On the other hand, there are several reasons to think that the burden estimated here might be understated for women and children:

- The likely impact of IAP on birth outcome, including birthweight, will have an effect not only on perinatal death, but also on a range of other non-respiratory diseases of childhood and later. Thus, for example, some childhood diarrhea and sudden infant death may be accounted to IAP exposures during pregnancy. Since the burden calculated here only includes ARI and asthma, there is likely a substantial underestimation from this effect.
- The "healthy mother" effect may not be accounted, i.e., a mother ill because of IAP may not be able to care for her children as well increasing their risks of diseases other than ARI, including diarrhea, for example.
- The GBD framework accounts TB secondary to HIV as HIV cases. Thus, actual TB cases are understated in the TB row of the GBD tables. Since IAP apparently acts to suppress respiratory immunity, however, it probably produces excess TB in HIV victims as well as in normal TB-positive persons, but this is not calculated in the results here, which start with the TB as listed in the GBD.
- Few deaths are directly accounted to cataracts in the GBD. There is evidence, however, that blind people in LDCs have substantially higher general mortality rates than the non-blind.[5] Including indirect impact of cataracts would increase the total deaths and DALYs due to IAP.
- As discussed above, due either insufficient data for quantification, no estimates have been included of the IAP burden from mouth, nose, and throat cancers; trachoma; interstitial lung disease; silicosis; *cor pulmonale;* or a range of respiratory symptoms such as cough, wheeze, lowered lung function, etc., even though there are studies in each case showing such effects in developing-country households using solid fuels.

7. Lastly, because of data limitations, the analysis in this study only provides estimates for women and young children. No attempt has been made to calculate the disease burden for youths or adult men. It is likely that the relative impact is smaller in these populations because of their exposure patterns. Given the known impact of particulate air pollution at even relatively low levels (by developing country norms), however, the impact may be still be important. It may thus be useful to focus a few future studies on these groups, particularly on female youths (5-15) who, because of their household roles as daughters and young wives, may experience significant exposures.

[5] See Evans in (6), p. 250

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