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Impact of cooking and heating fuel use on acute respiratory health of preschool children in South Africa

J Wichmann, KVV Voyi

Dependence on polluting fuels (wood, coal, crop residues, animal dung, paraffin) for cooking and heating exposes countless women and young children in developing countries to elevated air pollution concentration indoors. This study explored the connection between polluting fuel use for cooking and heating with childhood (<5 years) acute lower respiratory infections (LRIs) in South Africa. Analysis is based on data from 4 679 children living in 2 651 households collected during the 1998 South African Demographic and Health Survey. Cases were defined as those who experienced cough accompanied by short, rapid breathing during the two weeks prior to the survey. Logistic regression was applied to estimate the odds of suffering from acute LRI among children from households using polluting fuels in combination with electricity or liquid petroleum gas/natural gas for cooking and heating relative to those using electricity or liquid petroleum gas/natural gas exclusively, after controlling for potentially confounding factors. Two-thirds of children lived in households using polluting fuels. Nineteen percent suffered from acute LRI. After adjustment, children in households using polluting fuels in combination with electricity or liquid petroleum gas/natural gas for cooking and heating were 27% more likely to have an acute LRI event than children from households using cleaner fuels exclusively (OR 1.27; 95% CI: 1.05-1.55). Although there is potential for residual confounding despite adjustment, international evidence on indoor air pollution and acute LRIs suggests that this association may be real. As nearly half of households in South Africa still rely on polluting fuels, the attributable risk arising from this association, if confirmed, could be substantial. It is trusted that more detailed analytical intervention studies will scrutinise these results in order to develop integrated intervention programmes to reduce children's exposure to air pollution emanating from cooking and heating fuels.

Introduction

The ultimate endeavour of epidemiology is to identify modifiable determinants of disease occurrence and progression and to contribute in testing the efficacy and effectiveness of interventions on these determinants.

A study conducted in 1990 reported that acute respiratory infections (ARIs), in the form of pneumonia, were then the principal cause of death amongst young children in large parts of South Africa.[1] This is supported by international findings that ARIs are a leading cause of childhood illness and death worldwide, accounting for an estimated 6.5% of the entire global burden of disease.[2] In addition there is no simple and rapid treatment for ARIs as is the case with diarrhoeal disease and oral rehydration therapy.

ARIs are classified as upper respiratory tract infections (URIs) or lower respiratory tract infections (LRIs).[3] The upper respiratory tract consists of the airways from the nostrils to the vocal cords in the larynx, including the paranasal sinuses and the middle ear. The lower respiratory tract covers the continuation of the airways from the trachea and bronchi to the bronchioles and the alveoli. ARIs are not confined to the respiratory tract and have systemic effects, because of possible extension of infection or microbial toxins, inflammation and reduced lung function. Diphtheria, whooping cough and measles are vaccine-preventable diseases that may have a respiratory tract component. The common LRIs in children are pneumonia and bronchiolitis. The respiratory rate is a valuable clinical sign for diagnosing acute LRI in children who are coughing and breathing rapidly.[3]

Respiratory ill health is the main reason for use of the health services in the country. However, much of what must be done to prevent respiratory symptoms and diseases lies outside of the sphere of healthcare. Therefore interventions should be targeted at risk factors and determinants, rather than only providing medical treatment for those already affected. South Africa, a middle income country, is faced by health risk factors from a first world situation (eg. industry, traffic, aging population) along those from a third world situation (eg. domestic burning of wood, animal dung, crop residues, coal and/or paraffin, poor sanitation, overcrowding). Thus intervention strategies deduced from studies conducted in developed countries are not merely applicable in this country. Developed countries focus mostly on intervention strategies to reduce outdoor air pollution, such as strict industry compliance monitoring and reduction in traffic emissions.[4]

Wood, animal dung, coal, crop residues and paraffin (hereafter 'polluting fuels') are at the bottom of the energy ladder regarding combustion efficiency and cleanliness, yet 41%, 48% and 23% of 11 million South African households used these fuels for cooking, heating and lighting, respectively during 2001, even when access to electricity was available.[5,6] Smoke from polluting fuel combustion produces numerous air pollutants that are detrimental to health, including respirable particulate matter, such as $PM_{2.5}$ (particulate matter < 2.5 μm in aerodynamic diameter) and

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PM_{10} (< 10 μm in aerodynamic diameter), carbon monoxide (CO), nitrogen oxides (NO_x), formaldehyde, benzene, 1,3 butadiene, polycyclic aromatic hydrocarbons (PAHs)(such as the carcinogen benzo[a]pyrene, B[a]P) and many other toxic volatile organic compounds (VOCs). The fuels are typically burned in simple, inefficient and mostly unvented household cooking stoves, which, combined with poor ventilation, generate large volumes of smoke indoors.

Bailie *et al* conducted an indoor exposure assessment study during winter in a poor urban environment in South Africa where a range of fuel types, including paraffin, was used.[5] The mean maximum hourly average was 28 $\mu g.m^{-3}$ (range 0451 $\mu g.m^{-3}$) for NO_2, 1 414 $\mu g.m^{-3}$ (range 0-17 723 $\mu g.m^{-3}$) for SO_2 and 34 $mg.m^{-3}$ (range 0-388 $mg.m^{-3}$) for CO. The number of households where standards were exceeded by the maximum hourly averages by NO_2 and CO was six (9%) and 20 (30%), respectively, (Hourly World Health Organisation (WHO) standard of 200 $\mu g.m^{-3}$ and 30 $mg.m^{-3}$, respectively) and for SO_2 the number was 28 (42%) (Hourly Californian standard of 655 $\mu g.m^{-3}$)(no WHO or US EPA standard for maximum *hourly* average for SO_2 exists).[7,8] Total suspended particulates (TSP) concentrations ranged from a minimum of 7 $\mu g.m^{-3}$ to a maximum of 433 $g.m^{-3}$. Comparisons of TSP concentrations with international standards have not been made, as these are now focused on PM_{10} and $PM_{2.5}$. No hourly standards or guidelines also exist for PM_{10} and $PM_{2.5}$. Röllin *et al* provided scientific evidence that even in partially electrified homes in South Africa levels of RSP were significantly lower (mean 77 $\mu g.m^{-3}$, median 37.5 $\mu g.m^{-3}$) relative to their un-electrified counterparts (mean 162 $\mu g.m^{-3}$, median 107 $\mu g.m^{-3}$)(p=0.012) during summer.[9] Stationary (kitchen CO) levels in un-electrified and electrified dwellings ranged from 0.36-20.95 ppm (0.42-24.44 $mg.m^{-3}$) and 0-11.8 ppm (0-13.8 $mg.m^{-3}$), respectively. The mean level of log (CO) in the kitchen was significantly higher in the un-electrified areas (1.25 vs. 0.69) (p=0.0004). The mean level of log (CO) for personal measurements conducted on children (<18 months) was higher in the un-electrified areas (0.83 vs. 0.34) (p<0.0001).

A local study by Thomas *et al* reported that on average 14% of households had children (<6 years) usually or always present when their mothers were cooking.[10] This percentage increased to 18.3% of households in the lowest wealth quintile. Paraffin stoves were burning in the lower wealth quintile homes on average four hours per day, with the evening meal taking over half of this time to prepare. Muller *et al* established in a local study that people spend on average two hours cooking indoors during both winter and summer.[11] Consequently in such situations children and women are exposed to much higher air pollution levels indoors than from outdoor sources.

The mechanisms by which polluting fuel smoke can boost the risk of ARIs are not entirely known; however, exposure has been associated with diminished pulmonary immune defence mechanisms.[12-15] Exposure to one of the numerous pollutants in biomass smoke, PM_{10}, has been reported to provoke a systemic inflammatory response that includes stimulation of the bone marrow, which can play a role in the pathogenesis of the cardiorespiratory morbidity.[12-15] Exposure to PAH, especially B[a]P, can cause immune suppression and can raise the risk of infection and disease.[16-18] Acute and chronic exposures to NO_x can increase bronchial reactivity and susceptibility to bacterial and viral infections.[19,20] It is thus probable that persistent exposure to high levels of polluting fuel smoke can weaken the pulmonary defence mechanisms, reduce lung function and intensify children's susceptibility to ARIs.

The review by Wichmann and Voyi focused on South African air pollution epidemiological studies and summarised information on international studies cited in reviews from the WHO, Smith *et al*, Bruce *et al* and Ezzati and Kammen regarding evidence on polluting fuel use and various health outcomes, such as ARIs.[21-25] From these reviews follows that no new South African or international studies were published on the impact of polluting fuel use on ARI prevalence during the past 10 years. Five international studies conducted in developing countries reported statistical significant associations between exposure to polluting fuel smoke and acute LRI in preschool children.[26-30] Three of these five studies had cohort designs[26-28] and two were case-control studies.[29,30] Three case-control studies conducted in developing countries reported no statistical significant associations between polluting fuel use and acute LRI in preschool children.[31-33] One case-control study reported a borderline association between exposure to polluting fuel smoke and acute LRI in preschool children.[34] Two case-control studies[35,36] and one case-fatality study[31] reported statistically significant associations between polluting fuel use and acute LRI deaths in preschool children. Two case-control studies conducted in a Navajo reservation in the USA reported statistically significant associations between exposure to polluting fuel smoke and acute LRI in preschool children.[37,38]

Notwithstanding warnings of high levels of indoor air pollution in informal and traditional housing in South Africa, barely any comprehensive epidemiological studies have been embarked on in the country.[21] Two local cross-sectional studies and one local case-control study established a significant link with indoor air pollution indicators and respiratory health of preschool children,[7,39,40] whilst two cross-sectional studies did not.[41,42] A local prospective cohort study did not quote the p value or confidence intervals of the association measure.[43] Wichmann and Voyi concluded that most of the local studies have dealt inadequately with confounding factors.[21] It is thus advisable to apply caution when interpreting results from local studies.

The review by the WHO stated that although consistent evidence is available that polluting fuel smoke does increase the risk of ARIs, it is not yet sure by how much.[25] The current study will attempt to add to the current body of knowledge regarding indoor air pollution exposure due to combustion of polluting fuels for cooking and heating and acute LRI in children (< 5 years). This study had the advantage of controlling for more possible confounders than previous local studies. In order to improve health for the unique South African population through epidemiological studies it is imperative that these studies should attempt to minimise systematic and random errors and subsequently strengthen their validity and accuracy. This study is based on the 1998 South African Demographic and Health Survey (SADHS).[44] The 1998 SADHS is the first national health survey conducted across the entire country. Data from this survey provided the opportunity to examine the prevalence and determinants of various respiratory symptoms and diseases in a representative national population rather than a selected high risk population, as has been the case in previous studies.

It is trusted that more detailed analytical intervention studies will scrutinise these results in order to develop integrated intervention programmes to reduce children's exposure to air pollution emanating from polluting cooking and heating fuels. Such research is important because a large proportion of households in South Africa and other developing countries rely on polluting fuels for household energy and acute LRIs are a leading cause of ill health and death in young children.

Materials and methods

Survey method

The 1998 SADHS had a cross-sectional design and was a national household survey of the population living in private households in all nine provinces of South Africa. Detailed information on the survey design is outlined elsewhere.[44] The first stage (proportional stratified sampling) of the two-stage sampling led to a total of 972 enumerator areas (EAs) being selected for the SADHS (690 in urban areas and 282 in non-urban areas). The second stage involved a systematic random sample of 10 and 20 houses in selected urban and rural EAs, respectively.

The SADHS questionnaires were translated into all nine official languages of South Africa and checked by back-translation. The questionnaires were pretested in November/December 1996 as part of a pilot study. Interviewers were trained over several weeks. Interviews were conducted after working hours. Interviewers were instructed to return twice if a suitable respondent was not found at home. Fieldwork commenced late January 1998 and was completed in September 1998. The response rate at the household level was 97% of 12 860 households in 966 EAs. For the women's health survey (which included 15-49-year-old women), the overall response rate was 92.3%.

Ethical approval was granted by the Ethics Committee of the South African Medical Research Council to conduct the 1998 SADHS. The survey obtained informed consent from each respondent (in this case, mothers of the children included in the women's health questionnaire) before asking questions. The analysis presented in this paper is based on secondary analysis of existing survey data with all identifying information removed.

Health outcome, exposure and confounder variables

For each child (<5 years), the mother was asked if the child had been ill with coughing in the two-week period preceding the survey interview. For children who had been ill with coughing in the last two weeks, the mother was additionally asked if the child, when ill with coughing, breathed faster than usual with short, rapid breaths. Children who suffered from coughing accompanied by short and rapid breathing at any time during the last two weeks are defined as having suffered from an acute LRI. This reported prevalence of acute LRI is the response variable in our analysis.

Exposure to cooking and heating smoke was ascertained indirectly by type of fuels used. This was the main independent variable. The survey question was: "What does your household use for cooking and heating?" Respondents indicated all the different fuel types that were used. The households were grouped into two categories representing the extent of exposure to cooking and heating smoke-pollution fuels (if either wood, dung, paraffin or charcoal was used in combination with liquid petroleum gas (LPG)/natural gas or electricity) and clean fuels (if LPG/natural gas or electricity was used exclusively). None of the households used wood, dung, paraffin or charcoal exclusively.

Confounders pertaining to a child included: age (in months, categorised in five groups), sex, birth order (categorised in four groups) and number of children in the household. Confounders related to the biological mother of a child included: age at birth (in years, categorised in three groups), education (in years, categorised in three groups) and ethnic identity (African/black, white, coloured, Asian/Indian). Under apartheid, South Africans were categorised into one of four socially defined groups: White (mainly European ancestry), Asian (Indian sub-continent ancestry), African or black (descent primarily from one of a number of Bantu ethnic groups in southern Africa) and coloured (general grouping, including a mixture of black, Malay, European and indigenous Khoisan ancestry). Race is very much linked to past access to resources and lastingly with socio-economic status and educational status.

Mishra analysed the 1999 Zimbabwean DHS data and calculated a household standard of living index (SLI) as a possible confounder in the association between household cooking fuel use and ARIs in preschool age children (<5 years).[45] The same approach was followed in this study. Mishra calculated the SLI by adding the following scores:[45] 3 for a car or tractor; 2 each for a scooter/motorcycle, TV, telephone, refrigerator, piped/public tap water, flush toilet, electricity, wood/vinyl/asphalt/ceramic/cement/carpet of main floor material; 1 each for a bicycle, radio. Index scores range from 0-2 for low SLI, 3-8 for medium SLI, 9-21 for high SLI. The location of the household was categorised on an urban/rural level and provincial level.

Data analysis

Data from the household and women's health questionnaires were merged in this analysis. The merged data file had 5 093 observations. Statistical analyses were conducted using STATA version 8. A small residual category of other fuels used for cooking and heating (n=6, 0.13% of the sample, N= 5 093) was excluded from the analysis due to unknown nature of fuels in that category. All children from multiple births (n=133, 2.61% of the sample, N=5 093) were excluded from the analysis as well as all children who had passed away (n=269, 5.28% of the sample, N=5 093). Eventually 4 679 children from 2 651 households were included in the analyses. The 1998 SADHS report pointed out that the risk factors might be correlated with each other.[44] Independence among risk factors was investigated with χ^2 tests. It was observed that most of the risk factors were significantly correlated at the 95% confidence level, although very poorly with correlation coefficients varying from 0.01 to 0.40. Consequently conventional logistic regression analysis was conducted, instead of a conditional analysis. Simple descriptive statistics were used to describe the characteristics (TAB command) of the sample and in calculating the prevalence of acute LRI for each characteristic (SVYTAB command).

The crude odds ratio (OR) and adjusted OR along with 95% confidence intervals (CI) were derived using the SVYLOGIT procedure. A weighting factor was applied to all observations to compensate for over-sampling of certain categories of respondents in the study design. The estimation of CI accounts for design effects due to clustering at the EA, provincial and household level. The adjustments for clustering at the EA and provincial levels were done using the SVYSET command.

Results

The data presented here represent a more detailed analysis of the first national survey of the symptoms and prevalence of acute LRI amongst preschool children in South Africa. Table 1 lists the characteristics of the 4 679 children from 2 651 households.

Two thirds of children live in households that used polluting fuels in combination with LPG/natural gas or electricity (Table 1). Children are relatively equally distributed by sex. Children aged 0-11 months are somewhat less represented compared to the other age groups. The percentage of children in the sample decreases from birth order 1 to 3. A quarter of children are born at birth order >3. Less than half of the children live in homes with other children (43%). Approximately the same number of children is born to mothers aged 15-24 and 25-34 years. More than half (57%)

Table 1: **Sample distribution of South African children (<5 years) by selected characteristics, reported prevalence of acute lower respiratory infections (LRI) during the two weeks preceding the survey and crude odds ratios**

Characteristic	Sample distribution (%)	Acute LRI prevalence (%)	OR (95% CI)
South Africa		19.26±3*0.76	
Cooking and heating fuel type			
Clean*	32.98	16.24	
Polluting	67.02	18.94	1.26 (1.04-1.54)
Age of child (in months)			
0-5*	10.86	18.90	
6-11	10.84	23.08	1.24 (0.90-1.17)
12-23	20.39	22.54	1.15 (0.85-1.56)
24-35	19.81	18.02	0.89 (0.65-1.23)
36-59	38.11	13.91	0.65 (0.48-0.88)
Sex of child			
Boy*	50.37	17.82	
Girl	49.63	18.22	1.08 (0.92-1.28)
Birth order			
1*	33.70	17.88	
2	24.56	17.75	1.06 (0.84-1.33)
3	15.26	19.61	1.16 (0.89-1.50)
>3	25.48	17.51	0.97 (0.75-1.24)
Number of children per household			
1*	56.66	19.95	
>1	43.34	15.48	0.70 (0.57-0.85)
Mother's age at childbirth			
15-24*	39.90	18.05	
25-34	42.62	18.30	1.01 (0.83-1.22)
35-49	17.48	17.24	1.01 (0.76-1.33)
Mother's education (in years)			
<3*	24.11	20.21	
3-6	57.47	17.78	0.96 (0.77-1.20)
>6	18.42	15.89	0.86 (0.64-1.14)
Ethnic identity			
Black/African	80.81	17.77	
Coloured	11.97	18.39	1.02 (0.78-1.33)
White	4.38	21.46	1.36 (0.86-2.16)
Asian/Indian	2.27	16.98	0.95 (0.49-1.84)
Household standard of living			
Low*	16.03	17.73	
Medium	36.25	17.87	0.97 (0.70-1.34)
High	47.72	18.23	0.99 (0.73-1.34)
Residence			
Urban	45.18	18.07	
Rural	54.82	17.97	1.06 (0.88-1.29)
Number of children	4 679	4 679	4 679

* *Reference category*

of them have mothers with three to six years of education at the time of the survey. The majority of the children (48%) live in high standard of living households, followed by medium (36%) and low (16%) SLI homes.

Roughly the same number of children lives in urban and rural areas. The majority of the children are classified as African/black, followed by 12% as coloured, 4% as white and 2% as Asian/Indian. The survey population does not quite reflect the ethnic make-up of the South African population for whites and coloureds according to the 2000 census data (Africans 77.2%, whites 10.5%, coloureds 8.8% and Indians 2.5%).[6]

Nineteen percent of children (<5 years) had an acute LRI event during the two weeks preceding the survey. Children aged 6-23 months are somewhat more probable to have experienced an acute LRI event than children under 6 months of age or older children.

The reported prevalence of acute LRI is higher for white children compared to the other ethnic groups. Children living in households with other children are less prone to have an acute LRI event (15% compared to 20%). Children with birth order 3 have a higher prevalence rate of acute LRI compared to the other groups (20% compared to 18%). Children whose mothers have less than three years of education at the time of the survey have more acute LRI events compared to the other groups. Prevalence of acute LRI does not fluctuate much by sex of child, mother's age at childbirth, household SLI or urban/rural setting.

Of all the variables, only cooking and heating fuel type, age of child and number of children in households are significantly associated with acute LRI in the unadjusted analyses (Table 1). Children living in households using polluting fuels are 26% more likely to have an acute LRI event compared to those living in households using low polluting fuels for cooking and space heating (OR 1.26; 95% CI: 1.04-1.54). Children aged 36-59 months are 35% less likely to have an acute LRI event compared to the other age groups (OR 0.65; 95% CI: 0.48-0.88). Children living in households with other children are 30% less likely to have an acute LRI event (OR 0.70; 95% CI: 0.57-0.85).

In the adjusted analysis, polluting fuel use (OR 1.27; 95% CI: 1.05-1.55), the oldest child age category (OR 0.66; 95% CI: 0.49-0.89) and having more than one child living in a household (OR 0.69; 95% CI: 0.56-0.83) are statistically associated with acute LRI (Table 2).

Table 2: **Adjusted odds ratio estimates of cooking and heating fuel type and other risk factors on acute lower respiratory infection (LRI) among South African children (< 5 years)**

Characteristic	OR (95% CI)
Cooking and heating fuel type	
Clean	
Polluting	1.27 (1.05-1.55)
Age of child (in months)	
0-5*	
6-11	1.27 (0.92-1.76)
12.23	1.15 (0.84-1.56)
24-35	0.87 (0.63-1.20)
36-59	0.66 (0.49-0.89)
Number of children in household	
1*	
>1	0.69 (0.56-0.83)
Number of children	4 679

* *Reference category*

Discussion

Acute LRI has been identified as a severe problem in South Africa, particularly for children under 5 years of age.[1] There is also a strong case for acknowledging the large public health risk arising from indoor air pollution exposure due to continued reliance on polluting fuels for cooking and heating in South Africa. Results of this study suggest that exposure to cooking and heating smoke from polluting fuels is significantly associated with acute LRI prevalence in young children, independent of a child's age or the number of children in a household.

The adjusted risk estimates for the type of fuel use are consistent with other South African studies that investigated the risk of indoor fuel use and acute LRI in children (<5 years),[39,40] whilst international studies conducted in other developing countries reported stronger associations.[26-30] These international studies had analytical study designs, such as cohort and case-control designs.[26-30] This study therefore provides further evidence that cooking and heating with polluting fuels may amplify the risk of acute LRI in young children.

There are some important limitations in this study, which should be taken into account when interpreting the results. The SADHS had a cross-sectional design. Cross-sectional studies are weak to prove causation as they are subject to difficulties interpreting the temporal sequence of events since health status and determinants are measured simultaneously. However, the biological plausibility of exposure to smoke from polluting fuels has been addressed.

Reliance on self-reported data does include a risk of misclassification of disease and exposure status resulting in statistical significance arising by chance. Information on acute LRI is based on mothers' reports and no clinical measurements were undertaken and smoke exposure was ascertained from type of fuel used for cooking and heating. Although the symptomatic definition used here is aimed to assess acute LRI in children, some acute URI may have been integrated in the conveyed prevalence. In developing countries such as South Africa, where clinical data on acute LRI are frequently unattainable or very weak, the symptomatic definition of illness used here is assumed to present a reasonably accurate estimation of acute LRI in the population. As previously mentioned, the respiratory rate is a valuable clinical sign for diagnosing acute LRI in children who are coughing and breathing rapidly.[3]

Notwithstanding the lack in the measurement of air pollution exposure and acute LRI, the uniformity in the significance of crude and adjusted effects of fuel use on childhood acute LRI implies that the association might be real.

No quantitative exposure assessment (including duration of exposure, as reflected by frequency and duration of fuel use for heating and cooking per day) was conducted during the SADHS. The type of food cooked inside and outside was also not ascertained. It is recommended that future SADHS should separate the type of fuels used for cooking and heating in two separate questions. Exposure to smoke from polluting fuels during heating is much longer than exposure during cooking.

Given the high prevalence of acute LRI and relatively small number of deaths in the sample (n=269, 5.28% of the sample, N=5 093), the impact of selection bias in the sample due to acute LRI-related mortality on the estimated effect is likely to be little. If such bias is prominent, the risk estimates of effect of cooking and heating fuel smoke on acute LRI will be downwardly biased as children living in households using medium and high polluting fuels are more likely to die from acute LRI.

It was found that children who have received treatment for acute LRI are more likely to have suffered from acute LRI than not (64% compared to 5%). So there is little bias due to underreporting of acute LRI due to lack of awareness that the child had an acute LRI event during the two-week reference period. This is supported by Kauchali *et al* who conducted a local rural study on maternal perceptions of childhood ARI (<5 years).[46] They reported that maternal recognition of respiratory distress was good (sensitivity 91.3%, 95% CI: 86.8-95.8%; specificity 95%, 95% CI: 89.5100%), with little variation between mothers (kappa = 0.704).

Other factors that might contribute to childhood acute LRI, such as outdoor and indoor air pollution sources (eg. mother's smoking status, location of household close to industry, transportation sources or waste fill sites, insecticide or fertiliser use, allergens such as pollen, dust, fungal spores from mildew and moulds) along with meteorological variables (precipitation, temperature, humidity), mother's pre-pregnancy weight, child's birthweight, mother's exposure to other pollution sources and risk factors during pregnancy as well as the current HIV/AIDS epidemic were not recorded. Excluding these risk factors from the analysis might introduce substantial bias (differential or nondifferential). Thus the direction of bias on the calculated association measures is not easy to predict. The definition of a confounder is important to remember: it must be associated with both the exposure variable of interest and the health effect. As the association between these factors and polluting fuel use is not available from the literature, it is impossible to predict the direction of the potential bias on the association measure.

The most common indicators used for measurement of socioeconomic status are income level, occupation and educational level.[47] We cannot rule out that the results would have been different with another measure. However, DHSs traditionally do not include questions on income and expenditure. Educational level measures one aspect of socioeconomic status and we cannot rule out that the results would have been different with another measure. More than a third (35%) of the women never married, so we could not assume that the current partner's job or education remained the same during the five years preceding the survey.

The current HIV/AIDS epidemic along with escalating number of TB infections could also influence the association between acute LRI and exposure to smoke from polluting fuels. The prevalence rate amongst household members clinically diagnosed with TB was 2% and did not indicate an association with acute LRI in preschool children.

During the analysis it was assumed that confounding is additive and not multiplicative. If confounding is additive, then the confounding variable would produce the same additional risk of a health outcome in the exposed and unexposed; but if the health outcome is rare in unexposed, it would follow that the confounder might account for a much larger proportion of health outcome in that group. Conversely, if two exposures act multiplicatively, the proportional increase in health outcome rates due to confounding would be the same in exposed and unexposed; but if the health outcome is more prevalent in the exposed group, the absolute increase would be larger in the exposed. This issue thus has important risk assessment and public health policy implications.

The generalisibility of data is determined by the non-response rate. The response rate was larger than 90% for both the household and women's health surveys. Thus the bias that might be introduced by non-response is relatively low for the SADHS data.

As mentioned previously, the review by the WHO stated that although consistent evidence is available that polluting fuel smoke does increase the risk of ARIs, it is not yet sure by how much.[25] It is hoped that future analytical studies will validate the magnitude of the risk posed by smoke from paraffin, coal, wood and dung combustion on children's acute respiratory health in South Africa. However, given the fact that only 5% of the research budget is spent on health-related research in South Africa, compared to 30% in developed countries,[48] it is important that analytical studies should not merely redocument the impact of known risk factors. Instead, such studies should provide a basis for designing technical or socio-behavioural interventions to minimise exposure to air pollution from cooking and heating fuels, such as the study by Smith-Sivertsen *et al.*[49] They conducted the very first ever published randomised control intervention trial in a poor rural community in Guatemala. South African intervention studies should include a comprehensive exposure assessment with indoor and personal measurements for SO_2, NO_2, O_3 and $PM_{2.5}$ and a detailed health assessment.

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