Chapter 7

POTENTIAL INFLUENCE OF COOKING AND HEATING FUEL USE ON 1-59 MONTH OLD MORTALITY IN SOUTH AFRICA

Objectives: To determine the association between dirty cooking and heating fuel use and 1-59 month old mortality in South Africa whilst allowing for a number of confounders or effect modifiers.

Methods: Data from the 1998 South African Demographic and Health Survey (SADHS) were analysed. The SADHS was the first national health survey conducted across the entire country and provided the opportunity to examine the prevalence and determinants of various morbidity and mortality outcomes in a representative national population rather than a selected high risk population, as has been the case in most previous studies in developed countries.

Results: The results from 3 556 children (142 deaths) from 2 828 households suggested that exposure to cooking and heating smoke from dirty fuels is significantly associated with 1-59 month mortality, after controlling for mother's age at birth, water source, asset index and household crowdedness (OR = 1.99, CI: 1.04-3.68).

Conclusions: Although there is potential for residual confounding despite adjustment, the better documented evidence on outdoor air pollution and mortality suggest this association may be real. As nearly half of households in South Africa still rely on polluting fuels and women of childbearing age perform most cooking tasks, 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.

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7.1 Introduction

The aim of epidemiology is to identify factors that cause disease, with the broader goal of identifying opportunities for prevention in order to reduce and eventually eliminate the burden of disease in human populations. Despite all the shortcomings of epidemiological studies, they are important in linking exposure to human health directly.[1-8] Determining the burden of disease due to preventable risk factors is important for identifying and prioritising environmental and public health interventions.

Notwithstanding technical advances that have improved survival of children (12-59 months) in developing countries, infant (< 12 months) mortality rates are still at least 10 times higher in developing countries than in developed countries.[9] Infant deaths mainly happen in the perinatal (< 7 days old) and neonatal periods (< 1 month old), mostly due to maternal characteristics, delivery factors, prematurity, intrauterine growth retardation and congenital causes, whilst later deaths are more likely to be the result of infection and environmental factors.[10-23] It is therefore important to identify risk factors that predict early infant and child mortality. This article will concentrate on indoor air pollution exposure due to the combustion of animal dung, wood, paraffin and coal (henceforth dirty fuels) as the source of energy for cooking and heating as a potential risk factor for 1-59 month old mortality. Over 40% of the global burden of disease attributed to environmental factors falls on children below five years of age, who account for only about 10% of the world's population.[24] Furthermore, air pollution is the largest single environment-related cause of ill health among children in most countries.[25] In other countries it is the second, after the scarcity of safe water. Globally, 2.6% of all ill-health is attributable to indoor smoke from dirty fuels, nearly all in poor regions.[26]

A recent report by the World Health Organisation accounted that there is currently substantial evidence concerning the adverse effects of air pollution - especially for outdoor respirable particulate matter (PM_{10}, particles with aerodynamic diameters below 10 μm) - on different pregnancy outcomes and infant health.[27] The evidence is sufficient to infer a causal relationship between particulate air pollution and respiratory deaths in the postneonatal period (28 days to 1 year of life)(WHO Monograph, 2004).

Thus this concrete evidence can be used to strengthen outdoor air pollution mitigation in South Africa. However, as about 47% of 11 million households in the country still rely on dirty fuels as the source of energy for cooking and heating and with 70% using electricity for lighting[28], it is obvious that indoor air pollution may be magnitudes higher than outdoor air pollution exposure. Although outdoor sources often dominate air pollution emissions, indoor sources frequently dominate air pollution exposures. Exposure is a function of both the pollutant concentration in an environment, and the person-time spent in the environment. Since most people spend the majority of their time in homes, schools and workplaces, human exposure to air pollution is largely a function of pollutant levels in indoor settings (which can arise from outdoor sources, and vice-versa).

As the exposure-response relationships and risk estimates for under five mortality have been derived for outdoor air pollution in developed country urban situations, it raises a number of issues about their suitability for application indoor air pollution due to dirty fuel combustion in developing countries.[29] Over the past 20 years, the hazards of indoor air pollution have been documented by a growing body of literature[30], but very few studies focused on its impact on infant and child mortality. South Africa, a middle income country, is faced by health risk factors from a First World situation (e.g. industry, traffic, aging population) along those from a Third World situation (e.g. domestic burning of dirty fuels, poor sanitation, overcrowding). The three global factors that directly or indirectly impact on health - the community and social environment, the physical environment and the family and individual environment – are different for developed and developing countries. In the South African context economical, social and cultural factors may render the population more vulnerable to increased air pollution exposure, due to factors such as poor hygiene, overcrowding, dusty environments, poor nutrition, open dwellings, outdoor lifestyles and the escalating HIV/AIDS epidemic. Thus there is a need to derive local risk estimates from local data in order to calculate the burden of disease due to indoor air pollution exposure.

Dirty fuels are at the bottom of the energy ladder regarding combustion efficiency and cleanliness.[31] Smoke from dirty fuel combustion produces numerous air pollutants that are detrimental to health, including respirable particulate matter (RSP, PM_{10}), 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 stoves, combined with poor ventilation, generate large volumes of smoke indoors. Even when the stoves are vented to the outside, combustion of unprocessed solid fuels produces enough pollution to significantly affect local neighbourhood pollution levels, with implications for total exposures.

The poorest and most vulnerable populations in developing countries are most exposed to indoor air pollution from fossil and biomass fuel combustion for cooking and heating. 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.[32] 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 4 hours per day, with the evening meal taking over half of this time to prepare. Muller et al established in another local study that people spend on average 2 hours cooking indoors during both winter and summer.[33]

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.[34] The mean maximum hourly average was 28 $\mu g.m^{-3}$ (range 0–451 $\mu g.m^{-3}$) 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 twenty (30%) respectively (Hourly WHO standard of 200 $\mu g.m^{-3}$ and 30 $mg.m^{-3}$, respectively) and for (sulphur dioxide) SO_2 the number was 28 (42%) (Hourly Californian standard of 655 $\mu g.m^{-3}$)(no hourly WHO or USEPA standard for SO_2 exists).[35,36] Total suspended particulates (TSP) concentrations ranged from 7-433 $\mu g.m^{-3}$. Comparisons of TSP concentrations with international standards have not been made, as these are now focused on PM_{10} and $PM_{2.5}$ particles. 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 non-electrified counterparts (mean 162 $\mu g.m^{-3}$, median 107 $\mu g.m^{-3}$)($p=0.012$) during summer.[37] Stationary (kitchen CO) levels in un-electrified and electrified dwellings ranged from 0.36-20.95 ppm and 0-11.8 ppm, 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) ($p<0.0001$).

The mechanism by which dirty fuel smoke can increase the risk of acute and chronic respiratory diseases, which may lead to premature death is not fully understood. Exposure has been associated with compromised pulmonary immune defence mechanisms in both animals and humans.[38-41] The special vulnerability and susceptibility of children in respect to air pollution exposure are related to several differences between children and adults: the ongoing process of lung growth and development, incomplete metabolic systems, immature host defences and high rates of infection by respiratory pathogens. Furthermore, activity patterns specific to children can lead to higher exposure to air pollution and higher doses of pollutants reaching the lungs. The efficiency of detoxification systems exhibits a time dependent pattern during pre- and post-natal lung development that in part accounts for increased susceptibility of young children to pollutants at critical time points. Tobacco smoke also has been shown to cause depressed immune system responses.[42-46] Of the specific pollutants in dirty fuel smoke, exposure to PM_{10} has been shown to induce a systemic inflammatory response that includes stimulation of the bone marrow, which can contribute to the pathogenesis of the cardiorespiratory morbidity.[38-41] Other evidence indicates that exposure to PAH (especially B[a]P, which is found in large quantities in dirty fuel smoke) can cause immune suppression and can increase the risk of infection and disease.[47-49] Moreover, acute and long-term exposures to NO_x, commonly found in dirty fuel smoke, can increase bronchial reactivity and susceptibility to bacterial and viral infections.[50,51] It is, therefore, possible that extended exposure to high levels of dirty fuel smoke can impair the pulmonary defence mechanisms, compromise the lung function, and render people more susceptible to acute respiratory infections (ARI) and developing asthma or increase the frequency and severity of attacks in asthmatic people.

The current study will add to the current body of knowledge regarding cooking and heating fuel use and 1-59 month old mortality, whilst considering a number of confounders or effect modifiers. The 1998 South African Demographic and Health Survey (SADHS) is the first national health survey conducted across the entire country.[52] Data from this survey provided the opportunity to examine the prevalence and determinants of various morbidity and mortality outcomes in a representative national population rather than a selected high risk population, as has been the case in most previous studies in developed countries. It is trusted that the results of this study will draw attention to risk factors and lead to debate on potential integrated intervention programs.

7.2 Methods

7.2.1 Survey method

The 1998 SADHS had a cross-sectional design and was a national household survey of the population living in private households in the country. Detailed information on the survey design is outline elsewhere.[52] The sampling frame for the SADHS was the list of approximately 86 000 enumeration areas (EAs) created by Central Statistics (now Statistics South Africa, SSA) for the Census conducted in October 1996. The EAs, ranged from about 100 to 250 households and were stratified by 9 provinces, urban and non-urban residence and by EA type. The number of households in the EA served as a measure of size of the EA.

The first stage (proportional stratified sampling) of the two-stage sampling led to a total of 972 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. Oversampling was conducted in some areas to enable inference to be made about differences across provinces and race – and in the Eastern Cape province, across health districts.

In addition to the main survey of households a women's health questionnaire was administered individually to women (15-49 years) in all the households selected for the main survey. The SADHS questionnaires were translated into 9 of the 11 official languages of South Africa and checked by backtranslation.[52] The questionnaires were pretested in November/December 1996 as part of a pilot study.

The household questionnaire characterised all household members, including their age, sex, race and education, household characteristics such as fuels use for cooking and heating (Refer to Appendix 1). The women's health questionnaire was designed principally to produce reliable estimates of demographic rates (particularly fertility and childhood mortality rates), of maternal and child health indicators and of contraceptive knowledge and use for the country as a whole, the urban and the non-urban areas separately and for the nine provinces (Refer to Appendix 3).

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, the overall response rate was 92.3%.

The analysis presented in this paper is based on secondary analysis of existing survey data with all identifying information removed.

7.2.2 Definitions

For each child under age 5, the mother was asked if the child was still alive and if not, at what age the child passed away (Refer to Appendix 3).[52]

Variables related to the household included exposure to cooking and space heating smoke, access to flush toilet facilities (coded 0 if own/shared; coded 1 if bucket/pit larine or no facility/bush/field), access to clean water (coded 0 if using piped water in dwelling/site/yard, tap water/water carrier/tanker, borehole/well or bottled water;

coded 1 if water from dam/river/stream/spring, rain water tank), number of rooms per people living in household (code 0 if ≤ 2; coded 1 if >2), nutritional status (coded 0 if household going hungry never/seldom; coded 1 if often/seldom) and asset index as an indicator of socio-economic status.

Exposure to cooking and space heating smoke was ascertained indirectly by type of fuels used. This was the main independent variable. The 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: dirty fuels (if either wood, dung, coal or paraffin was used in the fuel combination without using LPG/natural gas or electricity) and clean fuels (if LPG/natural gas or electricity was used exclusively in the fuel combination). The small residual category of other fuels (n=6, 0.12%, N=5001, 33 missing values) was excluded from the analysis due to unknown nature of fuels in that category.

A modified version of the method used by Mishra to calculate a household standard of living index (SLI) was applied to calculate an asset index.[53] This modified approach still used the scores as applied by Mishra, however the variables related to water supply and type of toilet facility were omitted from the modified approach.[53] This was done to assess the potential influence of water supply and type of toilet facility on 1-59 month mortality otherwise these variables would have been embedded in a SLI. The asset is calculated by adding the following scores: 3 for a car or tractor; 2 each for a scooter/motorcycle, TV, telephone, refrigerator, electricity, wood/vinyl/asphalt/ceramic/cement/carpet of main floor material; 1 each for a bicycle, radio. In this modified approach the asset index was coded as 0 if ≥ 35 and coded as 1 if <35.

Variables pertaining to a child included age (coded 0 if <12 months; coded 1 if ≥ 12 months), sex (coded 0 for a boy; coded 1 for a girl), birth order (coded 0 if 1; coded 1 if > 1), birth interval (coded 0 if <24 months; coded 1 if ≥ 24 months) and whether the child was breastfed (coded 0 if yes; coded 1 if no).

Variables related to the biological mother of a child included age at birth (coded 0, 1, 2 and 3 if <19, 19-24, 25-34 and ≥ 35 respectively). Education was not considered as the educational status at the birth of the child was not known and was not constant over the observation period.

The location of the household was categorised on an urban/rural level and provincial level. The child's year of birth is included to capture a time trend in child mortality.

7.2.3 Data analysis

All subsequent statistical analyses of results were done using STATA version 8. The household (N=12 209) and women's questionnaire (N=5 066) data were linked with a unique identification variable, containing the cluster number and household number. The merge data set had 5 060 observations. This analysis included only children whose mothers had indicated their ethnic identity as Africa/Black. This ethnic group comprised 81.9% (n=4 114, N=5 060 with 16 missing values) of the data with 237 deaths compared to 25 from the other 3 groups. 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 language groups in Southern Africa) and Coloured (general grouping, including a mixture of Black, Malay, European and indigenous Khoisan ancestry). Race is still very much linked to past access to resources, socio-economic status and educational status.

All children from multiple births (n=113, 2.75%, N=4 114 with 237 missing values) were excluded from the analysis as well as all children who did not live with their mothers (n=331, 8.54%, N=4 114 with no missing values), women who only visited the household during the survey (n=77, 1.87%, N=4 114 with 1 missing value) and deaths before 1 month since the cause of death for newborns is difficult to determine and may be due to quite different risk factors (n=27, 0.66%, N=4 114 with no missing values). Eventually 3 556 children, of whom 142 were deaths, were included in the analysis.

Simple descriptive statistics were used to describe the characteristics of the sample (TAB command) and in calculating the mortality incidence rate for each characteristic (STSUM command).

The 1998 SADHS report pointed out that the risk factors might be correlated with each other.[52] Correlations among risk factors were investigated with χ^2 analysis (PWCORR command). It was observed that most of the risk factors were significantly correlated at the 95% confidence level, although very poorly with correlations coefficients varying from 0.01 to 0.40.

To estimate the effects of the independent variables on 1-59 month old mortality, Cox proportional hazards analysis was performed (STCOX command), stratified by urban or rural. The time variable was either set as the child's current age (months since birth until interview date) or age of death (in months), respectively for those who were still alive and those who were deceased at the interview date. Time was fitted to estimate the hazard rate ratio, hereafter denoted relative risk, of mortality. The results were presented as the relative risk of mortality with 95% confidence intervals (CI).

The proportional hazards assumption was confirmed for each independent variable (STPHTEST command). First univariate analyses were run and subsequently a multivariate analysis with all the significant independent variables identified from the former procedure.

7.3 Results

The data presented here represent a more detailed analysis of the first national survey of under-five mortality in South Africa. Table 1 lists the characteristics of the 3 556 children from 2 828 households. The overall mortality incidence rate in the 5 years within the study was 1.473/1000.

Table 1 Number of observed person-months, incidence rates and deaths for risk factors under investigation

Risk factor	No.	%	No. of deaths	%	No. of person-months at risk	Incidence rates per 1000 person months
Age (months)						
1-11	2 740	77	120	85	91 710	1.309
12-59	816	23	22	15	4 666	4.715
Sex						
Boy	1 804	51	78	55	48 159	1.620
Girl	1 752	49	64	45	48 217	1.327
Birth order						
1	1 144	32	48	34	30 060	1.597
>1	2 412	68	94	66	66 316	1.418
Mother's age at birth (years)						
<19	375	11	26	18	10 331	2.517
19-24	1 116	31	44	31	29 782	1.477
25-34	1 443	41	42	30	39 360	1.067
≥35	622	17	30	21	16 903	1.775
Preceding birth interval (months)						
<24	3 222	91	123	87	86 437	1.423
≥24	334	9	19	13	9 939	1.912
Breastfed						
Yes	3 151	89	387	273	84 207	1.473
No	405	11	18	13	12 169	1.479
Area of residence						
Urban	1 262	35	36	25	34 963	1.030
Rural	2 294	65	106	75	61 413	1.726
Fuel use						
Clean	714	20	13	9	19 721	0.659
Dirty	2 819	79	129	91	76 112	1.695
Toilet						
No Flush	2 683	75	120	85	71 800	1.671
Flush	850	24	21	15	23 924	0.878
Water source						
Clean	2 487	70	74	52	27 670	2.458
Dirty	1 045	29	68	48	67 995	1.088
Asset index						
<35	1 956	55	97	68	52 411	1.851
≥35	1 600	45	45	32	43 965	1.024
Persons per room						
≤ 2	1 041	29	52	37	28 138	1.848
>2	2 515	71	90	63	68 238	1.319
Household going hungry						
Never/seldom	1 277	36	44	31	35 098	1.254
Often/sometimes	2 220	62	98	69	59 734	1.641

Table 1 (continues)
Number of observed person-months, incidence rates and deaths for risk factors under investigation

Risk factor	No.	%	No. of deaths	%	No. of person-months at risk	Incidence rates per 1000 person months
Year of birth						
1993	456	13	26	18	24 031	1.082
1994	662	19	30	21	28 718	1.045
1995	663	19	30	21	21 033	1.426
1996	736	21	25	18	14 994	1.667
1997	851	24	31	22	7 180	4.318
1998	188	5	0	0	420	0.000
Province				0		
Western Cape	57	2	2	1	1 439	1.390
Eastern Cape	1 070	30	55	39	2 8432	1.934
Northern Cape	107	3	4	3	3 030	1.320
Free State	236	7	9	6	6 378	1.411
KwaZulu-Natal	520	15	25	18	13 917	1.796
North West	302	8	7	5	8 512	0.822
Gauteng	271	8	8	6	7 531	1.062
Mpumalanga	442	12	15	11	11 867	1.264
Limpopo	551	15	17	12	15 270	1.113
Total	3 556	100	142	100	96 376	1.473

Children aged 12-59 months were somewhat less represented compared to the <12 months age group. Children were relatively equally distributed by sex. The minority of the children were first borns (32%). Most of the children were born to mothers aged 19-24 and 25-34 years and spaced within 24 months of their siblings. The majority of the children were breastfed (89%) at some stage.

Most of the children lived in rural areas (65%). The majority of the children lived in households that use dirty fuels for cooking and heating either exclusively or in combination with clean fuels (79%), with no access to a flush toilet (75%), with access to clean water (70%) and low asset index (55%). Most of the children lived in crowded households (>2 people/room)(71%) with poor nutritional status (hungry often/sometimes)(62%).

There were fewer births during 1998 compared to 1993-1997. By province of residence, the largest proportion was from the Eastern Cape (30%), nearly equal proportions from KwaZulu-Natal, Mpumalanga and Limpopo (12-15%) and smallest from Western Cape (2%).

In the univariate analysis only mother's age at birth, fuel use, access to clean water, asset index and people/room were significantly associated with an increase risk in 1-59 month old mortality (Table 2). In the adjusted model, all of them, except asset index, are still significantly associated with an increase risk in mortality (Table 3).

The impact of mother's age at birth on under-five mortality is not affected much in the adjusted model. Children born to mothers aged 19-24 and 25-34 were significantly less at risk from dying compared to those born to mothers younger than 19 years, whilst older mothers (≥ 35 years) had no significant health benefit. Compared to households using clean fuels, children in households using dirty fuels had a substantially higher mortality rate: from 2.22 (CI: 1.22-4.04) to 1.95 (CI: 1.32-2.90) in the univariate and adjusted analyses. Indeed, the negative effect of dirty fuels in the univariate model exceeded that of lack of clean water supplies. However, their effects were similar in the adjusted model. Children living in household without clean water supplies were nearly twice more at risk from dying compared to their counterparts (adjusted model: 1.96, CI: 1.32-2.90). The risk posed by lack of access to clean water decreased somewhat (7%) from the univariate to adjusted analyses. Surprisingly, children living in crowded households (> 2 persons/room) had a significantly lower risk of dying (37%) compared to their counterparts. The influence of a crowded household decreased somewhat (11%) from the univariate to adjusted analyses.

7.4 Discussion and conclusions

Results of this study suggest that exposure to cooking and heating smoke from dirty fuels is significantly associated with 1-59 month mortality, after controlling for mother's age at birth, water source, asset index and household crowdedness (OR = 1.99, CI: 1.04-3.68). It is intriguing that a household crowdedness decreases the risk of

Table 2 Relative risk of mortality with 95% confidence intervals obtained from univariate Cox regression analyses, stratified by area of residence

Risk factor	Relative risk	95% CI
Age (months)		
1-11★	1.00	-
12-59	1.54	0.95, 2.49
Sex		
Boy★	1.00	-
Girl	0.84	0.61, 1.17
Birth order		
1★	1.00	-
>1	0.87	0.62, 1.24
Mother's age at birth (years)		
<19★	1.00	-
19-24	0.60	0.37, 0.97†
25-34	0.44	0.27, 0.71†
≥35	0.71	0.42, 1.20
Preceding birth interval (months)		
<24★	1.00	-
≥24	1.35	0.83, 2.19
Breastfed		
Yes★	1.00	
No	1.11	0.67, 1.81
Fuel use		
Clean★	1.00	-
Dirty	2.22	1.22, 4.04†
Toilet		
Flush★	1.00	-
No flush	1.52	0.82, 2.83
Water source		
Clean★	1.00	-
Dirty	2.11	1.44, 3.10†
Asset index		
≥35★	1.00	-
<35	1.59	1.08, 2.32†
Persons per room		
≤ 2★	1.00	-
>2	0.71	0.50, 0.99†
Household going hungry		
Never/seldom[a]	1.00	-
Often/sometimes	1.21	0.84, 1.73
Province		
Western Cape★	1.00	-
Eastern Cape	0.92	0.21, 3.91
Northern Cape	1.01	0.18, 5.51
Free State	0.90	0.19, 4.21
KwaZulu-Natal	0.96	0.22, 4.15
North West	0.42	0.09, 2.09
Gauteng	0.88	0.19, 4.15
Mpumalanga	0.62	0.14, 2.81
Limpopo	0.50	0.11, 2.28
Year of birth	1.00	0.88, 1.13

★Referent category, †p<0.05 for stratum RR

Table 3 Relative risk of mortality with 95% confidence intervals obtained from multivariate Cox regression analyses, stratified by area of residence

Risk factor	Relative risk	95% CI
Mother's age at birth (years)		
<19★	1.00	-
19-24	0.58	0.36, 0.95†
25-34	0.43	0.26, 0.70†
≥35	0.67	0.40, 1.13
Fuel use		
Clean★	1.00	-
Dirty	1.99	1.04, 3.68†
Water source		
Clean★	1.00	-
Dirty	1.96	1.32, 2.90†
Asset index		
≥35★	1.00	-
<35	1.25	0.82, 1.88
Persons per room		
≤2★	1.00	-
>2	0.63	0.44, 0.89†

★Referent category
†p<0.05 for stratum RR

mortality in the multivariate model. A possible explanation might be that fewer fuels are burnt for space heating when more people are sharing a dwelling.

The potential risk estimates from the multivariate model were in general consistent with other developing country studies that focused on toilet facilities and clean water as risk factors for infant and childhood mortality. Macassa et al observed an 80% higher risk for 12-59 month mortality when households in urban areas of Mozambique had no flush toilet in a multivariate model.[54] They did not report any significant health benefits when households had clean water sources or for mothers to have babies when they are older than 19 years, as opposed to this study. Woldemicael reported that children born in urban areas of Eritrea had 59% and 44% decreased postneonatal and childhood mortality compared to children born to households without a flush toilet and piped water, respectively.[55] Gubhaju et al reported that the risk of death was 44% lower among Nepalese children born to households, which used piped water compared to their counterparts, even after controlling for socio-economic and demographic factors.[56] The study also indicated that the risk of death was 64% lower among infants born to households which had their own toilets compared to their counterparts.

Although most available evidence relating air pollution and mortality was obtained for adults using outdoor exposure data from developed countries, pollution has been also associated with increased mortality in children, but in a significantly smaller number of studies. Furthermore studies conducted in developing countries rather focused on outdoor instead of indoor air pollution. Conceicao et al reported estimated proportions of childhood respiratory deaths attributed to outdoor CO, SO_2 and PM_{10} exposure, when considered individually, are around 15, 13 and 7%, respectively in the city of São Paulo, Brazil.[57] Loomis et al found that excess infant mortality was associated with PM_{10} levels during the days before death, with the strongest association observed for the average concentration of fine particles during the 3-5 preceding days in Mexico City.[58] A 10 $\mu g.m^{-3}$ increase in the mean level of PM_{10} during those 3-5 days was associated with a 6.9% excess of infant deaths. Infant mortality was also associated with the levels of NO_2 and O_3 3-5 days before death, but not as consistently as with PM_{10}. Penna et al observed that, with the income variable included in the regression, a statistically significant association between the average annual level of particulates and infant mortality from pneumonia from an investigation in the Rio de Janeiro Metropolitan Area.[59]

A recent report by Statistics South Africa, listed the ten leading underlying natural causes of death for different age groups during 1997, 1999 and 2001.[60] Table 4 presents the variation across the three years of leading underlying natural causes of death for infants (< 12 months) and children (12-48 months).

Infant deaths were mostly due to causes related to the perinatal stage, as also reported in the literature.[10-23] This particular analysis excluded the perinatal age group. However, between 22.6% and 18.7% of infant deaths were due to unexplained causes. It is likely that some of these premature deaths may be attributed to high indoor air pollution exposure. Multiplying the number of deaths due to other causes with the attributable fraction (0.44, CI: 0.03-0.68) it is estimated that 2 684 (CI: 187-4 154), 2 697 (CI: 188-4 174) and 2521 (CI: 176-3 902) infant deaths could have been prevented if dirty fuel use were completely eliminated during 1997, 1999 and 2001, respectively. The top 3 leading causes of child mortality (12-48 months) across the three years were intestinal

Table 4 Ten leading underlying natural causes of death for each age group: 1997, 1999 and 2001[60]

Broad group of causes of death	1997			1999			2001		
	Rank	No.	%	Rank	No.	%	Rank	No.	%
Less than 1 year									
All causes		27 044	100.0		30 359	100.0		30 750	100.0
Respiratory and cardiovascular - perinatal (P20 - P29)[*]	1	6 797	25.1	1	7 983	26.3	1	9 388	30.5
Digestive disorders foetus and newborn (P75 - P78)	2	4 814	17.8	2	6 323	20.8	2	5 498	17.9
Other disorders - perinatal (P90 - P96)	3	3 368	12.5	3	3 308	10.9	3	3 419	11.1
Disorders related to gestation and foetal growth (P05 - P08)	4	1 598	5.9	4	1 563	5.1	5	1 418	4.6
Infections specific to the perinatal period (P35 - P39)	5	1 310	4.8	5	1 446	4.8	4	1 626	5.3
Foetus and newborn complications (P00 - P04)	6	1 216	4.5	6	1 125	3.7	7	690	2.2
Haemorrhagic and haematological. disorders of the foetus & newborn (P50 - P61)	7	610	2.3	8	645	2.1	8	682	2.2
Malnutrition (E40 - E46)	8	424	1.6	9	495	1.6	10	514	1.7
Transitory endocrine and metabolic disorders specific to foetus and newborn (P70 - P74)	9	404	1.5	…	…	…	9	563	1.8
Certain immune disorders (D80 - D89)	10	387	1.4	7	842	2.8	6	1 207	3.9
Human immunodeficiency virus [HIV] diseases (B20 - B24)	…[†]	…	…	10	484	1.6	…	…	…
Other causes		6 116	22.6		6 145	20.2		5 745	18.7
1-4 years									
All causes		7 735	100.0		9 780	100.0		11 170	100.0
Intestinal infectious diseases (A00 - A09)	1	1 611	20.8	1	2 274	23.3	1	2 308	20.7
Malnutrition (E40 - E46)	2	733	9.5	3	886	9.1	3	910	8.1
Influenza and pneumonia (J10 - J18)	3	626	8.1	2	931	9.5	2	1 453	13.0
Tuberculosis (A15 - A19)	4	288	3.7	4	373	3.8	4	640	5.7
Human immunodeficiency virus [HIV] diseases (B20 - B24)	5	219	2.8	6	338	3.5	6	334	3.0
Other forms of heart disease (I30 - I52)	6	164	2.1	7	141	1.4	9	153	1.4
Certain immune disorders (D80 - D89)	7	111	1.4	5	349	3.6	5	454	4.1
Inflammatory diseases of the central nervous system (G00 - G09)	8	110	1.4	9	125	1.3	8	175	1.6
Other bacterial diseases (A30 - A49)	9	102	1.3	…	…	…	…	…	…
Metabolic disorders (E70 - E88)	10	92	1.2	10	112	1.1	10	131	1.2
Other viral diseases (B25 - B34)	…	…	…	8	137	1.4	7	226	2.0
Other causes		3 679	47.6		4 114	42.1		4 386	39.3

[*] The causes of death were coded using procedures described in the Stats SA manual Guidelines for coders using ICD-10. ICD-10 is the tenth revision of the International Classification of Diseases developed by the World Health Organisation (WHO), which is followed worldwide in order to have a uniform way of classifying morbidity as well as causes of death.

[†] Category not in top ten

infectious diseases, malnutrition and influenza and pneumonia. Furthermore, there was a steady increase in the number and percentage of deaths due to intestinal infectious diseases and influenza and pneumonia. Certain disorders involving the immune mechanism appeared in all three years, as did HIV-related diseases. It is anticipated that indoor air pollution may exert its impact in unison with all the causes of death listed, except perhaps those from malnutrition and metabolic disorders. Thus from the 6 910, 8 782 and 10 129 deaths in 1997, 1999 and 2001 3 033 (CI: 212-4 693), 3 854 (CI: 269-5 965) and 4 445 (CI: 310-6 880) may be attributed to high indoor air pollution exposure.

While this study achieved its objective to determine the association between dirty cooking and heating fuel use and 1-59 month old mortality whilst allowing for a number of confounders or effect modifiers, there are numerous limitations. Since it was a cross-sectional design, it was hard to inspect any possible temporal relationships. The data signifies a specific point in time and determining a cause and effect relationship, therefore, can be limited. Any association reported in this study therefore does not necessarily indicate causation. The proportional hazards assumption was confirmed for each independent variable. However, this test cannot indicate slight changes in exposure variables over the 5 year period. A large proportion (43%) of women still lived in their current house when the child was born, so we assumed that the toilet facility and water source variables remained constant over time. Mother's education was not included in the analyses as it is assumed not to be constant over the 5 year period.

Some biases within the study may influence the generalisability of the results. There is probable recall bias among respondents answering questions involving events occurring in the past, such as household going hungry and breastfeeding patterns immediately after birth. Reporting bias may be present, since the possibility exists for respondents to answer in such a fashion that may be more socially desirable or in ways that they perceive would get a more approving response from the interviewers. There is also the potential for information bias. Other factors that might be detrimental to children's health, such as mother's size and pre-pregnancy weight, child's birthweight, mother's exposure to other pollution sources and risk factors during pregnancy, outdoor air pollution, insecticide and fertiliser use, meteorological variables along with current HIV/AIDS and TB epidemics, were not recorded. Furthermore, information was not collected on mother's smoking status. Excluding environmental tobacco smoke from the analysis might introduce substantial bias as 24% of women in South Africa smoke.[52] The current HIV/AIDS epidemic along with escalating number of TB infections could also influence the association between 1-59 month mortality and exposure to smoke from dirty fuels. As the SADHS survey did not collect indicators of potential HIV/AIDS status of the child, biological mother or any household member, the attributable fraction due to HIV/AIDS could not be calculated. However, the TB prevalence rate was low (2.4% among 13 826 adults).[52] Adult household members diagnosed with TB and who lived in households with smokers (34.2% among 13 826 adults), were not linked with the dataset as this reduced the number of deaths considerably.[52] Furthermore, although only 28% of children were vaccinated, no deaths were reported for unvaccinated children. Most women went for antenatal care check ups (97%).

Substantial evidence had shown that parents perceive the inherent healthiness of a child through knowledge of their own genetic endowments and health characteristics of the household and neighborhood.[61-63] If parents perceive that their child's inherent healthiness is low, they may alter their fertility decisions, leading to selection bias in the sample of potential births. However, we could not only consider first births in the analysis as this reduced the sample size considerably. Also, the number of children per age group decreased with increasing age and this is likely to be due to two contributing factors. First, close to 7% of the children in South Africa die by the time they reach 5 years of age and this high mortality rate may result in fewer older children in the sample.[64] Also, as children get older they are more likely to be sent away to live with relatives in urban areas. It was found that 331 black children did not live with their mothers (8.54%, N=4 114 with no missing values).

The most common indicators used for measurement of socioeconomic status are income level, occupation, and educational level.[65] We cannot rule out that the results would have been different with another measure instead of using an asset index. 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 over the 5 year period.

It is hoped that future analytic studies will scrutinise the potential risk factors of 1-59 month mortality that were identified in this investigation. This is important given the fact that large proportions of households in this country and other developing countries are still relying on these fuels for household energy. However, Yach et al addressed the methodological difficulties in undertaking epidemiological studies in developing countries.[66] They pointed out the use of ecological and cross-sectional studies in determining the relationship between risk factors and disease and consequently applying detailed analytical studies to determine the reasons for these relationships. In South Africa, detailed analytic epidemiology studies will have to compete with the demands on the public and research purse for work on common diseases of pressing current importance (e.g. HIV/AIDS). Therefore analytical studies should not merely redocument the impact of known risk factors, but should provide a basis for designing interventions, albeit technical or socio-behavioural.

In the last decade a program of providing electricity to three million homes has been underway in South Africa. However, the county's heavy reliance on coal for electricity generation confers substantial external costs, which need to be taken into account.[67] Nevertheless, it is much easier to control pollutant emissions from a few power plants than from millions of households where exposure is extremely high due to the proximity of the source. Furthermore, changing the type of fuel used is not that easily assimilated by the South African community. A local ongoing, community-based electrification programme has found that about 50% of households continue to use wood for cooking and heating after electrification. Economic, political, educational and cultural factors account for why so many households continue to use wood.[68]

Therefore, the efforts need to focus on providing improved cook stoves designed to reduce exposure to smoke by means of improved combustion and improved venting, and designing public information campaigns to inform people about the health risks of exposure to indoor smoke. For such programmes to be effective, local needs and community participation should receive high priority. It is important to note that 4.6 million South Africans aged 20 years and older have no formal schooling with an additional 4.1 million having some primary school education.[28] Thus more than 8 million (20%) South Africans may not be able to benefit from health promotion material that is designed for the more educated population.

Socio-behavioural interventions may include preventing children and pregnant women from being exposed to smoke from the dirty fuels. The national department of Health is implementing secondary and tertiary prevention strategies, such as the Integrated Management of Childhood Illness (IMCI) to reduce infant and child mortality.[69] All three components of IMCI (case management, improvement of the health system, and household/community care components) are being implemented in South Africa. However, the expansion of IMCI is slow due to lack of resources (financial, human and material in the form of transport) and the lack of a dedicated budget for child health. Chapter 6 suggested that South African children (< 60 months) living in households using dirty fuels for cooking and heating were 25-29% more likely to have suffered from ARI as children from households using clean fuels, after adjusting for child's age, sex, birth order, number of children per household, mother's age at childbirth, mother's education, household living standard, province of residence, race and treatment received. These results are consistent with international studies that have reported strong associations between exposure to dirty fuel smoke and ARI in preschool children.[70-73] Two other local studies established a significant link with indoor air pollution indicators and respiratory health of preschool children.[74,75] Thus as acute respiratory infections (ARI)(such as pneumonia) are currently the second biggest cause of death amongst young children in large parts of South Africa it is important that mothers recognise the signs of ARI in order to seek timely medical care to prevent premature death of their young children.[60] Kauchali et al have indeed found in a local study that mothers do recognise the signs of ARI and that traditional remedies were the preferred treatment.[76]

7.5 References

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