Chapter 8

GENERAL DISCUSSION

8.1 Main Findings

First the status quo of air pollution epidemiology in the country was elucidated in a narrative review (Chapter 2). The objectives of this review were (a) to examine the evidence from studies conducted in South Africa for possible associations between air pollution and ill health, and (b) to critically review these studies for methodological limitations in order to stress improvement of future studies. The literature search strategy and selection criteria involved a MEDLINE search until June 2005. Fourteen out of 267 journal articles were found which focused on air pollution epidemiology (excluding active smoking and on internal dose as a proxy for health outcomes).[1-18] Two studies were also located by word of mouth or through the references of the selected studies.[19,20] The local studies do provide some evidence of associations with a range of serious and common health problems. Three of the studies established a strong significant relationship with air pollution indicators and deteriorated human health.[2,3,13-16] Seven studies established a significant link with air pollution indicators and disease.[1,4,8-10,17,19] Four studies did not report any significant link between air pollution indicators and disease.[5,11,12,20] The lower limit of many of the association measures of some of the reviewed studies is more or less one.[1,4,8] The impact might still be relevant due to the vast number of people exposed to high air pollution levels in the country, the possible synergy with numerous risk factors and the increased vulnerability of particular subpopulations. Two studies mention a correlation between air pollution indicators and disease, but did not quote the p-value or the confidence interval of the association measure.[7,18] All the studies investigated the impact of air pollution on respiratory health. Studies also focused on birth weight, learning difficulties, immunological, hematological conditions[17] and gastrointestinal, dermal and occular conditions.[19] Eight of the studies addressed chronic respiratory health effects[1-3,9,10,12-16,20], whilst fifteen studies investigated acute respiratory health effects.[1-5,7-9,11-17,19] Ten of the studies had a cross-sectional design[1-5,9,11,12,19,20], two a case-control design[8,10] and four were prospective cohort studies.[7,13-16,17,18] No time-series or any ecological study was located. Local researchers Sitas and Thompson discussed the value of ecological epidemiological studies in developing countries.[21] They pointed out that although retrospective case-control or prospective (follow-up) studies are important epidemiological tools and have provided useful information on exposure disease associations, their application is inadequate in developing countries with limited research funds. These study designs are also implemented sometimes without acknowledging their limitations. These limitations are exacerbated when measures of exposure and disease are based on single measurements and where the population under investigation is homogenous with regard to exposure. The former is responsible for regression dilution bias (underestimation of effect) and the latter for a lack of contrasts between exposure groups. Both limitations would attenuate any exposure disease relationship. Ecological epidemiological studies, which are weaker in design, might offer advantages when conducted in a number of areas of varying exposure proportions and disease rates. As discussed in Chapter 2, indoor and personal air pollution concentrations often correlate poorly with outdoor air levels.[22-33] Indoor, personal and outdoor correlations are dependent on the pollutant under investigation. Nevertheless, time-series studies are at least steppingstones to address air pollution epidemiology in the country as they are relatively easy and economical to conduct, especially in a resource stricken country like South Africa. The lack of this design in local air pollution epidemiological studies is most likely resulting from the absence of an electronic health data management system together with electronic birth and cancer registries.

However, most of the local studies discussed in the review are fraught with systematic and random errors. This limits their validity and precision. Methodological limitations included lack of detailed and systematic pollution and/or exposure measurement and variations between studies in the way that disease outcomes are defined and cases found. Most of the studies to date have been observational rather than intervention studies which may ultimately result in more robust evidence on the nature of the relationship between air pollution and health. None of the studies established exposure-response curves for the criteria pollutants (CO, SO_2, NO_x, O_3, particulate matter and lead) due to the applied study design and the lack of quantitative air pollution exposure assessment. It is therefore impossible to use the results of the studies in risk assessment studies or to trace intervention efficiency in lowering air pollution concentrations. Lastly some studies have dealt inadequately with confounding factors, such as socio-economic status, family history of asthma symptoms and age.

Morbidity and mortality are caused by a complex network of risk factors, such as poor nutrition, rapid urbanisation, HIV/AIDS and TB, which usually act in concert. It may thus be tricky to recognise the signal attributable to air pollution beside a myriad of opposing causes of disease and death. Having reviewed the studies conducted in South Africa, it is obvious that environmental epidemiology studies need to be planned and executed better in order to notice the health impacts of air pollution in this country. Von Schirnding and Ehrlich also highlighted this important issue.[34] This issue will be elaborated upon later in Section 8.3.

In the light of the lack of unique South African exposure-response curves, the next chapter addressed the question whether outdoor air pollution is homogenously distributed in Cape Town, South Africa (Chapter 3). This is useful to know when conducting time-series studies, which outputs can be used to derive exposure-response curves. Many pollutants show complex spatio-temporal profiles, which complicates measuring or modelling exposure patterns and obscures subsequent estimation of human exposure. Nevertheless, the majority of air pollution epidemiological studies are based on exposure data from a single central outdoor monitor. This may introduce information bias, which impairs the validity of epidemiological studies. The temporal correlation among outdoor concentrations of a particular air pollutant measured at different sites (inter-site correlation) may be investigated to control information bias. The higher the inter-site correlation, the lower the anticipated information bias when using data from one site for another with similar air pollution sources and the more valid the exposure assessment of the epidemiological study. Exposure-response curves deduced from studies conducted in developed and even other developing countries are not merely applicable in this country. The three global factors that directly or indirectly impact on health – that is the community and social environment, the physical environment and the family and individual environment – are different between and amongst developed and developing countries.[35] 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. Cape Town was selected from the main air pollution hotspots in the country (such as Durban, Johannesburg, Pretoria, Richards Bay, Witbank, Vaal

Triangle) as the city adheres to stringent quality assurance guidelines from the US-EPA when monitoring outdoor air pollution.[36]

Air pollution monitoring sites in Cape Town are located in different types of areas. It is therefore anticipated that the spatial correlations for the different pollutants will differ. However, it is still necessary to quantify the temporal inter-site correlations instead of describing the situation qualitatively. It was found that in general 24-h average concentrations of PM_{10} mass, NO_2, NO, SO_2, O_3 and CO are not homogenously distributed during all seasons (Tables 3 to 5, Chapter 3). On average, the most homogeneously distributed pollutant is NO_2, followed by PM_{10} (including Khayelitsha data), PM_{10} (excluding Khayelitsha data), NO, CO, O_3 and finally SO_2 in the Cape Town air shed. Inter-site correlation coefficients for NO_2, NO, SO_2, CO and O_3 vary from 0.456 to 0.832; 0.212 to 0.791; -0.100 to 0.662; 0.302 to 0.676 and 0.123 and 0.557, respectively. PM_{10} measured at Bothasig, City Centre, Goodwood and Tableview presents correlations from 0.261 to 0.859. The PM_{10} inter-site correlation coefficients between Khayelitsha and the other sites (Bothasig, City Centre, Goodwood and Tableview) vary from 0.396 to 0.769. It is suggested that the City of Cape Town do not reduce the number of measuring sites. Limited resources constantly constrain outdoor air pollution measurement. Given the lack of air pollution epidemiological studies in the country, local cities should thus attempt to optimise and update their air quality monitoring networks in such a manner in order to serve both compliance monitoring and epidemiological exposure assessment. Furthermore, as outdoor concentrations of a particular air pollutant were heterogeneously distributed within the city area it is anticipated that there will be adequate outdoor exposure variation. Consequently health data can be linked to these outdoor air pollutant concentrations during future time-series analyses.

Detailed analytic epidemiology studies have to compete with the demands on limited public and research funds for research on common diseases of pressing current importance (such as HIV/AIDS). Another approach for risk estimation is that of health risk assessment studies or even more simply, compliance monitoring. Thus in Chapter 4, the current and future health implications due to outdoor PM_{10} mass exposure in the Khayelitsha sub-district in the City of Cape Town was investigated. The results indicate that elevated PM_{10} mass concentrations are frequently present. During autumn 1999 and winter 2003 the UK Daily Limit value

(50 μg.m^{-3})[38] was exceeded 44 times. The number of times the UK DLV may be exceeded should not be more than 35 during a year. Although this requirement was only surpassed twice, the preliminary trend analysis indicates an increase in monthly average and maximum daily average PM_{10} concentrations. The implication is that within a few years the UK Annual Limit value (40 μg.m^{-3}) will be exceeded. Consequently a higher proportion of the community might be at risk from suffering various detrimental health effects.

Due to the lack of a computerised health data management system in the country, it was not feasible to conduct a time-series study using the high quality outdoor air pollution data from Cape Town. Instead, the 1998 South African Demographic and Health Survey (SADHS) data were analysed in more detail than reported in the SADHS report.[37] The SADHS collected data on various household characteristics, including the type of fuels used for cooking and heating purposes. This endeavour resulted in the calculation of unique South African risk estimates for adult respiratory health (Chapter 5), under five respiratory health (Chapter 6) and 1-59 month old mortality (Chapter 7) due to exposure to indoor air pollution from using dirty fuels for cooking and heating purposes. Previously, most environmental epidemiological studies in South Africa focused only on children's health.[1,4,8,9,13-17,19]

The aim of the analysis reported in Chapter 5 was to determine the prevalence and determinants (occupational and environmental, socio-demographic, BMI, TB) of various respiratory symptoms and diseases in a representative adult population (15 years and older) of South Africa. Data from 13 826 adults from 6 457 households were included in the analysis. The survey revealed relatively low crude prevalence rates for doctor diagnosed asthma (3.7%), chronic bronchitis (2.4%), doctor diagnosed emphysema/bronchitis (4.2%) and TB (2.7%), but higher respiratory symptoms: wheeze and shortness of breath (11.1%), cough with phlegm (6.8%); nocturnal coughing (13.1%), nocturnal wheezing/tight chest (10.8%) (Table 3, Chapter 5). This reinstated the importance of recognising that clinical disease diagnosis only indicates the tip of the iceberg. The majority of people have symptoms. Nearly 1.7% of the respondents reported using asthma medication, whilst 0.5% was using TB medication. In general most of the potential risk factors were significantly related to the respiratory diseases and symptoms in the unadjusted models (Table 4, Chapter 5). The multivariate logistic regression analyses suggested that the prevalence of respiratory symptoms and diseases could be diminished in South Africa by health promotion predictors (increasing connection to electricity, having a medical aid and improved education) (Table 6, Chapter 5). This preliminary data analyses suggests that the following potential risk factors should be lessened in order to have a beneficial influence on the prevalence rates of respiratory symptoms and diseases: households going hungry, years smoked, households with smokers, exposure at work to fumes, smoke, dust or strong smells and period worked in such a job as well as BMI increase for the underweight and decrease of the obese. Other potential risk factors included age and race. Although there is potential for residual confounding despite adjustment in this preliminary analysis, the documented international evidence on most of the potential risk factors suggests that these associations may be real. The results from the SADHS can also be used in secondary or tertiary prevention, i.e. assess the need and demand for health services based on location of disease and risk hotspots and to evaluate intervention programs in specific target populations.

Chapter 6 reports on the connection between household dirty fuels use for cooking and heating with acute respiratory infections (ARI) in preschool children (<5 years) in South Africa. Two-thirds (67%) of the 4 679 children included in the analysis lived in households using wood, dung, coal and/or paraffin. Nineteen percent suffered from ARI during the 2 weeks prior to the survey (Table 1, Chapter 6). After adjustment, children in households using high and medium polluting fuels for cooking and heating were 26-29% more likely to have an ARI event than children from households using cleaner fuels (OR 1.26; 95% CI : 1.00-1.58 and OR 1.29; 95% CI : 1.02-1.62, respectively). Although there is potential for residual confounding despite adjustment, the better documented international evidence on indoor air pollution and ARI suggests that this association may be real. As nearly half of the 11 million households in South Africa still rely on polluting fuels, the attributable risk arising from this association, if confirmed, could be substantial. Thus the acceleration of implementing interventions to lower exposure to indoor air pollution derived from dirty fuel combustion is imperative in order to improve the health of millions of South African children. Chapter 2 reported on intervention strategies that had already been implemented in the country and recommendations were made regarding future intervention strategies.

The aim of Chapter 7 was to determine the association between dirty cooking and heating fuel use and 1-59 month old mortality in the country whilst controlling for a number of confounders or effect modifiers. Data from 3 556 African/Black children (142 deaths) living in 2 828 households were analysed. The overall mortality incidence rate in the 5 years within the study was 1.473/1000 person-months. 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%). The multivariate analysis 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, 95% CI=1.04-3.68)(Table 3, Chapter 7). 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. Suggested interventions to reduce 1-59 month old mortality are for women to give birth when they are 19-34 years as well as for households to use clean water and clean cooking and heating fuels. These interventions are based on the adjusted association measures derived in Chapter 7. Sections 8.3 and 8.6 will address recommendations regarding future intervention strategies.

8.2 Potential Bias and Limitations

There are some important study specific limitations in the analyses from Chapter 3 to 6, which should be taken into account when interpreting the results. These coincide with those addressed by Ritz et al.[40] They discussed the pros and cons of various systems for the examination of environmental health questions. Hill's causation guidelines should be kept in mind (Table 1, Chapter 1).

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. In Chapter

7 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 it was assumed that the toilet facility and water source variables remained constant over time.

There is a good chance that differential or nondifferential misclassification of disease and exposure status may be present in using the 1998 SADHS data due to recall bias, reporting bias and information bias. This results in statistical significance arising by chance with either an over- or underestimation of the association measures. Consequently the direction of bias on the association is not easy to predict. Recall bias may be present as respondents answered 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. Information bias may be due to the reliance on self-reported data. Respondents with current symptoms and diseases may be more likely to report exposures and remember past TB infections than asymptomatic respondents.

Self-reporting of emphysema and bronchitis can be used only as a very rough guide to the prevalence of chronic lung diseases for a variety of reasons. First, use of diagnostic terms reflects health service access, which in South Africa varies considerably by socio-economic status and geography. A term such as emphysema is likely to be used inconsistently by medical practitioners based on varying clinical criteria. Lung function testing, which contributes important information to diagnosis, is uncommon at primary care level. Bronchitis also is a non-specific term that would elicit reports of acute bronchitis as well as chronic bronchitis. Acute bronchitis is a common ailment, often a mild and self-limiting viral infection, which may occur without underlying chronic disease. A literature review of asthma symptoms assessed by questionnaire found that "physician-diagnosed asthma" had a mean specificity of 99% and a mean sensitivity of 68% for asthma defined by symptoms, suggesting that underdiagnosis is more likely than overdiagnosis.[41] Finally, asthma in adults is probably frequently misdiagnosed as bronchitis. On the one hand, self-reporting of asthma is likely to reflect some degree of underdiagnosis. On the other hand, asthma rates may be inflated by confusion with emphysema and chronic bronchitis, particularly in older age groups. Reporting of symptoms is less likely to be influenced by contact with health services than is reporting of diagnoses. The chronic bronchitis symptom complex is defined by chronic bronchitis every day for at least 3 months a year, for at least 2 successive years. It was one of the earliest symptom complexes to be defined by standard respiratory questionnaires, and has entered into common usage as both a clinical and epidemiological definition.

Information on ARI 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 lower respiratory infections (ALRI) in children, some acute upper respiratory illness may have been integrated in the conveyed prevalence. As it is impossible to separate ALRI from these data, the term ARI is used in this study, not ALRI. In developing countries such as South Africa, where clinical data on ARI are frequently unattainable or very weak, the symptomatic definition of illness used here is assumed to present a reasonably accurate estimation of ARI in the population. Furthermore, Kauchali et al conducted a local rural study on maternal perceptions of ARI in children under 5 years of age.[42] Maternal recognition of respiratory distress was good (sensitivity 91.3%, 95% CI=86.8-95.8%; specificity 95%, 95% CI=89.5–100%), with little variation between mothers (kappa = 0.704). Thus, following the results from Kauchali et al it is anticipated that most mothers' would at least have identified ARI among their children.[42] However, it is not so clear whether differential or nondifferential misclassification may be minimised by the supporting results of Kauchali et al.[42]

The generalisibility of data is determined by the non-response rate. The response rate at the household level was 97% of 12 860 households in 966 EAs. Of the 6 457 households selected for the adult survey, 95.3% were completed. At the individual level, 92.6% of eligible adults were included in the survey, although not all of them had all the measurements taken. The overall response rate for the adult survey was 89.7%. It was substantially lower in Gauteng (67.5%) where a large proportion of adults were not at home (13%). The response rate was higher in the non-urban than urban area. For the women's health survey, the overall response rate was 92.3%. Thus the bias that might be introduced by non-response is relatively low for the SADHS data.

Other factors that might contribute to adult and childhood morbidity and mortality, such as outdoor and indoor air pollution sources (location of household close to industry, transportation, waste fill site, insecticide and fertiliser use), town/city of household to request meteorological variables from South Africa Weather Bureau, mother's pre-pregnancy weight, child's birthweight, mother's exposure to other pollution sources and risk factors during pregnancy, 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 (differential or nondifferential) as 24% of women in South Africa smoke.[37] Thus the direction of bias on the calculated association measures is not easy to predict. 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 (2.7% among 13 826 adults)(Table 3, Chapter 5). Adult household members diagnosed with TB and who lived in households with smokers (34.2% among 13 826 adults), were not linked with the 1-59 month mortality dataset as this reduced the number of deaths considerably.

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 neighbourhood.[43-47] 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, considering first births exclusively in the analysis was not feasible 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 three 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.[48] Secondly, 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 (8.5%, N=4 114 with no missing values)(Chapter 7). Lastly, the survey was conducted between January and September 1998, resulting in lower birth counts compared to 1993-1997.

Notwithstanding the lack in the measurement of smoke exposure, the uniformity in the significance of crude and adjusted effects of dirty fuel use on adult respiratory, childhood ARI and 1-59 month mortality implies a probable 'exposure–response' relationship. Many households in South Africa in general use a combination of cooking and heating fuels. The calculated effects may be underestimated if only considering using high polluting fuels (wood and dung) exclusively and not in combination with paraffin, coal, LPG/natural gas and/or electricity. This is also expected when using medium polluting fuels (paraffin, coal) exclusively and not in combination with LPG/natural gas and/or electricity.

The most common indicators used for measurement of socioeconomic status are income level, occupation, and educational level.[49] However, Demographic and Health Surveys traditionally do not include questions on income and expenditure. Educational level measures one aspect of socioeconomic status and it cannot be ruled out that the results would have been different with another measure. However, the relation between socioeconomic status (SES) and socioeconomic factors with respiratory health in adults is not well understood. Existing studies are heterogeneous regarding the definition of the socioeconomic indicators used. More than a third (35%) of the women never married, so it could not be assumed that the current partner's job or education remained the same over the 5 year period in the 1-59 month mortality analysis. Mishra analysed the Zimbabwean DHS data and calculated a household standard of living index as a possible confounder in the association between household cooking fuel use and ARI in preschool age children (<5 years).[50] In Chapters 6 and 7 a similar approach was followed.

Another bias is that employed low-income men are underrepresented, as they work overtime, shifts or away from home. Furthermore, male worker hostels, a common form of housing for African migrant workers in mining and certain urban areas, were not surveyed. Nevertheless the results presented here are the first national survey of the symptoms and prevalence of chronic lung disease in South Africa.

Previous morbidity information was derived from surveys of selected adult populations only.[51,52]

There is a chance of some selection bias in the sample due to ARI-related mortality. The risk estimates of effect of cooking smoke on ARI are downwardly biased as children living in households using medium and high polluting fuels are more likely to die from ARI. Then again, given high prevalence of ARI and relatively small number (n=269, 5.28% of the sample, N=5 093) of deaths in the sample, the impact of this bias on the estimated effect is likely to be little.

Although the influence of susceptibility to the detrimental health impact of being exposed to emissions from dirty fuels and the selected confounders was controlled by adjusting for age, socio-economic status and gender, some residual susceptibility might still be present. Bias in risk estimates will arise if individuals with similar exposures but different susceptibilities are treated the same. This issue will be addressed later in Section 8.3.

Only controlling for confounding is not enough. Attention should also be paid to confounder measurement errors (random or systematic). Greenland has pointed out that errors in measurement of a confounding variable will tend to cause partial loss of an ability to eliminate confounding bias.[53] Kupper has shown that an inaccurate surrogate confounder can produce seriously misleading inferences.[54] The presence of random and/or systematic errors in the measurement of confounders will either influence the true value of the association measure between the exposure variable or health outcome towards or away from an insignificant association.

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 the 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. Again, Greenland has shown that errors in measurement of a covariate can distort its modifying effect and possibly introduce an apparent interaction where none exists.[53]

Limitations of using air pollution data from the City of Cape Town included the low PM_{10} data availability at Khayelitsha for most of the period under investigation, lack of meteorological data (temperature, relative humidity, wind speed, wind direction, rainfall) collected at each monitoring site and inter-pollutant correlations at each monitoring site.

8.3 Improving Secondary Health and Exposure Data Sources to enhance Public Health

As mentioned in Chapter 1 public health may be improved by primary, secondary or tertiary prevention. This thesis focuses on primary prevention, that is the identification of environmental risk factors, such as outdoor air pollution and the use of highly polluting fuels for cooking and space heating, whilst controlling for confounding. Chapter 1 also addressed the ultimate endeavour of epidemiology, namely to identify modifiable determinants of disease occurrence and progression and to contribute in testing the efficacy and effectiveness of interventions on these determinants including the health services. For public health to be improved by epidemiological studies it is imperative that these studies should attempt to minimise systematic and random errors and subsequently strengthen their validity and accuracy.

Recently, Ritz et al discussed the pros and cons of various systems for the examination of environmental health questions.[40] They highlighted that environmental public health tracking networks should be synonymous with a dynamic process requiring regular system updates to a) incorporate new technologies to improve population-level exposure and disease assessment, b) allow public dissemination of new data that become available, c) allow the policy community to address new and emerging exposures and disease "threads," and d) evaluate the effectiveness of these networks over some appropriate time interval. It will be necessary to weigh the benefits of surveillance against its costs, but the major challenge will be to maintain support for this important new system. They concluded that prevention might be the only rationale option (discussed later in this section and Sections 8.6), even if multifactorial diseases do not lend themselves to surveillance data driven evaluations of intervention strategies.

Given the lack of resources for outdoor air pollution measurement and the dearth of air pollution epidemiological studies in the country, local cities should thus attempt to optimise and update their air quality monitoring networks in such a manner as to serve both compliance monitoring and epidemiological exposure assessment (addressing issues raised by Ritz et al above).[40]

Stemming from the preliminary results of this investigation along with its associated limitations, the following thoughts are suggested to the City of Cape Town:

- Review the number and location of the air pollution monitors in the City;
- Increase the number of pollutants measured at Khayelitsha and Oranjezicht;
- Increase the data response at Khayelitsha for PM_{10};
- Collect meteorological data (temperature, relative humidity, wind speed, wind direction, rainfall) collected at each monitoring site;
- Increase the number of O_3 monitors in background areas;
- Place O_3 monitors downwind from precursor sources;
- Investigate the current air pollution trends against health guidelines and
- Establish the surrogate or confounder relationship between air pollutants in a time-series analyses (i.e inter-pollutant correlations at each monitoring site)

Although O_3 is not a primary pollutant, it is at the moment unclear whether it is generated in the Khayelitsha area. Furthermore, it is suggested not to reduce the number of measurements per day as hourly measurements are needed to indicate peaks and for acute health effects assessment. These suggested recommendations aim at increasing the accuracy and reliability of using the air quality network data in epidemiological studies. It is furthermore recommended that similar analyses be conducted using air quality data from the other major cities in the country that maintain relatively extensive air quality monitoring networks under rigorous quality assurance guidelines. If quality assurance guidelines are not adhered to, it is recommended that immediate provision be made to fulfil this criterion. It is recommended that all air quality monitoring networks in the country should apply for accreditation in the near future by the South African National Accreditation System (SANAS). Ideally a comprehensive exposure assessment study with outdoor, indoor and personal measurements for SO_2, NO_2, O_3 and $PM_{2.5}$ should also be conducted in the immediate future on a representative sample of the South African population along with information on distal and proximal causes of health outcomes, such as poverty, home design and socio-behavioural practices. Correlation coefficients between distal and proximal causes and quantitative personal, indoor and outdoor air pollution measurements can be determined and used to develop exposure assessment models. Validating and applying these models in future studies will save time and money by circumventing the measurement of quantitative personal, indoor and outdoor air pollution measurements in every study. The indoor and outdoor air pollution measurements as well as the individual distal and proximal causes might also be used as surrogates for personal air pollution measurements. However, explicit criteria for acceptable surrogate measures along with the need to take error into account when surrogates are used, should be set. Rosner et al have shown that for correlations between surrogate and true measures of exposure less than 0.8, the odds ratios estimated by logistic regression will differ markedly for the surrogate and the true exposure measure, while much less bias will occur when correlations between the two measures are 0.8 or greater.[55]

The local authorities are encouraged to consult the latest scientific literature with the assistance of research and academic institutions when updating or designing their air quality monitoring networks. Issues regarding improved collaboration in the field of air pollution epidemiology will be deliberated upon in Section 8.5. Chang and Tseng discussed the optimal evaluation of expansion alternatives for existing air quality monitoring networks in a growing metropolitan region, which poses many uncertainties such as the changing population density and the changing emission sources in the urban environment.[56] They discussed the principles for siting air quality monitoring stations through a multiobjective analysis and suggested that monitoring stations should be located in areas

- of high population density;
- where pollution concentrations are expected to be highest;
- where the highest frequency of violation can be detected;

- where significant growth is expected to occur and
- near major downwind sources.

The optimisation modelling they addressed considered three objectives: the maximisation of

- protection capability of the highest population density;
- detection capability of the highest pollution concentrations and
- detection capability of the highest frequency of violation of health guidelines/standards, along with cost, effectiveness and efficiency factors.

Chow et al reviewed the design of monitoring networks to present outdoor human exposure.[57] Kanaroglou et al discussed the establishment of an air pollution monitoring network for intra-urban population exposure assessment, which is quite relevant in epidemiological studies.[58] The impetus for their study was to address the limitation of locating monitors in an ad hoc fashion, which favours the placement of monitors in source "hot spots" or in areas deemed subjectively to be of interest. Their study addressed the development of a formal method of optimally locating a dense network of air pollution monitoring stations and the subsequent development of an exposure assessment model based on these monitoring data and related land use, population and biophysical information.

Before addressing issues on how to improve the next SADHS to ultimately reduce random and systematic errors and consequently improve the accuracy and validity of derived association measures, it is important to remember the general purpose and characteristics of health surveys as addressed in Section 1.2. The topics that the 1998 SADHS addressed can be classified according to the following three categories: Health status (disease specific morbidity, chronic conditions, self-assessed health, height and weight as well as lung function tests), lifestyle and health habits (various indicators) and medical consumption (hospitalisations, general practitioner consultations and use of medicines).

The SADHS addressed adequately the health status and medical consumption sections as it covered serious prevalent health conditions (albeit self-reported) in the country, such as ARI, chronic bronchitis and child mortality. However future SADHS should ideally also include other direct and indirect health consequences related to use of dirty fuels identified by Smith, Bruce et al, Ezzati et al and a WHO report (Table 1).[59-62]

However including more questions in any established survey will be a challenge as there are many other competing health risk needs and interests and against the overall limitations of questionnaire length. From the direct and indirect health consequences listed in Table 2 it is suggested to prioritise on the following: Birth defects, low birth weight, paraffin poisoning, restrictions on opportunities for education and issues arising from gender power imbalance.

Table 1 Other direct and indirect health consequences related to use of dirty fuels

Indicator
Direct
Birth defects
Low birth weight
Cataracts
Burns
Paraffin poisoning
Indirect
House fires
Opportunity costs of women's time
Injuries from carrying large loads of wood
Restrictions on opportunities for education (adult and child)
Leisure and economic activities in the home
Issues arising from gender power imbalance
Decision-making about the use of energy and appliances
Impact of inter-relationships between scarcity of fuel and stressed local environments

Mental and physical disability is not high on the agenda in South Africa, thus including a question on birth defects will improve this field of study. In general, birth weights should be better recorded in the country as most of the children had no birth weight indicated in the SADHS. Studies have found that underweight babies tend to be sicker later in health.[63-66] The use of paraffin is encouraged over the use of coal or wood for household energy needs, but the direct health impacts of paraffin use should also be highlighted, such as paraffin poisoning among young children. Restrictions on opportunities for education and issues arising from gender power imbalance are important to address in order to alleviate poverty, a distal cause of ill health. Of these five prioritised direct and indirect health consequences, low birth weight is the most likely to be influenced by random and systematic error (such as errors in reporting birth weight, recall bias). Although birth certificates are issued in the country (which are called "The Road to Health Cards"), they are lost or destroyed in most cases after a few years. An alternative should thus be sought to record birthweights in South Africa.

Comparing the limitations identified in using the 1998 SADHS data to those from the review in Chapter 2, it is evident that not much progress has been made in air pollution epidemiology in the country during this analysis. However, due to the large sample size and many risk factors identified in the 1998 SADHS, it had the advantage over previous local studies in that it attempted to deal more adequately with confounding factors (Table 2).

In order to address at least more confounders in air pollution epidemiology analyses (Table 3) it is recommended that the lifestyle and health habits sections of future SADHS need to be planned better. Furthermore, methodological limitations of previous South African air pollution epidemiology studies included the lack of detailed and systematic pollution and/or exposure measurements and variations between studies in the way that disease outcomes are defined and cases found. These limitations were also present in the 1998 SADHS. Neither the analyses of the 1998 SADHS data nor previous local studies established exposure-response curves for the criteria pollutants. This is due to the applied study designs and the lack of quantitative air pollution exposure assessment. It is hence not feasible to employ the results of the studies in risk assessment studies or to track intervention efficiency in reducing air pollution concentrations. As it is not feasible to collect personal, indoor and outdoor air pollution measurements in a DHS, it is thus important to capture more indoor air pollution exposure indicators in future SADHS (Table 4).

Table 2 Air pollution exposure indicators and confounders addressed in this thesis

Characteristics/feature	Adult respiratory health (Chapter 5)	Childhood ARI (Chapter 6)	1-59 month old mortality (Chapter 7)
Fuel use for cooking and heating	✓	✓	✓
Residence in urban/rural area	✓	✓	✓
Connected to electricity	✓		
Persons per room	✓		✓
Household going hungry	✓		✓
Covered by medical aid/medical benefit scheme	✓		
Payment of medicine	✓		
Age distribution in years/months	✓	✓	✓
Ethnic identity	✓	✓	
Ever smoked tobacco, used snuff or chewed tobacco	✓		
Ever smoked at least 100 cigarettes in lifetime	✓		
Years smoked on a daily basis – distribution	✓		
Frequency smoking	✓		
Household with smokers	✓		
Job with smokers	✓		
Ever worked in job where regularly exposed to smoke, dust, fumes or strong smells	✓		
Period worked in job exposed to smoke, dust, fumes or strong smells – distribution in years	✓		
Gender	✓	✓	✓
Educational status	✓		
BMI	✓		
Province of residence	✓	✓	✓
Birth order		✓	✓
Number of children in household		✓	
Mother's age at birth (years)		✓	✓
Mother's education (in years)		✓	
Household standard of living		✓	✓
Treatment received for ARI		✓	
Preceding birth interval (months)			✓
Breastfed			✓
Type of toilet facility			✓
Water source			✓
Year of birth			✓

Table 3 Confounders identified to be addressed in future SADHS

Confounder	Adult respiratory health (Chapter 5)	Childhood ARI (Chapter 6)	1-59 month old mortality (Chapter 7)	Feasibility to include confounder in SADHS
Mother's smoking status before birth of each child		✓	✓	✓
Mother's smoking status after birth of each child		✓	✓	✓
Mother's educational level at birth of child		✓	✓	✓
Partner's job/educational status at child birth			✓	✓
Mother's pre-pregnancy weight		✓	✓	
Child's birth weight		✓	✓	Perhaps
Mother's exposure to other air pollution sources during pregnancy		✓	✓	
Mother's exposure to other confounding risk during pregnancy		✓	✓	
Insecticide use at household during past 2 weeks	✓	✓	✓	✓
Fertiliser use at household during past 2 weeks	✓	✓	✓	✓
Meteorological variables	✓	✓	✓	
HIV/AIDS status of participant/mother/child	✓	✓	✓	Perhaps
Clinically diagnosed TB status of participant/mother/child	✓	✓	✓	✓
Perception of health risk due to dirty fuel use	✓	✓	✓	✓
Diet: list food consumed during past 2 weeks	✓	✓	✓	✓
Garbage removal service present	✓	✓	✓	✓
Outdoor air pollution sources near household (i.e. industrial, transportation, burning of residential waste close to home or waste fill site located close to home)	✓	✓	✓	✓
Susceptibility (i.e. family members with the health outcome; number, ages and relationships of family members at risk)	✓	✓		

Once more, including more questions in any established survey will be a challenge as mentioned previously. In order to prioritise on which confounders and air pollution indicators to focus in future SADHS, it is important to remember the need to measure confounders and indicators with minimum measurement errors (random or systematic). Table 3 indicates the confounders that are most feasible to include in a DHS with limited recall bias. HIV/AIDS status of participant/mother/child will be a challenge to determine due to the stigma attached to HIV/AIDS. However, it is important to address this challenge in order to compare the attributable burden of indoor air pollution exposure and HIV/AIDS on overlapping morbidity and mortality outcomes in South Africa. Black et al used a prediction model to estimate the distribution of deaths in children younger than 5 years by cause (namely diarrhoea, pneumonia, malaria, measles, AIDS, neonatal causes other causes and unknown causes).[67] No uncertainty bounds are available for the AIDS for 42 countries (including South Africa), which contributed 90% of all such deaths in 2000.[68] Estimates and uncertainty bounds were: 22% of deaths attributed to diarrhoea (14–30%), 21% to pneumonia (14–24%), 9% to malaria (6–13%), 1% to measles (1–9%), 3% to AIDS, 33% to neonatal causes (29–36%), 9% to other causes and fewer than 1% to unknown causes. No uncertainty bounds are available for the AIDS estimate as the model did not produce these data (country-level estimates from UNAIDS were used).[69]

The current SADHS included a question on the length of stay at the current dwelling. Thus bias due to migration is controlled for when posing a question on outdoor air pollution sources near household. Maternal education status and smoking status before birth and after a child's birth as well as the partner's job/educational status have been found to be important indicators of child health outcomes in previous studies.[70-74] Diet and nutritional status is also important for health. Although the frequency of a household going hungry was determined, a report by the South African Medical Research Council (MRC) on poverty and chronic diseases in the country also emphasised the lack of detailed adult nutritional data collected in the 1998 SADHS.[75]

Due to the high concentrations detected indoors when using insecticides it is important to address this confounder. Fertiliser use also has a huge influence on human health. Clinically diagnosed TB status of participant/mother/child is an important confounder in respiratory health. The presence of garbage removal service and other outdoor air pollution sources near households also warrant attention. It is necessary to address perception of health risk due to dirty fuel use for health promotion strategies.

Table 4 Indoor air pollution exposure indicators to be addressed in future SADHS

Indicator	Feasibility to include confounder in SADHS
Types of fuels used for cooking during past 12 months	✓
Types of fuels used for heating during past 12 months	✓
Types of fuels used for lighting during past 12 months	✓
Stove type used during past 12 months	✓
Current housing characteristics (i.e location of cooking; number and size of rooms; the relation between stove location and other rooms; number and size of doors and windows)	✓
Current socio-behavioural characteristics (i.e. length of cooking and heating intervals; status of doors and windows during cooking and heating; participation of individual household members in cooking and other energy related tasks; amount of time spent indoors and near the stove when burning)	✓

The issue of susceptibility raised in the previous section warrants some attention. There are a number of epidemiologic designs for assessing sensitivity to environmental exposures.[76] As a measurement problem, the central issue is whether the marker for sensitivity being examined is a measurement of the genotype itself, some host characteristic or family history. As it is not feasible to assess susceptibility via genotyping in SADHS data, it may be assessed by host characteristic or family history. For family history as a marker of susceptibility to a disease, the basic minimal information that needs to be collected is the identification of the family members with the disease and the number, ages and relationships of family members at risk. This information should be collected systematically for all first-degree relatives (parents, siblings, and offspring) and possibly for all second-degree relatives. As the objective is to examine family history as a marker of sensitivity to an environmental exposure, every effort should be made to obtain exposure information on all relatives, not just the affected ones. However, due to recall bias, it is not feasible to include questions on family history in the future SADHS.

Meteorological variables may be addressed in future SADHS if a question is included in which city/town the household is located. Data may then be requested from the South African Weather Service. All the indoor air pollution exposure indicators are feasible to address in the next SADHS. Lastly, future SADHS need to include male worker hostels, a common form of housing for Black migrant workers in mining and certain urban areas in order to reduce selection bias.

Chapter 2 identified that ten of the studies had a cross-sectional design, like the 1998 SADHS.[1-4,5,9,11,12,19,20] The inability to minimise measurement errors (random or systematic) of health, exposure and confounder variables is due to inherent limitations of any DHS study design (i.e. cross-sectional). It is also important to realise that most of the current and identified confounders as well as exposure indicators are only applicable in analyses involving acute diseases.

Future options to address the limitations posed by questionnaire length and the inherent study design of the SADHS need to be explored. A specific questionnaire can be designed for half of the households interviewed in the next SADHS or other surveys could include relevant questions for confounders and exposure indicators identified, such as the annual October household survey or smaller surveys conducted in typical South African settings. An indoor air pollution exposure questionnaire could also be applied in the three INDEPTH (International Network of field sites with continuous Demographic Evaluation of Populations and Their Health in developing countries) operational in the country.[77-80] INDEPTH has 33 demographic surveillance sites in 18 different countries. Its vision is to harness the collective potential of the world's community-based longitudinal demographic surveillance initiatives in resource constrained countries to provide a better, empirical understanding of health and social issues, and to apply this understanding to alleviate the most severe health and social challenges.

An option to circumvent the issue on measurement errors, participants can be asked whether they would like to be contacted in the future for inclusion on follow-up studies. Another identifying indicator than the South African identification number should be used in tracking people's use of health services. In general people do not inform the Department of Home Affairs of their new addresses after relocating. One might also ask them if they would mind that researchers track their future use of clinics and hospitals for application in follow-up studies. This would of course require a properly updated electronic health information system in the country.

Selection bias may be introduced in these suggested follow-up studies, as approximately 14.9% of the South African population was covered by a medical aid scheme in 2003.[81] People covered by medical aid schemes access private hospitals and clinics, whose databases are in general inaccessible to research institutions. Furthermore, the majority of the White population had access to a medical aid scheme (65.2%), followed by Indians/Asians (35.0%), and then Coloureds (19.3%). The African population had the smallest proportion of people with access to a medical aid scheme (8.0%). In a speech by the Health Minister during July 2005, it was announced that only 15-20% of South Africans have a high degree of access to health services.[82]

The psychosocial stress that may be associated with exposure to a perceived environmental hazard can potentially confound, mediate or modify any associations between the exposure and disease.[76] This issue will become a challenge in future SADHS as communities (hopefully) will be sensitised around the detrimental health impact of using dirty fuels. Stress might operate indirectly and cause exposed individuals to alter risk behaviours. Stress also could have an artificial association with the health outcome of concern due to changes in care seeking, diagnostic practices or self-reported health states. Alternatively, concern about environmental exposures could cause adverse outcomes other than those potentially associated with the perceived hazard, such as anxiety and depression.

The issue of stress as a confounder, effect modifier, mediator, indicator of some methodological bias or even as an exposure or outcome needs to be explicitly addressed in future environmental epidemiological research conducted on sensitised populations. Ozonoff et al and Roht et al developed some relevant methodology in studies of communities near toxic wastes to distinguish between biologic effects of exposure to hazardous substances at such sites and either symptoms of stress or altered symptom reporting.[83,84] These efforts include use of a scale to measure hypochondriasis and stratified analysis of self-reported symptoms to take account of subjects' perception about the source of pollution. Hatch and Thomas emphasised that environmental epidemiologists need to learn when and how to address the issue of psychosocial stress in order to clarify interpretation of health effects studies and to estimate the importance of stress in its own right.[76] Consideration should be given to measuring perceived stress and physiologic indicators of stress as well as to collecting data on methodological covariates such as motivation to participate, interest in receiving health care, and beliefs about the exposure in question as a cause of adverse health effects.

The influence of psychosocial stress may be controlled by clinical diagnosis during intervention studies. This approach is however impractical in future SADHS. The inclusion of specifically clinical diagnosed health outcomes should then be preferred above self-diagnosed ones. Questions should also be included whether the participant sought health care for the health outcome of concern.

The need for a central location for data storage of all exposure, demographic and health data is crucial in South Africa – linking back to the issues raised by Ritz et al above.[40] The collection of high quality outdoor air pollution data in all major cities in the country is needed, together with the implementation of an electronic health data management system along with electronic birth and cancer registries as soon as possible in order to conduct time-series studies.

8.4 Usefulness of Secondary Health and Exposure Data in enhancing Public Health

Despite the limitations mentioned in Section 8.2, the air quality data in the City of Cape Town is quite useful in conducting trend analysis or perform preliminary epidemiological studies. From the results in Chapter 3 it is advisable when conducting epidemiological studies to link clinic/hospital data with air pollution data collected from the nearest air quality monitor. This will reduce information bias. The air quality analysers continuously assess real-time concentrations of criteria pollutants using US-EPA equivalent methods in accordance with ISO 17025 guidelines.[36] These instruments measure the concentration of ambient air pollutants in 20 second scans and values can be expressed in short term (10 min), one hour, 24 hour, monthly or annual averages. Thus the data can be used to check compliance with air quality guidelines/standards (usually applying 24 hour average values), for air pollution alerts (usually applying values averaged over a few minutes to one hour), determination of acute and chronic human health and ecological effects (usually applying values averaged over one hour and 24 hours). Furthermore, the community can view the data on the City's web site soon after statistical analysis.[85]

Air quality data in the City of Cape Town can also be linked to school absenteeism as a proxy for child health until a health management system has been established for the country. While school absenteeism is a crude proxy measure of morbidity, which is also influenced by non-health-related factors, the majority of school absences are health-related and attributable to either respiratory infections or gastroenteritis. Excluding data from Mondays and Fridays may control confounding due to non-health-related factors. These days are often associated with non-health-related absence. Houghton et al suggested that school attendance data should be computerised.[86] This will facilitate the routine analysis of the relationship between pollution data and school absenteeism.

Table 5 lists the advantages and disadvantages of using 1998 SADHS data in air pollution epidemiological analyses. Furthermore, Hupkens et al pointed out that health surveys are especially relevant for health indicators that cannot be collected by means of hospital or clinic records, such as indicators on health status (for example as the prevalence of chronic conditions and self-assessed health as a measure for people's well-being), lifestyles (like smoking habits and alcohol consumption) and medical consumption (such as the use of medicines).[87]

Also modern health indicators like health expectancies and disability-adjusted life years (DALYs) can only be calculated with the help of survey data. Furthermore, the abundance of national health interview survey data makes these data valuable for studying the diversity in health in different country settings, which may advance the understanding of the determinants of health and disease. However, the value of these survey data for international comparisons depends on the comparability of the survey questions, frequency and methodology of the surveys (such as type of survey, sample frame and interview method). Given the large number of national health interview surveys, harmonisation may be a long, but also a promising endeavour. However, as most studies addressing air pollution epidemiology in Europe and North America are specifically designed for their unique purpose, the use of health survey data in these parts of the world are mainly to fulfil the objectives of the health survey and in international comparisons.

Table 5 Advantages and disadvantages of using 1998 SADHS data in air pollution epidemiological analyses

Advantages	Disadvantages
• Less time-consuming and costly than more rigorous prospective cohort studies	• Cross-sectional design and associated disadvantages
• Information on national representative sample of population	• Information on important confounders not collected
• Provide information on intercorrelations among numerous variables	• Unable to minimise measurement errors (random and systematic) of health, exposure and confounding variables
• Detect high-risk groups	
• Give hints about causal relations	
• Generate hypotheses	
• Provide a baseline for health and risk factor prevalence rates to be compared with future measurements	
• Provide information on need and demand for health services	
• Provide information to evaluate intervention programs in specific target populations	

The Bellagio Study Group on child survival recently discussed the requirement to transform knowledge into action, which included leadership, strong health systems, targeted human and financial resources and modified health system to ensure that poor children and mothers benefit from health research.[67,88-91] In order for the public to benefit from epidemiological results, these must be translated from theory into public health practice more efficiently. Population attributable fractions (PAFs) are useful for estimating the proportion of disease cases that could be prevented if one or more risk factors for that disease were reduced or eliminated.[92-99] Thus, how many cases of disease or premature mortality could be avoided if indoor air pollution due to combustion of dirty fuels for cooking and heating purposes could be eliminated completely in South Africa?

The results from Table 6 are calculated using equations 1 and 2.

$$\text{Attributable fraction} = \frac{(\%\ \text{population exposed} \times \text{relative risk*} + \%\ \text{population unexposed} \times 1) - 1}{\%\ \text{population exposed} \times \text{relative risk*} + \%\ \text{population unexposed} \times 1} \quad (1)$$

** The estimated odds ratios will be used in Table 6*

$$\text{Attributable burden} = \text{attributable fraction} \times \text{current disease level**} \quad (2)$$

*** Product of population size and prevalence rate of health outcome in Table 6*

Table 6 reflects the huge impact of indoor air pollution in the country. However, one should realise that epidemiological results alone will not change policy. This thesis does not by all means want to dictate to policy-makers how to apply these results. Rather, it is paving the way to open communication between epidemiological research and policy in South Africa. The Science-Policy-Interface (SPI) is complex, as was reported by the Thematic Network on Air Pollution and Health in Europe (AIRNET) initiative.[100] Communication between science (epidemiology studies) and policy is a dynamic process that is influenced by numerous factors. A detailed discussion of these factors is beyond the scope of this thesis and the reader is directed to Baker et al for an introduction.[101]

Decision-making is not a simple process. A decision-maker must choose between competing alternatives, and may face uncertainties at every step. These difficulties, however, are no excuse for lack of action. Given the strengths and weakness of the results (Section 8.2), increasing evidence about potential health problems could certainly aid the decision-making process, but waiting for more evidence implies that someone has to endure the suffering in the mean time.[102] As far back as 1965, Hill noted, "*All scientific work is incomplete – whether it be observational or experimental. All scientific work is liable to be upset or modified by advancing knowledge. That does not confer upon us a freedom to ignore the knowledge that we already have, or to postpone the action that it appears to demand at a given time.*"[103]

This thesis set out to identify the magnitude of health outcomes caused by indoor air pollution exposure. However, these results (when considering their strengths and weaknesses) can be utilised for economic analysis of exposure, environmental equity and evaluation of intervention and policies. The results cannot be used for standard or guideline setting as no quantitative exposure data were collected nor was the study design appropriate.

Table 6 Number of cases attributable to indoor air pollution due to medium and high polluting fuels†

	Chapter and Table	Fraction exposed	RR (95% CI)	Attributable Fraction	Prevalence of health outcome %	Population size	Attributable Burden
Adult nocturnal coughing due to *no* access to electricity	Chapter 5 Tables 3 and 5	0.35	1.72 (1.09; 2.70)	0.20 (0.03; 0.37)	13.1	30 454 485*	803 006 (121 833; 1 488 260)
Adult cough with phlegm due to *no* access to electricity	Chapter 5 Tables 3 and 5	0.35	1.64 (1.12; 2.44)	0.18 (0.04; 0.34)	6.80	30 454 485*	378 989 (83 472; 693 973)
<5 years ARI due to *high* polluting fuels use	Chapter 6 Tables 1 and 2	0.39	1.29 (1.02; 1.62)	0.10 (0.01; 0.19)	19.26	4 449 816**	87 082 (6 633; 166 879)
<5 mortality due to *dirty* fuels use	Chapter 7 Tables 1 and 3	0.79	1.99 (1.04; 3.68)	0.44 (0.03; 0.68)	-	41 171***	18 068 (1 261; 27 963)

† Refer to the individual chapters for the definition of fuel categories
** ≥15 year group[104]*
*** <5 year group[104]*
**** Total number of deaths for 0-4 year olds during 1998[105]*

These applications are dependent on one another and will be elaborated upon further. Economic analysis can utilise the attributable fractions calculated in Table 6 in valuing the health impacts of air pollution. Policymakers often need to assess relative importance of air pollution in setting priorities for health programs. Estimating the costs of ill health, suffering, and premature death is a highly debated, controversial subject. The valuation of health impacts is usually done using 'willingness to pay' or 'cost of illness' approaches. Both these approaches need to make some heroic assumptions about value of lost life, or lost workdays, pain, and suffering. The task is made more difficult by non-availability of local epidemiologic studies when additional assumptions about dose-response functions need to be made. Yet, policymakers cannot wait for more research and decisions need to be made based on best available information, appropriately adapted to the local setting as these presented in this thesis.

The results are of use to environmental equity and advocacy. It is actually incomprehensible that for so long, the health impacts of indoor air pollution have not been communicated to the general public. If they know about these health effects, they might better implement the technical and socio-behavioural interventions available. Technical interventions might be to reduce electricity costs for the poor in order to use electrical heaters instead of dirty fuels, to improve the ventilation rate in the homes or proper housing may also reduce dirty fuel use, such as built to enhance sunshine during winter time, tight houses with chimneys. Socio-behavioural interventions may include preventing children and pregnant women from being exposed to smoke from the dirty fuels. However, many factors influence the perception of risk. The reader is referred to Baker et al for an introduction on these as a thorough discussion is not within the reach of this thesis.[102] Chapter 2 addressed published results from interventions applied in the country. However, it is proposed that advocacy be encouraged in South Africa and the appropriate communication media used in awareness raising by the Health Promotion Department of the Department of Health. A significant 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.[104] More than 8 million South Africans may thus not be able to benefit from health promotion material that is designed for the more educated population. This should be considered when developing communication messages. The multi-cultural dimension of South African society furthermore represents a particular challenge to develop culturally appropriate interventions. The field of environmental health promotion should be nurtured in this country, to address the multidisciplinary actions needed to implement viable interventions.

Furthermore, Kauchali et al conducted a local rural study on maternal perceptions of ARI in children under 5 years of age.[42] The respiratory set of signs and symptoms were classifiable into five causative categories: supernatural, natural, tuberculosis, cold weather and unknown. They indicated that perceptions of causation differed greatly from biomedical concepts. For illnesses of perceived supernatural causation, mothers were reluctant to seek medical care and antibiotics were deemed inappropriate. Traditional remedies were preferred instead. These results have important implications in treating ARI (such as pneumonia), which is one of the top 3 leading causes of child mortality (12-48 months) in the country.[105] It is imperative that these issues be addressed in health promotion strategies.

The results can be applied in the evaluation of intervention and policies. Chapter 2 reported on intervention strategies that had already been implemented in the country and recommendations were made regarding future intervention strategies. Results from future SADHS may be used in trend analysis, during which time dirty fuel use will hopefully have been reduced by interventions and policies.

8.5 Other Sources of Data, Collaboration and Capacity Building

Given the advantages and disadvantages of using 1998 SADHS data in air pollution epidemiological analyses it is imperative that the country does not just rely on secondary data. For local public health to be improved by local air pollution epidemiological studies, other sources of data, collaboration and capacity building need to be investigated and enhanced.

Local researchers Sitas et al addressed the scarcity of health and risk factor data in the country more than 10 years ago.[107] Back then and currently still the primary routine system for morbidity data collection in South Africa is the register of notifiable diseases in which a number of conditions are notifiable by law. However, the information from such passive disease surveillance systems is assumed to be a reasonable measure of the incidence of a health outcome. This may be erroneous and Sitas et al addressed a number of reasons, such as ability for patient to attend a health facility, accessibility of health facilities, geographical differences in diagnostic standards, problem of linking a case to its appropriate catchment population with unique risk factor profiles.[107] In order to address these limitations, they suggested that active disease monitoring be introduced in a number of surveillance sites where the population has been properly enumerated in order to improve the usefulness of vital statistical information.

The need for a health data management system is covered in one of the indicators of the Department of Health Goals 2004 document and is also covered by its Ten Point Plan.[108,109] The reader is also directed to the Department of Health document on Essential National Health Research (ENHR) published in 2001.[110] The ENHR was introduced in Chapter I of this thesis. Several challenges remain in implementing the ENHR strategies, such as institutional roles and responsibilities, coordination of key components of ENHR among partners in health improvement, patterns of advocacy, capacity development and sources and levels of funding. In a recent series of editorials in the *Scandinavian Journal of Public Health* the value of an effective surveillance system for particularly poor countries has been discussed.[110-113]

Although cross-sectional studies cannot prove causation, they introduce hypotheses that could be tested in analytical intervention studies. This touches upon the issue of improved collaboration with the Department Environmental Affairs and Tourism, Department of Minerals and Energy, Department of Health, Medical Research Council, CSIR and tertiary academic institutions. The MRC report on poverty and chronic diseases in South Africa highlighted that in situations where data exists (such as records of medical aid societies of selected hospitals) they are seldom collated and presented in a format that could help inform the overall morbidity patterns. Research collaborations with private medical aid companies and the health services should thus start addressing this deficiency. This need for collaboration is to some extent addressed in the Ten Point Plan of the Department of Health, that is coordinating, supporting and conducting research and monitoring and evaluation activities.[109] The Ten Point Plan is a strategic plan for delivery of the Department of Health's goals in the next five years and recognises the importance of ENHR and partnership within the research community for achieving national health objectives. Thus far the institutional mechanisms have been strengthened by the constitution of a functional and widely representative ENHR committee with a wide range of representation. Sustainability and expansion of ENHR activities are guaranteed by the continued support from the Department of Health, Department of Arts, Culture, Science and Technology, Department of Education and other government, international and private sector organisations. However, several challenges remain and these include institutional roles and responsibilities, coordination of key components of ENHR among partners in health development, patterns of advocacy, capacity development and sources and levels of funding. Multi-sectoral collaboration is absolutely essential in order to benefit as much as possible from secondary data usage, such as conducting epidemiological studies whilst implementing interventions, such as the Basa njengo Magogo project by the Department of Minerals and Energy in Orangefarm, Johannesburg during the winter of 2003.[114] The Basa njengo Magogo of lighting a coal fire was introduced in Chapter 2.

The report by the WHO on indoor air pollution research needs stressed the importance of collaborative action and highlighted that multi-sectoral collaboration is not usually straightforward and often requires active development and support.[60] The report addressed three issues in multi-sectoral collaboration: a) The role of each sector needs to be more clearly defined in order to avoid duplication and confusion about responsibilities, b) multi-sectoral action requires good co-ordination, a function that will need to be put in place and c) collaborative action is often difficult for partners in practice: typically this requires an institutional or programme focus, leadership and adequate time for partners to learn how best to work together.

Local researchers Parry et al emphasised local, regional and international strategies to strengthen capacity building in health research.[115,116] This thesis specifically wants to stress the importance of developing the country's capacity in technical and research in *environmental* epidemiology, which ultimately attempts to improve public health. A country's ability to develop more sustainably depends on the capacity of its people and institutions to understand complex environmental and development issues in order to make the right development choices. The Foresight Series by the South African Department of Arts, Culture, Science and Technology pointed out that there is a general lack of highly trained experts in environmental epidemiology and health.[117] The latter is addressed in one of the indicators of the Department of Health Goals 2004 document, namely the transformation of Schools of Public Health.[105] However, capacity building can also be fostered by including postgraduate students in multi-sectoral collaboration projects. Furthermore, as addressed previously (Chapter 1, Section 1.2) the new National Health Act (Act 61 of 2003) may offer relief to the lack of political commitment to environmental health and improve the dilapidated function (including air quality measurements) in South Africa.[118] Regrettably environmental health is not presently a main concern in municipality budgets. This in turn will stress quality assurance when collecting environmental data and the application of the data in epidemiological analyses, which in turn can inform policy and boost public health.

As mentioned in Chapter 1, Ezzati et al pointed out that whilst conducting intervention and/or epidemiological studies, it does not help to just zoom in on accurate and valid quantitative personal, indoor and outdoor air pollution measurements and/or biomarkers without linking these measurements to the distal and proximal causes of disease, such as poverty, home design and socio-behavioural practices.[119] Epidemiological studies will then only focus on causation and miss its goal to introduce interventions to eliminate or reduce risk factors.

The use of biomarkers in local indoor air pollution epidemiology studies is also a debatable topic that warrants attention. Because of the difficulty of obtaining accurate and unbiased exposure information from study participants and the difficulty of estimating the doses that such exposures might produce, there has been great interest in the development of biologic markers (biomarkers).[76] These may be defined as "cellular, biochemical, or molecular alterations that are measurable in biological media, such as human tissue, cells, or fluids".[76] Biomarkers allow for considerable improvement in measurement of dose if used properly. Biomarkers have several advantages: (1) may prevent the errors arising from participants' lack of knowledge, memory failure, biased recall or deliberate misinformation; (2) prevent measurement errors arising due to individual pharmacokinetic and pharmacodynamic variations; (3) some markers can be used to detect biological interactions between the exposure of interest and critical tissues; (4) provide a quantitative or estimate of dose; (5) can serve as the gold standard for other information sources and (6) can provide a basis for error allowance procedures in studies that rely on less accurate exposure measures due to the cost of the marker.

To be valuable in environmental epidemiology studies, a biomarker should obviously be better than recall data or environmental measures; should permit differentiation between exposure levels; should be applicable on a large scale or should at least be acceptable to participants in a validation substudy.[76] Before markers are used in epidemiologic research, their sensitivity and specificity should be known from both the laboratory and epidemiologic perspectives; reproducibility of results within and between laboratories must also be known; and, very importantly, the particular time frame they reflect and during which they can be measured *in vivo* must be established so that they provide interpretable data regarding time and dose.[76]

At present, few exposure biomarkers satisfy these requirements. Some markers may provide a record of cumulative exposure (such as bone lead measurement), but most can assess only relatively recent exposures. Studies of biomarkers that use a case-control design and a cross-sectional marker of exposure can be difficult to interpret because of ambiguity about the temporal sequence of the marker and the disease. Indeed, such studies can be misleading. In addition to such problems in interpretation, biological measurements are often costly to perform. Furthermore, the need to obtain specimens can reduce the cooperation of participants and introduce the potential for selection bias to occur through initial refusal or later attrition, although these problems are probably not insurmountable if they are anticipated and addressed. Thus it is recommended to first pay attention to personal, indoor and outdoor air pollution measurements as well as distal and proximal causes of disease before applying biomarkers in local indoor air pollution epidemiology studies.

8.6 Main Conclusions and Recommendations

This thesis attempted to investigate the usefulness of analysing secondary South African air pollution exposure and health data to project risk estimates for adult respiratory health (older than 15 years), under five ARI and 1-59 month mortality due to exposure to indoor air pollution from using dirty fuels for cooking and heating purposes and ultimately improve public health in the country.

Despite the limitations of using the 1998 SADHS data, the results indicated that there is a strong case for acknowledging the large public health risk arising from air pollution exposure in South Africa. The findings can be utilised for economic analysis of exposure, environmental equity and evaluation of intervention and policies. The results cannot be used for standard or guideline setting as no quantitative exposure data have been collected nor was the study design appropriate.

Comparing the limitations identified in using the 1998 SADHS data to those from other local air pollution epidemiological studies, it is evident that not much progress has been made in air pollution epidemiology in the country during this analysis. However, due to the large sample size and many risk factors identified in the 1998 SADHS, it had the advantage over previous local studies in that it attempted to deal more adequately with confounding factors. Future SADHS surveys at regular intervals will allow the South African health care providers to assess if any progress has been made to relieve indoor air pollution exposure and if such progress has influenced health patterns in the country.

In order to improve the use of future SADHS data in air pollution epidemiological analyses it is important to capture more indoor air pollution exposure indicators and identified confounders. However, given the advantages and disadvantages of using 1998 SADHS data in air pollution epidemiological analyses it is imperative that the country does not just rely on secondary data. For local public health to be improved by local air pollution epidemiological studies, other sources of data, collaboration and capacity building need to be investigated and enhanced. Air pollution indicators can also be included in other national surveys or smaller surveys conducted in typical South African settings. An indoor air pollution exposure questionnaire could also be applied at demographic surveillance sites through out the country.

It is recommended that the country must develop environmental public health tracking networks, which incorporates various data sources from multi-sectoral collaborative intervention projects with an analytic study design, in all major cities in the country. The studies may address any of the following health outcomes: injuries, TB, cancer, respiratory infections or perinatal conditions. Ideally the studies should include a comprehensive exposure assessment with outdoor, indoor and personal measurements for CO, SO_2, NO_2, O_3 and $PM_{2.5}$. From these local exposure models can be used and validated in future studies. Interventions that may be addressed include technical or socio-behavioural ones, like the Basa njengo Magogo method, preventing vulnerable groups (such as children and pregnant women) from being exposed to smoke from the dirty fuels and opening windows and/doors when cooking. More research is needed in establishing socio-behavioural interventions when using dirty fuels for lighting and space heating. Future studies need to be planned well in advance. Postgraduate students should participate in these studies to strengthen capacity in air pollution epidemiology in the country. Future studies may also link air quality data in the City of Cape Town to school absenteeism as a proxy for child health until a health management system has been established for the country. It is recommended to first pay attention to personal, indoor and outdoor air pollution measurements as well as distal and proximal causes of disease before applying biomarkers in local indoor air pollution epidemiology studies. The use of Geographical Information Systems is also encouraged in linking exposure to health outcomes.

The air quality data in the City of Cape Town is quite useful for a number of reasons, despite the limitations identified. It is furthermore recommended that similar inter-site correlation analyses be conducted using air quality data from the other major cities in the country that maintain relatively extensive air quality monitoring networks under rigorous quality assurance guidelines. It is also recommended that all air quality monitoring networks in the country should be accredited in the near future by the South African National Accreditation System (SANAS). Given the lack of resources for outdoor air pollution measurement and the dearth of air pollution epidemiological studies in the country, local cities should thus attempt to optimise and update their air quality monitoring networks with the assistance of research and academic institutions in such a manner as to serve both compliance monitoring and epidemiological exposure assessment

The need for a central location for data storage of all exposure, demographic and health data is crucial in South Africa. The collection of high quality outdoor air pollution data in all major cities in the country is needed, together with the implementation of an electronic health data management system as well as electronic birth and cancer registries as soon as possible.

There is a need to add health policy courses to the health sciences curriculum in order to improve communication between epidemiological research and policy in the country.

The multi-cultural dimension of South African society furthermore represents a particular challenge to develop culturally appropriate interventions. The field of environmental health promotion should be nurtured in this country, to address the multidisciplinary actions needed to implement viable interventions.

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