The health benefits of attaining and strengthening air quality standards in Cape Town

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Abstract

The link between pollution and poor health and mortality has been established globally. Developing countries carry most of the burden of ill health from air pollution, and urban centres like the City of Cape Town even more so. Effective air quality management to protect human health relies on the attainment of air quality standards. This study uses the Benefits Mapping and Analysis Program (BenMAP) along with a locally derived exposure-response function and air quality monitor data to investigate whether the consistent attainment of current or more stringent air quality standards would avoid loss of life. The results show that attaining the PM_{10} 24-hour mean South Africa National Standard limit and the PM_{10} and SO_2 24-hour mean World Health Organisation guidelines in Cape Town reduces levels of pollutants and does reduce excess risk of mortality in Cape Town.

Keywords

health impact assessment, air pollution, mortality, BenMAP, Cape Town, PM_{10}, SO_2, South African National Standard (SANS) limit, World Health Organisation (WHO) guideline

Introduction

The link between ill health and mortality and air pollution has long been established, for both long- and short-term exposure (Brunekreef and Holgate 2002). This association is almost certainly greater in developing than in developed countries (Shah et al. 2015). One of the reasons for this increased vulnerability to the ill effects of poor air quality is the cumulative impact of poor environmental health (Norman et al. 2010).

In Cape Town, concerns about air quality have motivated investigation of the constituents and causes of poor air quality, for example the occurrence of a brown haze over Cape Town in the colder months of May to September (Wicking-Baird et al. 1997) and the unusually high concentrations of particulate matter (PM) in the township of Khayelitsha (City of Cape Town 2008). Studies of the association of local pollutant exposure and morbidity include health surveys near the local crude oil refinery and an audit of hospital admissions during periods of atmospheric temperature inversions (Truluck 1993; White et al. 2009), and note that parts of the City suffer a disproportionate burden of air pollution-related ill health (Scorgie and Watson 2004).

Air pollution in Cape Town is mainly attributed to traffic vehicles, industry and the oil refinery, as well as to the domestic burning of fuels and the burning of waste (including car-tyres). Air quality interventions by the City of Cape Town include random vehicle emissions testing and the requirement for industry to apply for air emissions licences. The main goal of the National Environmental Management Air Quality Act (NEM:AQA) is to attain air quality objectives, and to this end the City monitors ambient air quality.

A health impact assessment to quantify the impact of attaining air quality objectives is based on the exposure-response relationship and population exposure data, which is derived from air quality and population data. A shortage of local epidemiological research to quantify the exposure-response relationship has encouraged the use of functions from the international literature in order to estimate the impact of pollution on human health (Scorgie et al. 2004), albeit with the caveat to do so with caution (Wichmann 2005).

The World Health Organisation (WHO) recommends that local health impact assessments use multi-site study or meta-analytic summary health impact functions except where the target population differs from the aggregate in its response to air pollution (WHO 2001). Globally, South Africa bears a sixth of the burden of HIV/AIDS infection and is second only to Lesotho in incidence rates (WHO 2015a); co-infection of HIV/AIDS and tuberculosis profoundly compromises the immune system (Powlowski et al. 2012). In Cape Town, both HIV/AIDS and TB are recorded as being in the top ten causes of death (Lehohla 2014). These facts suggest that the health of the local population may be significantly more vulnerable than the aggregate in available metaanalyses and multi-site studies, which are predominantly based on developed country data (Wichmann 2005).

The only locally proposed exposure-response functions are based on City of Cape Town exposure to elevated 24-hour

mean levels of air pollutants and excess risk of mortality (with 95% confidence interval) for 2001–2006. The association was calculated for particulate matter of less than 10 µm (PM_{10}), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) with cerebrovascular, cardio-vascular and respiratory diseases (Wichmann & Voyi 2012). The study used a case-crossover study design with a time-stratified approach (using matching days of the week) to quantify associations of cerebrovascular disease mortality with inter-quartile range (IQR) increases of 12 µg/m^3 in PM_{10} 24-hour mean values; of cardiovascular and cerebrovascular disease mortality associated with elevated IQR levels of 12 µg/m^3 of NO_2; and of cardiovascular disease mortality and an IQR increase of 12 µg/m^3 of SO_2.

The case-crossover study design and use of impact lags of the same day to 5 days control for confounding factors that are considered constant in the short-term, for example seasonality or vulnerability attributable to smoking. The use of conditional regression analysis controlled for confounding as a result of temperature, humidity and day of week effects. The study conducted statistical analyses for the warmer months (September – April), cooler months (May – August), and the entire period to control for seasonality.

The study design employed by Wichmann and Voyi (2012) is not without limitation. Case-crossover design studies, as a specific type of time series studies, characteristically fail to identify displaced mortality, or 'harvesting', of sufferers of chronic exposure (Bateson & Schwartz 1999). This displaced mortality is identified by a sharp and temporary decrease in mortality immediately after a period of pollutant-associated excess mortality. This creates uncertainty as to whether the cause of excess mortality is acute exposure, longer-term lower level chronic exposure, or the incidence of both. However, the long-term data (over a period of decades) that would be needed to separate out and quantify the impact of chronic exposure (Rabl et al. 2011) are not available.

It is generally accepted that it is difficult to isolate the human health impact of any single pollutant. This is especially so for pollutants which tend to co-vary. SO_2 and PM are a good example of this, in part because SO_2 oxidises to sulphate, which coalesces with, and is then measured as part of the PM mass concentration (WHO 2006). In addition, vulnerability is driven by multiple factors (Norman et al. 2010) and few diseases are attributable to only one pollutant.

Notwithstanding the need to bear these limitations in mind when interpreting study results, the need for local data studies is well recognised (Wichmann 2005, Norman et al. 2010). This study uses the locally derived exposure-response function to investigate whether the consistent attainment of SANS limits and WHO guidelines would reduce associated excess mortality risk in Cape Town.

Materials and methods

The Benefits Mapping and Analysis Program (BenMAP) is open source software developed by the United States Environmental Protection Agency to calculate human health impacts and the economic costs thereof as a result of changes in ambient air pollution. Inputs to BenMAP include air quality morbidity or mortality incidence, population data, GIS shapefile(s) for the area of interest and a health-impact or exposure-response function. The program has been successfully applied for analyses globally and is effective in integrating data available at different scales (Hubbell et al. 2009).
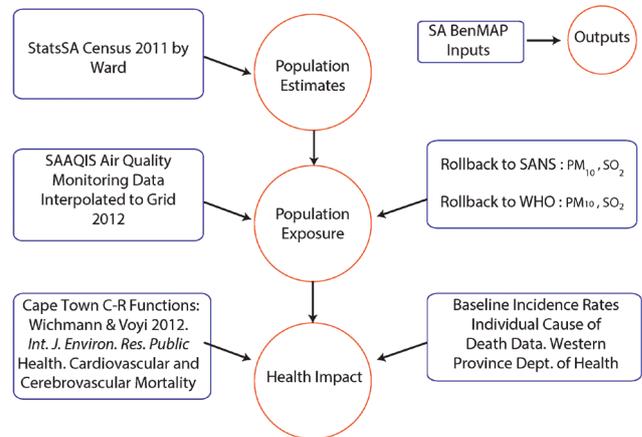

Figure 1: *Schematic of stepwise inputs and outputs for BenMAP calculations of health impacts.*

Data inputs

The health impact function is adopted from Wichmann and Voyi's (2012) epidemiological case-crossover study, which was based on 2001–2006 mortality data and 24-hour mean pollutant monitor data. The function is based on the 24-hour mean, so only the 24-hour mean SANS limits and WHO guidelines are applied in this study. The South African National Standard (SANS) limit for ambient concentrations of PM_{10} is 75 µg/m^3 and for SO_2 it is 125 µg/m^3 (SANS 1929: 2004). The more stringent WHO guidelines are 50 µg/m^3 and 20 µg/m^3, respectively.

Air quality monitoring data was downloaded from the City of Cape Town Open Data Portal (City of Cape Town 2014). The data was processed to remove all non-number entries and formatted for input to BenMAP. Analysis of data availability reveals considerable data gaps for some stations (Appendix: Table 1). Monitor stations are located where risk of exposure to pollutants is high because of proximity to pollutant sources and risk of population exposure. For areas that lack air quality data, either because there is no monitor station or because of gaps in data, BenMAP conducts user-specified interpolation. This study used the Voronoi Neighbour Averaging method, which uses data from more than one nearby monitor (the algorithm is more fully described in RTI International (2015)).

Individual cause of death data for the Western Cape was provided by the Western Cape Health Department. The WHO international statistical classification of diseases and related health problems, 10th revision (ICD-10) (WHO 2015b) was used to aggregate the data to broader categories including death as a result of cardiovascular and cerebrovascular disease and to calculate all age and gender mortality rates. This is in keeping with the method used to derive the exposure-response function (Wichmann and Voyi 2012).

Cape Town municipality and ward GIS shapefiles provided the grid on which BenMAP mapped the air quality, population and

incidence data. BenMAP calculated the incidence values using the mortality data and input Census 2011 ward population data (Statistics South Africa 2012).

Figure 2: Map of air quality monitor stations in the Cape Town Metropolitan area. (City of Cape Town. State of Environment Report. 2009)

Sensitivity analysis

To estimate the impact of a change in air quality related health endpoints, BenMAP runs the health impact function linking the monitor data and incidence data (the Baseline scenario) and a Rollback to a hypothetical case in which levels of air quality data are reduced or limited (the Control scenario). The health impact function form used in this study is:

$$\Delta Y = (1-(1 / EXP(Beta * \Delta AQ))) * Y_0 * Pop \qquad (1)$$

where Y_0 is the incidence function in the 'Baseline' scenario, Pop is the population, ΔAQ is the change in air quality between the Baseline and Control scenarios, and Beta is the impact function for an IQR increase in pollutant, given as the 95th percentile range in order to take account of the uncertainty in the effect estimates.

The incidence function is calculated by:

$$Mortality\ rate * Pop \qquad (2)$$

A Monte Carlo approach is used to create a normal distribution of incidence. The approach is well described elsewhere (RTI International 2015).

The sensitivity analyses for PM_{10} are set to the SANS limit of 75 µg/m³ and the WHO guideline of 50 µg/m³. The analysis for SO_2 uses the SANS limit of 125 µg/m³ and the WHO guideline of 20 µg/m³.

Results and discussion

BenMAP generated Baseline and Control air quality surface maps to overlay the GIS shapefile layers (municipality and ward boundaries). A third air quality surface map shows the reduction in pollution exposure (ΔAQ). Assuming uniform distribution of each ward population, the change in incidence (ΔY) was calculated on a ward by ward basis (each ward representing a shapefile grid cell). The wards near the monitors known for high concentration readings and with high population density benefitted most from attaining the WHO guidelines and SANS limit. The wards near the Khayelitsha monitor station (Figure 2) benefit most from reduced excess mortality risk as a result of attaining the PM_{10} SANS limit and WHO guideline. The wards with the Bellville South and with the Tableview monitor stations benefit notably from attainment of the SO_2 WHO guideline. Bellville South is an industrial area and Tableview is home to the oil refinery.
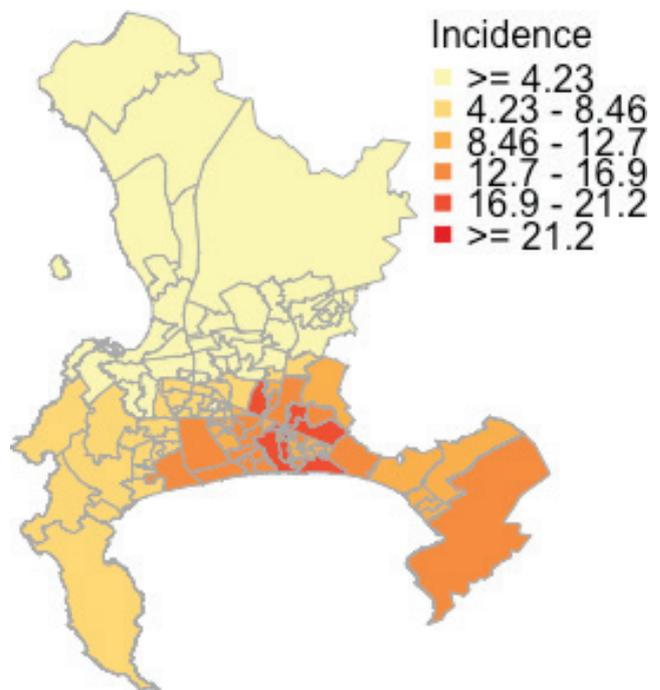

Figure 3: Reduction in excess mortality as a result of attaining the PM_{10} SANS 24-hour mean limit.

The inherent uncertainty in this impact assessment (as a result of incomplete input data-sets and health impact function limitations) should be considered in any interpretation of the results below. To minimise the risk of double counting, the
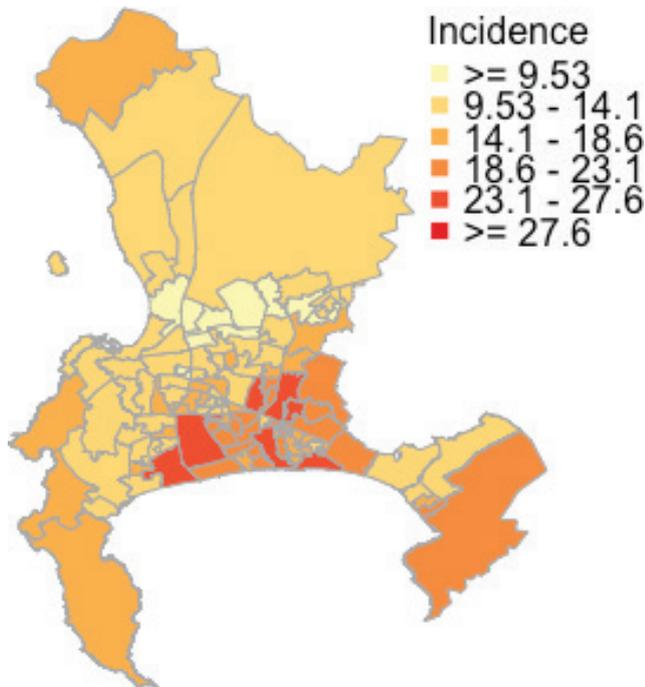
Figure 4: *Reduction in excess mortality as a result of attaining the PM$_{10}$ WHO 24-hour mean guideline.*
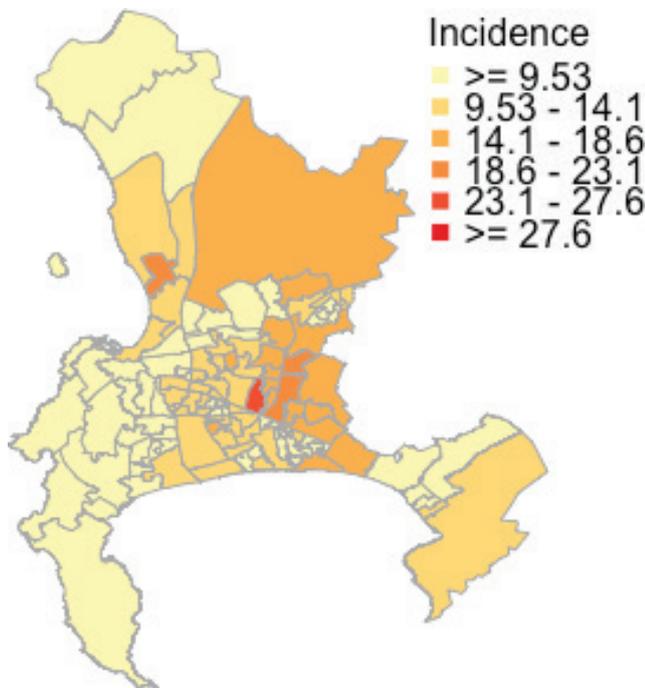

Figure 5: *Reduction in excess mortality as a result of attaining the SO$_2$ WHO 24-hour mean guideline.*

impact of reducing the two pollutants cannot be summed. The use of the ICD-10 classification reduces, but does not eliminate misattribution of pollutant with health endpoints. Acute exposure impacts might be under-estimated by any displaced mortality effect.

PM$_{10}$-related mortality reductions

Attaining the PM$_{10}$ SANS limit
Attaining the PM$_{10}$ SANS limit of 75 µg/m³ is estimated to reduce the excess mortality by a mean of up to 21 cases of excess mortality in the worst affected wards, and 857 cases across the City for the year.

Attaining the PM$_{10}$ WHO guideline
Attaining the PM$_{10}$ WHO guideline of 50 µg/m³ is estimated to reduce excess mortality by a mean of up to 28 cases of cerebrovascular-related deaths annually in some wards (Figure 4). Over the whole municipality the reduction is 1 690 cases of excess mortality for the year.

SO$_2$-related mortality reductions

Attaining the SO$_2$ SANS limit
There was no change in incidence brought about by limiting peak concentrations of SO$_2$ to no more than 125 µg/m³.

Attaining the SO$_2$ WHO guideline
Attaining the WHO guideline for SO$_2$ avoids a mean of 20 cases of cardiovascular-related excess daily mortality in some wards. Across the City, the estimated avoided excess mortality is 1 174 cases for the year (Figure 5).

Considerations, limitations and further work
The level of uncertainty in the results is driven in part by the level at which the input data is aggregated, largely by the absence of data, and in part by the use of interpolation for absent data. For example, in this study the population data is at ward level and the pollutant monitors, located in some wards only, report incomplete data sets. Loss of life data at ward level is not available in light of the need to protect anonymity. For this reason Health District level data was aggregated across the municipality.

The exposure-response function applied across the City is based on data from three air quality monitoring stations in relatively close proximity: City Hall, Goodwood and Tableview (Wichmann and Voyi 2012). In the light of social inequality across the city of Cape Town, the difference in risk factors for poor health varies considerably (Norman et al. 2010). More localised health impact functions, for example at the health district level, would likely reduce uncertainty in results. Uncertainty in health effect functions might be further reduced using multi-pollutant models and by long-term cohort studies to quantify the chronic impacts of air pollution.

Conclusions
The attainment of the SANS 24-hour mean limit for PM10 reduces annual excess mortality by 857 cases. This benefit is nearly doubled by attaining the WHO 24-hour mean PM10 guideline. The attainment of the SO2 24-hour mean limit reduces annual excess mortality by 1 174 cases. The areas of Cape Town that benefit most from the air quality improvements are those near

the Khayelitsha monitoring station, the Tableview monitoring station and local oil refinery respectively, and the industrial area of Bellville South. The production of locally estimated exposure-response functions has the potential to support the prioritisation of attaining air quality standards.

Acknowledgements

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Appendix A. Air quality monitor data availability and air quality targets

Table 1: Percentage of hourly mean air quality monitor data available for 2013.

Monitoring station	SO$_2$ (%)	PM$_{10}$
Atlantis	58%	-
Bellville South	88%	97%
Bothasig	77%	-
City Hall	98%	-
Foreshore	-	97%
Goodwood	19%	48%
Khayelitsha	68%	69%
Killarney	15%	29%
Plattekloof	53%	52%
Tableviews	89%	80%
Wallacedene	47%	50%