Chapter 4

POTENTIAL HEALTH IMPLICATIONS OF OUTDOOR PM_{10} MASS EXPOSURE IN THE KHAYELITSHA SUB-DISTRICT, CAPE TOWN, SOUTH AFRICA

Objectives: This study investigated the current and future potential health implications due to outdoor PM_{10} mass exposure in the Khayelitsha sub-district in the City of Cape Town in a preliminary analysis.

Methods: The PM_{10} mass data comprised of concentrations averaged at hourly and daily intervals from 1 March 1999 – 31 July 2003. Daily PM_{10} mass concentrations were compared to the United Kingdom (UK) Daily Limit value (DLV) (50 $\mu g.m^{-3}$) to assess current potential health implications. Preliminary trend analysis was conducted to investigate future potential health implications.

Results: The results indicate that elevated daily PM_{10} mass concentrations are frequently present. During autumn 1999 and winter 2003 the UK Daily Limit value (50 $\mu g.m^{-3}$) 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.

Conclusions: Currently PM_{10} mass concentrations frequently exceed the UK DLV. Health of sensitive sub-populations might therefore be more at risk. Within a few years the UK Annual Limit value (40 $\mu g.m^{-3}$) might be exceeded based on the preliminary trend analysis. Consequently a higher proportion of the community might be at risk from suffering various detrimental health effects in the future.

4.1 Introduction

Airborne particulate matter represents a complex mixture of organic and inorganic substances. Mass and composition tend to divide into two principal groups: coarse particles (between 2.5 and 10 μm in aerodynamic diameter)(PM_{10}) and fine particles mostly smaller than 2.5 μm in aerodynamic diameter ($PM_{2.5}$). The smaller particles contain the secondarily formed aerosols (gas-to-particle conversion), combustion particles and recondensed organic and metal vapours. The larger particles usually contain earth crust materials and fugitive dust from roads and industries. Particles less than 10 μm in diameter are considered respirable and capable of gaining access to the lower respiratory tract.

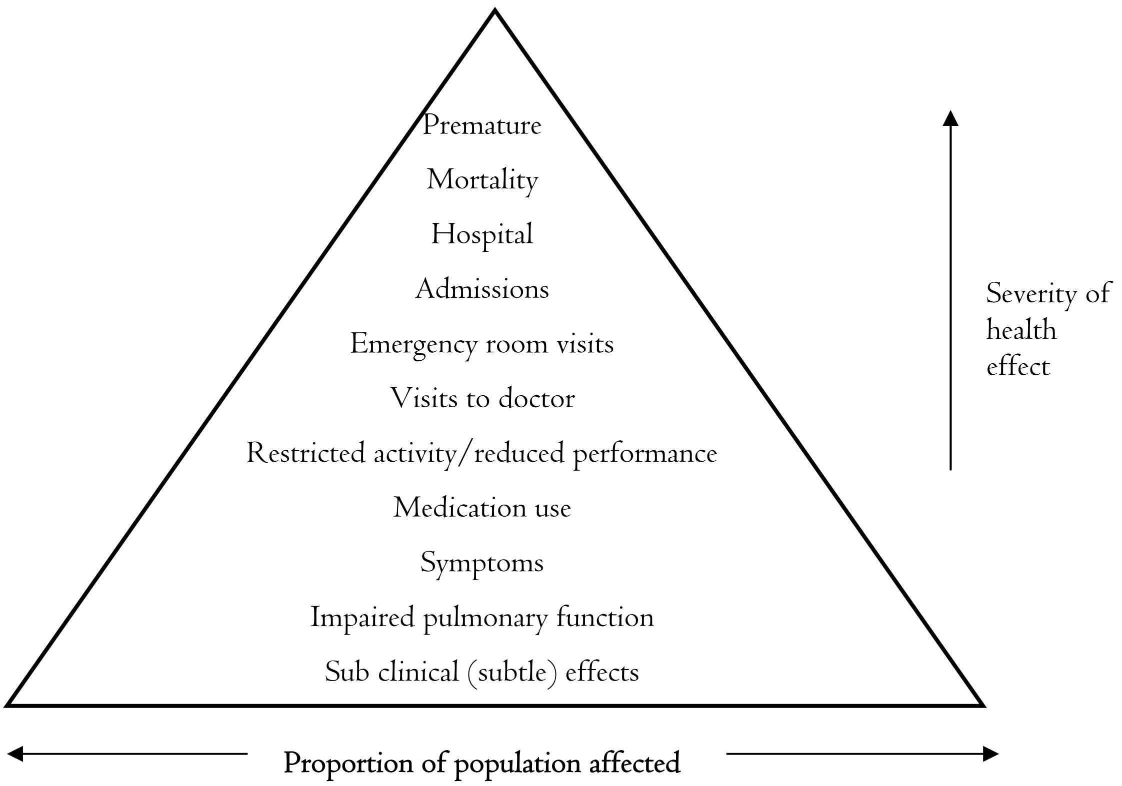


Figure 1 Air pollution health effects pyramid

Numerous epidemiological and toxicological studies have related PM exposure to a range of adverse health outcomes, ranging from mortality to subclinical respiratory symptoms (Figure 1).[1-4] Epidemiological studies also indicate associations between the size of inhaled particles and the development of pulmonary diseases.[5,6]

The majority of the air pollution epidemiological and exposure assessment studies are carried out in developed countries. It is important to conduct more air pollution epidemiological and exposure assessment studies in South Africa as it is faced by pollution caused by industry (First World situation) and by domestic burning of coal and dirty fuels (Third World situation). Study results (such as exposure-response curves) acquired in developed countries cannot be extrapolated with total conviction to developing countries.[7] The three global factors that directly or indirectly impact on health - the community and social environment, the physical environment and the family and individual environment – are different for developed and developing countries.

Very few quantitative exposure assessment or analytical epidemiological studies have been conducted in South Africa. Exposure is usually based on a proxy measure, such as smoking status[8,9] or use of dirty fuels (such as wood, coal, paraffin, animal dung, crops) for space heating.[10,11] In a review by Wichmann and Voyi four studies were identified that measured outdoor air pollution directly.[12-19] Wichmann and Voyi concluded that the local studies do provide some evidence of associations with a range of serious and common health problems.[12] Three of the studies established a strong significant relationship with air pollution indicators and deteriorated human health.[16-21] Seven studies established a significant link with air pollution indicators and disease.[8-10,22-24] Four studies did not report any significant link between air pollution indicators and disease.[13,15,25,26] 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.[14,27] The lower limit of many of the association measures of some of the reviewed studies is more or less one.[22-24] Most of the studies to date have had an observational rather than analytical or intervention design. The latter two study designs 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 any of the criteria air pollutants (lead, PM_{10}, SO_2, NO_2, O_3, CO) due to the lack of quantitative air pollution measurements. The repercussion of these limitations is that, although results are fairly confident that air pollution indicators do boost the risk of adverse health outcomes, it is not yet clear by how many people. It is therefore problematical to use the results of the studies in risk assessment studies.

For the purpose of this paper, Khayelitsha sub-district in Cape Town comprises of electoral wards 88 to 99.[28] The electoral wards do not always cover the same area as the sub-districts. The nearly 330 000 residents of the Khayelitsha sub-district are particularly vulnerable to the health implications of exposure to air pollution. The severity of health outcomes to air pollution increases with vulnerability. The predominant age group in the Khayelitsha sub-district is 15-34 years old (46%), followed by the 35-64 year olds (24%), 5-14 year olds (19%), 0-4 year olds (10%) and 65+ year olds (1%).[28] Seventy percent of entire population does not have any individual monthly income, whilst 25% earn less than ZAR1600 per month. The remainder earn between ZAR1600-ZAR6400 per month. In terms of the internationally comparable poverty line of $1 per capita per day, the level of poverty in Khayelitsha is about 75% ($1 = ZAR8). The unemployment rate is currently 50%. The majority of the homes fall within the informal category (65%), with the remainder under the formal type. Seventy percent of the households have 1-4 members. Most of the homes have 1-4 rooms (86%). HIV prevalence increased from 22.0% in 2000 to 24.9% in 2002.[29] The rate of tuberculosis in Khayelitsha is the second highest (977 per 1000 in 2002)(after the Nyanga sub-district) in the City of Cape Town (638 per 1000). It is well known that permanent lung damage is a side-effect of TB infection, even for person who successfully complete treatments.[30,31] The infant mortality rate during 2000 was 47 per 1000 compared the City of Cape Town (26 per 1000) and the national level (45 per 1000). Main causes of infant mortality are HIV/AIDS, diarrhoeal disease, short gestation/low birth weight and pneumonia. IMF decreased from 63 per 1000 in 1999 to the current rate. Under five mortality and low birth weight are the highest compared to the other sub-districts in the City of Cape Town.

This study investigated the current and future potential health implications due to outdoor PM_{10} mass exposure in the Khayelitsha sub-district in the City of Cape Town in a preliminary analysis.

It is important to point out that this study was done independently from the City of Cape Town. The City of Cape Town is responsible for developing an air quality management plan which should be incorporated into its integrated development plan according to the National Environment Management: Air Quality Act (Act 39 of 2004).[32] However, human resources capacity to investigate fundamental issues pertaining to air pollution exposure assessment in detail are *currently* not available at local government level.

4.2 Meteorology and topography

The City of Cape Town was established in December 2000 by the merging of the previous Cape Metropolitan Council and six Metropolitan Local Councils: Tygerberg, Oostenberg, Blaauwberg, South Peninsula, Helderberg and Cape Town. It is the southern most metropolitan area on the African continent and covers an area of 2 487 km^2. The Khayelitsha sub-district is a large, predominantly informal settlement located about 30km from the centre of Cape Town. Khayelitsha was established in 1983 and grew rapidly.

The City of Cape Town has a Mediterranean climate. Summer is from December to February with temperatures averaging at around 28°C. The prevailing wind during October to March (spring to autumn) is from SSE to SSW. It brings very little rain with it. Occasionally during summer the area will experience northerly "berg winds" with associated increase in temperatures. The Southeaster subsides slightly during February and March. The prevailing wind between May and August (autumn and winter) blows from N to NW. This wind is not as strong as the South Easter and occurs less frequently. It precedes a cold front and is therefore followed by much needed rain. The rainy season peaks during June and July. During March to August the area have calm atmospheric conditions and low level inversions.

4.3 Air pollution monitoring network

Figure 2 indicates the air quality monitoring sites in the City of Cape Town. PM_{10} mass monitoring commenced during March 1999 in the Khayelitsha sub-district using a TEOM 1400A analyser (Figures 3).[33] The analyser continuously assess real-time concentrations of PM_{10} mass using US-EPA equivalent methods in accordance with ISO 17025 guidelines. 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, twenty four hour, monthly or annual averages.

Minimum data completeness requirements for the calculation of period averages issued by the US-EPA in accordance with ISO 17025 guidelines for continuous monitoring are stipulated as follows:

- 24-hour average - requires at least 20 one-hour samples;
- Monthly average requires at least 80% of data days of >20 hours or more;

- Quarterly average requires 80% data capture and no more than 10 consecutive incomplete days;
- Annual average - requires 4 complete quarters.

The PM_{10} mass data are posted on the City's web site as soon as the data has been analysed statistically. The site can be visited at the City's Air Quality Department website.[34]

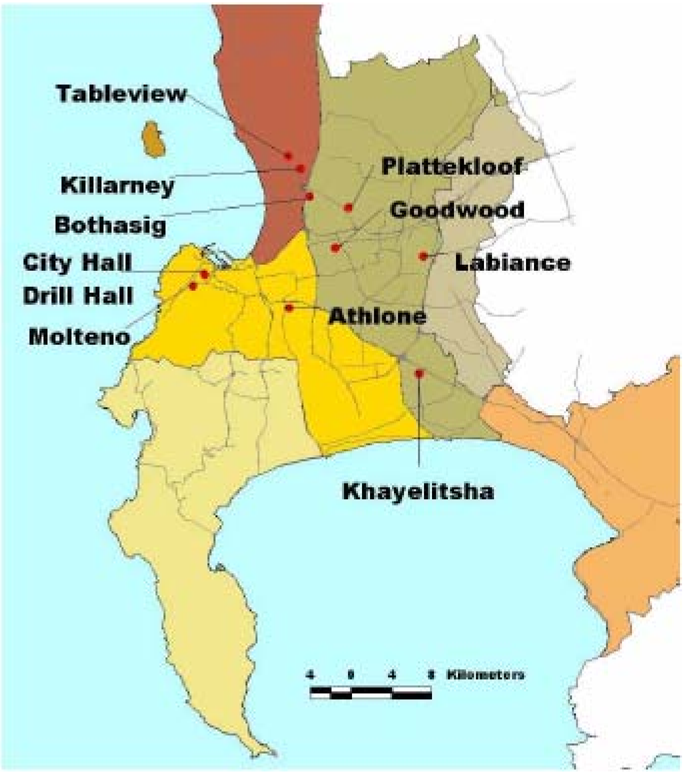


Figure 2 Air quality monitoring sites in the City of Cape Town[33]

4.4. Air pollution sources

Various environmental challenges confront the Khayelitsha sub-district. These are primarily the consequence of the growing population and their concurrent need for infrastructure, housing, employment and education.

Rapid urbanisation and urban growth have resulted in a larger population of the City of Cape Town and this in turn leads to a larger number of people making use of public and especially private transport to commute to work. During peak periods the capacity of some road networks is exceeded and other road networks are reaching their capacity. A large proportion of the residents of Khayelithsa live close to a busy highway (N2) and other busy roads (such as the R310) (Figure 3).

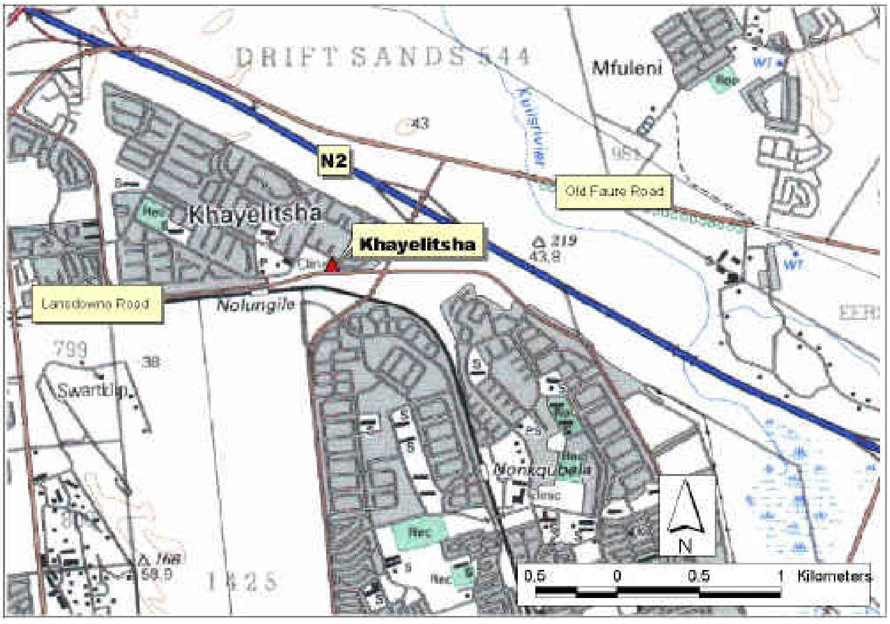


Figure 3 Location of air quality monitoring site in the Khayelitsha sub-district, City of Cape Town[33]

Paraffin, electricity and candles are used for lighting by 22%, 76% and 2% of the nearly 86 000 households in Khayelithsa, respectively.[28] Statistics on the energy use for cooking and heating are not available on a sub-district level. As nearly 100% of people living in Khayelithsa are Black, the energy use profiles for cooking and heating in Black households in the entire City of Cape Town will be quoted here.[28] Under Apartheid, South Africans were categorised into one of four socially defined groups: White (mainly European ancestry), Asian (Indian sub-continent ancestry), African or Black (descent primarily from one of a number of Bantu language groups in Southern Africa) and Coloured (general grouping, including a mixture of black, Malay, European and indigenous Khoisan ancestry). Race is very much linked to past access to resources, socio-economic status and educational status. The energy use profiles for cooking in Black households in the entire City of Cape Town are as follows: 45%, 4%, 49%, 1% and 1% for electricity, gas, paraffin, coal and animal dung, respectively.[35] The figures for heating are 33%, 1%, 57%, 4% and 4% respectively for electricity, gas, paraffin, wood and other unspecified fuels.[35] The Khayelitsha sub-district is also located close to an industrial area.

Outdoor air quality remains a key issue in the City of Cape Town as a whole, largely because of the visible air pollution, particularly during March to August - known as the 'brown haze'.[33] The brown haze is associated with calm atmospheric conditions and low level inversions. It occurs over most of the City and is typically most severe in the morning. Air pollutants (such as SO_2, NO_2, particulate matter and heavy metals) result from combustion processes in industry, services, agriculture, transport and homes.

4.5 Methods

SAS version 8 was used in the statistical analyses for data collected from 1 March 1999 – 31 July 2003. MS Excel was applied in the preliminary trend analysis. The data comprised of concentrations averaged at hourly and daily intervals. During the statistical analysis the ISO 17025 guidelines were adhered to, namely all 24-h averages and monthly averages are based on at least 20 1-h and at least 24 24-h averages, respectively. If this requirement was not met, a 24-h average or monthly average was set as a missing value. Percentages of hourly data available measured at Khayalithsa are: 26.4% (1 March 1999-29 February 2000), 73.4% (1 March 2000-28 February 2001), 56.7% (1 March 2001-28 February 2002), 16.6% (1 March 2002-28 February 2003) and 97.1% (1 March 2003-31 July 2003).

An exploratory data analysis was conducted in which the untransformed and log transformed data were tested for normality using the Kolmogorov-Smirnov test at the 95% confidence level. It was concluded that log transformations were ineffective in normalising the data. An alternative for normalising the data was attempted by the culling of extreme values above 61 $\mu g.m^{-3}$ (hereafter refer to as high values). This is practical as the data remain in their original units. This procedure was ineffective in normalising the data.

On average 92% of the hourly values of all the pollutants measured over the five year period were less than the threshold value of 61 $\mu g.m^{-3}$. As no hourly South African and UK limit values exist, no consideration was given to setting a threshold value based on these values. The daily and annual South African guideline values are 180 $\mu g.m^{-3}$ and 60 $\mu g.m^{-3}$, respectively. Those of the UK are 50 $\mu g.m^{-3}$ and 40 $\mu g.m^{-3}$, respectively. In its State of the Environment report of 1998, the City of

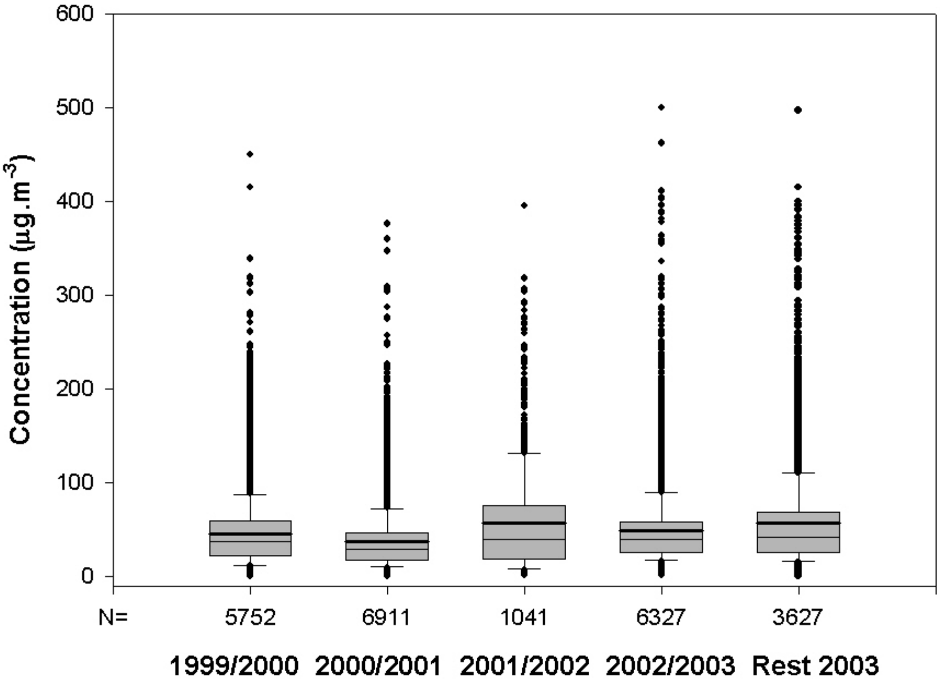
Cape Town implemented the guidelines and air quality banding system as adopted in the UK.[36] This was as the result of extensive research by the UK's Department of the Environment's Expert Panel on Air Quality Standards (EPAQS), which is linked with health advice from the UK's department of Health's Committee on the Medical Effects of Air Pollutants (COMEAP). The South African guideline system has been under review when writing this article.

4.6 Results

Figure 4 presents the descriptive statistics of the hourly and daily PM_{10} concentrations. The annual PM_{10} means cannot be computed as data are not composed of 4 complete quarters according to the ISO 17025 quality assurance guidelines. The hourly and daily PM_{10} concentrations both have a positively skewed distribution (Figure 4).

Figure 5 indicates the typical hourly variations of PM_{10} during the four seasons when all the hourly pollutant concentrations were averaged over the monitoring period. In general the concentrations were highest in winter, decreasing in spring and summer and increase again in autumn. The profiles shown in the figure show that the concentrations of PM_{10} closely follow the diurnal pattern of traffic with peak hour and off-peak hour differences as well as lighting, cooking and space heating times, i.e. the higher levels are usually observed in the morning between 8:00 and 9:00 and the evening rush hours 16:00 to 19:00. The low values (i.e. concentrations $\leq$ 61 $\mu g.m^{-3}$) are similar during all seasons (Figure 5b). The high values (i.e. concentrations >61 $\mu g.m^{-3}$) indicate a peak of 160 $\mu g.m^{-3}$ between 20:00 and 22:00 during winter (Figure 5c).

Figure 6 illustrates the maximum and minimum daily concentrations for the period under investigation. All the maximum and minimum daily concentrations are larger and smaller than the UK Daily Limit value (DLV) of 50 $\mu g.m^{-3}$, respectively. In general the minima concentrations appear to vary less over time compared to the maxima. The maxima initially indicate a declining trend followed by a sudden increase.



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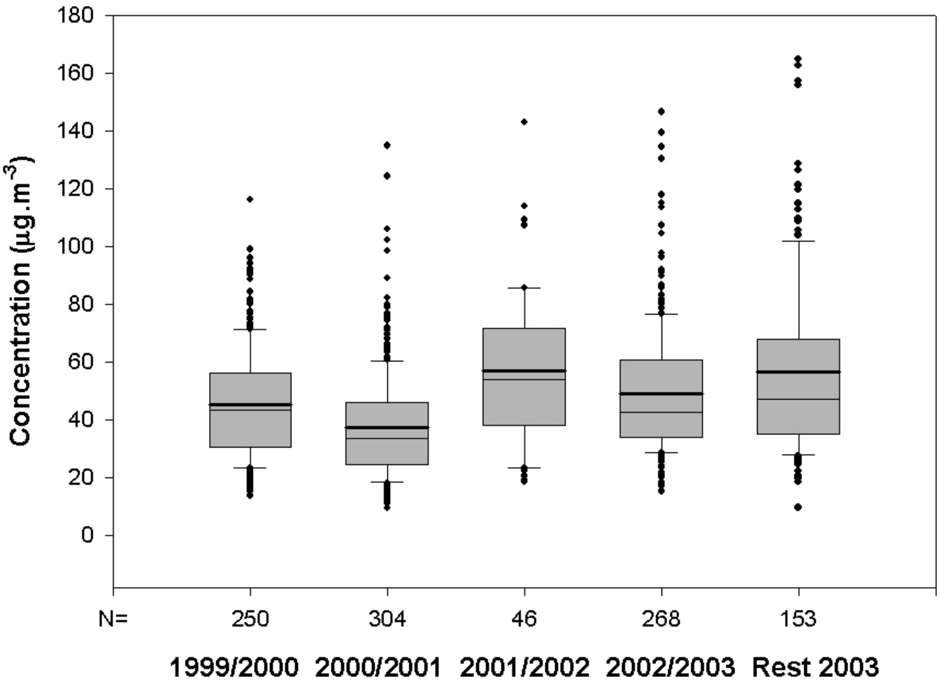

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Figure 4 Descriptive statistics of a) hourly and b) daily PM_{10} concentrations ($\mu g.m^{-3}$)

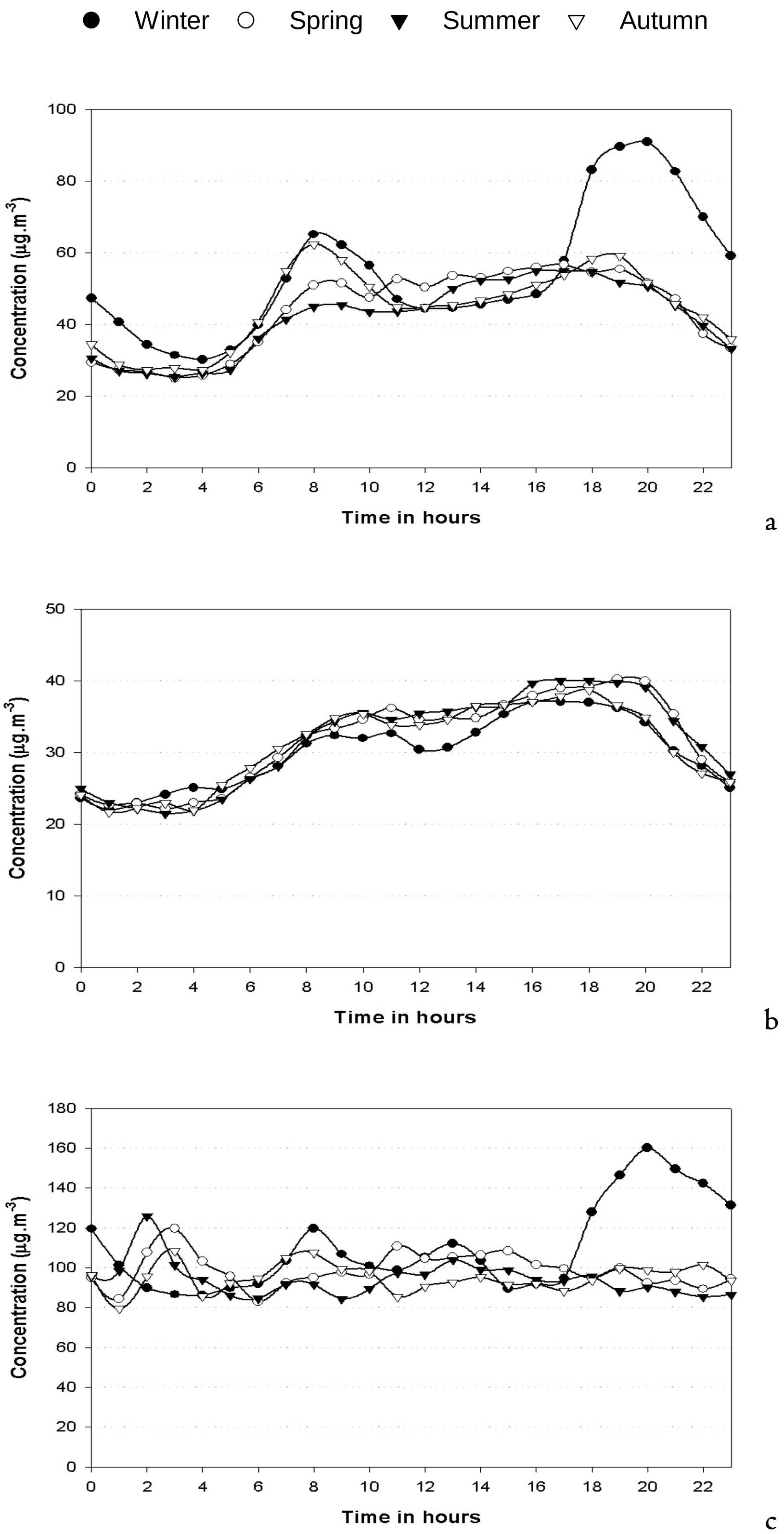

Figure 5 Seasonal diurnal trends of PM_{10} for a) all, b) low and c) high concentrations ($\mu g.m^{-3}$)

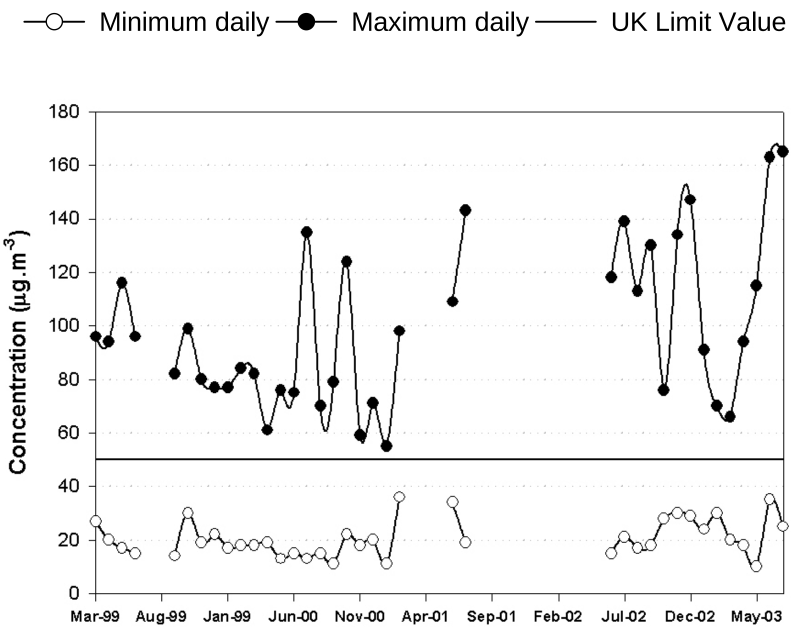

Figure 6 Daily minimum and maximum values (µg.m^{-3}) for PM_{10} during 1 March 1999 – 31 July 2003

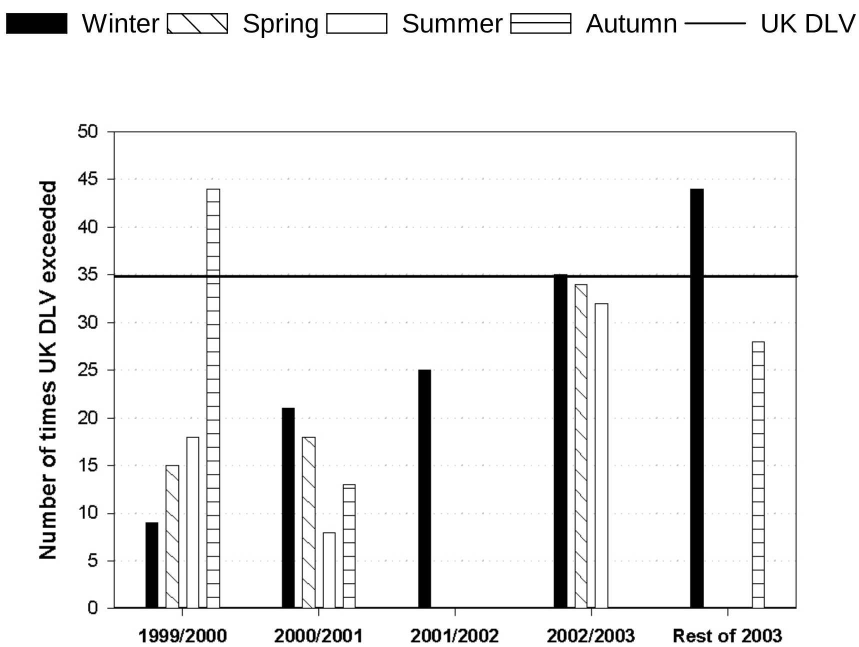

Figure 7 Number of times the UK Daily Limit value are exceeded for PM_{10} during 1 March 1999 – 31 July 2003

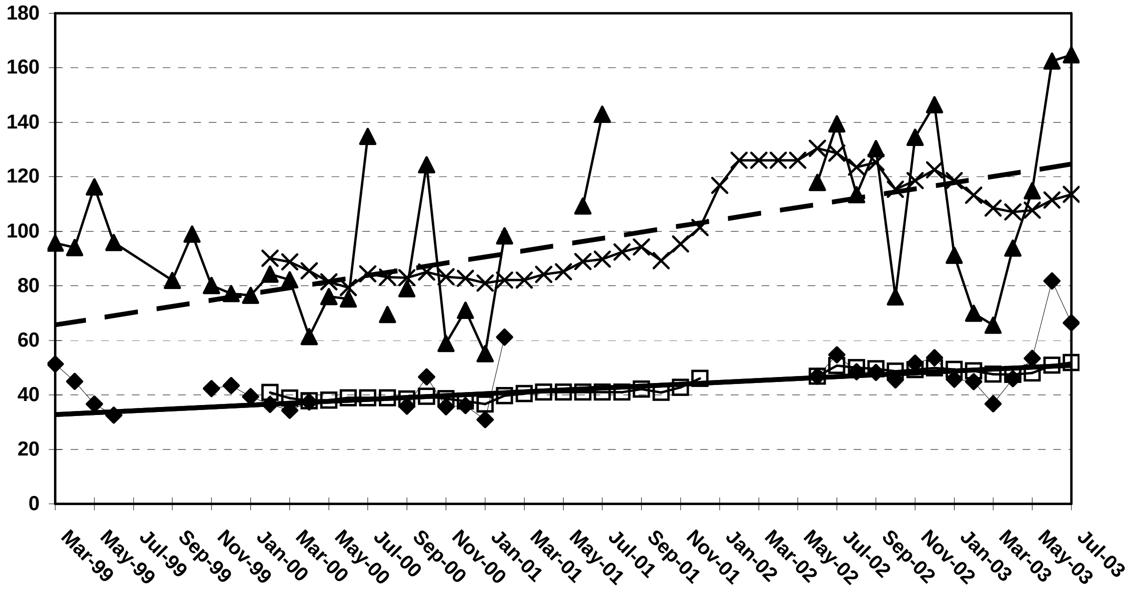

Figure 8 PM10 concentrations (μg.m-3) during 1 March 1999-31 July 2003 for monthly (solid trend line) mean and maximum daily per month (broken trend line)

12 MMA 12 month moving average, ◆ *monthly average,* □ *12 MMA,*
▲ *maximum daily,* ✕ *12 MMA of max daily*

Figure 7 presents the number of times PM_{10} concentrations exceeded the UK DLV. The number of times the DLV are exceeded increases for winter during the period of examination. This trend is not clear for other seasons due to the lack of data. The UK DLV may be exceeded 35 times during a year. During autumn 1999 and winter 2003 alone the UK DLV was exceeded 44 times on each occasion. Winter 2002 and Spring 2002 were close to exceeding the UK DLV more than 35 times.

A moving average provides trend information that a simple average of all historical data would mask. The trend can be used to forecast PM_{10} concentrations. From March 1999 to July 2003 the monthly and maximum daily PM_{10} concentrations increased from 33 $\mu g.m^{-3}$ to 49 $\mu g.m^{-3}$ and from 65 $\mu g.m^{-3}$ to 125 $\mu g.m^{-3}$, respectively according to the preliminary trend lines of the relevant 12 month moving averages (Figure 8). This translates into a rate of 1.22 $\mu g.m^{-3}$/month and 0.33 $\mu g.m^{-3}$/month, respectively. The slope of the trend line of the 12 month moving averages based on the maximum daily PM_{10} concentrations is steeper than the one based on the monthly PM_{10} concentrations.

4.7 Discussion

This study investigated the current and future potential health implications of exposure to outdoor PM_{10} mass in the Khayelitsha sub-district in the City of Cape Town.

During autumn 1999 and winter 2003 the UK DLV was exceeded 44 times (Figure 7). 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 (Figure 8). The maxima initially indicate a declining trend followed by a sudden increase – maxima during July 2001, December 2002 and July 2003. Possible reasons for the increased maxima trend are not clear as the maxima occur both in winter and summer. Figure 8 suggests that within a few years the UK Annual Limit value of 40 $\mu g.m^{-3}$ will be exceeded. The trend line of the 12 MMA based - on the maximum daily PM_{10} concentrations - has a steeper slope than the one based on the monthly PM_{10} concentrations. As there is a UK DLV the increase in the former trend line is important. This indicates that the UK DLV will be exceeded more in the future.

The preliminary results indicate that a higher proportion of the community is at risk from suffering reduced lung function, aggravation and developing of respiratory diseases and symptoms (e.g. asthma, emphysema, acute lower and upper respiratory tract infections, chronic bronchitis, chronic obstructive pulmonary disease, lung cancer) and cardiovascular diseases (Figure 1). Health effects from inhaled particles are influenced by the depth of penetration of the particles into the respiratory system, the amount of particles deposited in the respiratory system, and by the biological reaction to the deposited particles. The risks of adverse health effects are greater when particles enter the tracheobronchial and alveolar portions of the respiratory system. Small particles can penetrate into these deeper regions of the respiratory system. Mouth breathing becomes more prevalent during upper respiratory tract infections (e.g. blocked nose). This results in the functional loss of nasal filtering of PM with greater deposition of particulates and irritants to the lower respiratory tract .[37]

However, it is given that the trend lines might be misrepresentative of the true trend due to the lack of PM_{10} and meteorological data (temperature, relative humidity, rainfall, wind speed, wind direction). Nevertheless, this in turn points towards the requirement to improve data collection at Khayelitsha. Although no guideline or limit value exists for hourly PM_{10}, it is still important to take notice of the extent of exposure to maximum hourly PM_{10} concentrations (Figure 4a). The maximum hourly PM_{10} concentrations ranged between 376-500 $\mu g.m^{-3}$.

Figure 5 suggests traffic and dirty fuels as pressures to the state of the atmospheric environment in Khayelitsha. Consequently the City of Cape Town will need to address these two pressures in order to reduce PM_{10} emissions. It is acknowledged that meteorological conditions such as low inversions may also result in higher observed PM_{10} concentrations.

4.8 Conclusions and recommendations

This study investigated the current and future potential health implications due to outdoor PM_{10} mass exposure in the Khayelitsha sub-district in the City of Cape Town in a preliminary analysis.

Elevated PM_{10} mass concentrations are frequently experienced in Khayelitsha. The temporal variations in PM_{10} mass have repercussions for air monitoring strategies and epidemiological studies concerned with the relationship of exposure to PM_{10} mass and the health impact on populations. Micro variations in exposure need to be considered when assessing exposure to PM_{10} mass in epidemiological studies and improved awareness raised to collect accurate measures of environmental exposure in the light of considerable variations which may occur temporally.

In the South African context economical, social and cultural factors may render the population more vulnerable to increased exposure to PM_{10} mass, due to factors such as poor hygiene, overcrowding, dusty environments, poor nutrition, open dwellings, outdoor lifestyles and continued use of dirty fuels for lighting, heating and cooking. Recommendations are to increase data collection and extend monitoring to NO_x, SO_2, CO, O_3 and $PM_{2.5}$ in Khayelitsha. Future studies need to scrutinise these preliminary trend results in more robust autoregressive integrated moving average (ARIMA) analyses once data collection has been improved and a larger database established at the Khayelitsha sub-district site. ARIMA analysis removes any last traces of autocorrelation between the 24-hour average data that can lead to errors, which ordinary trend analysis (as applied in this investigation) is not capable of. These robust ARIMA analyses should ideally also include meteorological parameters. Future source apportionment studies may also clarify the contribution of traffic and dirty fuel use to PM_{10} levels. Epidemiological studies in South Africa need to link improved air pollution data to health effects. Health promotion interventions to reduce air pollution exposure can then be developed from these results.

4.9 References

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