

TITLE

AMBIENT SULPHUR DIOXIDE (SO<sub>2</sub>) AND PARTICULATE MATTER (PM<sub>10</sub>)  
CONCENTRATIONS MEASURED IN SELECTED COMMUNITIES OF NORTH AND  
SOUTH DURBAN.

Investigator: Yoganathan Gounden

Student Number: 203517129

MMedSci: Occupational and Environmental Health

Module: Research Project (OCEH8V1)

Date: December 2006

Submitted in partial fulfilment of the academic requirements for the Master in Occupational and Environmental Health in the School of Family and Public Health Medicine, University of KwaZulu-Natal.

## Abstract

The industrial basin in the south of Durban is an area of ongoing contention between the residents and major industries, regarding environment health issues especially poor air quality resulting from industrial air pollution. This region is a result of poor urban planning that began in the early 1960's which saw rapid industrialisation alongside expanding communities, which has now resulted in a major environmental dilemma for the city of Durban, eThekweni Municipality. Durban is seen as a key area of growth in South Africa: it has the busiest harbour on the continent; it is a regional hub of the chemical industry and a major motor and metal manufacturer centre; and Durban's population continues to grow at ~4% per annum, all of which are destined to have significant environmental impacts.

As part of a large epidemiological study and health risk assessment in this industrial basin, particulate matter smaller than 10 microns ( $PM_{10}$ ) and sulphur dioxide ( $SO_2$ ) were measured in seven community sites across Durban: four in the South, (Wentworth, Bluff, Merebank and Lamontville) and three in the north (Kwamashu, Newlands East and Newlands West). The south sites are located in an industrial basin near two petroleum refineries and a paper mill, while the north comparison sites are ~25 km North West from major industries in the Basin. 24 hour  $PM_{10}$  samples were collected gravimetrically every day during four, three-week intensive phases and thereafter every 6<sup>th</sup> day using high, medium and low volume samplers.  $SO_2$  was monitored every 10 minutes with active continuous analysers (European monitor labs and API) according to internationally accepted methods. Rigorous quality assurance methods were followed for both pollutants.

$SO_2$  followed a distinct spatial distribution where the mean difference in  $SO_2$  concentrations between the southern and the northern region was 6.7 ppb, while for  $PM_{10}$  similar concentrations were found across all sites with the highest mean concentration at Ngazana in the north ( $59 \mu\text{g}/\text{m}^3$ ) > Assegai in the south ( $\sim 58 \mu\text{g}/\text{m}^3$ ) with all other sites ~1 to  $10 \mu\text{g}/\text{m}^3$  less in mean concentration.  $SO_2$  diurnal variations display two maxima from 5:00AM to 10:00AM being repeated in the latter part of the day from 20:00PM to 24:00PM.

Seasonal pattern of PM<sub>10</sub> and SO<sub>2</sub> to a lesser extent, display very similar mean variations for all sites - the highest levels seen in the colder months of May, June, July of 2004 and 2005. Weak to strong intersite correlations were found for SO<sub>2</sub> ranging from 0.16 to 0.22 among the south sites; 0.06 to 0.64 among the north sites, while PM<sub>10</sub> ranged from 0.73 to 0.88 among the south sites and 0.86 to 0.91 among the north sites. A cross regional correlation of PM<sub>10</sub> by sites displayed a moderate to strong correlation ranging from 0.73 to 0.88, while intrasite SO<sub>2</sub> with PM<sub>10</sub> correlations displayed weak to moderate correlations from 0.35 to 0.53.

Meteorological conditions wind speed, temperature, pressure and humidity differed across Durban. The difference in temperature and humidity between “summer” and “winter” was on average, approximately 7 °C and 10-15% respectively. These temperature and humidity patterns closely track the increase in SO<sub>2</sub> and PM<sub>10</sub> during “winter” explaining the effects of winter inversions on pollutant levels. Also of interest is the variability of meteorological parameters between south and north Durban with the two regions being 35 km apart. Meteorological conditions impact differently on each pollutant e.g. rain is more likely to decrease PM<sub>10</sub> concentrations than it would SO<sub>2</sub>.

In general relationships between pollutants and meteorological parameters differ on a site-by-site basis. For instance, wind direction at Assegai increases SO<sub>2</sub> levels whereas wind direction at Ngazana decreases SO<sub>2</sub> levels. Another independent variable that proved to be a consistent and important predictor for SO<sub>2</sub> and PM<sub>10</sub> across most sites was the previous day’s pollution events; this was a much stronger predictor for PM<sub>10</sub> rather than SO<sub>2</sub>. These findings suggest that pollutants are not fully removed from the atmosphere during a 24 hour period and that the previous day’s pollution levels will contribute to current levels, a finding that has important implication when implementing early warning pollution systems as envisaged for the Durban South Basin.

## **Acknowledgements**

I would like to thank:

The South Durban Health Study Teams, consisting of various field and laboratory technicians and those institutions providing analytical assistance;


All participating schools;

The Principal Investigator of the SDHS and my supervisor Professor Rajen Naidoo;

All funding organisations that contributed to the SDHS

## **Declaration**

I declare that this is the original work of Mr. Yoganathan Gounden, except where specific indication is given to the contrary. This master's research project makes use of air pollution monitoring data (SO<sub>2</sub>, PM<sub>10</sub> and Meteorological data) collected in the South Durban Health Study. This work has not been submitted previously to this or any other University.

  
Mr Y. Gounden

28/02/2008  
Date

MEDICAL SCHOOL  
Place

## Acronyms and Abbreviations

BMI	-	Body mass index
CO <sub>2</sub>	-	Carbon dioxide
FEV <sub>1</sub>	-	Forced expiratory volume in one second
FVC	-	Forced vital capacity
GP	-	General practitioner
IP	-	Intensive phase
NEMA	-	National Environment Management: Air Quality Act, 2004
NO <sub>2</sub>	-	Nitrogen dioxide
O <sub>3</sub>	-	Ozone
PM	-	Particulate matter
PM <sub>10</sub>	-	Particulate matter of fraction size of <10 micro meter diameter also known as inhalable particulates.
PM <sub>2.5</sub>	-	Particulate matter of fraction size of < 2.5 micro meter diameter also known as respirable particulates.
PPB	-	Parts per billion
PPM	-	Parts per million
µg/m <sup>3</sup>	-	Micrograms per cubic meter
RH	-	Relative Humidity
SDHS	-	South Durban health study
SDIB	-	South Durban Industrial Basin
SMR	-	Standardised mortality ratio
SO <sub>2</sub>	-	Sulphur dioxide
SVOC	-	Semi volatile organic compounds
VOC	-	Volatile organic compounds

## CONTENTS PAGE

<b>1.1</b>	<b>BACKGROUND.....</b>	<b>1</b>
<b>1.2</b>	<b>OVERALL OBJECTIVE.....</b>	<b>2</b>
<b>1.3</b>	<b>SPECIFIC AIMS.....</b>	<b>2</b>
<b>2.1</b>	<b>LITERATURE REVIEW.....</b>	<b>3</b>
<b>2.2</b>	<b>NATURE OF PARTICULATE POLLUTION.....</b>	<b>3</b>
	2.2.1    Continuum of Sizes.....	4
	2.2.2    Sources.....	4
<b>2.3</b>	<b>NATURE AND SOURCES OF SO<sub>2</sub>.....</b>	<b>5</b>
<b>2.4</b>	<b>INTERACTIONS BETWEEN AIR POLLUTANTS AND METEOROLOGICAL FACTORS.....</b>	<b>5</b>
<b>2.5</b>	<b>HEALTH EFFECTS OF PM AND SO<sub>2</sub>.....</b>	<b>9</b>
<b>2.6</b>	<b>AIR POLLUTION STANDARDS.....</b>	<b>13</b>
<b>2.7</b>	<b>STUDIES IN THE SOUTH DURBAN INDUSTRIAL BASIN.....</b>	<b>14</b>
<b>3.1</b>	<b>METHODOLOGY.....</b>	<b>19</b>
<b>3.1.1</b>	<b>STUDY DESIGN.....</b>	<b>19</b>
	3.1.2    STUDY LOCATIONS AND RATIONALE FOR SELECTION.....	19
	3.1.3    AMBIENT POLLUTANT MONITORING.....	20
<b>3.2</b>	<b>DATA COLLECTION.....</b>	<b>21</b>
	3.2.1    PM MONITORING.....	21
	3.2.1.1    PM COLLOCATION STUDY.....	23
	3.2.2    DETERMINATION OF PARTICULATE MATTER CONCENTRATIONS IN THE ATMOSPHERE.....	24
	3.2.2.1    Gravimetric Laboratory conditions.....	24
	3.2.2.2    Filter handling, conditioning and weighing.....	24
	3.2.2.3    Sources of bias.....	26
	3.2.3    METHODOLOGY OF AMBIENT PM MONITORING.....	28
	3.2.3.1    Sampler operation.....	29
	3.2.3.2    Filter archiving.....	31
	3.2.3.3    PM <sub>10</sub> mass concentration calculation.....	31
	3.2.4    SULPHUR DIOXIDE MONITORING.....	31
	3.2.5    DETERMINATION OF SULPHUR DIOXIDE IN THE ATMOSPHERE.....	32
	3.2.6    MEASUREMENT OF OTHER ASSOCIATED VARIABLES.....	34

<b>3.3 DATA MANAGEMENT AND ANALYSIS.....</b>	<b>35</b>
3.3.1 DATA MANAGEMENT.....	35
3.3.2 ANALYSIS OF DATA.....	39
<b>4.1 RESULTS.....</b>	<b>43</b>
<b>4.1.1 DESCRIPTION OF SO<sub>2</sub>, PM<sub>10</sub> &amp; METEOROLOGICAL PARAMETERS.....</b>	<b>43</b>
<b>4.1.2 RELATIONSHIP BETWEEN SO<sub>2</sub>, PM<sub>10</sub> &amp; METEOROLOGICAL PARAMETERS.....</b>	<b>54</b>
<b>4.1.3 PREDICTION EQUATIONS OF SO<sub>2</sub>, PM<sub>10</sub> &amp; METEOROLOGICAL PARAMETERS.....</b>	<b>66</b>
<b>4.1.4 AIR POLLUTION EXCEEDANCES FOR SO<sub>2</sub> AND PM<sub>10</sub> STANDARDS.....</b>	<b>76</b>
<b>5.1 DISCUSSION.....</b>	<b>79</b>
5.1.1 SO <sub>2</sub> Spatial and Temporal Pollution Patterns.....	79
5.1.2 PM <sub>10</sub> Spatial and Temporal Pollution Patterns.....	82
5.1.3 Meteorological Influences on Pollution Patterns.....	82
5.1.4 Limitations.....	86
<b>5.2 CONCLUSION.....</b>	<b>87</b>
<b>5.3 RECOMMENDATIONS.....</b>	<b>88</b>
<b>APPENDIX 1: DESCRIPTION OF MONITORING SITES.....</b>	<b>94</b>
<b>APPENDIX 2: AIR QUALITY STANDARDS FOR SOUTH AFRICA.....</b>	<b>97</b>
<b>APPENDIX 3: GRAVIMETRIC DATA SHEET FOR MASS CALCULATION.....</b>	<b>101</b>

## TABLES

Table 1: International [Ambient Air Quality] Guidelines for SO <sub>2</sub> and PM <sub>10</sub> .....	14
Table 2: Monitoring sites and pollutants measured.....	20
Table 3: Flag codes for sample duration .....	38
Table 4: Flag codes for sample volume.....	38
Table 5: Total number of SO <sub>2</sub> & PM <sub>10</sub> observations for final datasets .....	43
Table 6: 24 hour SO <sub>2</sub> (ppb) concentrations .....	44
Table 7: 24 hour PM <sub>10</sub> (µg/m <sup>3</sup> ) concentrations (weighted averages).....	45
Table 8: 24 hour meteorological data.....	49
Table 9: Multiple comparison test - SO <sub>2</sub> Data.....	52
Table 10: Multiple comparison test - PM <sub>10</sub> Data.....	53
Table 11: Correlation ( <i>rho</i> ) between SO <sub>2</sub> , area inter-site comparison .....	54
Table 12: Correlation ( <i>rho</i> ) between PM <sub>10</sub> , area inter-site comparison .....	55
Table 13: Correlation ( <i>rho</i> ) between PM <sub>10</sub> , inter-site comparison.....	55
Table 14: Correlations ( <i>rho</i> ) of SO <sub>2</sub> versus PM <sub>10</sub> (Intra-Site).....	58
Table 15: Correlations ( <i>rho</i> ) of SO <sub>2</sub> with PM <sub>10</sub> – Regional comparison .....	58
Table 16: Correlations ( <i>r</i> ) of SO <sub>2</sub> & PM <sub>10</sub> with Meteorological Parameters .....	60
Table 17: Correlations ( <i>rho</i> ) of SO <sub>2</sub> & PM <sub>10</sub> with Met Parameters - Regional comparison.....	61
Table 18: Regression Model 1: Excluding previous days pollution .....	69
Table 19: Regression Model 2: Including previous days pollution.....	72
Table 20: 10 minutes SO <sub>2</sub> exceedances during the study period. ....	77
Table 21: 24 hour SO <sub>2</sub> and PM <sub>10</sub> exceedances during the study period.....	77
Table 22: Annual SO <sub>2</sub> and PM <sub>10</sub> - May 2004 to May 2005 .....	78



## FIGURES

Figure 1: Boxplots SO <sub>2</sub> & PM <sub>10</sub> concentrations from southern and northern Sites .....	46
Figure 2: Diurnal trends of SO <sub>2</sub> concentrations over every hour of the study period .....	47
Figure 3: Seasonal variation of SO <sub>2</sub> monthly means, Apr 2004 – May 2005 .....	48
Figure 4: Seasonal variation of PM <sub>10</sub> monthly means, May 2004 – Oct 2005 .....	48
Figure 5: Boxplots meteorological parameters between South & North Met Stations .....	50
Figure 6: Temperature South & North      Figure 7: Humidity South & North.....	51
Figure 8: Scatter plot of Inter-site SO <sub>2</sub> concentrations.....	56
Figure 9: Scatter plot of Inter-site PM <sub>10</sub> concentrations.....	57
Figure 10: Scatter plot of Intra-site SO <sub>2</sub> versus PM <sub>10</sub> concentrations .....	59
Figure 11: Scatter plot of SO <sub>2</sub> concentrations with Wind Direction (° North).....	62
Figure 12: Scatter plot of SO <sub>2</sub> concentrations versus Wind Speed (m/s).....	62
Figure 13: Scatter plot of SO <sub>2</sub> & PM <sub>10</sub> concentrations versus Temperature (°C) .....	63
Figure 14: Scatter plot of SO <sub>2</sub> & PM <sub>10</sub> concentrations versus Humidity (%) .....	64
Figure 15: Scatter plot of SO <sub>2</sub> concentrations versus Pressure (hPa).....	64
Figure 16: Scatter plot of PM <sub>10</sub> concentrations versus Rainfall (mm) .....	65
Figure 17. Regression Model 1: PM <sub>10</sub> and SO <sub>2</sub> .....	67
Figure 18. Regression Model 2: PM <sub>10</sub> and SO <sub>2</sub> .....	68
Figure 19: Model 1: PM <sub>10</sub> Regression Analysis - Excluding Previous Days Pollution .....	70
Figure 20: Model 1: SO <sub>2</sub> Regression Analysis - Excluding Previous Days Pollution .....	71
Figure 21: Actual PM <sub>10</sub> & SO <sub>2</sub> versus Previous Days PM <sub>10</sub> & SO <sub>2</sub> .....	73
Figure 22: Model 2: PM <sub>10</sub> Regression Analysis - Including Previous Days Pollution .....	74
Figure 23: Model 2: SO <sub>2</sub> Regression Analysis - Including Previous Days Pollution .....	75
Figure 24: Map 16 x 30 km, showing study area, schools, monitoring sites & selected point sources .....	96

## CHAPTER 1

### 1.1 BACKGROUND

Air pollution arises from a variety of sources anthropogenic or geogenic, primary or secondary pollutants, of which the combustion of fossil fuels is the principal source. Air pollutants classified by source, chemical composition, size and mode of release into the ambient environment, are usually conventional or criteria pollutants and toxic pollutants.

Emission and transmission are pathways in the urban atmosphere, which results in ambient air pollution. Each pathway is influenced by different factors, such as meteorological, topographical characteristics etc. Emissions from vehicle traffic, apart from industrial sources, are a very important source group throughout the world. During transmission, air pollutants are dispersed, diluted and subjected to photochemical reactions [37]. Ambient air pollutants such as Sulphur dioxide (SO<sub>2</sub>), Particulate matter (PM), Total suspended particulates (TSP), Nitrogen oxides (NO<sub>x</sub>) and Ozone (O<sub>3</sub>) are known to display temporal and spatial variability.

Air pollution is a contentious issue plaguing residents in the South Durban Industrial Basin, situated southeast from Durban's central business district, in the eThekweni Municipality, KwaZulu-Natal, South Africa. The region's unique topography, and inappropriate progressive industrialisation including two petrochemical refineries, pulp & paper manufacturer, waste water treatment plant, airport and numerous smaller chemical and other industries and urbanisation have given rise to serious and continuous air pollution problems.

This research uses ambient air pollution data namely, SO<sub>2</sub> and PM<sub>10</sub> collected in a study entitled: ‘THE HEALTH STATUS AND RISK FACTORS ASSOCIATED WITH ADVERSE HEALTH OUTCOMES AMONG THE DURBAN SOUTH COMMUNITY’, known as the South Durban Health Study (SDHS). The SDHS was in response to the call for tenders by the Durban Metropolitan Health authority.

## **1.2 OVERALL OBJECTIVE**

To describe the characteristics of ambient pollutants, SO<sub>2</sub> and PM<sub>10</sub> measured in selected communities of the greater Durban area.

## **1.3 SPECIFIC AIMS**

1. To interrogate the data to determine validity.
2. To describe SO<sub>2</sub> and PM<sub>10</sub> pollutant concentrations in the north and south communities of the Durban metropolitan area and to determine whether geographic differences in pollutant levels exist within the city and the spatial variation within locations in different geographic regions in the city (exploring inter and intra site differences).
3. Investigate the relationship between SO<sub>2</sub> and PM<sub>10</sub> concentrations.
4. To determine if meteorological factors (wind speed, wind direction, humidity, temperature and precipitation / rainfall) influence pollution differences and trends.
5. To determine whether the concentrations are in legal compliance with the South African ambient air quality standards promulgated under the National Environmental Management Act. NO.39 of 2004: National Environmental Management: Air Quality Act, 2004.

## **CHAPTER 2**

### **2.1 LITERATURE REVIEW**

Uncontrolled air pollution has the capacity to negatively impact public health in the short and long term, especially in communities living in close proximity to areas with increased industrial growth and development.

Air pollution in urban areas is a major health concern and numerous studies have linked air pollutants to various acute health outcomes (such as decreased peak flow levels, FVC and FEV<sub>1</sub> in asthmatics, increased frequency of reporting respiratory symptoms such as sore throat and throat irritations, rhinitis, eye irritations, nausea, and cough with phlegm, annoyance reactions from chemical odours etc. in diary studies) [9, 15, 32, 38, 39] and chronic health outcomes (such as chronic wheeze, cough, doctor diagnosed asthma, bronchitis, abnormal pulmonary function, shortening life expectancy, cardiovascular effects, development of malignant and non-malignant tumours etc) [4, 6, 14, 22, 27] in developed and developing countries. There is an overwhelming body of evidence, identifying specific or a combination of air pollutants as causative agents of ill health at different severity levels on impacted populations, exerting its most adverse effects on infants, the elderly and other susceptible populations.

### **2.2 NATURE OF PARTICULATE POLLUTION**

Perhaps no other pollutant is as complex as particle pollution; also called particulate matter – (PM). Particle pollution is a mixture of solid particles and liquid droplets found in the air made up of different chemical components. The major components are carbon, sulphate and nitrate compounds, and crustal materials such as soil and ash.

The different components that make up particle pollution come from specific sources and are often formed in the atmosphere. Some particles, such as dust, dirt, soot, or smoke, are large or dark enough to be seen with the naked eye. Others are so small they can only be detected using an electron microscope. These tiny particles come in many sizes and shapes and can be made up of hundreds of different chemicals. Some particles are emitted directly from a source, while others form in complicated chemical reactions in the atmosphere with the ability to change back and forth from gas to particle form. Particle pollution also varies by time of year and by location and is affected by several aspects of weather, such as temperature, humidity, and wind [1].

### **2.2.1 Continuum of Sizes**

For practical reasons under aspects of emission measurements, PM is characterised by particle size (aerodynamic diameter). Several metrics have been and are still used with total suspended particles (TSP) being the most comprehensive term including particles of any size suspended in air [9]. Suspended particulate pollutants, designated as ambient particulate matter (PM), are classified into 3 categories. Coarse PM (aerodynamic diameter, 2.5 – 10  $\mu\text{m}$ ) is derived from abraded soil, road dust (e.g. brake and tire dust), construction debris, or aggregation of smaller combustion particles, whereas fine (<2.5  $\mu\text{m}$ ) and ultra fine (<0.1  $\mu\text{m}$ ) PM is primarily formed during the combustion of fossil fuel products [4].

In the atmosphere, coarse and fine particles behave in different ways. Larger coarse particles may settle out from the air more rapidly than fine particles and usually will be found relatively close to their emission sources. Fine particles, however, can be transported long distances by wind and weather and can be found in the air thousands of miles from where they were formed [1].

### **2.2.2 Sources**

Particulate matter includes “primary” PM, which is directly emitted into the air, and “secondary” PM, which forms indirectly from fuel combustion and other sources. Generally, coarse PM is made up of primary particles, while fine PM is dominated by secondary particles.

*Primary PM* consists of carbon (soot), emitted from cars, trucks, heavy equipment, forest fires, burning waste and crustal material from unpaved roads, stone crushing, construction sites, and metallurgical operations. *Secondary PM* forms in the atmosphere from gases. Some of these reactions require sunlight and or water vapor. Secondary PM includes:

- *Sulfates* formed from sulfur dioxide emissions from power plants and industrial facilities
- *Nitrates* formed from nitrogen oxide emissions from cars, trucks, and power plants
- *Carbon* formed from reactive organic gas emissions from cars, trucks, industrial facilities, forest fires, and biogenic sources such as trees.

### **2.3 NATURE AND SOURCES OF SO<sub>2</sub>**

Sulphur forms two main oxides; the gas sulphur dioxide (SO<sub>2</sub>) and the liquid sulphur trioxide (SO<sub>3</sub>). SO<sub>2</sub> is a dense colourless gas, which is soluble in water, and has a suffocating and unpleasant smell of burnt matches. It has a melting point of -72.7°C, and a boiling point of -10°C. SO<sub>2</sub> gas can be made directly by heating its constituent elements. Burning molten sulphur in either air or pure oxygen leads to a reaction, which produces a pale blue coloured flame[13].

SO<sub>2</sub> belongs to the family of sulfur oxide (SO<sub>x</sub>) gases which are formed when fuel containing sulfur (mainly coal) is burned and during metal smelting, refining and other industrial processes. The highest monitored concentrations of SO<sub>2</sub> have been recorded in the vicinity of large industrial facilities [2].

### **2.4 INTERACTIONS BETWEEN AIR POLLUTANTS AND METEOROLOGICAL FACTORS**

An understanding of pollution sources, emissions, transmission and their interaction with terrain and the atmosphere, is an important first step in developing appropriate air pollution management strategies. Without this knowledge, incorrect decision making in terms of air pollution management is possible, creating wasted resources and undesirable results. Therefore, having insufficient air quality information, the strategic planning for air quality management would be ineffective.

Air pollution studies have considered and investigated the interaction of air pollutants and meteorological factors in the transmission of various pollutants. The effects of some meteorological parameters on SO<sub>2</sub> and TSP concentrations in Erzurum, Turkey, were investigated using multiple linear regression analysis, which found strong associations between SO<sub>2</sub>, TSP and temperature ( $p < 0.01$ ), revealing that pollutant concentrations decreased with increasing temperature. For a unit increase in temperature SO<sub>2</sub> would decrease by 3.143 µg/m<sup>3</sup> and TSP would decrease by 4.514 µg/m<sup>3</sup>. Pollutant concentrations decreased with increasing wind speed possibly due to dilution and dispersion effects ( $p < 0.01$ ). A strong association was also evident between pollutants and pressure ( $p < 0.01$ ), pollutant concentrations decreased with decreasing pressure. An absence of a statistically significant association was noted between pollutants and precipitation ( $p > 0.05$ ) and pollutants and relative humidity ( $p > 0.01$ ). The previous day's pollutant concentrations for SO<sub>2</sub> and TSP were significantly correlated with actual SO<sub>2</sub> and TSP concentrations with an  $r^2 = 0.84$  and  $0.53$ , respectively ( $p < 0.01$ ). This meant that meteorology was not always able to disperse and clean pollutant concentrations completely from the atmosphere and that daily pollutant concentration contribute to the next day's pollution concentrations. This phenomena is important to note during extended periods of calm weather (especially during winter) when temperature inversions can last for days resulting in the accumulation of trapped pollutants exerting negative effects on susceptible populations (especially persistent asthmatics) [37].

A study aimed at analysing the correlation between air pollution and wind direction during the winter months from 1994 to 1997 in urban Trabzon, Turkey, displayed very small decreases in air pollution (PM and SO<sub>2</sub>) concentrations with wind direction. The strongest relationship between air pollution concentrations (APCs) and wind direction was NE (with the lowest wind speed of 4.33 m/s) with SO<sub>2</sub> ( $R^2 = 0.28$ ,  $T = -1.41$ ) and PM ( $R^2 = 0.22$ ,  $T = -1.20$ ) resulting in a slight decline of pollutant concentrations. According to the authors despite the geographical and topographical peculiarities of the area, a coastal city straddling the Black Sea and situated on the slope of hills, seem to suggest that prevailing winds could transport APCs. The results showed no effective correlation of APCs with wind direction in urban Trabzon [8].

From the map provided one is able to identify that towards the north easterly direction is located the Black Sea, presumably wind blowing from over the sea is cleaner which would explain the decrease in air pollutants, although this is not mentioned by the authors.

Also important to note is that the study analysed air pollution and wind direction for winter, a period in which the authors noted increased use of biomass fuels by residence for heating purposes. In the presence of temperature inversions, numerous point sources from residential furnaces and unknown sampling location, any wind direction not from over the Black Sea (North west to North east) is unlikely to help decrease SO<sub>2</sub> and TSP levels but rather circulate these in the present air mass. This study did not consider industrial locations in terms of wind direction and pollutant concentrations.

Meteorological influences of urban air pollutants (PM<sub>10</sub>, SO<sub>2</sub>, NO<sub>2</sub>, O<sub>3</sub> & CO) in Cairo, Egypt, indicated that high atmospheric loading for air pollutants occurred in the wintertime (December – February). NO<sub>2</sub> (70-80 ug/m<sup>3</sup>) and O<sub>3</sub> (44-80 ug/m<sup>3</sup>) were highest with winds from the easterly direction and also from the south where an iron and steel factory is located, while PM<sub>10</sub> (179-189 ug/m<sup>3</sup>), SO<sub>2</sub> (21-32 ug/m<sup>3</sup>) and CO (5-6 ug/m<sup>3</sup>) followed the directionality of wind from the south to southwesterly direction. It is unclear from the report as to what are the possible westerly or northern contributors to pollution in Cairo. The highest average concentration for O<sub>3</sub> (63 ug/m<sup>3</sup>) and NO<sub>2</sub> (83 ug/m<sup>3</sup>) occurred at relative humidity (RH) ≤40%, which was attributed to the enhanced oxidation of hydrocarbons in the afternoon, which support ozone production. PM<sub>10</sub> (367 ug/m<sup>3</sup>), SO<sub>2</sub> (41 ug/m<sup>3</sup>) and CO (7 ug/m<sup>3</sup>) had higher average concentrations at RH >80%, where the increase in humidity was explained to reflect an updraft of boundary layer air masses to the 3km level, leading to a higher level of air pollution. The highest average concentration for SO<sub>2</sub> (58 ug/m<sup>3</sup>) NO<sub>2</sub> (107 ug/m<sup>3</sup>) and O<sub>3</sub> (85 ug/m<sup>3</sup>) occurred at ambient temperature >30°C and for PM<sub>10</sub> (237 ug/m<sup>3</sup>) and CO (8 ug/m<sup>3</sup>) the highest concentrations occurred at temperatures between 10 and 20°C. Pollutants such as PM<sub>10</sub>, SO<sub>2</sub>, NO<sub>2</sub>, O<sub>3</sub> & CO are highest at different RH and temperature levels [13].



The monthly mean concentrations of  $\text{NO}_x$ ,  $\text{SO}_2$  and TSP for a coastal region in India were in the range of  $19.5 - 59.0 \text{ ug/m}^3$ ,  $8.6 - 51.3 \text{ ug/m}^3$  and  $88.2 - 199.3 \text{ ug/m}^3$ , respectively, with TSP strongly correlated with  $\text{NO}_x$  and  $\text{SO}_2$ , (correlation coefficient of 0.83 and 0.82, respectively). The correlation coefficients for TSP,  $\text{NO}_x$  and  $\text{SO}_2$  with wind were -0.78, -0.78 and -0.88, respectively [20].

In Hong Kong the oxides of nitrogen ( $\text{NO}$ ,  $\text{NO}_2$  and  $\text{NO}_x$ ) followed a diurnal pattern of traffic with higher levels usually in the morning (~09:00 h) and evening (~19:00 h).  $\text{O}_3$  diurnal patterns are different from those of  $\text{NO}$ ,  $\text{NO}_2$  and  $\text{NO}_x$ . Generally, the higher  $\text{O}_3$  concentrations correspond to lower  $\text{NO}$ ,  $\text{NO}_2$  and  $\text{NO}_x$  levels, and vice versa during the same 24-h period, which is explained as ozone forming by photochemical reactions of its precursor pollutants such as  $\text{O}_2$ ,  $\text{NO}_x$  and VOC under sunlight, but in the meantime, ozone is also largely consumed through catalytic processes. A strong correlation existed between  $\text{NO}_x$  and  $\text{NO}$  in traffic impacted areas, where the typical pollutant variations during 24 hour period generally follow the diurnal pattern of traffic with peak hour and off-peak hour differences a  $R^2$  ranged from = 0.74 - 0.93, with the residential areas being at the lower end of this range, compared to the mixed residential/ commercial/ industrial areas at the higher end.  $\text{O}_3$  production increased with increasing  $\text{NO}_x$ , with a stronger relationship in the mixed commercial/residential areas ( $R^2$  ranging from 0.76-0.79) than the residential areas ( $R^2$  ranging from 0.64-0.66), which is explained by mixed commercial/residential areas having a combination of vehicular and industrial pollutant sources and high pollution than the residential areas which is without industrial activities [23].

As evident from these studies the investigation of the interactions between individual air pollutants and various meteorological parameters is essential in understanding pollutant concentration, transmission and dispersion in relation to its source to enable effective air pollution management strategies. An increase in one pollutant maybe related to an increase in another pollutant or vice versa, e.g. the relationship shown with increasing TSP being strongly correlated with increasing  $\text{NO}_x$  and  $\text{SO}_2$  [20]. An increase in  $\text{O}_3$  concentrations displayed a positive correlation with increasing  $\text{NO}_x$  [23].

It is possible provided that favourable conditions are present that an increase in NO<sub>x</sub> concentrations is a good precursor for increasing O<sub>3</sub> concentrations in the environment.

## **2.5 HEALTH EFFECTS OF PM AND SO<sub>2</sub>**

Exposure to particulates can lead to a variety of serious health effects, particularly respiratory outcomes. The largest particles are not able to penetrate to the lower respiratory tract, thus causing fewer harmful respiratory effects. Coarse and fine particles pose the greatest problems because they can get deep into the lungs, and some may even get into the bloodstream. Scientific studies show links between these small particles and numerous adverse health effects. Long-term exposures to PM, such as those experienced by people living for many years in areas with high particle levels, are associated with problems such as decreased lung function, development of chronic bronchitis, and premature death. Short-term exposures to particle pollution (hours or days) are associated with a range of acute effects, including decreased lung function, increased respiratory symptoms, cardiac arrhythmias, heart attacks, hospital admissions or emergency room visits for heart or lung disease, and premature death. Subpopulations at greatest risk include people with heart or lung disease, older adults, and children [1].

High concentrations of SO<sub>2</sub> can result in temporary respiratory impairment for asthmatic children and adults who are active outdoors. Asthmatic individuals exposed to short term elevated SO<sub>2</sub> levels during moderate exertion may result in reduced lung function that may be accompanied by symptoms such as wheezing, chest tightness, or shortness of breath. Other effects that have been associated with longer-term exposures to high concentrations of SO<sub>2</sub>, in conjunction with high levels of PM, include respiratory illness, alterations in the lung defences, and aggravation of existing cardiovascular disease. The subgroups of the population that may be affected under these conditions include individuals with cardiovascular disease or chronic lung disease, as well as children and the elderly.

Respiratory and irritant health effects study of a population living in a petrochemical-polluted area in Taiwan, in comparison to a relatively unpolluted control area ~120 km north of the study area, used air pollution data (SO<sub>2</sub>, NO<sub>2</sub>, and PM<sub>10</sub>) retrieved from air quality monitoring stations for 1995 from the Environmental Protection Administration of Taiwan, and interview data from study participants. The study found that subjects living in the exposed area had higher risks for selected respiratory symptoms e.g. cough (OR=1.50, CI=0.96-2.33), phlegm (OR=1.91, CI=1.18-3.10), wheezing (OR=1.58, CI=0.89-2.82) and chronic bronchitis (OR=1.55, CI=0.61-3.90) but had a lower rate of dyspnoea (OR=0.39, CI=0.25-0.60), while monitoring stations in the exposed area showed consistently higher concentration for air pollutants SO<sub>2</sub> (geometric mean 10.60 ppb in Sanwei, the polluted area and 2.59 ppb in Taicei, the comparison area), NO<sub>2</sub> (geometric mean 17.43 ppb in Sanwei and 8.29 ppb in Taicei) and PM<sub>10</sub> (geometric mean 93.57 ug/m<sup>3</sup> in Sanwei and 62.79 ug/m<sup>3</sup> in Taicei) [38].

These findings are contrary to those found in a UK study investigating the health of residents near cokeworks, with the potential for high levels of exposure to PM. The study found no overall evidence for a health effect associated with living near operational cokeworks in England or Wales for people aged 65 or over for all respiratory disease (RR=0.95, 95% CI=0.93-0.98), for stroke (RR=0.96, 95% CI=0.93-1.00) and for coronary heart disease (RR=1.04, 95% CI=1.00- 1.08). For children less than 5 years a trend of higher risk with proximity was found, a combined RR estimate (per km proximity) of 1.08 (95% CI 0.98 to 1.20) for all respiratory disease and 1.07 (95% CI 0.98 to 1.18) for asthma. The authors suggested that these results are due to possible improper modelling of emissions for both the cokeworks and other major industrial sources in the area and non allowance for migration in and out of the study area [3].

A similar study found a small excess of mortality among residents near cokeworks and for all causes of mortality there was a significant decline in risk with distance from cokeworks for all adult age groups [11].

The short-term effects of air pollution (PM<sub>10</sub>, SO<sub>2</sub>, NO<sub>2</sub>, O<sub>3</sub> & CO) on respiratory morbidity of children were assessed from hospital admission records in the city of Sao Paulo. Findings indicated that current ambient air pollution concentrations in the city had short-term adverse effects on children's respiratory morbidity, when air pollution concentrations increased on the same day or previous day, admissions of children to hospital increased. For pneumonia and asthma PM<sub>10</sub> had relative risks of 1.05 (0.98–1.12) and 1.05 (0.92–1.19), SO<sub>2</sub> 1.02 (0.96–1.09) and 1.10 (0.98–1.24), NO<sub>2</sub> 1.09 (1.01–1.17) and 1.10 (0.94–1.30), O<sub>3</sub> 1.07 (1.01–1.14) and 1.01 (0.89–1.13) and CO 1.01 (0.96–1.07) and 1.08 (0.98–1.19) respectively [19].

The editorial, "Particulate air pollution and acute health effects," by Seaton, A., et al (1995), emphasized that epidemiological studies have shown associations between particulate air pollution and exacerbations of illness in people with respiratory diseases and rises in the number of deaths from cardiovascular and respiratory diseases among older people. Studies in fourteen different locations have shown that overall daily mortality increases as the concentration of small particles in the air rises. Evidence links particulate air pollution with acute attacks of asthma and other respiratory diseases [35].

It's been reported that PM<sub>10</sub> (particles) at lag 0, 95% CI 0.09 to 0.68; and NO<sub>2</sub> at lag 2, 95% CI 0.03 to 0.70, were associated with the daily count of deaths in Rome. The 95% CI of the particles effect (0.08 to 0.69) and of the NO<sub>2</sub> effect (0.09 to 0.78) changed only slightly when overdispersion was taken into account. The association of particles and NO<sub>2</sub> with total mortality in the metropolitan area was significantly stronger in the warmer season (p=0.04 and p=0.02, respectively). Mortality increased by 3.8%, the risk estimates were higher among citizens living in the city centre (5.8%) and only slight evidence of an association between O<sub>3</sub> and mortality was found [28].

The respiratory health of 4860 children aged 1-11 years residing near opencast coal mining sites was found to display positive associations between daily respiratory symptoms (wheeze, cough risk estimates) and daily concentrations of PM<sub>10</sub>. A positive association was found between daily concentrations of PM<sub>10</sub> and GP consultations for respiratory, skin and eye conditions with living near opencast sites [33].

A peak expiratory flow (PEF) decrease in children was found to be associated with elevated PM<sub>10</sub> levels during episodes of air pollution in a rural area of the Netherlands and several studies in Utah Valley where the main source of PM<sub>10</sub> pollution is a steel mill. Increases in respiratory symptoms and medication use were found to be associated with high PM<sub>10</sub> concentrations. Children with chronic respiratory conditions had more serious acute health effects than non-symptomatic children. The daily mean prevalence of acute respiratory symptoms was high in the study population with cough being reported most frequently (above 50%) and air pollution levels were associated with exacerbations of existing symptoms rather than the prevalence of symptoms. There was also an increase of moderate to severe symptoms of up to 50% associated with an increase of PM<sub>10</sub> with 100ug/m<sup>3</sup> [12].

Asthma as a disease syndrome has captured a great deal of scientific attention for several years. One of the perplexing aspects to asthma is that the prevalence is increasing in most industrialised countries. The reasons for widespread increases are largely unknown, but outdoor air pollution levels have been shown to exacerbate asthma and have been associated with a broad spectrum of adverse health effects in individuals with asthma [21].

A study investigating the association of fine particles and meteorological conditions and lung function in children with asthma living near two power plants in Israel, found that lung function dropped with increasing air pollution by fine particles (PM<sub>10</sub> and PM<sub>2.5</sub>) after controlling for meteorological and seasonal conditions (temperature and barometric pressure), physical and clinical conditions (BMI and severity of asthma), and socio-demographic parameters ( $P = 0.000$ ). At one site the sequential day and interaction between the sequential day and temperature were significantly ( $p=0.00$ ) associated with a drop 3.88%, in peak expiratory flow rate (PEF) (CI= -6.24 -1.52). In another site PM<sub>2.5</sub> was significantly ( $p=0.00$ ) associated with a drop 2.74% in PEF (CI= -3.95 -1.53). In Sderot, an interaction between PM<sub>10</sub> and the sequential day were significantly ( $p=0.00$ ) associated with a drop 1.61% in PEF (CI=-2.43 -0.79) [31].

Two earlier studies in Teesside, North East England, investigated the effects of smoking and industrial pollution on lung cancer and mortality from bronchitis, implicated industrial air pollution as a contributor to the high rates of these diseases.

In Teesside the public perceived air pollution to be the top ranking environmental problem and identified industry as a major contributor. The research team's strategy was to study the geographical area where concern was the greatest and used proximity to industry as a surrogate for long-term exposure to air pollution. Monitoring in Teesside showed persistently higher pollution in areas close to industry SO<sub>2</sub> (45–211 µg/m<sup>3</sup>). The industrial contribution to NO<sub>x</sub> (59% in 1994) and benzene (78% in 1994) was reported to be above the national average by 38% and 32% respectively. Some reported health outcomes were chronic bronchitis OR = 1.29 (1.03 to 1.63) and SMR for lung cancer in women aged 0–64 , standardised to England and Wales mortality data, was 387 (95% CIs 277–525) [5].

## 2.6 AIR POLLUTION STANDARDS

Standards for air pollution are concentrations over a given time period that are considered to be acceptable in the light of what is known about the effects of each pollutant on health and on the environment. They can also be used as a benchmark to see if air pollution is getting better or worse. An exceedence of a standard is a period of time (which is defined in each standard) where the concentration is higher than that set down by the standard. In order to make useful comparisons between pollutants, for which the standards may be expressed in terms of different averaging times, the number of days on which an exceedence has been recorded is often reported.

There are both short-term and long-term air quality guidelines for SO<sub>2</sub> and PM existing in South Africa, promulgated under the National Environmental Management; Air Quality Act No. 39, 2004. Prior to 2004 South Africa relied on unenforceable air quality guidelines, the revised National Department of Environment and Tourism (DEAT) guidelines (Government Notice No. 1387 of Government Gazette 22491, 21 December 2002) for air pollution control. (Refer to Appendix two for the newly promulgated Air Quality Standards for South Africa and corresponding International Standards).

**Table 1: International [Ambient Air Quality] Guidelines for SO<sub>2</sub> and PM<sub>10</sub>**

<b>Pollutant</b>	<b>Average Time</b>	<b>South Africa</b>	<b>WHO</b>	<b>US EPA</b>
<b>SO<sub>2</sub> (ppb)</b>	<b>10-min</b>	191	191	
	<b>24-hour</b>	48	48	140
	<b>Annual</b>	19	19	30
<hr/>				
<b>PM<sub>10</sub> (ug/m<sup>3</sup>)</b>	<b>24-hour</b>	180		150
	<b>Annual</b>	60	50	50

South Africa has basically adopted the World Health Organisation Guidelines for SO<sub>2</sub> which is better than the recommended US EPA standards. The South African PM<sub>10</sub> standards are not as stringent as that of WHO and US EPA.

## **2.7 STUDIES IN THE SOUTH DURBAN INDUSTRIAL BASIN**

Literature has shown that, while urban air quality has been improving in most western industrialised countries, it has deteriorated in developing countries. In South Africa, for instance, in the Vaal Triangle, Cape Town and Durban is no exception to the air quality problems facing major industrial cities. In Durban, the area most affected by poor air quality is the Durban South Industrial Basin (SDIB), in which the country's petrochemical and chemical industries are concentrated, as well as a large number of other manufacturing industries [24].

A vulnerability study of South African communities to air pollution in South Africa, in the SDIB and the Vaal Triangle identified as high air pollution areas, highlighted other factors such as, socio economic status, unemployment, education, gender, nutrition, quality housing, poor land-use and rapid urbanisation, health status (hypertension, diabetes) and access to medical treatment, opportunistic infections (HIV), lifestyle and genetics, as factors that enhances a persons vulnerability to the harmful affects of air pollution [26].

In 2000, a cross-sectional questionnaire study, investigated the prevalence of asthma and respiratory symptoms in SDIB in the communities of Merewent and Austerville. The study included 213 households consisting of 367 children and 693 adults, with about 10% of children and 12% of adults reporting doctor diagnosed asthma; 37 – 40% self-reported prevalence rates for wheezing and 16 – 28% reported attacks of shortness of breath with wheeze. The prevalence rates for other respiratory symptoms included 33 – 35% for chronic cough, 31 – 32% for chronic phlegm, 44 – 50% for frequent blocked-runny nose, and 16 – 27% for sinusitis. This study revealed that the 10% doctor diagnosed asthma prevalence in the children was twice and three times higher than in children in countries like USA, UK, Norway, Sweden, Finland, Denmark, Indonesia, Papua New Guinea and China. However similar doctor diagnosed asthma prevalence were found in urban areas, of Cape town, SA, in Hong Kong, Malaysia, London and Baltimore, Detroit and Seattle in the USA. This study explored the associations for asthma among children and adults, where home dampness was implicated as a potential risk factor for wheezing (OR: 2.1; 95% CI: 1.0-4.8) in adults, while the association with air pollutants was not investigated [30].

A health risk assessment for SO<sub>2</sub> pollution in South Durban was undertaken adopting an U.S. Environmental Protection Agency (EPA) health risk assessment model. The resultant model provided a hazard quotient (HQ) based on the modelled SO<sub>2</sub> data, including, calculated average daily dose of SO<sub>2</sub> and the acute exposure rate and the exposure duration in days. HQ values <1.0 indicates that SO<sub>2</sub> is not likely to induce adverse health effects, whereas HQ values >1.0 indicate risk levels that are likely to induce adverse effects. Results from this study showed that for normal exposure conditions, the risk of South Durban individuals developing SO<sub>2</sub> related health problems was low (HQ < 1) for all levels of exposure, ranging from acute to chronic. The HQs based on the modelled SO<sub>2</sub> data for acute, intermediate, and chronic scenarios are also less than 1 over the entire area. The authors acknowledge that these results were somewhat surprising, particularly in view of the frequency with which National and Local Sulfur Dioxide (SO<sub>2</sub>) guideline values were exceeded and that these results were also contrary to the anecdotal evidence from the local population, many of whom claim that their health is negatively affected by pollution.



For the worst-case scenario in which individuals are assumed to spend the maximum time outdoors, the HQ values were  $>1.0$  for 1-yr-old infants (since 1-yr-olds are unlikely to spend considerable amounts of time outdoors this HQ may not be applicable) and 6-yr-old children for intermediate and long term exposure, and  $>1.0$  for 12-yr-old children for intermediate exposure. These results suggest that these particular groups would be at risk of developing SO<sub>2</sub> related respiratory problems under the worst-case scenario. The maximum HQ values were located over the central South Durban basin, in the vicinity of two refineries and numerous other chemical industries, where the pollution dispersion pattern was spread along a north-easterly / south-westerly axis as a result of prevailing wind directions that parallel the coast were HQ values are less than 1.0 over the entire domain, although they are close to the critical threshold for infants under intermediate exposure conditions [25].

Spectral analysis of averaged hourly SO<sub>2</sub> pollution in the SDIB for the period 1997–99 revealed the presence of diurnal cycles during winter and autumn strongly for three out of four monitoring sites (AECI, Athlone, Southern Works and Wentworth). The SO<sub>2</sub> diurnal cycle displayed distinctive peaks with mean values greater than 50 ppb at 08:00 and 10:00 at Wentworth and Southern Works, suggestive of fumigation peaks from surface temperature inversions, reported to occur at least 80% of the time in winter compared to 30% in summer. Wentworth also displayed a nocturnal source of pollution peaking at 08:00 and 24:00. The dependence of SO<sub>2</sub> concentration on wind speed displayed intra-site variability. High SO<sub>2</sub> values ~40 ppb were recorded under low wind conditions at Southern Works. Overall relatively high SO<sub>2</sub> concentrations were recorded at low wind speeds, with decreasing levels as wind speed rose, but then a critical wind speed was reached after which the trend was reversed. Researchers related these phenomena to stack down drafting in the presence of strong winds which give rise to high SO<sub>2</sub> concentrations at ground level. High SO<sub>2</sub> events were also associated with northeasterly winds at AECI and Athlone, with southwesterly winds at Wentworth and with both wind directions at Southern Works [10].

The 8 years of continuous SO<sub>2</sub> monitoring from July 1996 to December 2003, identified wind directions predominantly from the NNE and SSW to SW with light nocturnal land breezes (most prevalent during winter) from NNW to west.

SO<sub>2</sub> concentrations were highest at Southern Works, exceeding the National Department of Environment and Tourism annual average guideline of 19 ppb for all years except 2002. Wentworth also exceeded the guideline during the first four years of measurement. Annual average SO<sub>2</sub> concentrations at Settlers and Wentworth are comparable with the lowest average at AECL. Long term trends in monthly average SO<sub>2</sub> indicate distinct seasonal fluctuations with higher SO<sub>2</sub> concentrations during winter compared to summer at Wentworth [16].

Regression analysis indicated a gradual decline in SO<sub>2</sub> concentrations from 1996 to 2003 at Wentworth, Southern Works and Settlers. The daily average SO<sub>2</sub> guideline exceedances during 1997 to 2003 were most frequent at Wentworth ranging from >0 to <50, Southern Works from >10 to <60, Settlers with 10 to 20 from 2000 to 2003, Athlone Park with <10 during 1997 to 1998 and AECL with zero exceedances. Ten minute average guideline exceedances during 2002 to 2003 at Wentworth was 37 and 9, Southern Works 37 and 440, Settlers School 119 and 118 and AECL was 1 and 1 respectively. Wind roses indicated that at Wentworth, most exceedances were related to light westerly to WSW winds, indicating possible sources from the Jacobs, Mobeni area, recorded during early morning correlating with atmospheric stability and poor dispersion conditions. At southern works, 91% of the 10 minute average exceedances were measured during moderate to fresh winds from the SSW, the most likely sources, Sapref and Mondi. At Settlers School the contrast is different with typically elevated SO<sub>2</sub> concentrations during moderate to fresh northerly to NNE winds, which correspond to the direction of the Engen refinery [16].

Various studies conducted in different countries have shown that pollutants (e.g. SO<sub>2</sub>, PM, TSP, NO<sub>x</sub>, O<sub>3</sub>) display a spatial variation between sites and cities. This is important to note when there are limited air pollution monitoring sites which provide information into air quality management strategies, since site variations in pollutant levels may lead to misclassification of exposure levels among impacted populations.

For purposes of this research the SDIB has been selected as an area for focus, where SO<sub>2</sub> has been identified as the area's key pollutant and residents have long believed that they resided in highly polluted communities (Merebank, Austerville, Wentworth and the Bluff) with higher prevalence of respiratory outcomes due to air pollution. Conventional pollutants of particulate matter with an aerodynamic size fraction of 10 microns and sulphur dioxide will be investigated in term of it's location of measurement and association to meteorological factors.

## **CHAPTER 3**

### **3.1 METHODOLOGY**

#### **3.1.1 STUDY DESIGN**

This is a time series study using available ambient SO<sub>2</sub>, PM<sub>10</sub> and meteorological data measured in the SDHS between May 2004 to October 2005, from selected southern and northern communities of the Durban metropolitan area.

#### **3.1.2 STUDY LOCATIONS AND RATIONALE FOR SELECTION**

The study area consisted of the following primary schools and communities, four in south Durban: Nizam Primary (Merebank), Assegai Primary (Austerville), Dirkie Uys Primary (Bluff), Entuthukweni Primary School (Lamontville) and three from north Durban: Briardale Primary (Newlands West), Ferndale Primary (Newlands East) and Ngazana Primary (KwaMashu). An additional site located in Wentworth, south Durban and referred to as the “Wentworth supersite” was also used for pollution monitoring (Figure 24).

The participating schools were selected on the bases of fulfilling the epidemiological objectives of the SDHS. Included among these were site location criteria such as proximity of the schools location to major roadways and nearby industries. All school sites had to have availability of infrastructure (electricity supply) and a secure location (security) for the placement of air pollution monitoring equipment at the schools. Monitoring sites had to be located in an open area, unobstructed by nearby buildings, walls, fences or trees that would create turbulence in the atmosphere affecting air flow over the samplers.

The selection criteria used, ensured that the communities from the two regions had similar characteristics only differing by presence of a highly industrialised area with multiple sources of pollution in the south compared to the northern residential areas. The schools mentioned above were selected from each community, having met the selection criteria. Each school selected was a representative point for the community in which it was located - thus serving as an air pollution monitoring station for that community.

### 3.1.3 AMBIENT POLLUTANT MONITORING

All school/community sites were monitored for the following:

**Table 2: Monitoring sites and pollutants measured**

No.	Site Name	SO <sub>2</sub>	NO <sub>2</sub>	NO	NO <sub>x</sub>	CO	PM <sub>10</sub>	PM <sub>2.5</sub>	O <sub>3</sub>	VOC	SVOC	Region
1	Assegai	x				x	x					South
2	Dirkie Uys	x				x	x					South
3	Nizam	x				x	x	x		x	x	South
4	Lamontville	x				x	x					South
5	Wentworth	x	x	x	x	x	x	x	x		x	South
6	Briardale	x				x	x					North
7	Ferndale	x	x	x	x	x	x	x		x	x	North
8	Ngazana	x				x	x					North

**X = pollutant monitored at each site**

For purposes of this report, only SO<sub>2</sub> and PM<sub>10</sub> data were reviewed. SO<sub>2</sub> and PM<sub>10</sub> were sampled at all sites. This study is reliant on the use of available sources of data collected for the SDHS, the purposes for which the environmental monitoring was twofold: (1) to provide estimates of environmental exposure to investigate exposure-health outcome relationships in an epidemiological study and (2) provide data for a broader health risk assessment. In addition to these two criteria pollutants, a variety of other pollutants were also monitored during the SDHS, including carbon monoxide, volatile organic compounds etc. These findings are not included in this report.

Ambient criteria pollution monitoring (SO<sub>2</sub> and PM<sub>10</sub>) commenced at the beginning of the second school term in May 2004. For the purposes of the epidemiological study, four intensive phases of health assessments coincided with intensive ambient pollution monitoring. The sampling framework, detailed under “Data collection,” varied based on the pollutant of interest, but the sampling duration for ambient pollution monitoring remained consistent i.e. 24 hours.

The intensive phases (IP) of the study were conducted during the following time frames IP 1 = 30/05/2004 – 21/06/2004; IP 2 = 22/08/2004 – 14/09/2004; IP 3 = 24/10/2004 – 16/11/2004 and IP 4 = 06/02/2005 – 01/03/2005.

The purpose of conducting the study over differing months of the year was to include and investigate seasonal variations that may be present, influencing the health exposure variables under investigation. SO<sub>2</sub> was monitored on a continuous 10 minute interval throughout 2004 to 2005, whereas PM<sub>10</sub> was monitored on a 24-hour basis continuously during the intensive phases and on a six day cycle in between intensive phases, as recommended by US EPA. Pollution data for SO<sub>2</sub>, PM<sub>10</sub> from all the school sites and meteorological data (from South African Weather Service) during periods of intensive and non-intensive phase monitoring was reviewed for this report. Only pollutant data from the seven participating schools was used for this report, the “Wentworth supersite” was excluded.

## **3.2 DATA COLLECTION**

### **3.2.1 PM MONITORING**

PM was measured on a continuous basis (24 hours) at all school sites. Three models of PM samplers were used, these were Digitel High Volume Samplers, Thermo Medium Volume Samplers and Partisol 2000 and 2025 Samplers.

Three Thermo Sequential Medium Volume Samplers (FH 95 SEQ Sequential Particulate Samplers) were deployed at Ferndale, Briardale and Ngazana. This instrument operated at an air flow rate of 2.3 m<sup>3</sup>/h, designed for automatic sequential sampling on 16 filter cassettes held in a filter cassette magazine. The sampler was programmed to collect 24-hr samples from noon-to-noon, on 47 mm Millipore glass fibre filters.

Three Digitec DHA 80 High Volume Samplers were deployed at Assegai, Dirkie Uys and Lamontville. These samplers are capable of sampling from 100 to 1000 L/min (6 - 60 m<sup>3</sup>/hr) and designed for sequential sampling on 16 ring assemblies holding 150 mm diameter filters (Ederol Glass Fibre – microfilter 227/1/60) at a flow rate of 30 m<sup>3</sup>/hr.

R&P Partisol-FRM Model 2000 Air Sampler collected PM<sub>10</sub> at Nizam. This is a single channel sampler meeting US EPA specifications for both PM<sub>2.5</sub> and PM<sub>10</sub> (RFPS-0498-117 and RFPS-1298-126, respectively) sampling. This sampler used a PM<sub>10</sub> inlet at a flow rate of 16.7 L/min (1m<sup>3</sup>/h), and a filter holder containing a 47 mm dia glass fibre filter. System electronics maintained the volumetric flow rate, recorded the elapsed sampling time, and calculated the total sample volume.

The rationale behind the use of different PM sampling equipment with different flow rates relates to the anticipated particulate matter concentrations at specific sites. It is best to use a sampler with a low flow rate as opposed to a high flow rate at sites with higher PM concentrations, to prevent over sampling occurring. A high flow rate sampler would be used in locations suspected of having lower PM concentrations. Although the use of different PM samplers has the potential to introduce bias in the sampling process, this was controlled for by the conduct of a PM “collocation study”.

### 3.2.1.1 PM COLLOCATION STUDY

Prior to initiating monitoring in the SDHS, a “collocation study” was conducted to compare the performance of the various PM monitors and to refine the monitoring protocols. A total of 12 samplers of 4 types were tested at the Wentworth site over a three week period. Due to space and power limitations, 6 to 8 samplers were tested simultaneously at this site. The Partisol 2025 sampler was used as a reference sampler since it met the USEPA PM<sub>10</sub> reference designation RFPS-1298-127 and was operated continuously through this period. Concentrations obtained by the reference sample (average =  $37.4 \pm 11.6 \mu\text{g m}^{-3}$ ) closely matched simultaneous 24-hr PM<sub>10</sub>, Tapered element oscillating microbalance (TEOM) measurements obtained at three sites operated by eThekweni Municipality (City Hall ~7.7km, King Edward ~6.5km, Ganges ~1.7km; average =  $37.0 \pm 11.5 \mu\text{g m}^{-3}$ ) (Figure 24).

Previous studies have indicated that TEOM losses are generally below 10% for PM<sub>2.5</sub>, and a lower fraction is expected for PM<sub>10</sub>. On the assumption that PM<sub>10</sub> gradients are small (as shown below) and that losses of volatile and semi-volatile PM components on the heated TEOM are small relative to gravimetric measurements, it is reasonable to consider that the more sensitive monitors at the other sites are likely to describe the PM concentration at Wentworth. Therefore the similar results from the reference monitor imply a valid result.

The collocation comparisons included 19 days in which 126 PM<sub>10</sub> measurements were obtained (average of 10.5 measurements per sampler, 18 – 38 measurements per sampler type). Concentrations during this period spanned a large range (19 to  $102 \mu\text{g m}^{-3}$  based on the reference sampler), thus providing an excellent test. Study results indicated that 97% of the samples fell within 20% of the reference sampler. Some small variations were identified by sampler type, as indicated by the regression results below:

(Partisol 2000) = $1.01 \mu\text{g/m}^3 \times$ (Partisol 2025)	$R^2 = 0.91 \quad n = 18$
(DHA 80 HiVol) = $0.919 \mu\text{g/m}^3 \times$ (Partisol 2025)	$R^2 = 0.84 \quad n = 32$
C(FG 95 MedVol) = $0.921 \mu\text{g/m}^3 \times$ (Partisol 2025) + intercept	$R^2 = 0.89 \quad n = 38$



Mean and absolute mean biases were 0.6 and 6  $\mu\text{g m}^{-3}$ , respectively. Overall, the agreement, and small variations suggest that  $\text{PM}_{10}$  measurements obtained by the five types of samplers (Partisol 2000, Partisol 2005, DHA Hivol, FG MedVol, TEOM) are comparable [29].

### **3.2.2 DETERMINATION OF PARTICULATE MATTER CONCENTRATIONS IN THE ATMOSPHERE**

The method for the measurement of the mass concentration of  $\text{PM}_{10}$  in ambient air over a 24 hour period is described in this section.

#### **3.2.2.1 Gravimetric Laboratory conditions**

A laboratory environment was identified in the Durban Institute of Technology (Environmental Health Laboratory), in which gravimetric analysis was performed. This room was controlled for humidity (by two dehumidifiers) and temperature (via air conditioning unit). Access to the room was controlled by an electronic security code restricting access to departmental staff. The internal environmental conditions of the gravimetric laboratory were set up by operating the two dehumidifiers continuously and setting the internal temperature control to 20 degrees Celsius, to ensure that the microclimate remained stable, and was continuously monitored. The internal temperature ranged from 22 - 25 degrees Celsius, while the relative humidity ranged from 47 - 60%.

#### **3.2.2.2 Filter handling, conditioning and weighing**

Pre-sampling required that each filter be inspected for correct type, size and for pinholes, particles, loose material, discoloration, non-uniformity, and other imperfections, such as tears, chaff or flashing or fraying edges etc. A filter information record was established and an identification number assigned to each filter. Numbered and pre-weighed filters were installed in the samplers following the instructions provided in the sampler operation manual.

All new and sampled filters were weighed following a 24 - 48 hour equilibration period for relative humidity and temperature in the laboratory environment. This protocol was followed for the pre and post weighings, in determining the net weight (mass) gain from collected PM<sub>10</sub>. This required the taking of three pre and three post weighings for each filter and calculating the average weight. If pre weighings differ by 2µg or more the weighing sessions were stopped and the filters re-weighed at a later stage when laboratory conditions stabilised. The total volume of air sampled was determined by the sampler from the measured flow rate at actual ambient temperature and pressure and the duration of sampling. The mass concentration of PM<sub>10</sub> in the ambient air was computed as the total mass of collected particles in the PM<sub>10</sub> size range divided by the actual volume of air sampled, and expressed in micrograms per cubic meter of air (mg/m<sup>3</sup>).

During the weighing process, a quality control (QC) filter was weighed along with the sample filter, to determine any variations between the masses of the two filters during the weighing process. A laboratory blank was also used to determine if contamination occurred within the weighing room. A unique labelling system was used for each filter according to the sampling equipment it was allocated to e.g. a filter labelled as P2K1/092, would be decoded as; P2 referring to Partisol 2000 (the type of the sampler), K1 referring to the sampler number (the sampler number allowed for linking the sampler to the site at which it was located) and 092 referring to a specific filter number starting from 001.

All PM data from the laboratory was managed in Microsoft Excel statistical package for data analysis. Pre-conditioned and weighed filters were stored in Millipore petri-slide filter holders; with airtight seals to protect filters from contamination of passive settling dust. Millipore petri-slide filter holders protect the integrity of the filter from external contamination during filter transportation, filter transfer and filter storage in the laboratory. Quality assurance of future analysis e.g. such as compositional analysis for metals is maintained.

The analytical microbalance used to weigh filters was a five decimal point Ohaus 11378-050 with readability to 10µg, the balance was calibrated as specified by the manufacturer at installation and recalibrated immediately prior to each weighing session.

New filters and sampled filters were placed in the conditioning environment immediately upon retrieval from the monitoring site and stored until the completion of the weighing sessions. The analytical microbalance was located in the same environment in which the filters were conditioned, such that the filters would be weighed immediately following the conditioning period without intermediate or transient exposure to non-equilibration conditions. To ensure accuracy in the weighing process and to eliminate interpersonal errors the same analyst using the same analytical balance performed both the pre and post weighings of all filters for the duration of the study.

New blank filters were weighed along with the pre-sampling (tare) weighing of each batch of PM filters. Blank filters were transported to the sampling site, placed in the PM sampler, retrieved from the sampler without being sampled on, and re-weighed as a quality control check. Any gain or loss in weight on the blank filters (laboratory blanks, field blanks and quality control filters) was used to determine expected changes on the final mass concentration of the sampled filter.

### **3.2.2.3 Sources of bias**

Key factors affecting precision and accuracy associated with gravimetric analyses

#### **1. Temperature and humidity variation**

Temperature and humidity fluctuations caused changes in the weight of the filters during the equilibration periods resulting in post weighting of sampled filters having a smaller mass than the non-sampled pre weighted filters. A stable laboratory environment was achieved by:

- Ensuring that the gravimetric laboratory was located inside another laboratory, with no direct interaction with the outside environment.
- All gaps between doors and windows in the gravimetric laboratory were re-sealed to ensure that when the door was closed an airtight seal was formed.
- The gravimetric laboratory had its own air conditioning system to the larger laboratory.
- Electronic temperature and relative humidity monitors were in use to monitor the microenvironment.

- Dehumidifiers were installed to regulate the RH.
- Restricting laboratory access to only the laboratory technician and the environmental pollution monitoring team.
- The laboratory technician worked alone in the laboratory, and number of persons in the room at any given time was restricted to the laboratory tech.

## 2. Accuracy of weighing

To increase the precision of the weighings to the closest decimal place a microbalance with 5 or more decimal point is preferred and recommended, such as the one used Ohaus 11378-050 with readability to 10 µg.

## 3. 100% replicate weighings

Since numerous weighings were performed on each filter from which the average weight was calculated it was essential that the deviation in weights between pre and post weighing be small. To achieve this the same laboratory technician performed all gravimetric weighings, on a sturdy, solid table top specific for gravimetric analysis was used (see controls for point 1 above).

## 4. Control of static charge

Build up of static charge on the filter and the microbalance weighing pan (metal) from friction can result in the filter (or particles on or from the filter) adhering to the pan.

This results in filter loss, which is reduced by the recommended method of control of anti-static mat, which was not available, although no effects of static were noted by the laboratory technician during the study.

## 5. Aging of new filters

New filters were equilibrated 24 to 48 hours in the laboratory to minimise the impacts of the external laboratory environment where differences in temperature and relative humidity would bias filter weights by increasing or decreasing filter weights.

#### 6. Weighing a sufficient number of laboratory blank filters

Laboratory blanks for various filter types and each batch of filters weighed were used. Laboratory blanks remain in the laboratory, in constant equilibration with the laboratory environment, where substantial changes in the laboratory environment (temperature and humidity) would be reflected in changes of weight of the laboratory blanks. This serves to inform the laboratory technician when the laboratory environment is not conducive for gravimetric analysis and that weighing should only commence when the environment stabilises.

#### 7. Accounting for buoyancy errors caused by variability in barometric pressure.

Standard atmospheric pressure at sea level is 1013 kPa and since the gravimetric analysis laboratory was situated at ground level ~2.5km from the sea, effects from atmospheric pressure are assumed to be negligible.

#### 8. Filter losses due to handling during deployment and retrieval.

Delicate filters e.g. glass fibre and quartz, when subjected to inappropriate handling would result in frayed edges contributing to filter loss. To control such losses field technicians were trained in the proper handling and transferring of filters whilst in their custody.

### **3.2.3 METHODOLOGY OF AMBIENT PM MONITORING**

Electrically powered air samplers were used to draw ambient air at a constant volumetric flow rate into a specially shaped inlet and through an inertial particle size separator (impactor) where the suspended particulate matter in the PM<sub>10</sub> size range was separated for collection onto 47mm Millipore glass fibre filters and Ederol Glass Fibre – microfilter 227/1/60 and pallflex filters over a 24 hour sampling period. The choice of filter media (glass fibre and pallflex filters) was selected as per manufacturer recommendation.

For the intensive phases of monitoring these automated samplers were equipped with a week's supply of filters (seven filters), all deployed at once and all filters retrieved on completion of the weeks monitoring during the following week's deployment.

At Nizam (the southern most site in the SDHS) which was equipped with R&P Partisol-FRM Model 2000 Air Sampler, required the deployment and retrieval of filters on a daily basis.

### **3.2.3.1 Sampler operation**

During deployment, the 47mm filters were transported to the sampling site in the Millipore petri-slide filter holder, while the larger 150mm filters were transported in their numbered sampling rings in sealed plastic buckets. On arrival at the site, filters were deployed into the unit with speed and accuracy, to reduce the exposure time of filters to the environment, protecting filters from contaminants. The 47mm filters were transferred from the Millipore filter holders to the sampling rings and placed into the sampling unit using a pair of Teflon tipped forceps. Filters were not handled with bare hands.

Sampling equipment was checked on a regular basis for error codes relating to interruptions in the flow rate, inappropriate sample time, date, filter number settings (due to incorrect sampling input criteria), depending on the type of sampler these error codes were rectified by following the relevant trouble-shooting guidelines in the user manual or resetting the machine. Some samplers like the Thermo Medium Volume and Digitel High Volume samplers, would on occasion not load the filter into the sampling position which required mechanical intervention from the field technician. On most occasions resetting the sampler or deleting the previous operational input and sampling parameters was most effective. The samplers were programmed to sample for 24 hours on a predetermined filter. A blank filter was also placed in the unit as an important quality checkpoint, which served as an indication of particulate contamination inside the unit and during deployment and retrieval.

The retrieval process of the filters required speed (to maintain the shortest duration filters were exposed to external environmental elements following completion of sampling) and accuracy. Forceps was used to retrieve the filter from the unit. Filters were returned into their respective labelled Petri-slide filter holders. The blank was also retrieved for gravimetric analysis.

The samplers were checked and prepared for sample collection in accordance with instructions provided in the sampler operation manual and with the specific quality assurance program established for the sampler. The samplers were programmed to start sample collection at the beginning of the sample period (12 noon) and stop sample collection 24 hours later (12 noon the following day). This strategy was adopted due to logistics of having to change filters daily on three partisol samplers, plus 2 to 3 teams were utilised to deploy filters simultaneously. Since samples were still collected over 24 hours this is unlikely to impact PM results. Information related to the sample collection (site location or identification number, sample date, filter identification number, and sampler model and serial number) was recorded and the sampler commenced sampling for the prescribed duration 24 hours (1440 minutes).

At the end of the sampling period, the filters, contained in the filter cassette, were carefully removed from the sampler, following the procedure provided in the sampler operation manual and the quality assurance programme, and placed in the protective filter container, ensuring no contact was made with the filter's sampled surface. The protective container contained no loose material that could be transferred to the filter. The total sample volume in actual cubic meters ( $m^3$ ) for the sampling period and the elapsed sample time was obtained from the sampler and recorded. All samplers warning flag indications and other information required by the local quality assurance program was recorded.

Factors related to the validity of the samples, such as sampler malfunctions, usually due to power failures (power supply to equipment being switched off) and incomplete sampling periods were recorded during the retrieval of the sampler filter data. These events would occur indiscriminately at the various sites due to overloading of electrical circuits (persons interfering with the power switch) or incorrect operational input by the field technician. This resulted in incomplete sample periods < 1440 minutes, not representative of a 24 hour sample, (refer to "Data management and Analysis," for how data in such situations were handled). To prevent persons interfering with the power supply, heavy-duty cable-ties were secured around the plug points and some power units were relocated to the inside of the sampling cages. After retrieval from the sampler, the exposed filters were transported to the laboratory for equilibration and subsequent post weighing.

### 3.2.3.2 Filter archiving

Following the post-sampling gravimetric analysis, filters were archived at the gravimetric analysis laboratory. These archived filters were made available for supplemental analyses to provide information on the metal composition of PM. The archived filter samples were stored in clean, dust-proof, covered containers.

### 3.2.3.3 PM<sub>10</sub> mass concentration calculation

The PM concentrations were calculated as follows:

$$PM = (W_f - W_i) / V_a$$

Where:

PM = Mass concentration of PM  $\mu\text{g}/\text{m}^3$ ;

W<sub>f</sub>, W<sub>i</sub> = Final and initial weights, respectively, of the filter used to collect the PM particle sample, mg;

V<sub>a</sub> = Total air volume sampled in actual volume units, as provided by the sampler,  $\text{m}^3$ .

Note: Total sample time of between 1380 and 1500 minutes (23 and 25 hrs) were used to represent a full valid PM sample (Refer to “Data Management and Analysis,” for how sample times outside of this range were identified and handled).

## 3.2.4 SULPHUR DIOXIDE MONITORING

Sulphur dioxide pollution was monitored continuously at the seven school sites with direct reading analysers, by ultraviolet fluorescence spectrometry using USEPA reference methods. These analysers were programmed to measure SO<sub>2</sub> concentrations every 10 minutes. All study sites (same as PM<sub>10</sub> sites) were equipped with its own SO<sub>2</sub> analysers.



- Assegai Primary School initially used an API 100A but was replaced with a Monitor Laboratory ML 2015 in May 2004 due to problems (UV fluorescence spectrometer needed replacing);
- Dirkie Uys had a API 100A which failed and was replaced with a Dasibi 4108 in January 2005 (due to excessive analyser drift);
- Nizam Primary School used an API 100A, which was replaced in January 2005 with a similar instrument (taken from Lamontville, due to calibration failure)
- Lamontville (Entuthukweni) School used an API 100A, which failed, was repaired, and then moved to Nizam.
- Briardale used a TECO 43A instrument.
- Ferndale used a Monitor Labs ML 9850B instrument (serial no. M1873–M702).
- Ngazana Primary School used a Monitor Lab ML 9850B instrument.

Analyser failure occurred on an regular basis between most sites, these failures resulted in periods of missing data or in very poor data quality (extended periods of negative or very high positive values). How this type of data was handled is discussed in more detail under “Data Management.” SO<sub>2</sub> data was stored in data loggers connected to the analyser via a RS232 serial port and fitted with an internal power supply (12v battery pack). The analysers also had an external pump to draw in air at a constant flow rate of 650 - 700 cc/min. Although different models of SO<sub>2</sub> analysers were used, the sampling flow rate (650 - 700 cc/min) and internal analytical methodology (UV detection method) were identical and unlikely to provide any basis in the measured SO<sub>2</sub> concentration between analysers.

### **3.2.5 DETERMINATION OF SULPHUR DIOXIDE IN THE ATMOSPHERE**

SO<sub>2</sub> monitoring was undertaken using continuous SO<sub>2</sub> analysers (API, Europe Monitor Laboratorys and TECO), installed at all study sites. All analysers used the proven UV fluorescence principle coupled with state of the art microprocessor technology to provide accurate and dependable measurements of low level SO<sub>2</sub>.

A serial port connected data logger allowed for data acquisition by logging multiple parameters, including averaged or instantaneous concentration values, date and time, calibration data and operating parameters such as lamp intensity or internal temperature. Stored data was easily retrieved through the RS-232 port by means of a laptop or manually from the front instrument panel.

The analysers used U.V. fluorescence technology to measure concentrations of SO<sub>2</sub>. This method depends on the fluorescent radiation produced by the SO<sub>2</sub> molecules when excited by U.V. radiation. The excitation of U.V. radiation is measured by the reference detector and the fluorescent radiation is measured by a photomultiplier tube (PMT). The two measurements are compared by ratio in a classical dual channel technique to compensate against the effects of variation in source intensity, optical contamination, and common PMT drift characteristics. Aromatic hydrocarbons are removed by a unique 'kicker' that uses differential partial pressure technique to selectively remove aromatics across the permeable membrane, without influencing the SO<sub>2</sub> sample. The final concentration of SO<sub>2</sub> is corrected for temperature and pressure changes and can be displayed in ppm or mg/m<sup>3</sup>.

## QUALITY CONTROL

- For quality data to be retrieved, proper quality control measures were implemented. The following were the steps taken to ensure the availability of reliable, quality data:
- Span and zero checks were conducted on the analysers on a monthly basis by field technicians to establish if the analyser was sampling SO<sub>2</sub> at the correct concentration.
- The span checks with permeation tubes and zero checks with charcoal scrubber bag were conducted using reference values (known concentration of permeation tube).
- The zero check passes the sample air through a charcoal bag (scrubber) to remove any trace concentrations of SO<sub>2</sub>. The analyser's response time and stability at zero is recorded.
- Span values were read off on the analyser at the end of the test to determine the sensitivity of the analyser in measuring a known SO<sub>2</sub> concentration.

- Any person handling any of the SO<sub>2</sub> analysers were required to fill out a logbook, indicating the nature, date, time and reason of the visit.

Routine inspections were also carried out on the analysers. This was done to ensure there was no dirt or dust build up clogging the sampling tubes or lines leading into the analyser.

All functional properties were checked and reported on, using a diagnostic sheet for maintenance. These checks were conducted in conjunction with the span and zero checks.

- The pre-filter and charcoal bags were replaced on a regular basis.
- SO<sub>2</sub> downloads were also conducted weekly by the field technicians.
- All information stored in the analyser's data logger was downloaded onto a laptop.
- The data was named and stored in separate files according to monitoring site and date in Microsoft excel statistical programme on the computer.
- External quarterly calibrations were also performed on the analyser by external consultants.

### **3.2.6 MEASUREMENT OF OTHER ASSOCIATED VARIABLES**

Meteorological data, wind speed, wind direction, temperature, relative humidity, pressure and precipitation were measured in south and north Durban by meteorological stations managed by the South African Weather Services. The south meteorological station is located on the premises of the Durban International Airport ~3.5km from the southern school sites, while the north meteorological station is located on the premises of Tongaat Hullets a sugar processing plant ~5.5km from the northern located school sites. Meteorological data was provided in hourly and 24 hour averages, which is to be used in regression analysis with daily SO<sub>2</sub> and PM<sub>10</sub> pollutant averages.

Temperature ( $T$  in °C) and relative humidity (RH in %) was measured with the use of a Vaisala Y50 sensor, checked against a HMP45D temperature and humidity probe. Wind speed (WS in ms<sup>-1</sup>) and wind direction (WD in degrees) were measured with RM Young wind sensor, replaced once a year.

Pressure was measured with PTB 100A Vaisala pressure sensor, and verified against a PA11 pressure sensor. Rain was measured with use tipping bucket, and calibration checked every year, 6.3mm to 0.2mm.

### **3.3 DATA MANAGEMENT AND ANALYSIS**

This section provides clarification on the processes adopted for data management i.e. data coding, cleaning and censoring to achieve the final dataset which was analysed. Various decision rules in respect to data handling needed to be documented as part of the quality control and assurance processes to ensure a standardised data management approach, preventing deviations from the written protocol.

#### **3.3.1 DATA MANAGEMENT**

The SO<sub>2</sub> and PM<sub>10</sub> data were subjected to internally standardised verification in keeping with the quality assurance methods, from analyser installation, data acquisition to data analysis. The following explains how collected pollution data was handled to ensure data quality and integrity.

SO<sub>2</sub> data was handled in Microsoft Excel spreadsheets, since data was downloaded and saved in electronic format as text files it was exported into Microsoft Excel, by setting delimiters to separate the data into station number, date, time, SO<sub>2</sub> concentrations measured and internal instrument temperature. This data was then checked and appended to the last data point from the previous downloads, matched to the preceding date and time. During periods of missing data, the date and time was recorded while SO<sub>2</sub> concentrations were represented as not available (N/A).

Missing data was identified resulting from instrument failure, power failure or when instrument temperature increased etc. These events were flagged as such and the resultant data censored for exclusion from data analysis.

Other data events that warranted data flagging and censoring were results from the span and zero checks and quarterly calibrations. These data points were identified as extreme outliers that would adversely influence the true atmospheric SO<sub>2</sub> concentrations.

The raw SO<sub>2</sub> data was subjected to a series of quality control checks to achieve a cleaned and useable data set. The criteria used for the coding, adjustment, cleaning and censoring of the raw SO<sub>2</sub> data for specified periods is referred to as the technical quality control process. This process was reliant on the use of the following records:

- External quarterly calibration reports compiled for each SO<sub>2</sub> analyser following calibration;
- Internal span and zero checks;
- Records retrieved from the analyser event logs following data acquisition;
- Recorded events and actions noted in the analyser logbooks by field technicians during data acquisition, maintenance and site visits.

At each site except Ferndale SO<sub>2</sub> data was collected as 5 min averages, which was processed to 1 hour averages if half of the data for that hour were available. The 1 hour averages were processed to 24 hour averages, from noon to noon, if half of the hourly data in the period were available. Several of the monitors at the school sites experienced drift problems, probably a result of inadequate temperature control in the instrument or in the enclosure. Drift resulted in slowly varying negative or positive biases that was easily detected. Bias was corrected on a monitor-specific basis by subtracting the long term baseline, computed as a running average (typically considering a 400 h window) of low (1<sup>st</sup>) percentile hourly concentrations in a time window typically 68 hours before and 4 hours after the current value. Minimum values were allowed to vary only slowly (< 5 ppb) otherwise a new window was utilised. This approach is reasonable since background SO<sub>2</sub> values at all sites approached zero almost every day due to strong variation in source emissions and meteorology, and since background levels were negligible. Statistical and visual checks ensured that this approach yielded reasonable and robust values. Some small (< -1 ppb) negative values remain after this correction, a normal result for this measurement, even at monitors that do not experience excessive drift [29].

PM<sub>10</sub> data was received in a Microsoft Excel Spreadsheet containing a unique identification number, date, time, temperature, humidity and individual weightings of filters for each weighting session and labelled according to the sampler in which it was to be deployed. (APPENDIX 3: Gravimetric data sheet for mass calculation).

Following the 24 hour sampling period, “field filter data” relating to a sampled filter, documenting the start and end time, date, total time sampled, average total volume of air sampled, average flow rate, average temperature, average pressure was retrieved manually from the sampling equipment. This “field filter data” information was for the filter that was sampled on the previous day of sampling. All field and laboratory data were compiled into this Microsoft Excel spreadsheet, which included the formulae for automatic calculation of the final mass concentration calculation for each filter.

Mass concentration calculations were also performed on the field and laboratory blanks to determine possible sources of contamination, inside or outside the laboratory or during deployment and retrieval of the sampled filters. Extreme negative and positive values for both control and sample filters were flagged and investigated to identify the cause, such as filter contamination or filter loss due to tears etc. These filters were compared to laboratory blanks for similar variations. The dataset was further explored to identify times when analyser failure occurred. These episodes were identified from analyser deployment records (“field filter data”) and from examining the total sample time (ideally 1440 minutes) and total volume (depending on sampler type). Data which was determined to result from these episodes were flagged or censored from further data analysis.

A flag coding was established for the data set to aid in identifying when PM<sub>10</sub> data was acceptable for use, these were:

1. The sample duration: - was described as the total time a sampler was in operation during a 24 hour sampling period.

**Table 3: Flag codes for sample duration**

<b>Flag Code</b>	<b>Description - Sample Duration</b>	<b>Time (min)</b>
<b>0</b>	Sample duration of 90% to 100%	1296 -- 1440
<b>1</b>	Sample duration of 80% to 90%	1152 -- 1440
<b>2</b>	Sample duration less than 80%	< 1152
<b>3</b>	Not sampled	0
<b>4</b>	Sample duration greater than 100%	> 1440

A flag code of 0 and 1 was used to identify acceptable sample durations, indicating that the data was of acceptable quality for further use. Data with a flag code of 2 or 4 could not be used due to reliability concerns about the data. Data with flag code 3 did not produce any results and therefore censored.

2. The volume sampled: - was described as the total volume of air passed through the filter during the 24 hour sampling period (this value varied according to the type of PM analyser).

**Table 4: Flag codes for sample volume**

<b>Flag Code</b>	<b>Description - Sample Volume</b>
<b>0</b>	Volume OK – normal operation
<b>1</b>	Volume <5% of operating volume
<b>2</b>	Volume <10% of operating volume
<b>3</b>	Zero volume due to analyser failure
<b>4</b>	Volume > operating volume of sampler

A flag code of 0 and 1 was used to identify a sample volume as being acceptable and representative of a full sample volume. Data with a flag code of 2 or 4 was not used due to reliability issues of the data. Data with flag code 3 did not produce any results and therefore censored.

### 3.3.2 ANALYSIS OF DATA

The daily 24 hour PM<sub>10</sub> averages were calculated using the formula provided in section “3.2.3.3 PM<sub>10</sub> mass concentration calculation.” The calculations were processed in Microsoft excel. Quality assurance precision checks required the calculation for all field blanks and laboratory blanks to determine possible interferences in the weightings as a result of temperature, humidity, filter loss or contamination.

PM concentrations were calculated as follows:

$$\text{Filter Concentration} = \text{Difference in filter tare weights} / \text{Flow Volume} \times 10^6$$

Where,

$$\text{Difference in filter tare} = \text{Average filter post weight} - \text{Average filter pre weight}$$

Concentration uncertainties were also calculated using the standard deviation from the pre and post sampling measurements. PM<sub>10</sub> mass concentrations with filter mean average deviation (MAD) < 5µg/m<sup>3</sup> was flagged for censoring from the final data set. The final mass concentration values (24 hour averages) were dependent on the total sample time, total sample volume and the mass difference between the pre and post weightings. The filter based gravimetric method employed provides a time weighted average (TWA) over 24 hours without the definition to identify peak exposures that may have occurred during the 24 hour period.

Unlike PM<sub>10</sub>, SO<sub>2</sub> was measured with continuous direct reading analysers, providing raw 10 minute averages. Once the 10 minute data set passed the data cleaning process the 24 hour SO<sub>2</sub> concentrations were calculated from averaging the preceding 24 hours, 144 observations starting at midnight to midnight the following day (a total of 1440 minutes) and so on, over the study period. These calculations were performed in Microsoft excel with the use of pivot tables which allowed for easy visualisation and quick reference for individual data points which were averaged over differing time intervals (10 min to 1 hour to 24 hour) during the study period. Pivot tables equip the data handler with an array of diagnostic tools and the ability to perform various descriptive data analysis over specified time periods.



Data analysis was performed on continuous 24 hour data sets for both pollutants and meteorological data. Data captured, cleaned and coded in Excel was exported into a statistical software package, STATA Intercooled version 9, for more detailed analysis.

After correction of the SO<sub>2</sub> data to compensate for analyser drift there were still numerous negative values in the dataset. Descriptive statistics and distribution of variance performed with Stata revealed a positively skewed dataset. A ladder and gladder analysis provided no options on how the SO<sub>2</sub> datasets could be normalised. This meant that a decision rule had to be applied to censor all negative values from this dataset. Once this rule was applied another ladder and gladder analysis revealed that the data could be normalised, either by a square root or log function. PM<sub>10</sub> data was also positively skewed but could be normalised following a ladder analysis. The normalised / log transformation of the data (dependent variables SO<sub>2</sub> and PM<sub>10</sub>) was only computed for use in the regression analysis.

Formal statistical analysis was used to calculate, frequency tables and descriptive statistics such as means and variances of the variables (SO<sub>2</sub>, PM<sub>10</sub> and meteorological data) of interest. Statistical analyses proceeded from univariate analyses, which were used to describe the characteristics of SO<sub>2</sub> and PM<sub>10</sub> among southern and northern sites and to examine the crude associations between variables of interests. For continuous dependent and independent variables, correlation coefficients were calculated. Meteorological data for wind direction, wind speed, temperature, humidity, pressure and rain were subjected to Wilcoxon rank sum (Mann-Whitney) test for non parametric data, to test significance between the variables from south and north Durban.

Temporal data analysis of hourly SO<sub>2</sub> data allowed for the identification of diurnal patterns (variation) over time during a 24hour period (day). This allowed for the identification when peak SO<sub>2</sub> exposures were most likely to occur. This analysis was only possible for SO<sub>2</sub> due to its sampling interval of 10 minute averages compared to a 24 hour gravimetric averages for PM<sub>10</sub> which is impossible to determine hourly variations.

Seasonal distribution of SO<sub>2</sub> and PM<sub>10</sub> was also investigated, by calculating monthly averages which allowed for the identification of seasons, spring (September, October, November), summer (December, January, February), autumn (March, April, May) winter (June, July, August).

Since SO<sub>2</sub> and PM<sub>10</sub> data was found to have a non-parametric distribution, Kruskal-Wallis test for (SO<sub>2</sub> and PM<sub>10</sub>) was performed to determine if significant differences exist between the medians of SO<sub>2</sub> and PM<sub>10</sub> between southern and northern sites. A bonferonni procedure was used to adjust for multiple comparisons among the seven sites. In order to determine if significant differences exist between the medians of SO<sub>2</sub> and PM<sub>10</sub> between the south Durban area and the north Durban area, two-sample Wilcoxon rank-sum (Mann-Whitney) test was conducted. Kruskal-Wallis test identified that a significant difference existed between the medians of SO<sub>2</sub> and PM<sub>10</sub> between sites, which required that Dunn's Multiple comparison tests be performed to identify which sites were significantly different. Dunn's Multiple comparison test is an Anova test which is specific for the analysis of non-parametric data.

The key associations of interest involved investigating the relationship between dependent variables such as SO<sub>2</sub> and PM<sub>10</sub> with independent variables, meteorological parameters such as wind direction, wind speed, temperature, humidity, pressure and precipitation (rainfall). The previous days pollutant concentrations (one day lag concentrations) were also of interest and used in predicting the next days atmospheric pollution concentrations. The one day lag variable of interest was then classified with the meteorological parameters as an independent variable in the regression model. Other key association of interest examined was the relationship between SO<sub>2</sub> and PM<sub>10</sub> on an intra and inter site basis.

These relationships between SO<sub>2</sub>, PM<sub>10</sub> and Meteorological parameters were explored with the aid of Spearman correlation (*rho*) coefficients, using bonferonni adjusted significance level. This is to determine if an inter-site relationship exists between SO<sub>2</sub> levels; if an inter-site relationship exists between PM<sub>10</sub>; if an intra-site relationship exists between SO<sub>2</sub> with PM<sub>10</sub> levels; and to determine if an inter-site relationship exists between SO<sub>2</sub> with Meteorological parameters and PM<sub>10</sub> with Meteorological parameters.

For regression analysis log normalised dependent variables of SO<sub>2</sub> and PM<sub>10</sub> for the south Durban region and the north Durban region were used in the models. Multiple linear regression analysis was performed on the pollutant data sets. Two models per pollutant were created.

Model 1 for SO<sub>2</sub> and PM<sub>10</sub> consisted of the independent variables of wind direction, wind speed, temperature, humidity, pressure, rain and area (location in north or south Durban). The area code was coded as 0 = north Durban and 1 = south Durban.

Model 2 for SO<sub>2</sub> and PM<sub>10</sub> consisted of the independent variables of wind direction, wind speed, temperature, humidity, pressure, rain, area (location in north or south Durban) plus the previous days pollution levels for SO<sub>2</sub> and PM<sub>10</sub>.

Regression diagnostics of the models consisted of density graphs of residuals with a normal distribution superimposed on the graph to verify that residuals are normally distributed, a check for sensitive to deviance near the mean of the distribution and for sensitive to deviances from normality in the tails of the distribution, plots of the residuals versus a predicted values the goodness of fit of the models. A test for variance inflation factors (VIFs) to show by how much the variance of a single  $\beta$  goes up due to the correlations across explanatory variables to test for multicollinearity in the models.

Ten minute, 24 hour and annual averages for SO<sub>2</sub> and PM<sub>10</sub> calculated were used to determine compliance to the ambient air quality standards for South Africa (in accordance with NEMA). The calculation of the annual average considered all pollutant measurements from 29 May 2004 to 29 May 2005, over 365 days, all other measurements following 29 May 2005 were excluded.

## CHAPTER 4

### 4.1 RESULTS

#### 4.1.1 DESCRIPTION OF SO<sub>2</sub>, PM<sub>10</sub> & METEOROLOGICAL PARAMETERS

**Table 5: Total number of SO<sub>2</sub> & PM<sub>10</sub> observations for final datasets**

Sites	Final SO <sub>2</sub> Data		Final PM <sub>10</sub> Data	Deleted SO <sub>2</sub> Data		Deleted PM <sub>10</sub> Data
	Hourly (n)	24 hour (n)	24 hour (n)	Hourly (n)	24 hour (n)	24 hour (n)
Assegai	6618	315	138	318	0	2
Dirkie	5806	260	135	1237	40	2
Nizam	7821	351	168	685	9	2
Lamont	5174	231	131	583	16	2
Briardale	4883	215	132	2523	105	2
Ferndale	7407	331	139	270	4	2
Ngazana	6202	268	139	1242	45	2
<b>Total</b>	<b>43911</b>	<b>1971</b>	<b>982</b>	<b>6858</b>	<b>219</b>	<b>14</b>

Table 5, indicates the number of observations that passed the data quality control and assurance processes described in Chapter 3, Methodology. Majority of the data points / observations censored / deleted were from the SO<sub>2</sub> data set. The censoring of the SO<sub>2</sub> datasets was a result of internal and external calibrations, span and zero checks, analyser drift and analyser failure. Assegai had the least amount of hourly SO<sub>2</sub> data censored (318 observations) and Briardale had the most amount of hourly SO<sub>2</sub> data censored (2523 observations). The PM<sub>10</sub> data set had two 24 hour observations for all sites deleted from the data set.

Approximately 14 % of the SO<sub>2</sub> dataset was censored due to analyser drift and failure span and zero checks, internal and external calibrations and residuals from span and zero checks.

These deletions are not expected to have any negative implication on the results owing to the current SO<sub>2</sub> dataset fulfilling QA requirements for SO<sub>2</sub> as specified in Chapter 3, Methodology (refer to section 3.3.1 DATA MANAGEMENT).

Nizam had more PM<sub>10</sub> samples taken since it was also a designated site for metals sampling. These additional filters were also subjected to the same standard filter handling and processing methods described in Chapter 3. These filters were also subjected to gravimetric analysis before they were digested for metals analysis.

24 hour SO<sub>2</sub> concentrations (ppb) were calculated from the hourly data and 24 hour PM<sub>10</sub> concentrations (µg/m<sup>3</sup>) were obtained from gravimetric analysis. Table 6 and Figure 1

**Table 6: 24 hour SO<sub>2</sub> (ppb) concentrations**

	South Durban Sites					North Durban Sites			
	Assegai	Dirkie Uys	Nizam	Lamont	South Region	Briardale	Ferndale	Ngazana	North Region
<b>Obs</b>	315	260	351	231	1194	215	331	268	835
<b>Mean</b>	11.88	6.99	8.34	6.72	8.65	1.58	2.54	1.18	1.85
<b>Std.Dev</b>	10.13	5.51	8.36	8.04	8.17	2.62	2.16	1.2	2.03
<b>Min</b>	0.43	0.17	0.01	0.05	0	0	0	0	0
<b>10th</b>	2.43	1.62	1.24	0.84	1.4	0.07	0.63	0.06	0.17
<b>25th</b>	4.37	3.11	2.67	1.48	2.73	0.31	1.08	0.31	0.58
<b>50th</b>	8.8	5.48	5.85	2.89	6.17	1.06	1.93	0.76	1.3
<b>75th</b>	16.52	9.35	11.4	8.96	12	1.71	3.56	1.72	2.47
<b>90th</b>	24.46	14.96	17.98	18.7	19.62	2.83	5.03	2.73	4.12
<b>95th</b>	31.81	18.46	24.36	24.02	24.46	4.54	6.76	3.79	5.36
<b>99th</b>	44.3	25.86	42.75	32.3	38.56	16	10.61	5.36	10.28
<b>Max</b>	73.37	32.24	61.91	46.81	73.37	24.12	16.3	6.04	16.77

Note: Lamont = Lamontville

**Table 7: 24 hour PM<sub>10</sub> (µg/m<sup>3</sup>) concentrations (weighted averages)**

	South Durban Sites					North Durban Sites			
	Assegai	Dirkie Uys	Nizam	Lamont	South Region	Briardale	Ferndale	Ngazana	North Region
<b>Obs</b>	138	135	168	131	572	132	139	139	410
<b>Mean</b>	57.85	45.64	50.14	51.63	51.28	40.88	45.29	59.01	48.52
<b>Std.Dev</b>	34.55	24.17	25.19	26.27	28.01	23.8	29.99	45.89	35.43
<b>Min</b>	1.2	1.4	14	9.6	1.2	1.9	4.5	0.7	0.7
<b>10th</b>	22.1	22.1	25.3	24.9	24.1	15.6	17.2	15.8	15.9
<b>25th</b>	34.2	29.8	33.55	32.7	32.3	24.9	25.4	30	26.2
<b>50th</b>	51.15	41.5	45.9	45.4	45.7	34.7	37	43.5	38.1
<b>75th</b>	75.3	54.9	57.95	64.4	62.05	51.35	56.4	74.9	59.8
<b>90th</b>	105.7	79.2	88.4	89.3	90.1	73.8	89.6	126.4	91.55
<b>95th</b>	128.8	90.4	98.2	99.2	103.9	90.6	103.5	152.6	124.6
<b>99th</b>	155.9	130.2	145.4	124	152.5	124.9	147.7	237.2	178.7
<b>Max</b>	208	170.6	179.4	173.8	208	133.8	178.7	266.6	266.6

**Note: Lamont = Lamontville**

Sites with the highest SO<sub>2</sub> concentrations were Assegai (11.9 ppb), Nizam (8.3 ppb), Dirkie Uys (6.9 ppb) and Lamontville (6.7 ppb) from the south, while Ferndale to Ngazana from the north ranged from 2.5 ppb to 1.18 ppb respectively.

The higher mean SO<sub>2</sub> concentrations at the southern sites were indicative of a higher spatial distribution, with 2 to 3 times higher SO<sub>2</sub> concentrations than the north sites. Inter-site SO<sub>2</sub> concentration gradients between the southern sites follow a distinct spatial distribution: Assegai (11.9 ppb) > Nizam (8.3 ppb) > Dirkie uys (~7 ppb) > Lamontville (6.7 ppb). Inter-site SO<sub>2</sub> concentrations between the northern sites revealed the following spatial distributions: Ferndale (2.5 ppb) > Briardale (1.58 ppb) > Ngazana (1.18 ppb). The mean SO<sub>2</sub> concentration for the southern region is 8.6 ppb compared to the northern region 1.9 ppb.

PM<sub>10</sub> concentrations are very similar across all sites with inter-site spatial distribution of mean PM<sub>10</sub> concentrations being highest at Ngazana (59 µg/m<sup>3</sup>) > Assegai (~58 µg/m<sup>3</sup>) > Lamontville (~52 µg/m<sup>3</sup>) > Nizam (50 µg/m<sup>3</sup>) > Dirkie Uys (~46 µg/m<sup>3</sup>) > Ferndale (45 µg/m<sup>3</sup>) > Briardale (~41 µg/m<sup>3</sup>). Ngazana in the north also had the highest maximum concentration at 267 µg/m<sup>3</sup> compared to Assegai in the south of 208 µg/m<sup>3</sup> the second highest site.

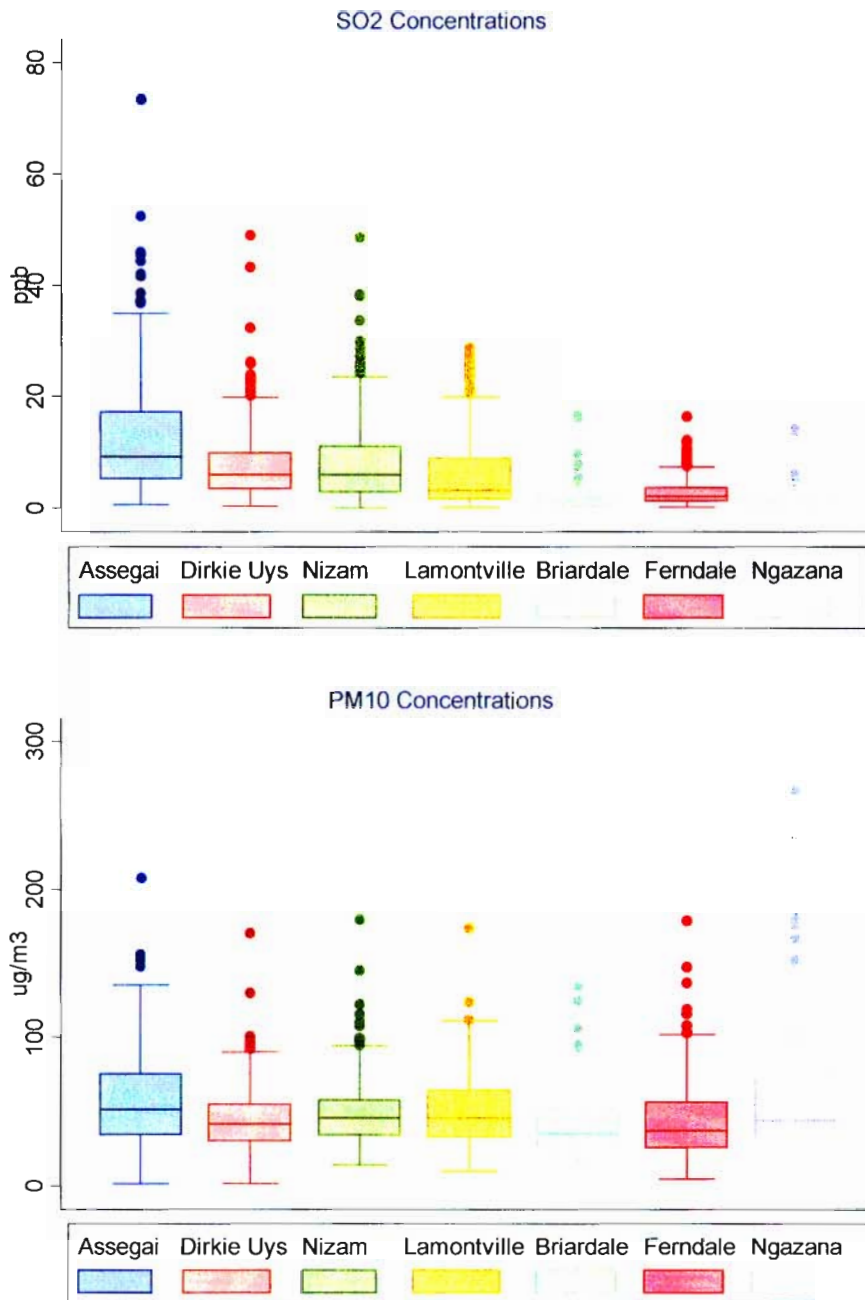


Figure 1: Boxplots SO<sub>2</sub> & PM<sub>10</sub> concentrations from southern and northern Sites

Diurnal trends (Figure 2) in SO<sub>2</sub> concentrations were computed to establish a SO<sub>2</sub> cycle during the 24 hour period. Hourly averages of SO<sub>2</sub> data over the study period for all study sites presented variability with SO<sub>2</sub> concentrations over the 24 hour cycle the sites in the south track each other with similar peaks and lows and the sites in the north do the same with much less variability at a much lower concentration. Among the southern sites the highest concentrations is during the morning from 5:00AM to 10:00AM, following which concentrations being to fall around 11:00AM to 19:00. In the later hours of the night from 20:00 to 24:00 SO<sub>2</sub> concentrations begin to steadily increase.

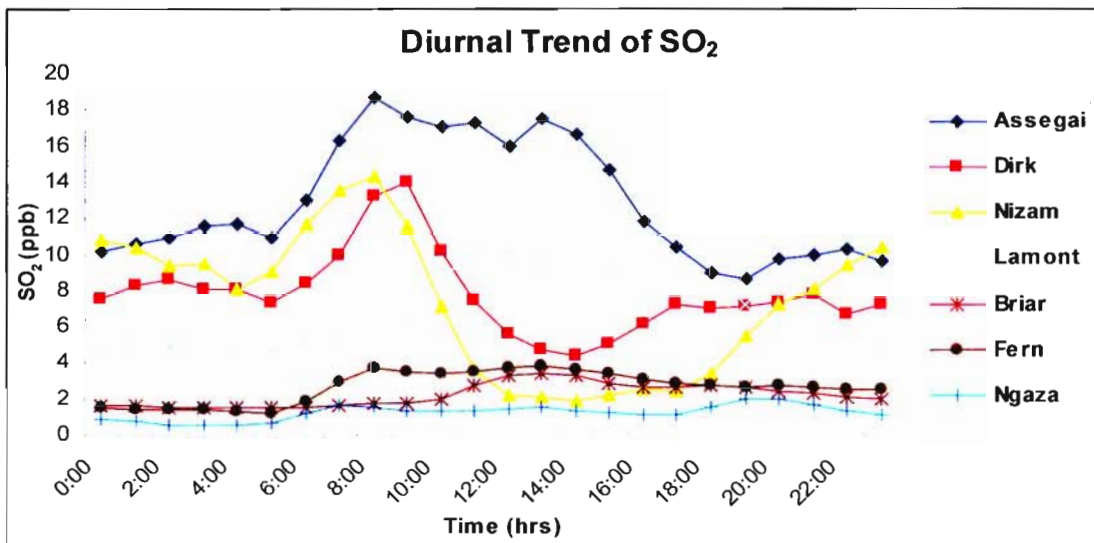
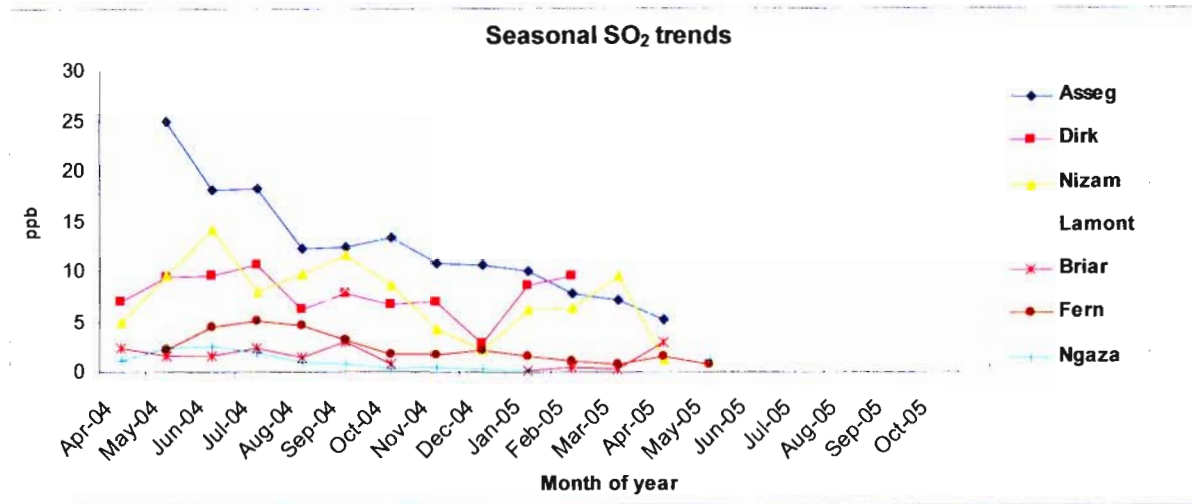


Figure 2: Diurnal trends of SO<sub>2</sub> concentrations over every hour of the study period

Note: Lamont = Lamontville

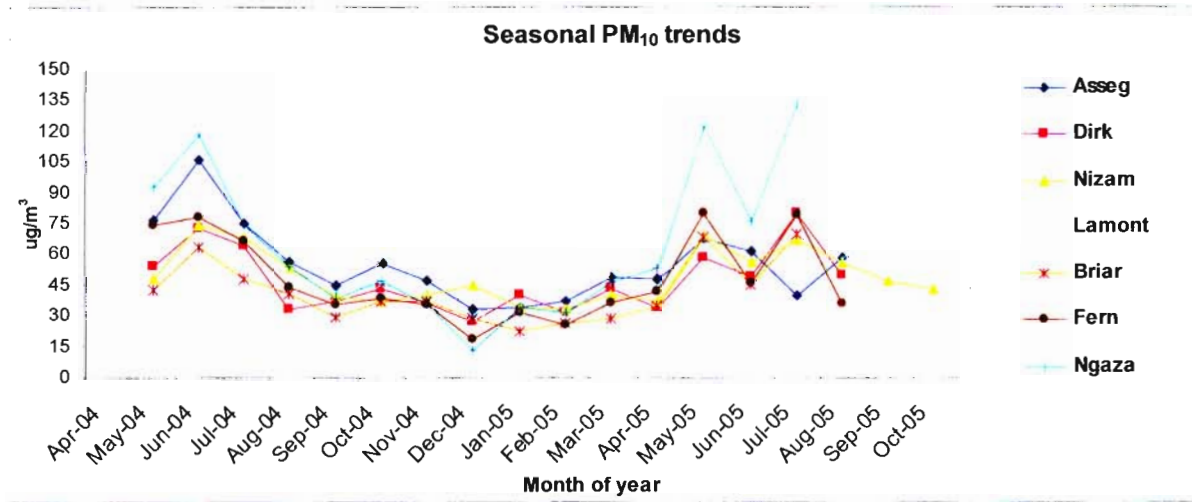
Seasonal trends (Figure 3 and Figure 4). for SO<sub>2</sub> and PM<sub>10</sub> were also established by calculating monthly averages over the monitoring period by segregating the study period into seasonal months, September to November (Spring), December to February (Summer), March to May (Autumn) and June to August (Winter). SO<sub>2</sub> does not display any distinctive seasonal variations in concentrations during the year, with large intra and inter site variability, however, a general downward trend is noted at most sites. PM<sub>10</sub> concentration closely track each other across all sites displaying strong seasonal trends with the winter months June 2004/05, July 2004/05 and August 2004/05 having the higher PM<sub>10</sub> concentrations as compared to October 2004 through to April 2005, the slightly warmer summer months having lower PM<sub>10</sub> concentrations.





**Figure 3: Seasonal variation of SO<sub>2</sub> monthly means, Apr 2004 – May 2005**

Note: Lamont = Lamontville



**Figure 4: Seasonal variation of PM<sub>10</sub> monthly means, May 2004 – Oct 2005**

Note: Lamont = Lamontville

**Table 8: 24 hour meteorological data**

	WD (°N) (South) <sup>†</sup>	WD (°N) (North) <sup>‡</sup>	WS (m/s) (South) <sup>†</sup>	WS (m/s) (North) <sup>‡</sup>	Temp (°C) (South) <sup>†</sup>	Temp (°C) (North) <sup>‡</sup>	Hum (%) (South) <sup>†</sup>	Hum (%) (North) <sup>‡</sup>	Pres (hPa) (South) <sup>†</sup>	Pres (hPa) (North) <sup>‡</sup>	Rain (mm) (South) <sup>†</sup>	Rain (mm) (North) <sup>‡</sup>
<b>Obs</b>	579	580	579	580	579	579	579	579	579	577	560	577
<b>Mean</b>	<b>155.20</b>	<b>100.80</b>	<b>3.90</b>	<b>2.00</b>	<b>20.50</b>	<b>18.50</b>	<b>75.10</b>	<b>78.10</b>	<b>1018.00</b>	<b>1007.00</b>	<b>1.40</b>	<b>1.10</b>
Std.Dev	58.10	59.10	1.60	0.90	3.10	3.30	8.50	9.10	5.80	6.00	5.30	3.80
Min	10.00	3.00	0.90	0.00	11.80	9.70	48.80	35.30	1005.00	966.50	0.00	0.00
<b>10<sup>th</sup></b>	66.00	33.00	2.10	1.00	16.50	14.00	63.00	64.70	1011.00	999.40	0.00	0.00
<b>25<sup>th</sup></b>	110.00	46.00	2.70	1.30	18.10	16.20	69.90	73.60	1014.00	1002.00	0.00	0.00
<b>50<sup>th</sup></b>	<b>163.00</b>	<b>92.50</b>	<b>3.60</b>	<b>1.90</b>	<b>20.30</b>	<b>18.40</b>	<b>76.50</b>	<b>80.00</b>	<b>1018.00</b>	<b>1006.00</b>	<b>0.00</b>	<b>0.00</b>
<b>75<sup>th</sup></b>	204.00	150.50	4.90	2.60	23.00	20.90	80.80	84.30	1023.00	1011.00	0.20	0.20
<b>90<sup>th</sup></b>	224.00	188.00	6.20	3.30	24.70	22.80	84.70	87.60	1026.00	1015.00	3.60	3.00
<b>95<sup>th</sup></b>	230.00	207.00	7.10	3.90	25.50	23.70	87.30	90.20	1028.00	1016.00	7.30	6.20
<b>99<sup>th</sup></b>	246.00	223.00	8.00	4.60	26.50	25.00	91.80	94.90	1032.00	1020.00	24.40	19.20
<b>Max</b>	<b>340.00</b>	<b>240.00</b>	<b>9.90</b>	<b>5.40</b>	<b>27.50</b>	<b>25.50</b>	<b>95.00</b>	<b>99.30</b>	<b>1036.00</b>	<b>1024.00</b>	<b>60.00</b>	<b>45.60</b>

(South)<sup>†</sup>: Meteorological data collected at Durban International Airport in South Durban

(North)<sup>‡</sup>: Meteorological data collected at Mt Edgecombe in North Durban

WD (°N): Wind direction degrees from North

WS (m/s): Wind speed in meters per second

Temp (°C): Temperature in degrees Celsius

Hum (%): Humidity in percent

Pres (hPa): Atmospheric pressure in hectopascals

Rain (mm): Rainfall in millimeters

Table 10: Multiple comparison test - PM<sub>10</sub> Data

Dunn's Multiple Comparisons Test

Comparison	Mean Rank Difference		P value
Assegai vs. Dirkie Uys	103.09	ns	P>0.05
Assegai vs. Nizam	47.484	ns	P>0.05
Assegai vs. Lamont	36.581	ns	P>0.05
Assegai vs. Briardale	168.16	***	P<0.001
Assegai vs. Ferndale	138.00	**	P<0.01
Assegai vs. Ngazana	45.675	ns	P>0.05
Dirkie Uys vs. Nizam	-55.609	ns	P>0.05
Dirkie Uys vs. Lamont	-66.513	ns	P>0.05
Dirkie Uys vs. Briardale	65.068	ns	P>0.05
Dirkie Uys vs. Ferndale	34.905	ns	P>0.05
Dirkie Uys vs. Ngazana	-57.419	ns	P>0.05
Nizam vs. Lamont	-10.904	ns	P>0.05
Nizam vs. Briardale	120.68	**	P<0.01
Nizam vs. Ferndale	90.514	ns	P>0.05
Nizam vs. Ngazana	-1.810	ns	P>0.05
Lamont vs. Briardale	131.58	**	P<0.01
Lamont vs. Ferndale	101.42	ns	P>0.05
Lamont vs. Ngazana	9.094	ns	P>0.05
Briardale vs. Ferndale	-30.163	ns	P>0.05
Briardale vs. Ngazana	-122.49	**	P<0.01
Ferndale vs. Ngazana	-92.324	ns	P>0.05

ns = not significant

\* = significant

Note: Lamont = Lamontville

#### 4.1.2 RELATIONSHIP BETWEEN SO<sub>2</sub>, PM<sub>10</sub> & METEOROLOGICAL PARAMETERS

Relationships between SO<sub>2</sub>, PM<sub>10</sub> and Meteorological parameters are explained and displayed with the aid of Spearman correlation (*rho*) coefficients, using bonferroni adjusted significance level.

Weak to good SO<sub>2</sub> correlation exists between sites in the south, with correlation coefficients (*rho*) ranging from 0.2 (Lamontville vs Dirkie Uys) through to 0.6 (Dirkie Uys vs Assegai). There was a single statistically significant correlation between sites in the north - between Ferndale and Briardale, a good correlation of 0.6,  $p < 0.001$  (Table 11 and Figure 8).

**Table 11: Correlation (*rho*) between SO<sub>2</sub>, area inter-site comparison**

	Sites	rho	n	p value
South	Dirkie SO <sub>2</sub> Vs Assegai SO <sub>2</sub>	0.61*	238	0.00
	Nizam SO <sub>2</sub> Vs Assegai SO <sub>2</sub>	0.26*	295	0.00
	Nizam SO <sub>2</sub> Vs Dirkie SO <sub>2</sub>	0.45*	271	0.00
	Lamont SO <sub>2</sub> Vs Assegai SO <sub>2</sub>	0.16	195	0.44
	Lamont SO <sub>2</sub> Vs Dirkie SO <sub>2</sub>	0.22*	228	0.01
	Lamont SO <sub>2</sub> Vs Nizam SO <sub>2</sub>	0.42*	238	0.00
North	Ferndale SO <sub>2</sub> Vs Briardale SO <sub>2</sub>	0.64*	207	0.00
	Ngazana SO <sub>2</sub> Vs Briardale SO <sub>2</sub>	0.06	149	1.00
	Ngazana SO <sub>2</sub> Vs Ferndale SO <sub>2</sub>	0.32*	226	0.00

rho = Spearman correlation coefficient; n = number of observations; p value = level of significance at 0.05%;  
\* = significant; Lamont = Lamontville

PM<sub>10</sub> has stronger correlation coefficients (*rho*) at  $p < 0.05$  across all sites irrespective of location, South or North. The South site with the strongest PM<sub>10</sub> correlation was between Lamontville PM<sub>10</sub> and Assegai PM<sub>10</sub> ( $\rho = 0.88$ ,  $p = 0.00$ ) and from the North sites, the strongest PM<sub>10</sub> correlation was between Ferndale PM<sub>10</sub> and Briardale PM<sub>10</sub> ( $\rho = 0.91$ ,  $p = 0.00$ ). Table 12 and Figure 9; demonstrates the strong correlation that is present with PM<sub>10</sub> across all sites.

**Table 12: Correlation (*rho*) between PM<sub>10</sub>, area inter-site comparison**

	Sites	rho	n	p value
South	Dirkie PM <sub>10</sub> Vs Assegai PM <sub>10</sub>	0.78*	125	0.00
	Nizam PM <sub>10</sub> Vs Assegai PM <sub>10</sub>	0.73*	120	0.00
	Nizam PM <sub>10</sub> Vs Dirkie PM <sub>10</sub>	0.74*	119	0.00
	Lamont PM <sub>10</sub> Vs Assegai PM <sub>10</sub>	0.88*	122	0.00
	Lamont PM <sub>10</sub> Vs Dirkie PM <sub>10</sub>	0.82*	119	0.00
	Lamont PM <sub>10</sub> Vs Nizam PM <sub>10</sub>	0.82*	113	0.00
North	Ferndale PM <sub>10</sub> Vs Briardale PM <sub>10</sub>	0.91*	128	0.00
	Ngazana PM <sub>10</sub> Vs Briardale PM <sub>10</sub>	0.86*	130	0.00
	Ngazana PM <sub>10</sub> Vs Ferndale PM <sub>10</sub>	0.91*	134	0.00

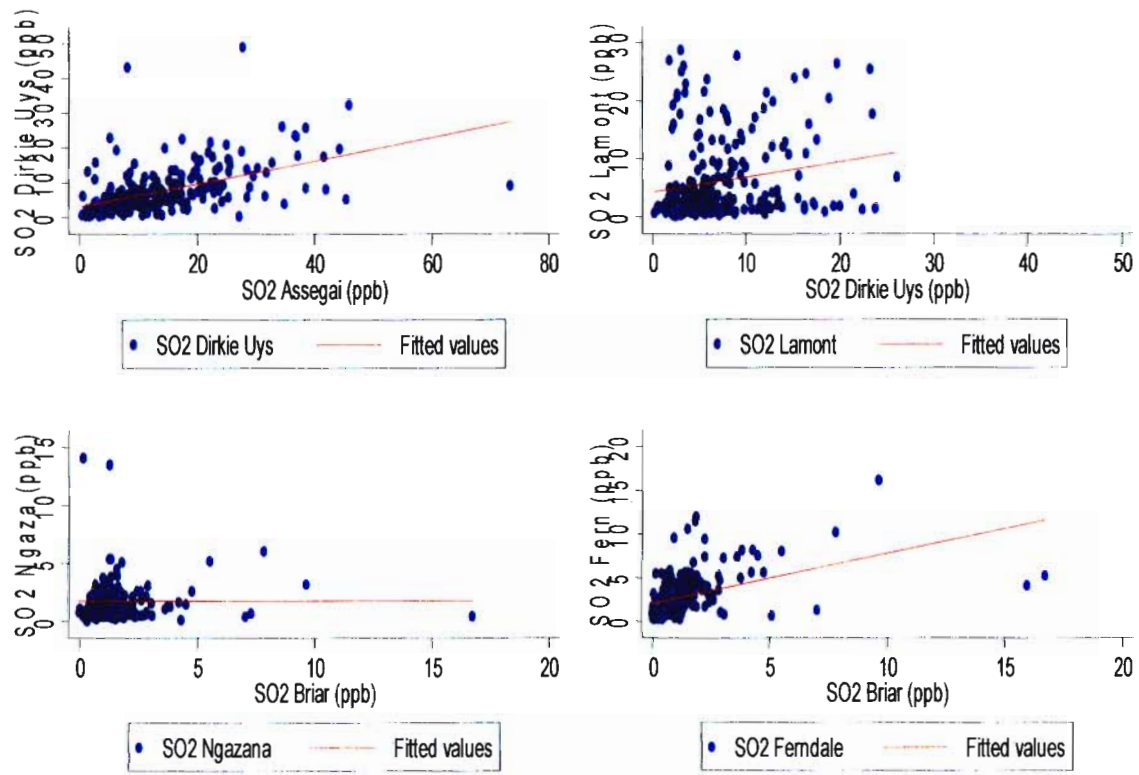
rho = Spearman correlation coefficient; n = number of observations; p value = level of significance at 0.05%;  
 \* = significant; Lamont = Lamontville

PM<sub>10</sub> also displayed stronger correlation coefficients (*rho*) at  $p < 0.05$  on a regional inter-site bases across southern and northern sites. The strongest significant cross regional correlation for PM<sub>10</sub> was between Ngazana (north) and Lamontville (south)  $\rho = 0.89$  ( $p = 0.00$ ) and the weakest significant cross regional correlation was between Briardale (north) and Assegai (south)  $\rho = 0.72$  ( $p = 0.00$ ) (Table 13 and Figure 9).

**Table 13: Correlation (*rho*) between PM<sub>10</sub>, inter-site comparison**

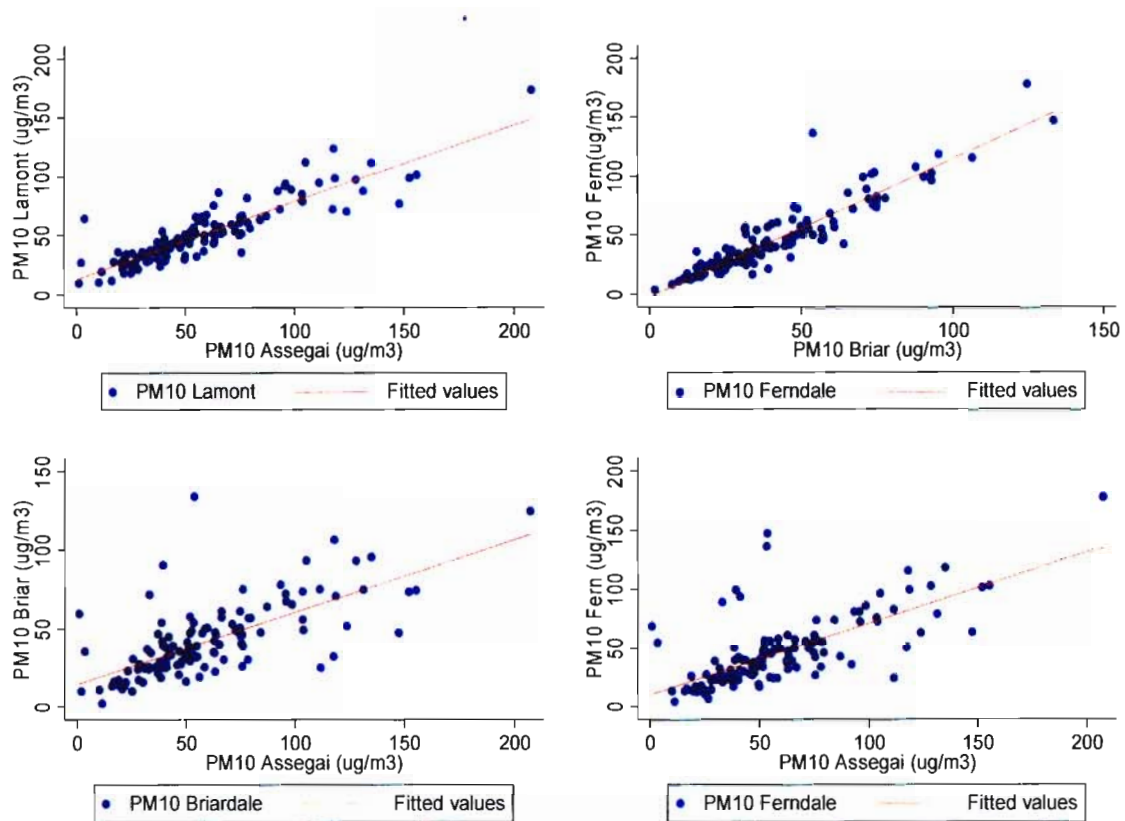
Sites		South Sites				
		Assegai PM <sub>10</sub>	Dirkie PM <sub>10</sub>	Nizam PM <sub>10</sub>	Lamont PM <sub>10</sub>	
North Sites	Briardale PM <sub>10</sub>	rho	0.72*	0.73*	0.79*	0.79*
		n	124	121	118	118
		p value	0.00	0.00	0.00	0.00
	Ferndale PM <sub>10</sub>	rho	0.72*	0.77*	0.79*	0.84*
		n	127	125	123	120
		p value	0.00	0.00	0.00	0.00
	Ngazana PM <sub>10</sub>	rho	0.76*	0.80*	0.80*	0.88*
		n	128	126	124	120
		p value	0.00	0.00	0.00	0.00

rho = Spearman correlation coefficient; n = number of observations; p value = level of significance at 0.05%;  
 \* = significant; Lamont = Lamontville



**Figure 8: Scatter plot of Inter-site SO<sub>2</sub> concentrations**

**Note: Lamont = Lamontville**



**Figure 9: Scatter plot of Inter-site PM<sub>10</sub> concentrations**

**Note: Lamont = Lamontville**

Correlation coefficients ( $\rho$ ) for SO<sub>2</sub> with PM<sub>10</sub> were also calculated to establish if a relationship exists between SO<sub>2</sub> with PM<sub>10</sub> on an intra-site basis. Generally, significant intra-site correlations exist between SO<sub>2</sub> with PM<sub>10</sub> at most sites. This ranges among the south sites, from a correlation coefficient of 0.53 at Dirkie Uys ( $p = 0.00$ ) to 0.38 at Nizam ( $p = 0.00$ ). Similar intra-site ranges exist in the north with Ngazana have the best overall correlation of 0.50 ( $p = 0.00$ ) (Table 14 and Figure 10).

**Table 14: Correlations (*rho*) of SO<sub>2</sub> versus PM<sub>10</sub> (Intra-Site)**

	Site	Pollutant	rho	n	p value
South	Assegai	SO <sub>2</sub> versus PM <sub>10</sub>	0.42*	117	0.00
	Dirkie Uys	SO <sub>2</sub> versus PM <sub>10</sub>	0.53*	81	0.00
	Nizam	SO <sub>2</sub> versus PM <sub>10</sub>	0.37*	110	0.00
	Lamontville	SO <sub>2</sub> versus PM <sub>10</sub>	0.43*	75	0.00
North	Briardale	SO <sub>2</sub> versus PM <sub>10</sub>	0.35	73	0.19
	Ferndale	SO <sub>2</sub> versus PM <sub>10</sub>	0.47*	119	0.00
	Ngazana	SO <sub>2</sub> versus PM <sub>10</sub>	0.50*	94	0.00

rho = Spearman correlation coefficient; n = number of observations; p value = level of significance at 0.05%;  
\* = significant

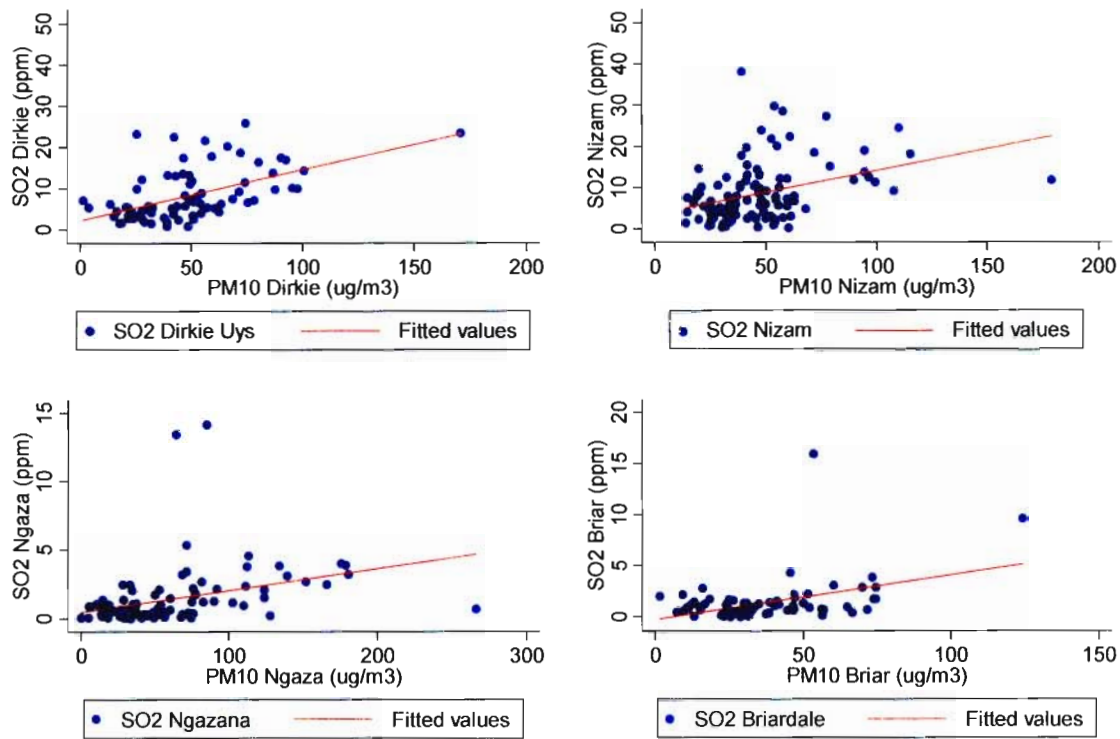
The correlation of pollutants across each region (south vs north) was weak but significant for SO<sub>2</sub> (rho = 0.24, p = 0.00), but very much stronger for PM<sub>10</sub> (rho = 0.72, p = 0.00). Intra-site correlation of PM<sub>10</sub> with SO<sub>2</sub> within the south and north was weak but significant (p < 0.05) (Table 15).

**Table 15: Correlations (*rho*) of SO<sub>2</sub> with PM<sub>10</sub> – Regional comparison**

	rho	n	p value
SO <sub>2</sub> South Vs SO <sub>2</sub> North	0.24*	681	0.00
PM <sub>10</sub> South Vs PM <sub>10</sub> North	0.72*	373	0.00
PM <sub>10</sub> South Vs SO <sub>2</sub> South	0.40*	383	0.00
PM <sub>10</sub> North Vs SO <sub>2</sub> North	0.35*	286	0.00

rho = Spearman correlation coefficient; n = number of observations; p value = level of significance at 0.05%;  
\* = significant





**Figure 10: Scatter plot of Intra-site SO<sub>2</sub> versus PM<sub>10</sub> concentrations**

Although the pollutants were generally statistically significantly correlated with the various meteorological variables, these were not very strong, with correlation coefficients ranging from 0.1 to 0.5. Temperature (Figure 13) and humidity (Figure 14) was consistently significantly correlated with both pollutants across all sites in the expected direction (rise in temperature or humidity is related to an decrease in pollutant level). Rain (Figure 16) was significantly consistently correlated for PM<sub>10</sub>, but not so for SO<sub>2</sub> at four of the seven sites. Wind speed (Figure 12), wind direction (Figure 11) and pressure (Figure 15) was only significantly correlated with SO<sub>2</sub> only at a couple of sites in each instance (Table 16). All meteorological parameters impact SO<sub>2</sub> and PM<sub>10</sub> in the expected direction, while wind direction (Figure 11) is related to an increase in SO<sub>2</sub> only at Assegai and Dirkie Uys in the south.

Table 16: Correlations ( $r$ ) of SO<sub>2</sub> & PM<sub>10</sub> with Meteorological Parameters

		Assegai		Dirkie Uys		Nizam		Lamontville		Briardale		Ferndale		Ngazana	
		SO <sub>2</sub>	PM <sub>10</sub>	SO <sub>2</sub>	PM <sub>10</sub>	SO <sub>2</sub>	PM <sub>10</sub>	SO <sub>2</sub>	PM <sub>10</sub>	SO <sub>2</sub>	PM <sub>10</sub>	SO <sub>2</sub>	PM <sub>10</sub>	SO <sub>2</sub>	PM <sub>10</sub>
AvWD	rho	<b>0.46*</b>	0.08	<b>0.31*</b>	0.15	-0.15	0.09	-0.15	0.20	-0.01	-0.25	-0.03	-0.19	<b>-0.26*</b>	-0.14
	n	314	138	278	135	356	168	242	131	224	132	335	139	276	139
	pvalue	0.00	1.00	0.00	1.00	0.53	1.00	1.00	1.00	1.00	0.64	1.00	1.00	0.00	1.00
AvWS	rho	-0.06	-0.14	0.02	-0.09	0.11	-0.25	-0.09	-0.13	<b>-0.32*</b>	-0.19	<b>-0.32*</b>	-0.25	<b>-0.38*</b>	-0.26
	n	314	138	278	135	356	168	242	131	224	132	335	139	276	139
	pvalue	1.00	1.00	1.00	1.00	1.00	0.11	1.00	1.00	0.00	1.00	0.00	0.36	0.00	0.24
Temp	rho	<b>-0.40*</b>	<b>-0.35*</b>	<b>-0.32*</b>	<b>-0.40*</b>	<b>-0.27*</b>	<b>-0.40*</b>	<b>-0.31*</b>	<b>-0.48*</b>	<b>-0.51*</b>	-0.25	<b>-0.49*</b>	<b>-0.40*</b>	<b>-0.53*</b>	<b>-0.44*</b>
	n	314	138	278	135	356	168	242	131	223	132	334	138	276	138
	pvalue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.00	0.00	0.00
Hum	rho	<b>-0.39*</b>	<b>-0.45*</b>	<b>-0.43*</b>	<b>-0.50*</b>	<b>-0.35*</b>	<b>-0.41*</b>	-0.16	<b>-0.51*</b>	<b>-0.26*</b>	<b>-0.38*</b>	<b>-0.31*</b>	<b>-0.42*</b>	<b>-0.31*</b>	<b>-0.56*</b>
	n	314	138	278	135	356	168	242	131	223	132	334	138	276	138
	pvalue	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pres	rho	0.11	0.14	0.07	0.13	0.11	0.17	0.10	0.17	<b>0.30*</b>	0.12	<b>0.20*</b>	0.21	<b>0.52*</b>	0.27
	n	314	138	278	135	356	168	242	131	223	132	333	138	274	138
	pvalue	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.02	1.00	0.00	0.21
Rain	rho	-0.16	<b>-0.38*</b>	-0.07	<b>-0.36*</b>	<b>-0.22*</b>	<b>-0.46*</b>	-0.11	<b>-0.43*</b>	-0.21	<b>-0.46*</b>	<b>-0.32*</b>	<b>-0.48*</b>	<b>-0.37*</b>	<b>-0.53*</b>
	n	296	126	260	126	338	157	224	119	222	132	333	137	276	137
	pvalue	0.94	0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00

rho = Spearman correlation coefficient; n = number of observations; p value = level of significance at 0.05%; AvWD = wind direction; AvWS = wind speed; Temp = temperature; Hum = Humidity; Pres = Pressure; Rain = rainfall; \* = significant

Correlation analysis by region and meteorological variables was less consistent than when considering individual sites – the range of the correlation remained low to moderate, from 0.1 – 0.5. Wind speed and direction was only statistically significantly correlated with SO<sub>2</sub> in the north and south respectively, while rainfall was significant for PM<sub>10</sub> in both regions, but not for SO<sub>2</sub>. Humidity and temperature was significantly correlated for both pollutants in both regions. Again all meteorological parameters impact SO<sub>2</sub> and PM<sub>10</sub> on the regional scale in the expected direction, while wind direction is related to an increase in SO<sub>2</sub> only in the south (Table 17).

**Table 17: Correlations (*rho*) of SO<sub>2</sub> & PM<sub>10</sub> with Met Parameters - Regional comparison**

		South Durban Region		North Durban Region	
		SO <sub>2</sub> South	PM <sub>10</sub> South	SO <sub>2</sub> North	PM <sub>10</sub> North
<b>Wind Direction</b>	rho	0.48*	0.07	-0.00	-0.24
	n	314	138	224	132
	pvalue	0.00	1.00	1.00	0.11
<b>Wind Speed</b>	rho	-0.10	-0.12	-0.33*	-0.20
	n	314	138	224	132
	pvalue	1.00	1.00	0.00	0.52
<b>Temperature</b>	rho	-0.42*	-0.33*	-0.49*	-0.26
	n	314	138	223	132
	pvalue	0.00	0.00	0.00	0.05
<b>Humidity</b>	rho	-0.37*	-0.42*	-0.26*	-0.39*
	n	314	138	223	132
	pvalue	0.00	0.00	0.00	0.00
<b>Pressure</b>	rho	0.13	0.13	0.27*	0.13
	n	314	138	223	132
	pvalue	0.52	1.00	0.00	1.00
<b>Rainfall</b>	rho	-0.15	-0.37*	-0.19	-0.45*
	n	296	126	222	132
	pvalue	0.26	0.00	0.10	0.00

rho = Spearman correlation coefficient; n = number of observations; p value = level of significance at 0.05%;  
\* = significant

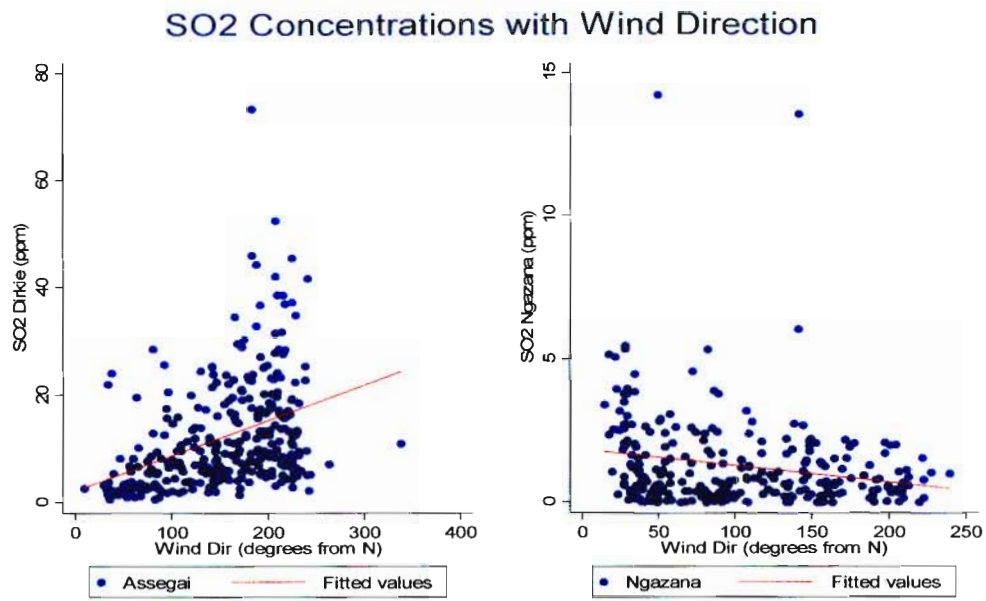


Figure 11: Scatter plot of SO<sub>2</sub> concentrations with Wind Direction (<sup>o</sup> North)

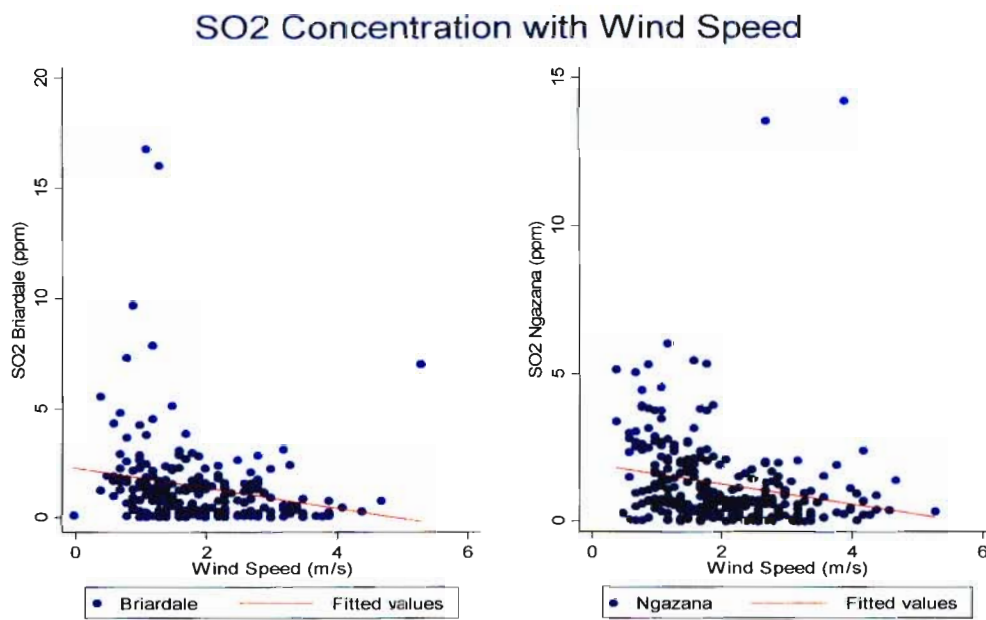


Figure 12: Scatter plot of SO<sub>2</sub> concentrations versus Wind Speed (m/s)

### SO<sub>2</sub> & PM<sub>10</sub> Concentrations with Temperature

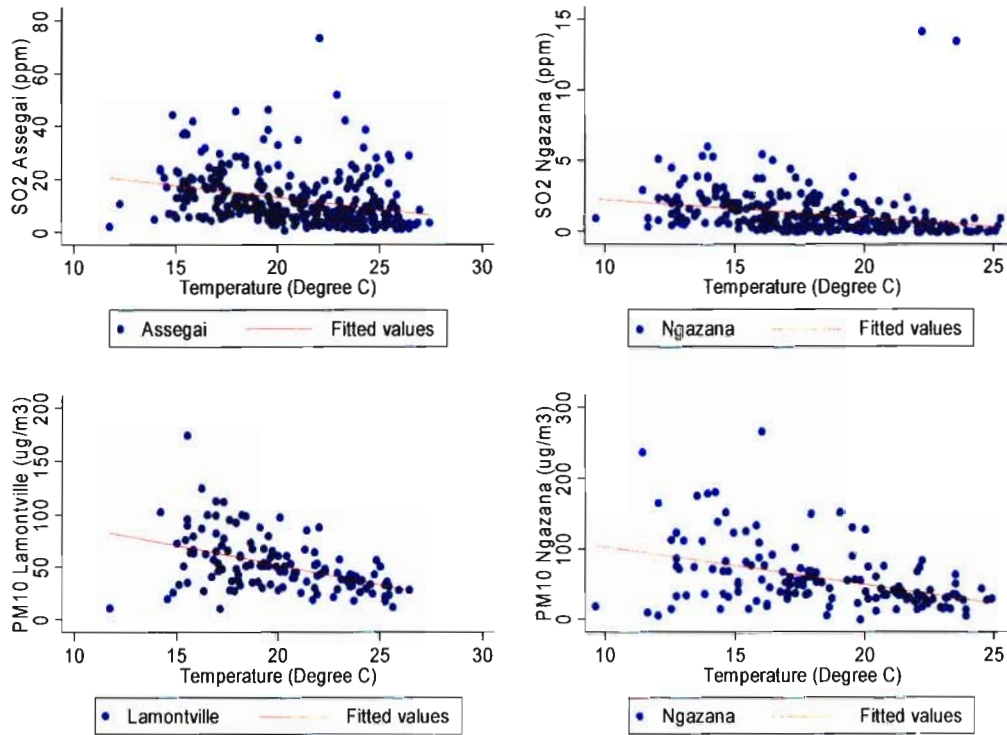


Figure 13: Scatter plot of SO<sub>2</sub> & PM<sub>10</sub> concentrations versus Temperature (°C)

### SO<sub>2</sub> & PM<sub>10</sub> Concentrations with Humidity

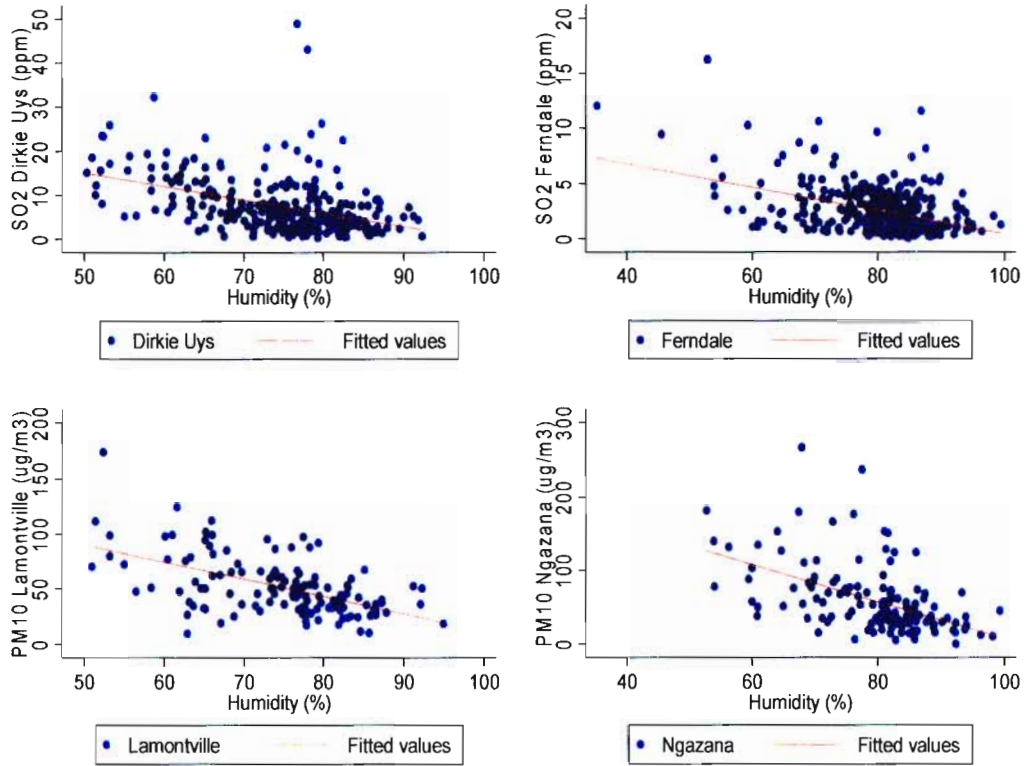


Figure 14: Scatter plot of SO<sub>2</sub> & PM<sub>10</sub> concentrations versus Humidity (%)

### SO<sub>2</sub> Concentrations with Pressure

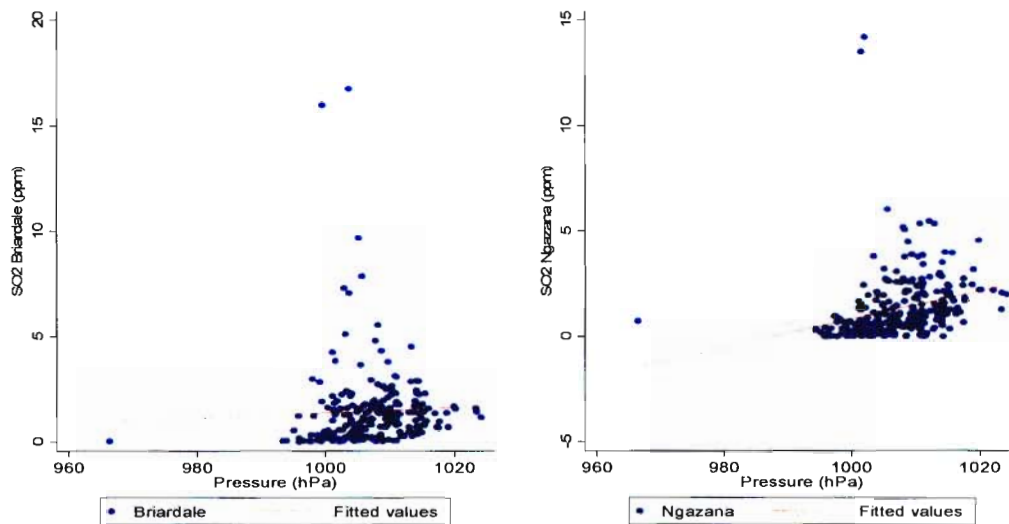
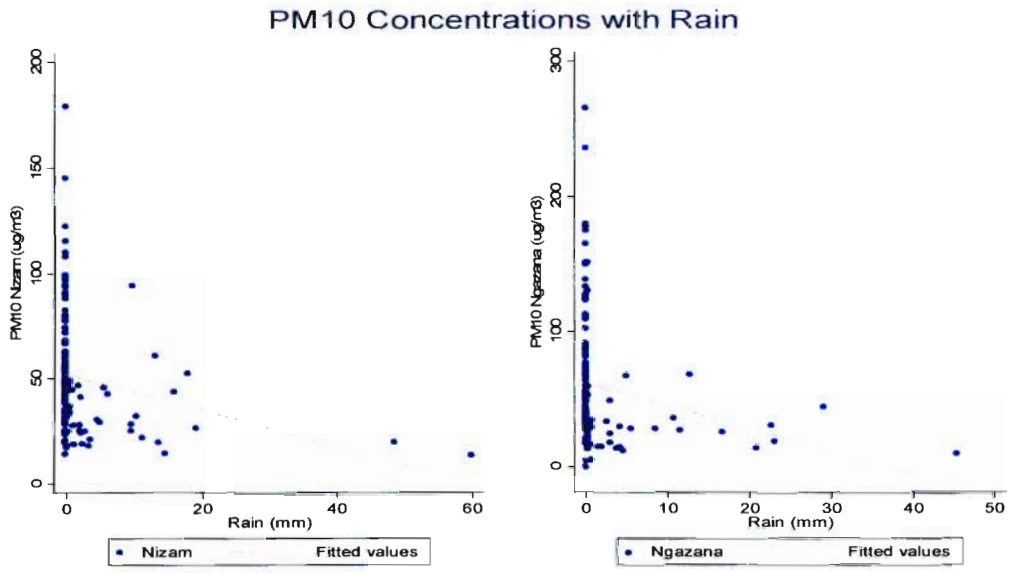


Figure 15: Scatter plot of SO<sub>2</sub> concentrations versus Pressure (hPa)



**Figure 16: Scatter plot of PM<sub>10</sub> concentrations versus Rainfall (mm)**

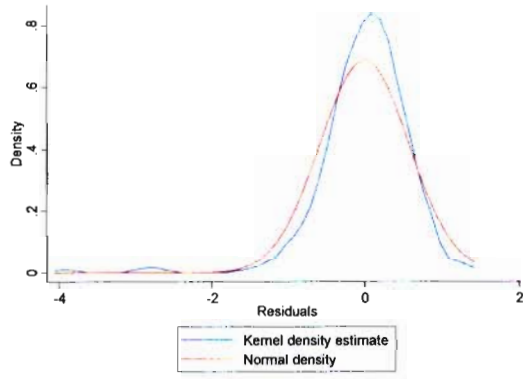
### **4.1.3 PREDICTION EQUATIONS OF SO<sub>2</sub>, PM<sub>10</sub> & METEOROLOGICAL PARAMETERS**

Regression models were developed for SO<sub>2</sub>, PM<sub>10</sub> and meteorological data for the south region (consisting of Assegai, Dirkie Uys, Nizam and Lamontville) and the north region (consisting of Briardale, Ferndale and Ngazana). For each pollutant (SO<sub>2</sub> and PM<sub>10</sub>) two models were developed: the first model (Table 18) explored the pollutants relationship with meteorological parameters and area location (south or north) and the second model, while exploring the same relationships considered the pollution contribution of the previous days pollutant levels for SO<sub>2</sub> and PM<sub>10</sub> (Table 19). In spite of establishing correlations between SO<sub>2</sub> and PM<sub>10</sub> with meteorological factors in the bivariate analyses, some of the independent variables were not statistically significant with the regression models. This being the case these variables were still included into the regression models due to their intended directional effects on SO<sub>2</sub> and PM<sub>10</sub>.

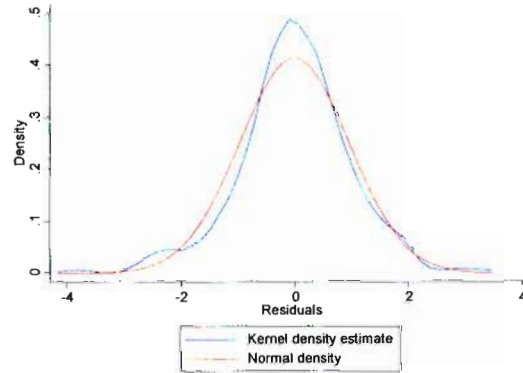
Regression diagnostics of the models consisted of density graphs of residuals with a normal distribution superimposed on the graph which verified that the residuals were normally distributed (Figure 17 and Figure 18); a check for sensitive to deviance near the mean of the distribution and for sensitive to deviances from normality in the tails of the distribution, also a plot of the residuals versus a predicted values (Figure 17 and Figure 18) resulted in residuals forming a random pattern around zero when plotted against the fitted values. The absence of any trend or pattern was an indication of good model fit. A test for variance inflation factors (VIFs) which show by how much the variance of a single  $\beta$  goes up due to the correlations across explanatory variables showed that multicollinearity in these models is relatively mild since none of the VIFs were excessively high ( $> 10$ ).



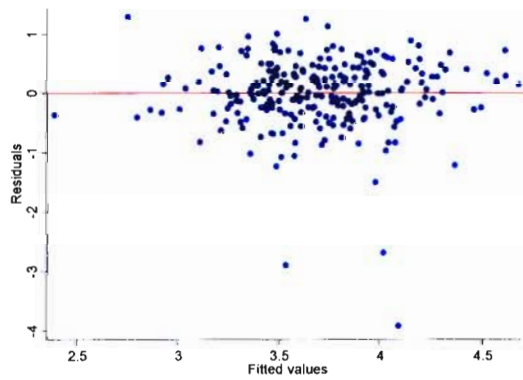
**Model 1: (a) PM<sub>10</sub>**



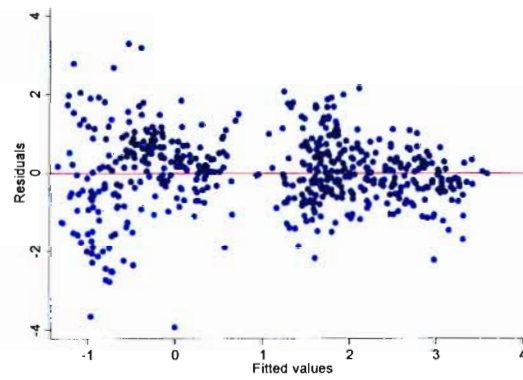
**Model 1: (b) SO<sub>2</sub>**



**Model 1: (c) PM<sub>10</sub>**



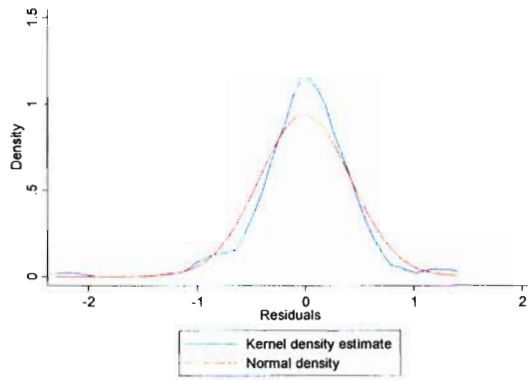
**Model 1: (d) SO<sub>2</sub>**



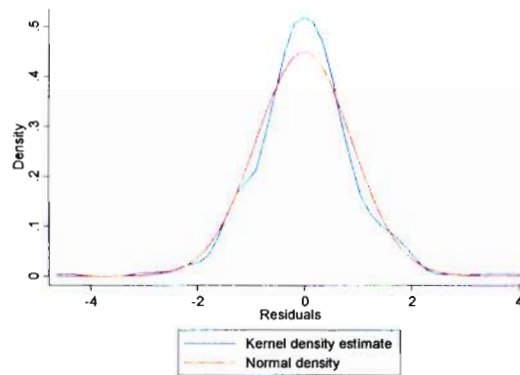
**Figure 17. Regression Model 1: PM<sub>10</sub> and SO<sub>2</sub>**

**Figure 17 (a) & (b) displays density graphs of residuals with a normal distribution superimposed on the graph. Figure 17 (c) & (d) produces a plot of the residual versus a specified predictor, used after regress or anova.**

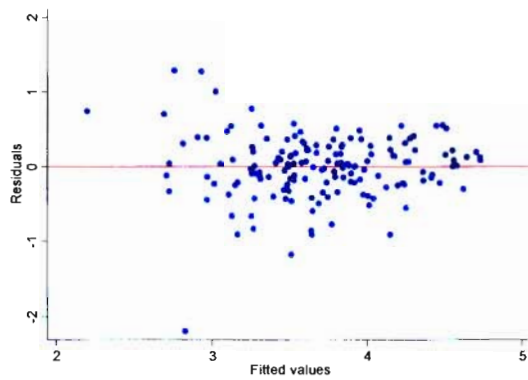
**Model 2: (a) PM<sub>10</sub>**



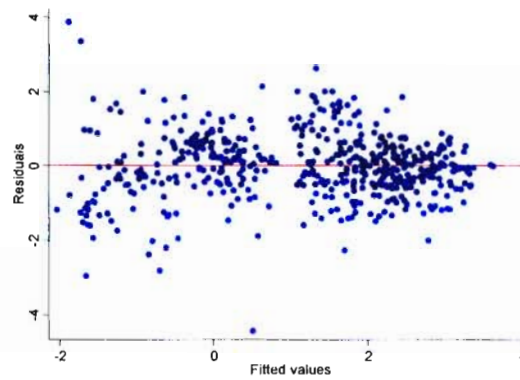
**Model 2: (b) SO<sub>2</sub>**



**Model 2: (c) PM<sub>10</sub>**



**Model 2: (d) SO<sub>2</sub>**



**Figure 18. Regression Model 2: PM<sub>10</sub> and SO<sub>2</sub>**

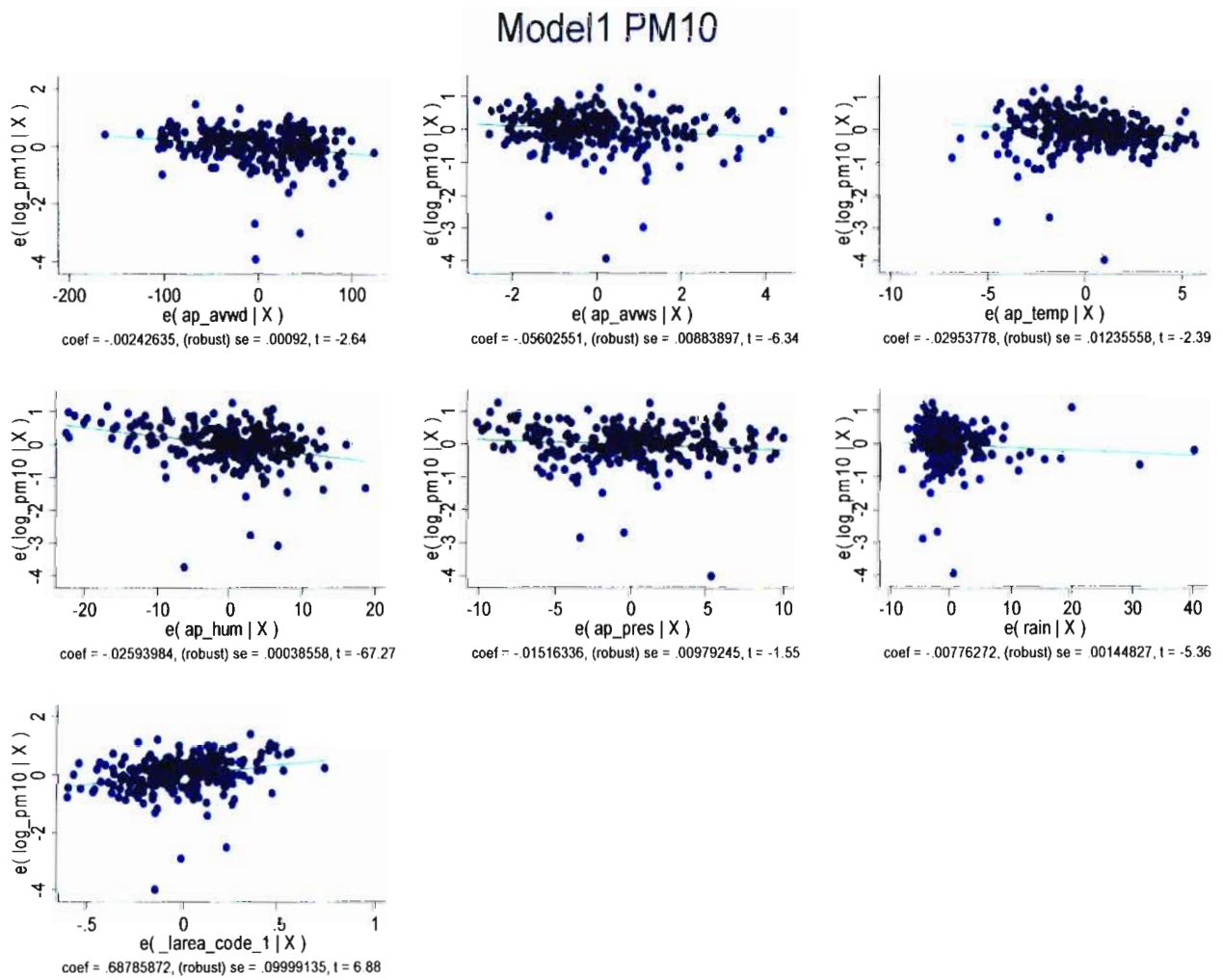
Figure 18 (a) & (b) displays density graphs of residuals with a normal distribution superimposed on the graph. Figure 18 (c) & (d) produces a plot of the residual versus a specified predictor, used after regress or anova.

Explanatory variables in Model 1 (Table 18), PM<sub>10</sub> returned an  $R^2 = 0.27$ , all meteorological parameters had a decreasing influence on PM<sub>10</sub> concentrations with humidity being significant ( $p < 0.05$ ), while the southern region, compared to the northern region had increased PM<sub>10</sub> levels (Figure 19). Explanatory variables in Model 1 (Table 18), SO<sub>2</sub> returned an  $R^2 = 0.66$ , with all meteorological parameters having a decreasing influence on SO<sub>2</sub> concentrations, except wind direction and regional location, the southern region having increased SO<sub>2</sub> levels. The significant explanatory variables in this model was humidity and region (south) ( $p < 0.05$ ) (Figure 20).

**Table 18: Regression Model 1: Excluding previous days pollution**

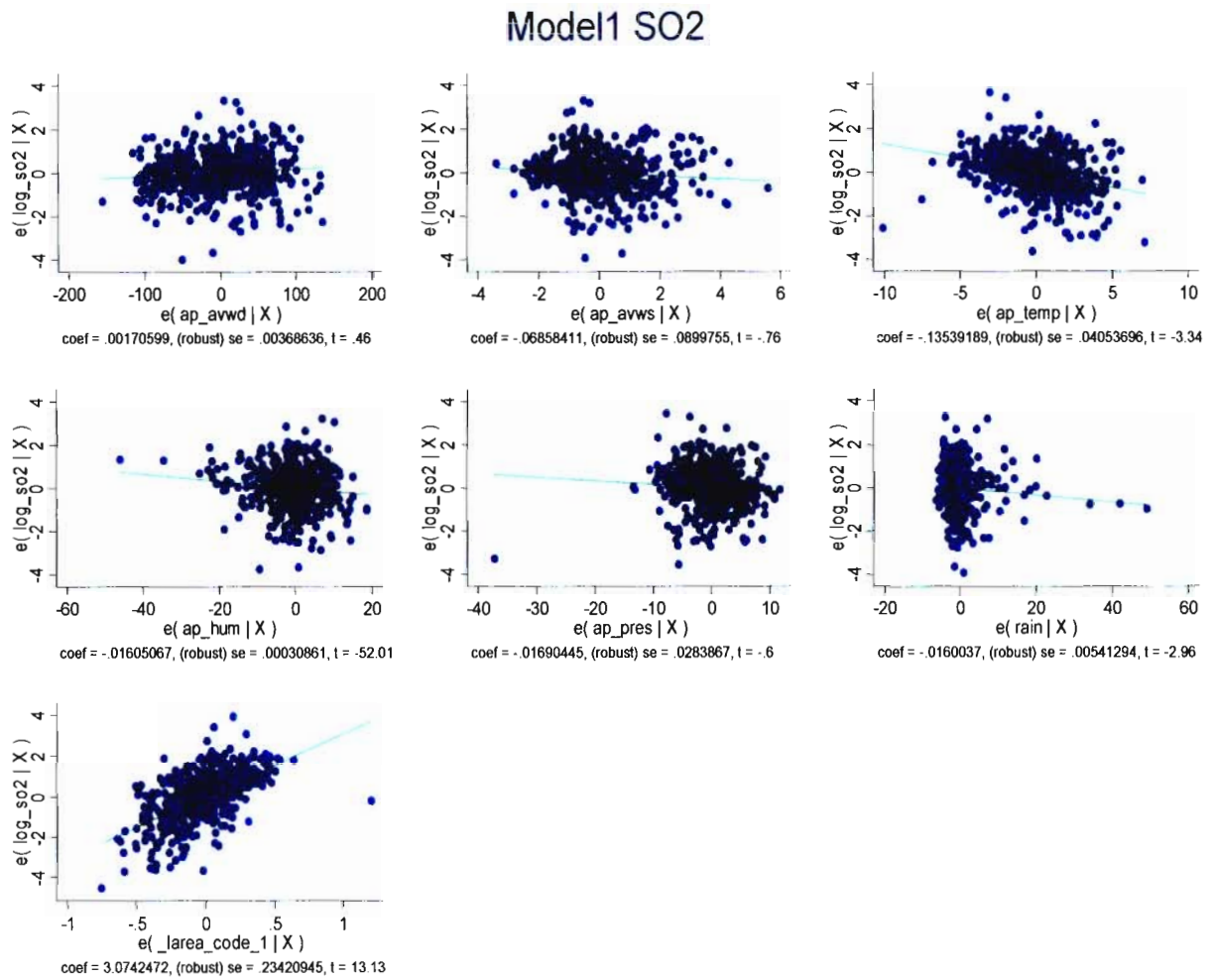
Dependent	Independent	Coefficients	SE	P	95% CI	
PM <sub>10</sub>	Wind Direction (°N)	-0.24	0.00	0.23	-1.41	0.93
	Wind Speed (m/s)	-5.60	0.01	0.10	-16.83	5.63
	Temperature (0C)	-2.95	0.01	0.25	-18.65	12.75
	Humidity (%)	-2.59	0.00	0.01	-3.08	-2.10
	Pressure (hPa)	-1.52	0.01	0.37	-13.96	10.93
	Rain (mm)	-0.78	0.00	0.12	-2.62	1.06
	Region Code (N-S)	68.79	0.10	0.09	-58.27	195.84
	Constant	2177.67	10.04	0.28	-10580.47	14935.81
SO <sub>2</sub>	Wind Direction (°N)	0.17	0.00	0.72	-45.13	4.85
	Wind Speed (m/s)	-6.86	0.09	0.59	-1211.83	107.47
	Temperature (0C)	-13.54	0.04	0.19	-650.46	37.97
	Humidity (%)	-1.61	0.00	0.01	-19.97	-1.21
	Pressure (hPa)	-1.69	0.03	0.66	-377.59	34.38
	Rain (mm)	-1.60	0.01	0.21	-84.78	5.28
	Region Code (N-S)	307.42	0.23	0.05	98.33	605.02
	Constant	2040.88	27.30	0.59	-326509.10	36732.68

PM<sub>10</sub>, log normalised PM<sub>10</sub> (ug/m<sup>3</sup>); SO<sub>2</sub>, log normalised SO<sub>2</sub> (ppb); SE, standard error; P, significance level (0.05%); CI, confidence interval. Coefficients & CI calculated from back transformation (antilog) of the log normalised dependent variables.



**Figure 19: Model 1: PM<sub>10</sub> Regression Analysis - Excluding Previous Days Pollution**

- $e(\log_{pm10} | X)$  = log of PM<sub>10</sub>
- $e(ap\_avwd | X)$  = Average wind direction
- $e(ap\_avws | X)$  = Average wind speed
- $e(ap\_temp | X)$  = Average temperature
- $e(ap\_hum | X)$  = Average humidity
- $e(ap\_pres | X)$  = Average barometric pressure
- $e(ap\_rain | X)$  = Average rainfall
- $e(\_larea\_code\_1 | X)$  = code for region, north =0 to south =1



**Figure 20: Model 1: SO<sub>2</sub> Regression Analysis - Excluding Previous Days Pollution**

- $e(\log\_so2 | X)$  = log of SO<sub>2</sub>
- $e(ap\_avwd | X)$  = Average wind direction
- $e(ap\_avws | X)$  = Average wind speed
- $e(ap\_temp | X)$  = Average temperature
- $e(ap\_hum | X)$  = Average humidity
- $e(ap\_pres | X)$  = Average barometric pressure
- $e(ap\_rain | X)$  = Average rainfall
- $e(larea\_code\_1 | X)$  = code for region, north =0 to south =1

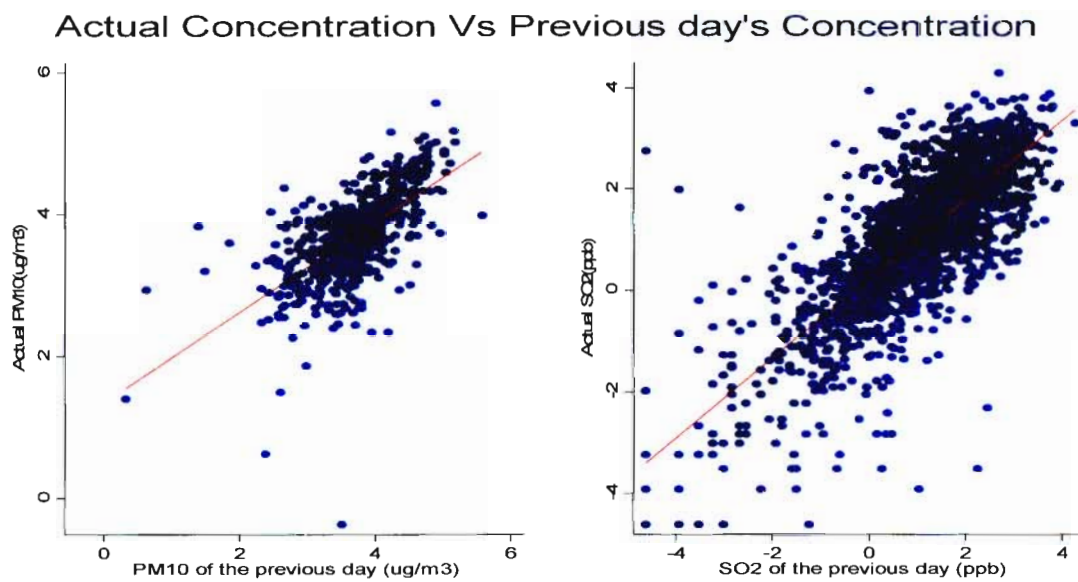
Explanatory variables in Model 2 (Table 19), PM<sub>10</sub> returned an R<sup>2</sup> = 0.57, with all meteorological parameters having a decreasing influence on PM<sub>10</sub> concentrations, while the previous day's pollution (Lag1 of PM<sub>10</sub>), pressure and regional location in the south, increased PM<sub>10</sub> levels. The inclusion of the previous day's PM<sub>10</sub> pollutions increased the explanation of the variability in the model predicting PM<sub>10</sub> levels by approximately 30% (Figure 22). Explanatory variables in Model 2 (Table 19), SO<sub>2</sub> returned an R<sup>2</sup> = 0.71, with all meteorological parameters having a decreasing influence on SO<sub>2</sub> concentrations, except the previous day's pollution (Lag1 of SO<sub>2</sub>), wind direction and regional location in the south, increased SO<sub>2</sub> levels. The inclusion of the previous days SO<sub>2</sub> pollution was able to improve on the previous model by approximately 5% (Figure 23).

**Table 19: Regression Model 2: Including previous days pollution**

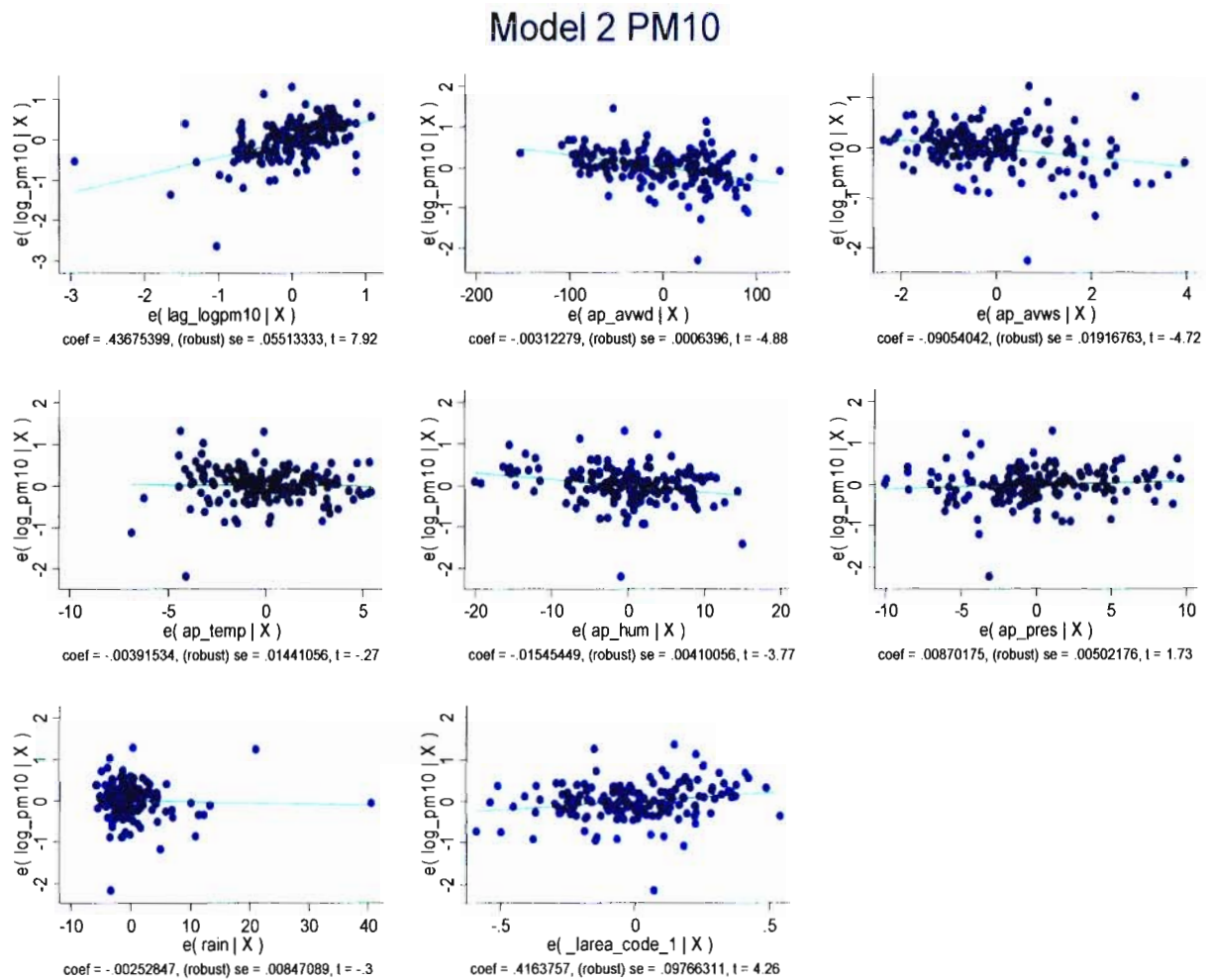
Dependent	Independent	Coefficients	SE	P	95% CI	
PM <sub>10</sub>	Lag1 of PM <sub>10</sub>	1.55	0.00	0.24	0.77	3.12
	Wind Direction (°N)	-0.31	0.00	0.13	-1.12	0.50
	Wind Speed (m/s)	-9.05	0.02	0.19	-33.41	15.30
	Temperature (0C)	-0.39	0.02	0.68	-18.70	17.92
	Humidity (%)	-1.55	0.01	0.24	-6.76	3.66
	Pressure (hPa)	0.87	0.01	0.29	-5.51	7.25
	Rain (mm)	-0.25	0.01	0.80	-11.02	10.51
	Region Code (N-S)	41.64	0.21	0.40	-82.46	165.73
	Constant	-498.33	8.89	0.40	-7898.53	6901.87
SO <sub>2</sub>	Lag1 of SO <sub>2</sub>	1.44	0.01	0.51	0.10	20.86
	Wind Direction (°N)	0.14	0.00	0.78	-4.21	4.50
	Wind Speed (m/s)	-2.70	0.07	0.58	-71.86	66.45
	Temperature (0C)	-8.54	0.05	0.21	-23.59	6.50
	Humidity (%)	-0.92	0.00	0.02	-4.22	2.38
	Pressure (hPa)	-1.43	0.03	0.63	-43.02	40.15
	Rain (mm)	-1.72	0.01	0.22	-8.74	5.31
	Region Code (N-S)	197.06	0.15	0.03	-543.62	937.75
	Constant	1643.35	25.60	0.56	-40124.18	43410.87

PM<sub>10</sub>, log normalised PM<sub>10</sub> (ug/m<sup>3</sup>); SO<sub>2</sub>, log normalised SO<sub>2</sub> (ppb); Lag1 of PM<sub>10</sub>, the previous days pollution of log normalised PM<sub>10</sub> (ug/m<sup>3</sup>); Lag1 of SO<sub>2</sub>, the previous days pollution of log normalised SO<sub>2</sub> (ppb); SE, standard error; P, significance level (0.05%); CI, confidence interval. Coefficients & CI calculated from back transformation (antilog) of the log normalised dependent variables.

The inclusion of the previous day's pollutions for SO<sub>2</sub> and PM<sub>10</sub> drastically improves the R<sup>2</sup> of the regression model; Model 2 (Table 19). Pearson's correlation of the actual SO<sub>2</sub> concentrations versus SO<sub>2</sub> concentration from the previous day returned a correlation coefficient (r) = 0.63, p < 0.00, with 611 observations. Pearson's correlation of the actual PM<sub>10</sub> concentrations versus PM<sub>10</sub> concentration from the previous day returned a correlation coefficient (r) = 0.78, p < 0.00, with 1973 observations (Figure 21).



**Figure 21: Actual PM<sub>10</sub> & SO<sub>2</sub> versus Previous Days PM<sub>10</sub> & SO<sub>2</sub>**

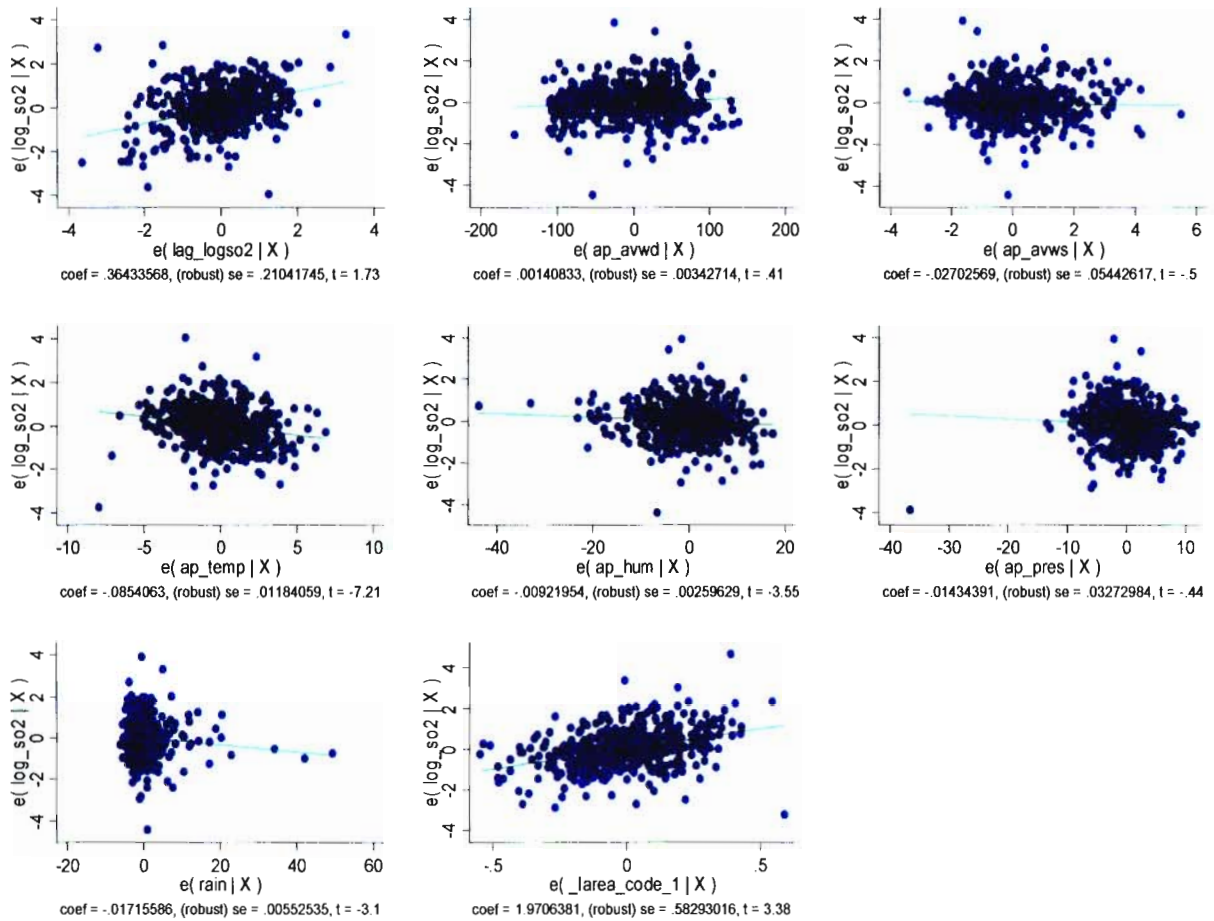


**Figure 22: Model 2: PM<sub>10</sub> Regression Analysis - Including Previous Days Pollution**

- $e(\log\_pm10 | X)$  = log of PM<sub>10</sub>
- $e(\log\_logpm10 | X)$  = log of the previous days PM<sub>10</sub>
- $e(ap\_avwd | X)$  = Average wind direction
- $e(ap\_avws | X)$  = Average wind speed
- $e(ap\_temp | X)$  = Average temperature
- $e(ap\_hum | X)$  = Average humidity
- $e(ap\_pres | X)$  = Average barometric pressure
- $e(ap\_rain | X)$  = Average rainfall
- $e(\_larea\_code\_1 | X)$  = code for region, north =0 to south =1



## Model 2 SO2



**Figure 23: Model 2: SO<sub>2</sub> Regression Analysis - Including Previous Days Pollution**

$e(\log\_so2 | X)$  = log of SO<sub>2</sub>

$e(\log\_logso2 | X)$  = log of the previous days SO<sub>2</sub>

$e(ap\_avwd | X)$  = Average wind direction

$e(ap\_avws | X)$  = Average wind speed

$e(ap\_temp | X)$  = Average temperature

$e(ap\_hum | X)$  = Average humidity

$e(ap\_pres | X)$  = Average barometric pressure

$e(ap\_rain | X)$  = Average rainfall

$e(\_larea\_code\_1 | X)$  = code for region, north =0 to south =1

#### 4.1.4 AIR POLLUTION EXCEEDANCES FOR SO<sub>2</sub> AND PM<sub>10</sub> STANDARDS

10 minute, 24 hour and annual standards for SO<sub>2</sub> and PM<sub>10</sub> (where applicable) was examined for exceedances in accordance to South Africa legislation, No.39 of 2004: National Environmental Management: Air Quality Act, 2004. SO<sub>2</sub> has a regulated instant 10 minute peak of 191 ppb, a 24 hour average of 48 ppb and annual average of 19 ppb. PM<sub>10</sub> has a regulated 24 hour average of 180 µg/m<sup>3</sup> and an annual average of 60 µg/m<sup>3</sup>.

10 minute SO<sub>2</sub> exceedances were recorded only in the south sites, specifically at Assegai (191 – 259 ppb), Nizam (192 – 233.4 ppb) and Lamontville (192.7 – 208 ppb) totalled 19, 16 and 4 respectively. A total of 4 24-hour SO<sub>2</sub> exceedances were measured, all among the south located sites: Assegai had two exceedances of 25.37 ppb and 4.41 ppb above the regulatory standard. PM<sub>10</sub> had a total of 4 exceedances and three near exceedances with concentrations of 179.4 µg/m<sup>3</sup> at Nizam, 178.7 µg/m<sup>3</sup> at Ferndale and 179.2 µg/m<sup>3</sup> at Ngazana. Ngazana in the north had 3 exceedances at 1.2 µg/m<sup>3</sup>, 86.6 µg/m<sup>3</sup> and 57.2 µg/m<sup>3</sup> above the regulatory standard, while Assegai in the south had one exceedance of 28 µg/m<sup>3</sup> above the regulatory standard. Ngazana and Assegai are just within the regulated annual average standard for PM<sub>10</sub> by 1 µg/m<sup>3</sup> and 2 µg/m<sup>3</sup> respectively.

Table 20: 10 minutes SO<sub>2</sub> exceedances during the study period.

SO <sub>2</sub> (10 min average exceedances)	Assegai		Nizam		Lamont	
	Number of exceedances	ppb	Number of exceedances	ppb	Number of exceedances	ppb
May-04	9	199.9 - 232	2	197 - 213.2	0	
Jun-04	1	259	0		0	
Jul-04	0		0		0	
Aug-04	1	191	2	204.3 - 232.7	0	
Sep-04	0		6	192.4 - 224.6	0	
Oct-04	8	192 - 237	0		4	192.7 - 208
Nov-04	0		2	201 - 231.7	0	
Dec-04	0		0		0	
Jan-05	0		1	223.1		
Feb-05	0		0			
Mar-05	0		3	192 - 233.4		
Apr-05	0		0			
<b>Total</b>	<b>19</b>		<b>16</b>		<b>4</b>	

Table 21: 24 hour SO<sub>2</sub> and PM<sub>10</sub> exceedances during the study period

SO <sub>2</sub> Exceedances		PM <sub>10</sub> Exceedances	
Sites	Concentration (ppb)	Sites	Concentration (µg/m <sup>3</sup> )
Assegai	73.37	Assegai	208
	52.41	Nizam	179.4**
Dirkie Uys	49.01	Ferndale	178.7**
Nizam	48.58	Ngazana	179.2**
			266.6
			181.2
			237.2
<b>Total</b>	<b>4</b>		<b>4</b>

\*\* indicates sites with PM<sub>10</sub> concentrations which are just within the 24-hour National Environmental Management: Air Quality Act standard of 180 µg/m<sup>3</sup>. These concentrations are not exceedances of the regulated standards.

**Table 22: Annual SO<sub>2</sub> and PM<sub>10</sub> - May 2004 to May 2005**

<b>Annual Avg Exceedances</b>	<b>Assegai</b>	<b>Dirkie Uys</b>	<b>Nizam</b>	<b>Lamont</b>	<b>Briardale</b>	<b>Ferndale</b>	<b>Ngazana</b>
<b>SO<sub>2</sub></b>	12.29	7.66	7.89	6.17	1.43	2.59	1.29
<b>PM<sub>10</sub></b>	57.85	45.64	50.14	51.64	40.88	45.29	59.01

## CHAPTER 5

### 5.1 DISCUSSION

This study provides evidence of the spatial and temporal variations in two criteria pollutants in the greater Durban metropolitan area. The two pollutants under study, SO<sub>2</sub> and PM<sub>10</sub> differ in their distribution between the northern and southern communities, as well as in time. In addition, the distribution patterns between the pollutants also vary – i.e. there seems to be no evidence of the close tracking of one pollutant with the other.

This study, in assessing the factors likely to predict pollutant levels, provides an opportunity to understand this variation.

#### 5.1.1 SO<sub>2</sub> Spatial and Temporal Pollution Patterns

SO<sub>2</sub> concentrations among the south Durban sites are on average approximately 2 to 3 times higher than SO<sub>2</sub> concentrations measured among the north Durban sites (mean SO<sub>2</sub> concentration in the south = 8.7 ppb vs mean SO<sub>2</sub> concentration in the North = 1.9 ppb). This is an expected finding given the preponderance of heavy industry in the south of the city. Differences in SO<sub>2</sub> concentrations were also noted between sites in the south and north respectively (Table 6). These descriptive findings suggest several factors could be influencing pollutant concentrations, including those that were intensively studied in this project, such as the meteorological factors.

Diurnal SO<sub>2</sub> patterns (Figure 2) are more visible for the south Durban sites and is largely owing to the higher concentrations from the numerous generation sources.

SO<sub>2</sub> diurnal variation showed basically two maxima, levels begin to rise from 5:00AM and peak around 10:00AM with the cycle being repeated in the latter part of the day: levels rising from 20:00PM and peaking at 24:00PM. SO<sub>2</sub> diurnal patterns for Assegai and Lamontville in the south which are similar to those reported by Diab.R et.al (2002), among Wentworth and AECl respectively, also located in the South Durban industrial basin. Although this study did not attempt to characterise the reasons, these diurnal changes in pollutant levels could be attributed to industrial activities, peak traffic periods and meteorological changes, during the very early morning and late hours of night which result in atmospheric conditions that are slightly colder and more stable (in the presence of low or no wind) resulting in very little too no air mixing as a result of low wind speeds. These stable conditions (in the presence of low or no wind) with reduced air mixing and temperature inversions contribute to the accumulation of gaseous pollutants such as SO<sub>2</sub>. As the ambient temperature rises during the course of the day, unstable atmospheric conditions (in the presence of increasing wind speeds) results in the dissipation of the inversion layer. The increase in air mixing, dilutes and releases the trapped air pollutants. These conditions would result in the lowering of pollutant concentrations [13].

Assegai in south Durban displays a trend that is slightly contrary to a typical diurnal cycle (Figure 2). Unlike the diurnal changes at the other sites, Assegai maintains a steady SO<sub>2</sub> concentration throughout most of the day. This observation is possibly as a result of the much higher SO<sub>2</sub> pollutant level at Assegai compared to any of the remaining sites (Table 6). The positive correlation coefficient of 0.5 for SO<sub>2</sub> and wind direction (identified from between the south-west to east) which transports SO<sub>2</sub> from the direction of the refineries and pulp-paper manufacturer to Assegai could represent another reason for this phenomenon (Table 16). Although these findings suggest that the refineries between a south-west to easterly direction is the potential source of higher levels of pollution aided by the wind blowing from that direction a detailed source apportionment study is necessary to verify this assumption.

In a previous study conducted in the SDIB, Diab. R et.al (2002), measured SO<sub>2</sub> concentrations at the nearby Wentworth site, approximately 150 meters from the current Assegai site. This study reported findings for Wentworth that are similar to Assegai when comparing diurnal trends, both sites had corresponding SO<sub>2</sub> peaks at 8h00 and 22h00, however Wentworth had a substantially higher averaged SO<sub>2</sub> concentration for the years 1997 to 1999, ranging from 20 to 33ppb, compared to Assegai for May 2004 to October 2005, ranging from 0.5 to 12ppb [10].

Although SO<sub>2</sub> seasonal patterns (Figure 3) are not remarkable, slightly higher concentrations are observed during the colder months. This results in a downward trend in concentrations over time during the one year study period, which may be due either to decreasing SO<sub>2</sub> concentrations in the south Durban industrial basin over a period of time – possibly due to better pollution control [34], or as result of seasonal variation. The latter is a likely explanation, given that the monitoring commenced during the winter months, and continued to the end of the summer months the following year, so this trend is likely a winter seasonal high to a summer seasonal low. Not having a full seasonal cycle monitored, a true reflection of seasonal variation across all sites is not possible. However, findings of associations of short term pollutant changes with varying temperature seem to support this assertion. The lower concentrations of SO<sub>2</sub> during the warmer periods could also be as a result of SO<sub>2</sub> being chemically transformed in the presence of sunlight and water vapour [10, 17, 18].

The inter-site correlations (Table 11 and Figure 8) observed in the data suggest that a “site-distance” relationship exists, particularly of sites within the two geographic regions (i.e. north and south) respectively e.g. between Assegai and Dirkie Uys (<1km apart) and Lamontville and Nizam (~2.5km apart) (Figure 24). The inconsistencies of inter-site correlation, particularly between sites in the north compared to sites in the south can be explained by the presence of site-specific sources of pollutant at a particular site.

### **5.1.2 PM<sub>10</sub> Spatial and Temporal Pollution Patterns**

PM<sub>10</sub> concentrations do not differ much in concentration between the south Durban and north Durban sites with all sites having very similar 24 hour averaged PM<sub>10</sub> concentrations. These results display PM<sub>10</sub> as more of a regional phenomenon with various point sources other than just industrial or vehicular emitters. The north located site Ngazana, had the highest mean PM<sub>10</sub> concentrations and the highest recorded PM<sub>10</sub> concentrations over the Study period (Table 7). Besides industrial or vehicular emitters other possible sources for the high PM<sub>10</sub> concentrations identified in the north are large open fields, regular field fires, sugar cane fires and domestic burning of garden and other refuse, plus major earthworks and construction. Since there are no known records of SO<sub>2</sub> or PM<sub>10</sub> monitoring being undertaken in or around the northern study sites prior to this study, these findings could be regarded as a baseline for future comparison.

The seasonal pattern of PM<sub>10</sub> concentrations from monthly means display very similar variations for all sites (Figure 4). Pollutant levels are the highest in the colder months of May, June, July 2004/05. These are expected results which are primarily effects of meteorology when more frequent inversions occur during the colder months and are known to result in atmospheric conditions that promote higher pollutant concentrations [7, 10, 13, 17, 18, 37, 24].

### **5.1.3 Meteorological Influences on Pollution Patterns**

Meteorological conditions differ between south and north Durban, with the south having slightly higher wind speed, temperature and pressure and lower humidity. Durban, between “summer” and “winter” on average has approximately a 7 °C difference in temperature (Figure 6) and approximately 10-15% difference in humidity (Figure 6). The Durban temperature and humidity patterns seen in the study are closely tracked with the increase in pollutant levels SO<sub>2</sub> and PM<sub>10</sub> during “winter” explaining the effects of winter inversions on pollutant levels (Figure 6 and Figure 7). The variability of meteorological parameters between south and north Durban is interesting. These two regions are 35 km apart, which according to spatial scale classification of the US EPA is categorised as being of an Urban Scale (range 4 km to 50 km) (Figure 24), EPA, CFR, Appendix D of part 58, title 40 [35].



This Scale, is useful in the classification of a geographical area to identify the spatial scale the southern and northern sites maybe categorised as. If one considers a 50 km radius, all the southern and northern sites are within the same urban scale. Considering meteorological parameters within this scale implies that even sites in close proximity of each other may be subjected to localised meteorological conditions due to geographical and topographical differences which would result in varying pollutant concentrations at an inter- or intra-site level, as was found in this study. This suggests that the measurement of meteorological data together with pollution data is necessary rather than generalising meteorological conditions to surrounding sites where the true interaction of meteorological parameters with pollutants can be either underestimated or overestimated.

Unlike SO<sub>2</sub>, there is no “site-distance” effect noticeable with the particulate matter. The correlation between south and north sites for PM<sub>10</sub> e.g. Assegai, Dirkie Uys, Nizam, Lamontville (south sites) versus Briardale, Ferndale and Ngazana (north sites), (Table 13), supports the finding of PM<sub>10</sub> having a strong regional distribution. This wide geographic distribution / correlation of particulate matter (PM<sub>10</sub>) has also been replicated in previous studies [17, 18]. PM<sub>10</sub> and smaller size fractions have the ability to be re-suspended and remain in the atmosphere for relatively long periods a day. For PM<sub>10</sub> the previous days pollution contributes to a significant portion of today's PM<sub>10</sub> levels (Table 19), while SO<sub>2</sub> is particularly higher if favourable wind direction are from the vicinity of closer generation sources. In the case of SO<sub>2</sub> communities in closer proximity are at most risk, while PM is capable of negative health implication distances away. Air pollution control strategies therefore need to be proactive in implementing processes that limit pollutant production, while control measures target reduction at sources should be complimentary.

In this study the multiple linear regression analysis returned the following equations (a) and (b):

$$(a). \text{SO}_2 = 1643.35 + 1.44[\text{previous day's SO}_2] + 0.14[\text{wind direction}] - 2.70[\text{wind speed}] - 8.54[\text{temperature}] - 0.92[\text{humidity}] - 1.43[\text{pressure}] - 1.72[\text{rain}] + 197.06[\text{region-south}]$$

$$(b). \text{PM}_{10} = -498.33 + 1.55[\text{previous day's PM}_{10}] - 0.31[\text{wind direction}] - 9.05[\text{wind speed}] - 0.39[\text{temperature}] - 1.55[\text{humidity}] + 0.87[\text{pressure}] - 0.25[\text{rain}] + 41.64[\text{region-south}]$$

Turalioglu, et.al, (2005) using multiple linear regression analysis reported similar findings for SO<sub>2</sub> (equations c), where a one unit increase in temperature and wind speed would decrease SO<sub>2</sub> concentrations and a unit increase in the previous days's SO<sub>2</sub> would increase SO<sub>2</sub> concentrations;

$$(c). \text{SO}_2 = -1392.95 + 0.416[\text{previous day's SO}_2] - 3.143[\text{temperature}] + 1.778[\text{pressure}] - 2.527[\text{wind speed}] + 1.099[\text{precipitation}]$$

$$(d). \text{TSP} = -2091.25 + 0.045[\text{previous day's TSP}] - 4.514[\text{temperature}] + 2.630[\text{pressure}] - 6.882[\text{wind speed}] + 29.774[\text{relative humidity}]$$

Unlike Turalioglu, et.al, (2005), this study considered the influence of wind direction and found that for a one unit change in wind direction from 0 degrees north, SO<sub>2</sub> would increase by 0.14ppb while PM<sub>10</sub> would decrease by -0.32ug/m<sup>3</sup>. Also in this study a one unit increase in humidity (%) resulted in a 0.92ppb decrease in SO<sub>2</sub> and 1.55ug/m<sup>3</sup> decrease in PM<sub>10</sub> concentrations, compared to Turalioglu, et.al, (2005), where for SO<sub>2</sub> (equation c) relative humidity was not considered and for TSP (equation d) a one unit increase in humidity resulted in a large increase in TSP by approximately 29.77ug/m<sup>3</sup>.

The strength of the moderate correlation (between 0.3-0.5) between PM<sub>10</sub> and SO<sub>2</sub> found in this study (Table 14, Figure 10) could be as a result of the chemical properties of the pollutants: SO<sub>2</sub> a gas is prone to being transformed to H<sub>2</sub>SO<sub>4</sub> in the presence of sunlight and water vapour, while PM<sub>10</sub> a complex aerosol may settle out much quicker from the atmosphere decreasing it's concentration. Meteorological conditions impact differently on each pollutant e.g. rain is more likely to decrease PM<sub>10</sub> concentrations than it would SO<sub>2</sub> (Table 16 and Table 17). The lifetime of different sized TSP in the atmosphere is more unstable than gaseous compounds because of prevailing meteorological factors. While fine particles in TSP (<1 μm) remain in the atmosphere for days, coarse particles (~10 μm) remain for a few hours, and coarser particles settle quicker. This may provide an alternate explanation for the only moderate correlation between the pollutants [37].

These findings imply that future air pollution control strategies being developed will target exposure control of smaller sized particulate fractions, mainly due to their ability to be suspended for longer periods in the atmosphere and their having more pronounced respiratory health implications for susceptible populations being exposed. Since smaller sized particulate matter, PM<sub>2.5</sub> and smaller are products of combustion processes along with various gaseous pollutants e.g. CO, CO<sub>2</sub> and SO<sub>2</sub> etc. the emergence of dual pollution control devices for particulate and gaseous pollutants will be forthcoming.

Meteorological factors seemingly have a greater impact on particulate matter than on gaseous pollutants. Temperature, humidity and rainfall (Table 16 and Table 17), result in a drop in ambient PM<sub>10</sub> concentration while SO<sub>2</sub> is only impacted similarly upon by temperature. PM<sub>10</sub> concentrations are more likely to be reduced in the atmosphere as a result of elevated temperature and humidity following the passing of a weather front (rain) through Durban.

In general, relationships between pollutants and meteorological parameters differ on a site-by-site basis. For instance, wind direction at Assegai increases SO<sub>2</sub> levels whereas wind direction at Ngazana decreases SO<sub>2</sub> levels (Table 16). Another independent variable that proved to be a good and important predictor for SO<sub>2</sub> and PM<sub>10</sub> across most sites was the previous day's pollution events, this was a much stronger predictor for PM<sub>10</sub> rather than SO<sub>2</sub>. These findings suggest that pollutants are not fully removed from the atmosphere (more so for PM<sub>10</sub> than SO<sub>2</sub>) during a 24 hour period and that the previous day's pollution levels will contribute to current levels, a finding that has important implication when implementing early warning pollution systems as envisaged for the Durban South.

Previous researchers have found similar results [7, 8]. Turalioglu, et.al, 2005, reported for TSP negative correlations for temperature (-0.8), wind speed (-0.6), precipitation (-0.07) and positive correlation for pressure (0.5), relative humidity (0.13); and for SO<sub>2</sub> negative correlations for temperature (-0.7), wind speed (-0.5), precipitation (-0.13) and positive correlation for pressure (0.5), relative humidity (0.02).

In this study PM<sub>10</sub> displayed similar negative correlations at all sites for temperature (-0.25 to -0.53), wind speed (-0.09 to -0.26), precipitation (-0.36 to -0.53) and relative humidity (-0.38 to -0.56) and a positive correlation for pressure (0.12 to 0.27). SO<sub>2</sub> displayed a negative correlation at all sites for temperature (-0.27 to -0.53), wind speed (-0.06 to -0.38), precipitation (-0.07 to -0.37) and relative humidity (-0.16 to -0.43) and positive correlation for pressure (0.07 to 0.52). Relative humidity in this study displayed a negative correlation with PM<sub>10</sub> and SO<sub>2</sub> at all sites which is contrary to the findings of Turalioglu, et.al, (2005), who found a positive correlation although both studies report similar average humidity levels of 78 and 75% respectively. Turalioglu, et.al, (2005) also displayed much stronger correlations for all of the above mentioned meteorological parameters e.g. temperature which was not as strongly correlated in this study. In the presence of meteorological conditions that are favourable for increasing pollution levels prevail for extended durations poor air quality would result.

#### **5.1.4 Limitations**

The pollutant data for SO<sub>2</sub> and PM<sub>10</sub> analysed in this study was taken from an epidemiological designed study the SDHS, for which the monitoring protocol served that purpose, as seen with the frequency of PM<sub>10</sub> monitoring over “intensive phases” and on a 6<sup>th</sup> day cycle and the span of SO<sub>2</sub> monitoring. SO<sub>2</sub> monitoring did not span a complete year and analyser failure and drift problems resulted in missing data and data censoring which could have resulted in the under estimation of reported SO<sub>2</sub> concentrations for southern and northern Durban. However, detailed analyses of the data, characterisation of the missing, unusual and outlier datapoints, allowed for the establishment of a dataset that followed methods well documented by other researchers. On this basis, one can be confident that the dataset is valid and representative of the exposures of the areas under study.

Sites that did not have their own meteorological monitoring stations and had to relay on meteorological data from SA Weather Services and analysis of meteorological data showed there were significant difference between these parameters measured within a 50km radius.

These variations not measured at individual sites was assumed to be representative of sites in the south and north which could have resulted in over or underestimation of SO<sub>2</sub> and PM<sub>10</sub> relationships with meteorological parameters. Bias introduced by this lack of meteorological data is likely to have affected all sites within a particular geographic region equally, and thus any effect is likely to have biased the data toward the null – thus resulting in a smaller effect than is truly prevalent.

## 5.2 CONCLUSION

Based on the findings of two key ambient pollutants SO<sub>2</sub> and PM<sub>10</sub> concentrations among selected communities in the greater Durban area, the southern communities experience generally higher pollution levels, especially with SO<sub>2</sub>, a pollutant with known adverse health effects on the respiratory health of exposed and susceptible persons. The distribution of particulate matter, PM<sub>10</sub> across the city tends to follow a more even distribution than SO<sub>2</sub>.

Meteorology has a pattern of having a larger impact on air pollution, with higher concentrations of pollutants during winter months (with frequent inversions) than during summer months (effects due to the absence of vertical mixing). Seasonal variation / cycles in air pollutants are more pronounced for PM<sub>10</sub> than for SO<sub>2</sub>, where PM<sub>10</sub> has a better accumulative effect on today's concentrations as compared to SO<sub>2</sub>, as seen in the Model 2 regression analysis.

The findings of this study indicate that temperature, humidity and rain to a certain degree are very important meteorological parameters and are the most influential on the daily concentration of SO<sub>2</sub> and PM<sub>10</sub> across Durban. The contribution of the previous day's PM<sub>10</sub> pollution to the next days pollution is a significant finding considering that PM<sub>10</sub> a coarse particle compared to PM<sub>2.5</sub> is capable of remaining airborne for longer than expected periods. This is important when considering exposure to, and health implications of PM<sub>10</sub> and PM<sub>2.5</sub> (also including gaseous pollutants) where exposure lags warrant investigation.

In the event that an early warning system for air quality be implemented in south Durban, analysis of the pollution sources and meteorological conditions associated with high concentrations of SO<sub>2</sub> and PM<sub>10</sub> (including PM<sub>2.5</sub> and possibly other pollutants) should be undertaken to aid forecasting, dispersion modelling and source apportionment. In light of meteorological conditions this data could be used to compile air quality indices to be broadcast on a daily basis for specific pollutants. Source apportionment studies using both source and receptor modelling would be helpful to identify sources of pollutants thereby directing and targeting the air quality management programme to focus on the major contributors.

Further emission reduction from new and old sources is necessary in light of the not infrequent SO<sub>2</sub> exceedances that have occurred during May 2004 to March 2005. In order to attain ambient air standards stipulated in NEMA, a reduction strategy and timeframe for SO<sub>2</sub> should be developed and implemented. Source apportionment studies could also be used to identify culprit sources for legal action.

The key findings of this study highlight the importance for considering the influences meteorological parameters (wind direction and speed, rain, humidity, pressure and temperature) exert on SO<sub>2</sub> and PM<sub>10</sub> concentrations, therefore the current NEMA air pollution standards account for the influence from temperature and atmospheric pressure on SO<sub>2</sub> but not PM<sub>10</sub> (refer Appendix 2). It's imperative that future developments in air pollution standards take into consideration the impact of specific meteorological parameters on individual pollutants and also the establishment of more stringent winter air pollution standards particularly in industrial impacted regions. These findings also hold true for those who undertake air pollution monitoring, to account for the influence from meteorological factors and also the contribution of the previous days pollution on the current days pollution levels. Also when considering site location and predominate wind direction and wind speed, industries identified as having the most significant impact on receptor populations must consider switching over to the use of cleaner fuels such as liquid petroleum gas.

## REFERENCES

1. Air Trends - Particulate Matter [homepage on the Internet]. United States Environmental Protection Agency. [updated 2006 June 11; cited 2006 July 8]. Available from: <http://www.epa.gov/airtrends/pm.html>
2. Air Trends - Sulphur Dioxide [homepage on the Internet]. United States Environmental Protection Agency. [updated 2006 June 11; cited 2006 July 8]. Available from: <http://www.epa.gov/air/airtrends/sulfur.html>
3. Aylin P, Bottle A, Wakefield J, Jarup L, Elliott P. Proximity to coke works and hospital admissions for respiratory and cardiovascular disease in England and Wales. *Thorax*. 2001; 56:228-233.
4. Bernstein JA. Health effects of air pollution. *Journal of Allergy and Clinical Immunology*. 2004; 114:1116-1123.
5. Bhopal RS, Moffatt S, Pless-Mullooli T, Phillimore PR, Foy C, Dunn CE, Tate JA. Does living near a constellation of petrochemical, steel, and other industries impair health?. *Occupational Environmental Medicine*. 1998; 55:812-822.
6. Chen PC, Lai YM, Wang JD, Yang CY, Hwang JS, Kuo HW, et al. Adverse effects of air pollution on respiratory health of primary school children in Taiwan. *Environmental Health Perspectives*. 1998; 106: 331-335.
7. Cuhadaroglu B, Demirci E. Influence of some meteorological factors on air pollution in Trabzon city. *Energy and Building*. 1997; 24:179-184.
8. Demirci E, Cuhadaroglu B. Statistical analysis of wind circulation and air pollution in urban Trabzon. *Energy and Building*. 2000; 31:49-53.
9. Devalia JL, Rusznak C, Wang J, Khair OA, Abdelaziz MM, Calderon MA, et al. Air pollution and respiratory hypersensitivity. *Toxicology Letters*. 1996; 86:169-176.
10. Diab R, Prause A, Bencherif H. Analysis of SO<sub>2</sub> pollution in the South Durban Industrial Basin. *South African Journal of Science*. 2002; 98:543-546.
11. Dolk H, Thakrar B, Walls P, Landon M, Grundy C, Saez Lloret I, et al. Mortality among residents near cokeworks in Great Britain. *Occupational Environmental Medicine*. 1999; 56:34-40.

12. Dusseldorp A, Kruize H, Brunekreef B, Hofschreuder P, de Meer G, van Oudvorst AB. Associations of PM<sub>10</sub> and airborne iron with respiratory health of adults living near a Steel Factory. *American Journal of Respiratory Critical Care Medicine*. 1995; 152:1932-1939.
13. Elminir HK. Dependence of urban air pollution on meteorology. *Science of the Total Environment*. 2005; 350:225-237.
14. Englert N. Fine particles and human health – a review of epidemiological studies. *Toxicology Letters*. 2004; 149:235-242.
15. Forsberg B, Stjernberg N, Linne R, Segerstedt B, Wall S. Daily air pollution levels and acute asthma in southern Sweden. *European Respiratory Journal*. 1998; 12:900-905.
16. Gaustella L, Mjoli D. Sulphur dioxide measurements in South Durban: The culmination of 8 years of monitoring. *Clean Air Journal*. 2005; 14:17-24.
17. Gehrig R, Buchmann B. Characterising seasonal variations and spatial distribution of ambient PM<sub>10</sub> and PM<sub>2.5</sub> concentrations based on long-term Swiss monitoring data. *Atmospheric Environment*. 2003; 37:2571-2580.
18. Gomiscek B, Hauck H, Stopper S, Preining O. Spatial and Temporal variations of PM<sub>1</sub>, PM<sub>2.5</sub>, PM<sub>10</sub> and particle number concentration during the AUPHEP - project. *Atmospheric Environment*. 2004; 38:3917-3934.
19. Gouveia N, Fletcher T. Respiratory diseases in children and outdoor air pollution in Sao Paulo, Brazil: A time series analysis. *Occupational Environmental Medicine*. 2000; 55:477-483.
20. Gupta AK, Patil RS, Gupta SK. Influence of meteorological factors on air pollution concentration for a coastal region in India. *International Journal of Environmental Pollution*. 2004; 21:253-262.
21. Koenig JQ. Air pollution and asthma. *Journal of Allergy and Clinical Immunology*. 1999; 104:717-722.
22. Lewis PR, Hensley MJ, Wlodarczyk J, Toneguzzi RC, Westley-Wise VJ, Dunn T, et al. Outdoor air pollution and children's respiratory symptoms in the steel cities of New South Wales. *Medical Journal Australia*. 1998; 169:459-463.



23. Lu WZ, Wang XK. Interaction patterns of major air pollutants in Hong Kong territory. *Science of the Total Environment*. 2004; 324:247-259.
24. Matooane L, Diab RD. Air pollution carrying capacity in the South Durban Industrial Basin. *South African Journal of Science*. 2001; 97:450-453.
25. Matooane M, Diab B. Health risk assessment for sulfur dioxide pollution in South Durban, South Africa. *Archives of Environmental Health*. 2003; 58:763-770.
26. Matooane M, John J, Oosthuizen R, Binedell M. Vulnerability of South African communities to air pollution. *Proceedings of the 8<sup>th</sup> World Congress on Environmental Health*; 2004 Feb 22-27; Durban, South Africa.
27. Maynard R. Key airborne pollutants – the impact on health. *Science of the Total Environment*. 2004; 9:334-335.
28. Michelozzi P, Forastiere F, Fusco D, Perucci CA, Ostro B, Ancona C, et al. Air pollution and daily mortality in Rome, Italy. *Occupational Environmental Medicine*. 1998; 55:605-610.
29. Nriagu J, Robins T, Gary L, Liggins G, Davila R, Supuwood K, et al. Prevalence of asthma and respiratory symptoms in south central Durban, South Africa. *European Journal of Epidemiology*. 1999; 15:747-755.
30. Peled R, Friger M, Bolotin A, Bibi H, Epstein L, Pilpel D, et al. Fine particles and meteorological conditions are associated with lung function in children with asthma living near two power plants. *Public Health*. 2005; 119:418-425.
31. Peters JM, Avol E, Navidi W, London SJ, Gauderman WJ, Lurmann F, et al. A study of twelve southern California communities with differing levels and types of air pollution. *American Journal of Respiratory Critical Care Medicine*. 1999; 159:760-767.
32. Pless-Mullooli T, Howel D, King A, Stone I, Merefield J, Bessell J, et al. Living near opencast coal mining sites and children's respiratory health. *Occupational Environmental Medicine*. 2000; 57:145-151.
33. Naidoo R, Gquleni N, Batterman S, Robins T. *South Durban Health Study: Health Study and Health Risk Assessment*. University of KwaZulu Natal and University of Michigan: Durban, SA. 2006; 268.

34. United States. Network design and site exposure criteria for selected noncriteria air pollutants. Research Triangle Park, NC: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, 1984.
35. Seaton A, MacNee W, Donaldson K, Godden D. Particulate air pollution and acute health effects. *The Lancet*. 1995; 345:176-178.
36. Thompson DM. Sulphur Dioxide - SO<sub>2</sub> Molecule [monograph on the Internet]. United Kingdom: Winchester College; 2003 [cited 2003 December 1]. Available from: <http://www.chm.bris.ac.uk/motm/so2/so2h.htm>
37. Turalioglu FS, Nuhoglu A, Bayraktar H. Impacts of some meteorological parameters on SO<sub>2</sub> and TSP concentrations in Erzurum, Turkey. *Chemosphere*. 2005; 59:1633-1642.
38. Yang CY, Wang JD, Chan CC, Chen PC, Huang JS, Cheng MF. Respiratory and irritant health effects of a population living in a petrochemical-polluted area in Taiwan. *Environmental Research*. 1997; 74:145-149.
39. Van der Zee S, Hoek G, Boezen HM, Schouten JP, van Wijnen JH, Brunekreef B. Acute effects of urban air pollution on respiratory health of children with and without chronic respiratory symptoms. *Occupational Environmental Medicine*. 1999; 56:802-812.

## APPENDIX 1: DESCRIPTION OF MONITORING SITES

This appendix provides descriptions of the microenvironments near monitoring sites.

1. *Assegai Primary School*. The monitoring site was established on a concrete surface approximately 12 m from the administration block and 20 m from the access road, Austerville Drive. The site is adjacent to a grassy bank that leads to Austerville Drive. The school itself is located on an apex of a hill (elevation = ~ 60 m) that overlooks surrounding residential areas; small industries approximately 330 m to the South West and North West; a major roadway, the Southern Freeway, is ~ 1.1 km to the East. The closest major industry is the Engen refinery, which is approximately 800 m to the South East.

2. *Dirkie Uys Primary School*. The monitoring site was established on a large grassy field approximately 25 m from the school buildings, 160 m from the access road, and 220 m from Tara Road. The school is located in the lower lying area of the Bluff, with a wooded area immediately to the West, residential areas North and East, and the Engen Refinery 1.5 km to the South East. Small industries are ~ 0.75 km to the south and north West, and a major roadway, the Southern Freeway, is 1.7 km West. To the left of the woods is the Wentworth Hospital, below that the open area appears to be a cemetery.

3. *Nizam Primary School*. The monitoring site was established on a tarred surface close to a grassy bank. The site is ~ 100 m from Nizam Road and ~ 10 m from the classrooms. The school is in a small residential area located amidst major industrial activities: 0.73 km to the North East is the Engen Refinery; 0.81 km to the North West is the Southern Waste Water Treatment Plant; 0.85 km to the West is the Mondi Pulp Paper Plant; and 0.88 km to the South West is the Sapref Refinery. The nearest major roadway, the Southern Freeway, is ~ 1.9 km to the North West. The Durban International Airport is approximately 2.5 km to the South West.

4. *Entuthukweni Primary School*. The site was established on a tarred surface ~3 m from a lower lying grassed/sandy soccer pitch. This site is in the midst of a residential area adjacent to a small informal housing settlement to the North West.

It is ~1 km from any of the small industries. Of the sites in the South Basin, this is the furthest from major industries: 2.4 km from Mondi; 2.7 km from Sapref Refinery; 2.9 km from Southern Waste Water Works; and 3.5 km from the Engen refinery. The Durban International Airport is ~1.7 km to the South East. This site is close to three major roadways: 0.45 km from the N2 Freeway; 0.73 km from South Coast Road; and 1.1 km from the Southern Freeway; all to the South East.

5. *Briardale Primary School*. The monitoring site was established on the grassy field ~15 m from the administration block and classrooms. The area is hilly and residential, with open spaces on steeper slopes. The closest industries are located ~3 km to the South East at the Springfield Industrial Park. The major roadways are Inanda Road, 300 m distant, and the larger N2, 3 km distant, stretching from the South East to the North East.

6. *Ferndale Primary School*. The site was established by the school's parking lot, on a grassy patch ~10 m from the road and 15 m from the administration block. The school is on a hilltop; the area is largely residential with significant fractions of open space. The closest industries are located ~2 km to the South East in the new River Horse Valley Industrial Park and Briardene Industrial Park. The major roadways are Inanda Road, 600 m and the N2, 2 km to the South East.

7. *Ngazana Primary School*. The monitoring site was established on a grassy field in the centre of the school, which has a horse shoe design. This is an assembly and play area for the school. The residential site is the most densely populated of the three northern sites monitored. The closest industries are ~3 km to the North East in the Phoenix Industrial Park, which contains light industrial activities, e.g., metal work, warehousing, lumber and hardware supply, courier services, pneumatics, engineers, galvanizing etc. The major roadways are Malendela Road, 0.40 km North and the KwaMashu Highway, 3 km North East.

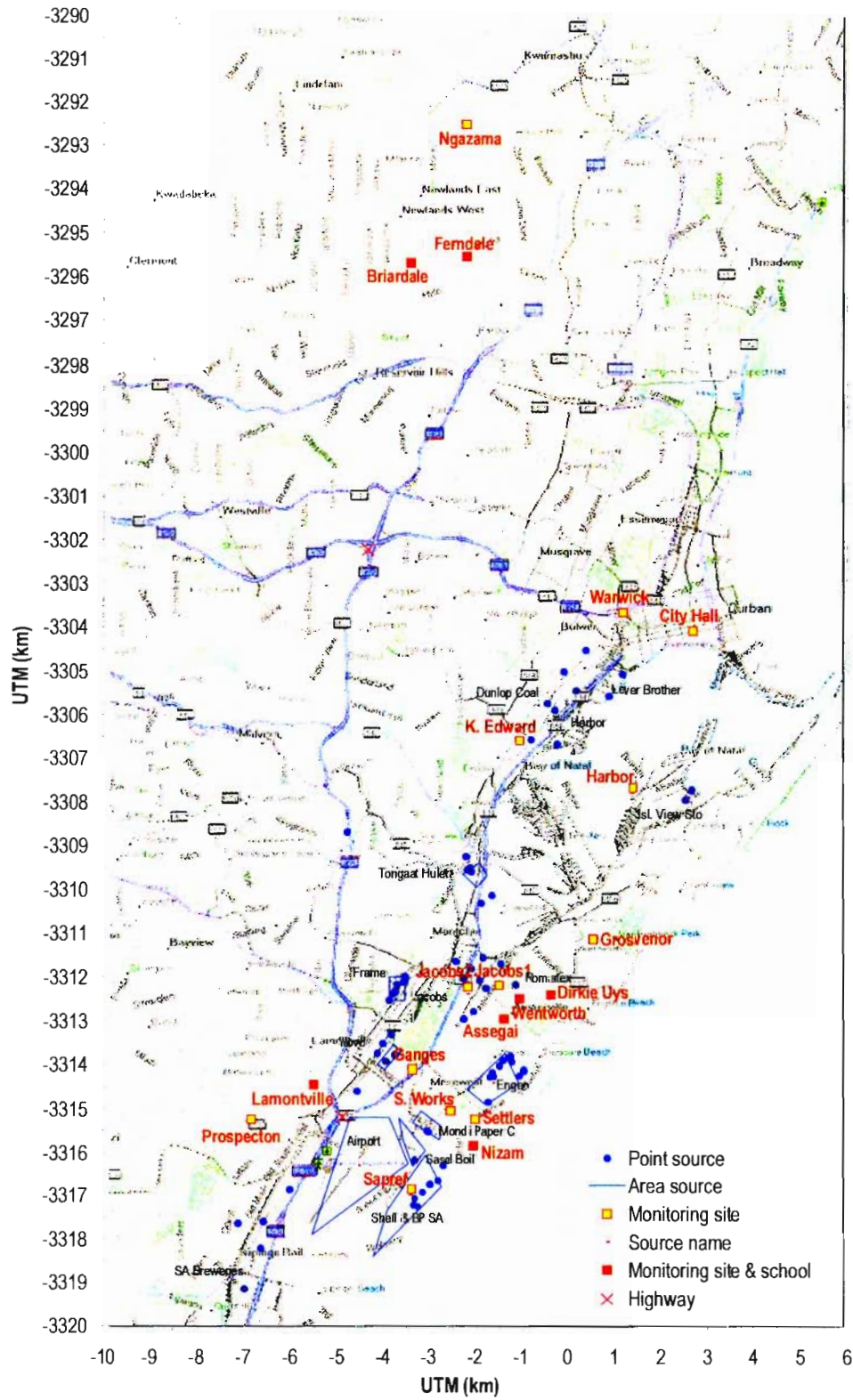


Figure 24: Map 16 x 30 km, showing study area, schools, monitoring sites & selected point sources

## APPENDIX 2: AIR QUALITY STANDARDS FOR SOUTH AFRICA

### AIR QUALITY GUIDELINES FOR SA

The following provide a comparison of a number of International Air Quality Standards and Guidelines for some common air pollutants. South Africa has promulgated ambient air quality standards under the National Environmental Management; Air Quality Act No. 39, 2004.

#### SCHEDULE 2

##### (Section 63)

#### Ambient air quality standards

**1. Ambient concentrations of ozone (O<sub>3</sub>) may not exceed—**

- (a)* an instant peak of 0.25 parts per million measured at 25°C and normal atmospheric pressure; or
- (b)* a one-hour average of 0.12 parts per million measured at 25°C and normal atmospheric pressure.

**2. Ambient concentrations of the oxides of nitrogen (NO<sub>X</sub>) may not exceed—**

- (a)* an instant peak of 1.4 parts per million measured at 25 °C and normal atmospheric pressure;
- (b)* a one-hour average of 0.8 parts per million measured at 25°C and normal atmospheric pressure;
- (c)* a 24-hour average of 0.4 parts per million measured at 25 °C and normal atmospheric pressure and the 24-hour limit may not be exceeded more than three times in one year;
- (d)* a one-month average of 0.3 parts per million measured at 25°C and normal atmospheric pressure; or
- (e)* an annual average of 0.2 parts per million measured at 25°C and normal atmospheric pressure.

**3. Ambient concentrations of nitrogen dioxide (NO<sub>2</sub>) may not exceed—**

- (a)* an instant peak of 0.5 parts per million measured at 25°C and normal atmospheric pressure;
- (b)* a one-hour average of 0.2 parts per million measured at 25°C and normal atmospheric pressure;
- (c)* a 24-hour average of 0.1 parts per million measured at 25 °C and normal atmospheric pressure and the 24-hour limit may not be exceeded more than three times in one year;
- (d)* a one-month average of 0.08 parts per million measured at 25 °C and normal atmospheric pressure; or
- (e)* an annual average of 0.05 parts per million measured at 25°C and normal atmospheric pressure.

**4. Ambient concentrations of sulphur dioxide (SO<sub>2</sub>) may not exceed—**

- (a)* a ten-minute average instant peak of 0.191 parts per million measured at 25°C and normal atmospheric pressure;
- (b)* an instant peak of 500 micrograms per cubic meter (ug/m<sup>3</sup>) measured at 25°C and normal atmospheric pressure;
- (c)* a 24-hour average of 0.048 parts per million or 125 micrograms per cubic meter (ug/m<sup>3</sup>) measured at 25°C and normal atmospheric pressure;
- (d)* an annual average of 0.019 parts per million or 50 micrograms per cubic meter (ug/m<sup>3</sup>) measured at 25 °C and normal atmospheric pressure.

**5. Ambient concentrations of lead (Pb) may not exceed - a one-month average of 2.5 micrograms per cubic meter (ug/m<sup>3</sup>).**

**6. Ambient concentrations of particulate matter with a particle size of less than 10 microns (u,) in size (PM<sub>10</sub>) may not exceed—**

- (a)* a 24-hour average of 180 micrograms per cubic meter (ug/m<sup>3</sup>) and the 24-hour limit may not be exceeded more than three times in one year; or
- (b)* an annual average of 60 micrograms per cubic meter (ug/m<sup>3</sup>).

**7. Ambient concentrations of total suspended solids may not exceed—**

(a) a 24-hour average of 300 micrograms per cubic meter (ug/m<sup>3</sup>) and the 24-hour limit may not be exceeded more than three times in one year; or

(b) an annual average of 100 micrograms per cubic meter (ug/m<sup>3</sup>).

INTERNATIONAL AIR QUALITY STANDARDS / GUIDELINES										
Substance (gaseous)	Averaging Time	Ambient Air Quality Standards, in parts per billion (ppb)								
		WHO	US EPA	Thailand	Canada	New Zealand	Bangkok	Korea	U.K. Recommendations	South Africa
Carbon Monoxide	15 min	87328								
	30 min	52397								
	1 hr	26198	35000		31000		30000	25000		
	8 hr	8733	9000	8960		10000		9000	10000	
Nitrogen Dioxide	1 hr	106	128	170		300	170	150	150	200
	annual	21	53		53			50	21	50
Ozone	1 hr			102	82		100	100		120
	8 hr	61	80					60	50	
	24 hr					125				
Sulphur Dioxide	Instant Peak									600
	10 min	191								
	15 min								100	
	1 hr				344		300	250		
	24 hr	48	140	115		125		140		100
	annual	19	30					30		30



Substance (in suspended particulate matter)	Averaging Time	Ambient Air Quality Standards, in micrograms per cubic metre (ug/m <sup>3</sup> )								
		WHO	U.S. EPA	Thailand	Canada	New Zealand	Bangkok	Korea	U.K. Recomm endations	South Africa
PM10	annual	50	50				120	80		60
	24 hr		150	120		120			50	180
PM2.5	annual	15	15							
Lead (Pb)	1 month									2.5
	3 months		1.5							
	annual	0.5							0.5	

### APPENDIX 3: GRAVIMETRIC DATA SHEET FOR MASS CALCULATION

	Pre-Weighing																						
	Pre-Weighing 1					Pre-Weighing 2					Pre-Weighing 3					Average & SD							
Filter No.	Date	Time	Temp oC	RH%	QA Filter	Mass	Date	Time	Temp oC	RH%	QA Filter	Mass	Date	Time	Temp oC	RH%	QA Filter	Mass	Temp oC	RH%	QA Filter	Mass	SD Mass

	Post-Weighing																						
	Post-Weighing 1					Post-Weighing 2					Post-Weighing 3					Average & SD							
Filter No.	Date	Time	Temp oC	RH%	QA Filter	Mass	Date	Time	Temp oC	RH%	QA Filter	Mass	Date	Time	Temp oC	RH%	QA Filter	Mass	Temp oC	RH%	QA Filter	Mass	SD Mass

FIELD WORK																
Instrument Data										Mass Concentration (MC)						
DATE	FILTER No.	STATUS	AMB. Temp oC	ATM. Pressure	Start Time	Stop Time	Valid Time	Total Time	Flow(l/min)	Vol (m <sup>3</sup> )	W <sub>F</sub> (µg)	W <sub>I</sub>	W <sub>F</sub> - W <sub>I</sub>	VOL(m <sup>3</sup> )	MC(µg.m <sup>-3</sup> )	SD(µg.m <sup>-3</sup> )

Notes:

1. Valid Time = valid time of sample collection, from sampler
2. Total Time = total time of sample collection, from sampler (used in the mass concentration calculation)
3. Flow(l/min) = flow rate of operating sampler in liters per minute
4. Vol (m<sup>3</sup>) = volume of air sampled during the 24 hour sampling period
5. W<sub>F</sub>(µg) = average of post gravimetric analysis in micrograms
6. W<sub>I</sub>(µg) = average of pre gravimetric analysis in micrograms
7. W<sub>F</sub> - W<sub>I</sub> = difference in post and pre gravimetric analysis in micrograms
8. MC(µg.m<sup>-3</sup>) = mass concentration of filter in micrograms per cubic meter of air
9. SD(µg.m<sup>-3</sup>) = standard deviation of the calculated mass concentration