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AN AIR QUALITY BASELINE ASSESSMENT FOR THE VAAL AIRSHED IN SOUTH AFRICA

by

René Georgeinna Thomas

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for the degree of

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DECLARATION

I hereby declare that the dissertation that I hereby submit for the degree MSc (Meteorology) at the University of Pretoria is my own work, and that it has not been previously submitted by me for degree purposes at any other university. I also declare that all the sources I have quoted have been indicated and acknowledged by complete references.

This dissertation reflects my input into the Vaal Triangle Priority Area Air Quality Management Plan – Baseline Characterisation report to the Department of Environmental Affairs and Tourism (DEAT). A formal letter by DEAT where permission is given for my input to be used as an MSc dissertation is provided.

_____ _____

Signature Date

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AN AIR QUALITY BASELINE ASSESSMENT FOR THE VAAL AIRSHED IN SOUTH AFRICA

René Georgeinna Thomas

Promoter: Prof. C.J.deW. Rautenbach
Department: Geography, Geoinformatics and Meteorology
University: University of Pretoria
Degree: Master of Science (Meteorology)

Summary

The Vaal Triangle is renowned for its highly industrialised activities. With the addition of domestic fuel burning, vehicle exhaust, mining and agricultural activities, the Vaal Airshed has become highly polluted. The concerns of the elevated concentrations in the area were raised by the Department of Environmental Affairs and Tourism (DEAT) when the Vaal Region was declared the first priority area on 21 April 2006. The basis for this declaration includes: areas that exceed or may exceed air quality standards, areas associated with significant air quality impacts and areas requiring specific air quality management actions to rectify the situation.

The purpose of this study is to determine the Status Quo of the Vaal Airshed. The emissions inventory for the study area includes industrial operations, mining activities, domestic fuel burning and vehicle tailpipe emissions along major national and regional routes. Priority pollutants (i.e. sulphur dioxide, nitrogen dioxide and inhalable particulate matter) are assessed with the aid of the US Environmental Protection Agency approved CALPUFF modelling suite, a non-steady-state Lagrangian Gaussian puff dispersion model.

From the dispersion simulations an air quality impact assessment is undertaken. The major findings of the air quality assessment indicate that particulate concentrations are elevated over most areas of the Vaal Airshed, particularly in residential areas where domestic coal burning occurs and areas neighbouring major industrial operations. Similarly, elevated sulphur dioxide concentrations occur over industrial and domestic coal burning areas. Elevated nitrogen dioxide concentrations have a regional impact over the Vaal Airshed.

Priority areas are identified based on the predicted ambient air concentrations from the priority pollutants and exposure potential. Source contributions are investigated based on the extent of their emissions and basis of impacts.

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This dissertation is dedicated to my husband

Robert von Gruenewaldt

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LIST OF SYMBOLS

C	:	Ground-level concentration (g/m³)
C_D	:	Surface drag coefficient
$\overline{C}$	:	Average concentration
da	:	Distance (m) from the puff centre to the receptor in the along-wind direction
dc	:	Distance (m) from the puff centre to the receptor in the cross-wind direction
dx, dy	:	The incremental X and Y distances travelled by the puff
Fr	:	Local Froude number
g	:	Gravitational acceleration constant (9.8 m/s²)
H	:	Effective height (m) above the ground of the puff centre
h	:	Mixed-layer height (m)
ht	:	Terrain height
Δht	:	An effective obstacle height (m)
k	:	Stability-dependent coefficient of exponential decay
L_e	:	Equilibrium length scale
N	:	Brunt-Väisälä frequency
Q	:	Pollutant mass (g) in the puff
R_k	:	Distance from the observational station k to the grid point
R	:	User defined weighting parameter for the Step 1 wind field
R	:	Distance (m) from the centre of the puff to the receptor
S_e	:	Equilibrium speed of the slope flow
s	:	Distance (m) travelled by the puff
s_0	:	The initial value of s at the start of the sampling step
u,v	:	Horizontal wind components
V	:	Domain-mean wind
|V|	:	Speed of the domain-mean wind
w	:	Vertical wind component (m/s) in Cartesian coordinates
x	:	Distance to the crest of the hill
Z	:	Terrain-following vertical coordinate (m)
z	:	Cartesian vertical coordinate (m)
θ	:	Potential temperature (K)
$\Delta\theta$	:	Potential temperature deficit with respect to the environment
α	:	Angle of the terrain relative to the horizontal
ε	:	Maximum allowable divergence
σ_x	:	Standard deviation (m) of the Gaussian distribution in the along-wind direction
σ_y	:	Standard deviation (m) of the Gaussian distribution in the cross-wind direction
σ_z	:	Standard deviation (m) of the Gaussian distribution in the vertical direction

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LIST OF ACRONYMS AND ABBREVIATIONS

APPA	The Atmospheric Pollution Prevention Act (No.45 of 1965)
AQA	Air Quality Act
AQG	Air Quality Guidelines
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BNM	Basa Njengo Magogo
CAPCO	Chief Air Pollution Control Officer
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COJ	City of Johannesburg
DEAT	The Department of Environmental Affairs and Tourism.
EC	The European Community
EHS	Environmental, Health and Safety
EIA	Environmental Impact Assessment
HC	Hydrocarbons
HCV	Heavy commercial vehicles
H_2S	Hydrogen Sulphide
LCV	Light commercial vehicles
LTO	Land-take-off cycle
MAS	Magical-angle-spinning
MCV	Medium commercial vehicles
MSVS	ArcelorMittal Steel Vanderbijlpark Steel
NATIS	National Traffic Information System
NO_x	Nitrogen Oxides
NO	Nitric oxide
NO_2	Nitrogen Dioxide
N_2O	Nitrogen Oxide
NMVOC	Non Methane Volatile Organic Compounds
O_3	Ozone
PM	Particulate Matter
PM2.5	Particulate Matter with an aerodynamic diameter of less than 2.5μm
PM10	Particulate Matter with an aerodynamic diameter of less than 10μm
ROM	Run of Mine
SA	South African
SABS	South African Bureau of Standards
SANAS	South African National Accreditation System
SANS	South African National Standards
SAPIA	South African Petroleum Industry Association
SAWS	South African Weather Service
SDM	Sedibeng District Municipality
SO_2	Sulphur Dioxide
TSP	Total Suspended Particulates
μ	Micron
UK	United Kingdom

US-EPA	United States Environmental Protection Agency
UV	Ultra Violet
VKT	Vehicle Kilometre Travelled
VOC	Volatile Organic Compounds
WB	The World Bank Group
WHO	The World Health Organisation

CHAPTER 1
BACKGROUND

1.1 Introduction

The Vaal Triangle is a highly industrialised area, encompassing numerous industries (such as petrochemical, iron and steel, ferro-alloy, etc.), a coal fired power station, and various smaller industrial and commercial activities giving rise to noxious and offensive gases. In addition to the industrial activities, the Vaal Triangle is also home to large informal settlements (viz. Boipatong, Bophelong, Evaton, Orange Farm, Sebokeng, Sharpville and Zamdela) using coal, wood and paraffin as a fuel source. A few mining operations, mainly coal collieries are located within this Airshed. Other sources of concern contributing to the pollution mixture within the area include vehicle tailpipe emissions, biomass burning, water treatment works and landfill areas, agricultural activities and various other fugitive sources. Due to the various emission release sources within the Vaal Airshed, significant health impacts have been identified as occurring in the region specifically due to the high airborne particulate concentrations.

The air quality within the Vaal Triangle region was extensively investigated during the 1990s with a range of air pollution and human health assessment studies undertaken. These studies, amongst others, included the Vaal Triangle Air Pollution Health Study that was initiated in 1990 to determine the effects of air pollution on human health (Terblanche *et al*, 1992). This study included the indoor, outdoor and personal exposure to pollutants over a three year period.

Other studies compiled by Muller (1992) and van Nierop (1994) investigated the emissions within the Vaal Triangle. Muller (1992), undertook a qualitative assessment of the industrial sources (including iron and steel operations, non-ferrous metal processing, coal fired power plants, coal-to-oil conversion plants, a manganese foundry, quarries, wood and rubber products and fertiliser factories) and area sources (including domestic fuel burning, veld fires, vegetation burning, wind blown dust, agricultural and construction soil dust and fugitive emissions from paved and unpaved road surfaces). Van Nierop (1994) extended this information by quantifying these emissions for a base case period of 1992. In 1999, Liebenberg, extended this study by investigating the exposure potential of inhalable particulate matter within the region. These earlier studies were important in terms of highlighting certain pollutants, areas and sources of concern in the Vaal Triangle.

In 2003, research was undertaken to consolidate the results of past studies (Scorgie, 2003). In addition, research aimed at quantifying the contribution of fuel-burning within various

sectors to human health impacts and the costs associated with such impacts was also undertaken (Scorgie *et al*., 2003a; 2003b).

1.2 The Vaal Airshed Declared a Priority Area

Considerable attention was placed on the Vaal Airshed when the Minister of Environmental Affairs and Tourism declared the Vaal Region a priority area on 21 April 2006. The boundaries of this area are illustrated in Figure 1-1. This region was the first to be declared a priority area within the country. Following the declaration government (national or provincial) is responsible for coordinating the development of a Priority Area Air Quality Management Plan. In order to undertake an Air Quality Management Plan it was essential to determine the status quo of the Vaal Airshed.

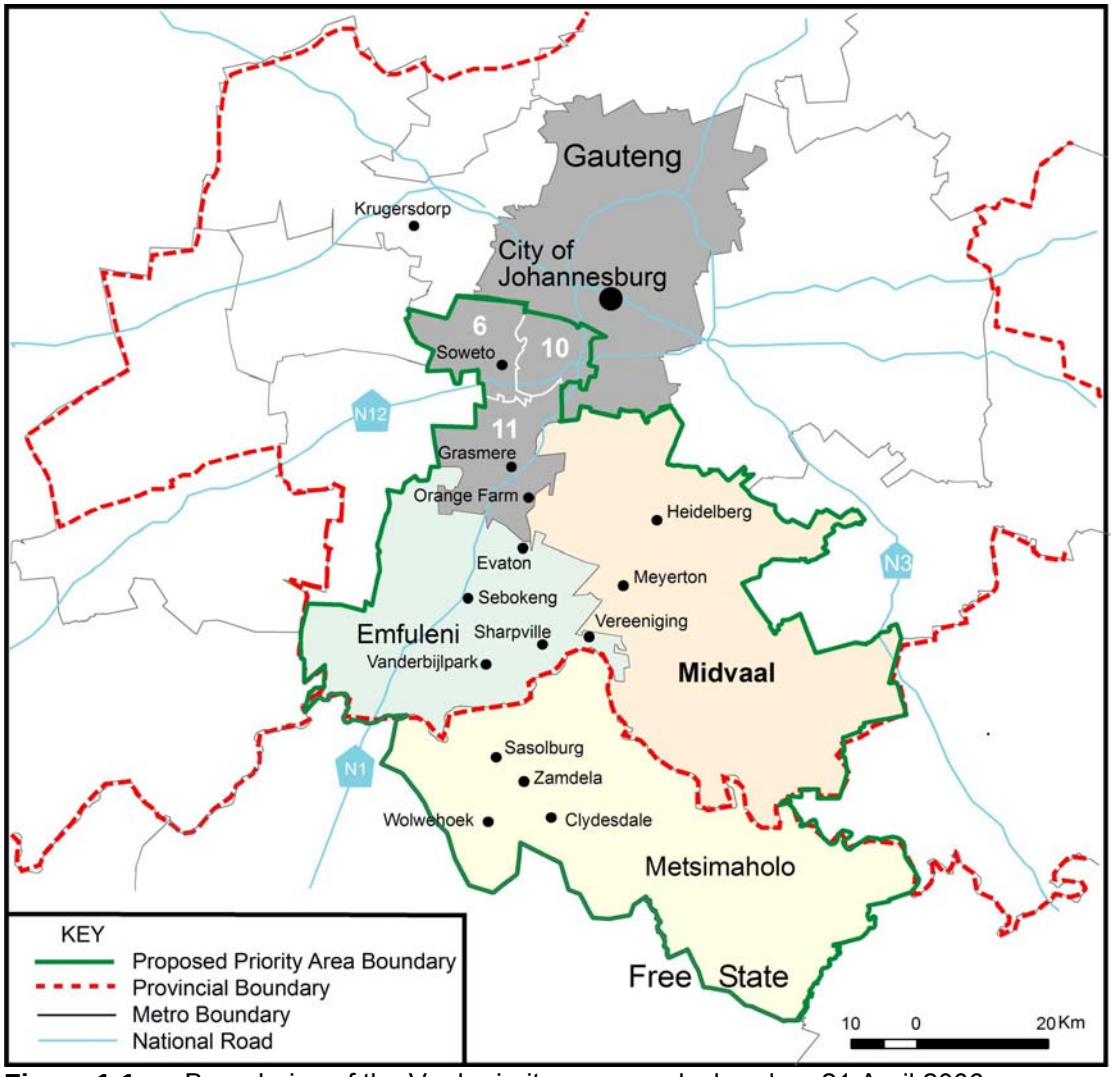


Figure 1-1: Boundaries of the Vaal priority area, as declared on 21 April 2006.

1.3 Aim of Study

The aim of the study was to determine the current air quality and impact sources within the Vaal Airshed. The original industrialised Vaal Triangle included an area stretching from Randvaal in the north to Sasolburg in the southwest and Deneysville in the east. The study area, however, extended to include in addition the major metropolitan areas of Johannesburg, Soweto, Lenasia, Ennerdale, Orange Farm, Evaton, Sebokeng and Meyerton which have the potential to influence the Airshed within the Vaal Triangle (Figure 1-2).

Figure 1-2: The extent of the area assessed during the current study including the Vaal Triangle and the major metropolitan areas of Johannesburg, Soweto, Lenasia, Ennerdale, Orange Farm, Evaton, Sebokeng and Meyerton.

The **objectives** of the research are as follows:

- Describe the synoptic climatology and meso-scale atmospheric dispersion potential based on available literature and meteorological data;
- Review legislative and regulatory requirements pertaining to air pollution control and air quality management, specifically local and international 'good practice' emission limits and air quality limits;
- Characterise existing air quality including the identification of existing sources and the analysis of existing air quality monitoring data;
- Compile an emissions inventory for the current emission sources within the Vaal Airshed, including industrial, commercial and residential activities;
- Application of the CALPUFF/CALMET dispersion modelling suit to predict baseline sulphur dioxide, nitrogen dioxide and inhalable particulate concentrations;
- Evaluate the compliance of air pollutant concentrations based on both local and international 'good practice' limits;
- Identify priority pollutants, sources and areas within the Vaal Airshed.

1.4 Assumptions and Limitations

The following limitations and assumptions were taken in consideration for this research:

- Limited background ambient air quality data was available since the Department of Environmental Affairs and Tourism (DEAT) monitoring network has only commenced during February to March 2007. Eskom's Makalu station was decommissioned at the end of 2004 thus providing mainly historical data. Some of the ambient monitoring stations are not SANAS accredited and it was assumed that the data obtained was correct. Ambient monitoring data was mainly limited to criteria pollutants.
- The Sasol stations (with the exception of Grootvlei) only had wind speed and wind direction data available for the last 3 months of 2006 due to technical problems experienced with the data averaging.
- No upper air meteorological data is recorded within the Vaal Airshed with the nearest station located at Irene in Pretoria. Use was therefore made of the South African Weather Services ETA data model results for the required period.
- A questionnaire was compiled for industrial and mining operations requesting all emissions data (Liebenberg-Enslin *et al*, 2007). A reply of 51% was received from the industries. Of the 51% updated emissions received, the main industries of Sasol, ArcelorMittal, Natref, Omnia, Eskom and Metalloys were included. For the mining operations use was made of information contained in previous Environmental Impact Assessments (EIAs). For the remaining sources of emissions for which no reply was received 37% could be covered by the NEDLAC

Dirty Fuels study or available EIA information. These industries include small boiler operations, brickworks, etc. The NEDLAC data is however based on pre-2004 information. Thus a total of 88% of the identified sources were included into the baseline study with 12% not accounted for.

- Based on the emissions information available only criteria pollutants were assessed. These were limited to inhalable particulate matter, sulphur dioxide and oxides of nitrogen. These criteria pollutants however are stipulated within the Atmospheric Pollution Prevention Act (No.45 of 1965) (APPA), Air Quality Act (AQA) and South African (SA) standards have been assigned to these pollutants to regulate ground level concentrations in terms of the legislation.
- Domestic fuel burning emissions were based on 2001 Census data for household coal, wood and paraffin use within the Vaal Airshed. Factors influencing emissions: type of house (formal house, planned / unplanned / backyard shack), whether or not a household is electrified, the number of people living in the house, the season, the availability of fuel types, the price of fuels and the household income. More recent surveys (2004/2005) conducted in Zamdela on the type of energy sources utilised were made available for use by the NOVA Institute. A current survey has been completed by NOVA including information on the number of household using the BNM method but this information was complete during the commencement of this study and thus could not be included.
- Vehicle emissions were limited to national and regional roads within the Vaal Airshed and the more congested areas within were treated as area sources.
- Total particulate matter from Sasol point sources were conservatively assumed to be inhalable particulate matter of <10µm in diameter as the inhalable particulate fraction was unknown for the current study.

1.5 Hypotheses

The hypotheses to be tested are as follows:

- Inhalable particulate concentrations are elevated within the Vaal Airshed;
- The main sources of inhalable particulate emissions are industrial, commercial and domestic fuel burning activities;
- Sulphur dioxide concentrations are elevated over built-up areas within the Vaal Airshed;
- The main sources of sulphur dioxide emissions are due to industrial, commercial and domestic fuel burning activities;
- Elevated nitrogen dioxide concentrations are limited within the Vaal Airshed;
- The main sources of nitrogen dioxide emissions are due to industrial activities;

1.6 Outline of report

The dissertation consists of eight chapters. **Chapter 1** describes the background research undertaken over the Vaal Airshed and the need for a baseline assessment of the area. The objectives and hypothesis of the research are introduced in this chapter. **Chapter 2** introduces the ambient air quality evaluation criteria that are available to assess the air quality within the study area. The dispersion simulation methodology is discussed in **Chapter 3** with the regional climate and atmospheric dispersion potential provided in **Chapter 4**. The measured ambient air quality in the study area is discussed in **Chapter 5**. The emissions inventory of the baseline emissions for the Vaal Airshed is given in **Chapter 6** and the impact assessment provided in **Chapter 7**. **Chapter 8** summarizes and concludes the findings of this research.

CHAPTER 2
LEGAL REQUIREMENTS AND HUMAN HEALTH CRITERIA

In order to assess the impacts due to emission sources within the Vaal Airshed, reference needs to be made to local and international guidelines/standards that regulate pollution concentrations at ground level.

Ambient air quality guideline values and standards provide safe daily exposure levels for the majority of the population, including the very young and the elderly, throughout an individual's lifetime. Air quality guidelines and standards are normally given for specific averaging periods which refer to the time-span over which the air concentration of the pollutant was monitored at a location. There are generally five averaging periods that are applicable (viz. instantaneous peak, 1-hour average, 24-hour average, 1-month average, and annual average).

The South African Bureau of Standards (SABS) was engaged to assist the department of Environmental Affairs and Tourism (DEAT) with the development of ambient air quality standards. A technical committee was established to provide input to the development of these standards. The technical committee came up with three working groups, namely (i) sulphur dioxide, particulates, oxides of nitrogen and ozone, (ii) lead and (iii) volatile organic compounds, specifically benzene. The process resulted in the publication of: (a) SANS 69 - South African National Standard - Framework for setting and implementing national ambient air quality standards, and (b) SANS 1929 - South African National Standard - Ambient Air Quality - Limits for common pollutants. The latter document includes air quality limits for particulate matter less than 10 µm in aerodynamic diameter (inhalable particulates), dustfall, sulphur dioxide, nitrogen dioxide, ozone, carbon monoxide, lead and benzene. The SANS documents were approved by the technical committee for gazetting for public comment, were made available for public comment during the May/June 2004 period and were finalized and published during November 2004.

The Department of Environmental Affairs and Tourism, however, adopted the outdated Chief Air Pollution Control Officer (CAPCO) guidelines as national standards on 11 September 2005 in the National Environmental: Air Quality Act[1].

The Minister has since announced his intention of setting new ambient air quality standards in terms of Section 9(1) (a) and (b) of the Air Quality Act on 2 June 2006. The proposed new standards (an adoption of the SANS limits) for all criteria pollutants were published for public comment in the Government Gazette of 9 June 2006. .

[1] The National Environmental Management: Air Quality Act (Act no.39 of 2004) commenced with on the 11th of September 2005 as published in the Government Gazette on the 9th of September 2005. Sections omitted from the implementation are Sections 21, 22, 36 to 49, 51(1)(e),51(1)(f), 51(3),60 and 61.

A document for the Establishment of National Standards for Ambient Air Quality was drafted on 24 October 2007 and circulated in a multi-stakeholder workshop for comment. This document is yet to be finalised and the figures provided in the following sections have been released for discussion purposes only.

As of **30 April 2007**, new versions of the World Bank Group Environmental, Health, and Safety Guidelines (known as the 'EHS Guidelines') are now in use. They replace those documents previously published in Part III of the Pollution Prevention and Abatement Handbook and on the IFC website.

The local and international ambient air quality guidelines and standards for pollutants relevant to the current study are presented in subsequent subsections. Air quality limits issued nationally by the DEAT and SABS are reflected together with limits published by the World Health Organisation (WHO), European Community (EC), World Bank (WB), United Kingdom (UK), and the United States Environmental Protection Agency (US-EPA).

2.1 Suspended Particulate Matter

Particulate matter is the suspension of air-borne solid particles of various sizes. A single particle may be made up of sulphate, nitrate, ammonia, chloride, elemental and organic carbon and crustal and biological materials (Vallius, 2005). Inhalable particulate matter with a diameter of < 10 µm (PM10) is able to reach the upper part of the lung. Smaller particles of this size fraction (i.e. PM2.5 and PM1.0) are able to penetrate deeper into the lung and reach the alveolar region (Figure 2-1). Particles with a diameter of less than 2.5 µm are often referred to as the “fine fraction” with particles with a diameter of between 2.5 µm and 10 µm referred to as the “coarse fraction” (Yu, 2001).

Although the size and composition of particulate matter depends on the emission process, these attributes will be influenced by atmospheric processes as well. Fine particulate fraction of ~ 1 µm form during high temperature processes in the atmosphere and carry inorganic and organic compounds. The mechanical processes of corrosion, erosion, etc. give rise to coarser particles (Vallius, 2005).

Numerous studies conducted on the health effects of particulate matter have shown increases in lower respiratory systems and reduced lung function in children with chronic obstructive pulmonary disease and reduced lung function in adults (Maddox, 2006; NRC, 2004).

In addition to health effects in humans, particulate matter has been found to cause environmental effects. Fine particulates (PM2.5) for instance, are a source of visibility reduction (haze). Larger particles that settle on water bodies, on the other hand, change the acidity and nutrient balance in these environments and thus the diversity of ecosystems.

Deposition of particulate matter has also been found to stain and damage stone and other materials resulting in the destruction of monuments and statues[2].

Air quality guidelines for particulates are given for various particle size fractions, including total suspended particulates, inhalable particulates or PM10 (i.e. particulates with an aerodynamic diameter of less than 10 µm), and respirable particulates of PM2.5 (i.e. particulates with an aerodynamic diameter of less than 2.5 µm). PM10 and PM2.5 are of concern due to their health impact potentials as they are able to deposit and damage the lower airways and gas-exchanging portions of the lung.

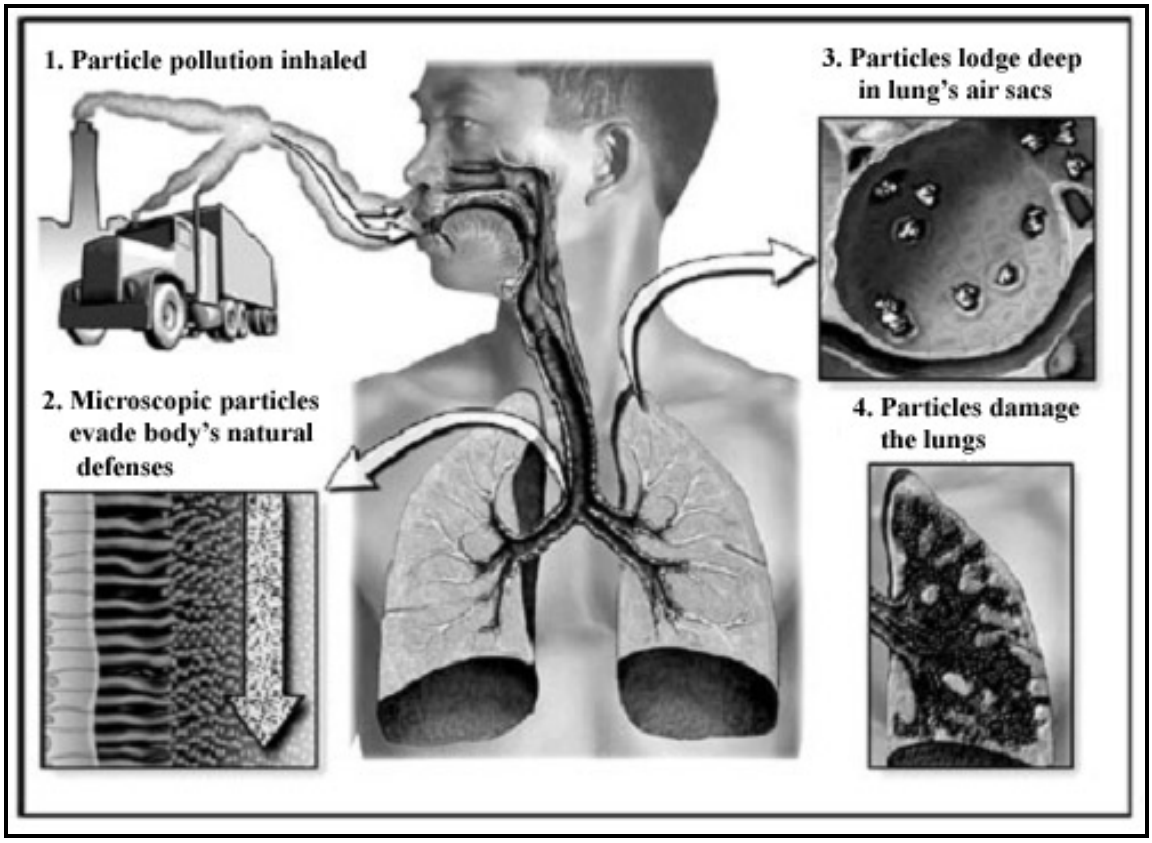


Figure 2-1: The effects of inhaled particulate matter to the human lung (after Maddox, 2006).

Inhalable particulate limits and standards issued locally and abroad are given in Table 2-1. The averaging periods for which inhalable particulate health standards and limits have been established consists of daily and annual time-frames. In addition to the inhalable particulate standards published in schedule 2 of the SA Air Quality Act, the Act also includes standards

[2] http://www.epa.gov/oar/particlepollution/health.html

for total suspended particulates, viz. a 24-hour average maximum concentration of 300 µg/m³ not to be exceeded more than three times in one year and an annual average of 100 µg/m³.

During 1990 the World Health Organisation (WHO) established that no safe thresholds could be determined for particulate exposures. It thus established linear dose-response relationships for PM10 and PM2.5 concentrations (WHO, 2000). This approach, however, was not well accepted by air quality managers and policy makers, as explicit objectives could not be extracted from the dose-response relationships. The WHO Working Group of Air Quality Guidelines thus recommended that the updated WHO air quality guideline document contain guidelines that define concentrations which, if achieved, would be expected to result in significantly reduced rates of adverse health effects. As developing countries would inevitably exceed the recommended WHO air quality guidelines (AQGs), the Working Group also proposed interim targets (IT) levels, in excess of the WHO AQGs themselves, to promote steady progress towards meeting the WHO AQGs (WHO, 2005). The air quality guidelines and interim targets issued by the WHO in 2005 for particulate matter are given in Tables 2-2 and 2-3.

Table 2-1: Air quality standards for inhalable particulate matter (PM10) for various countries and organisations.

Authority	Maximum 24-hour Concentration (µg/m³)	Annual Average Concentration (µg/m³)
SA standards (Air Quality Act)	180	60
RSA SANS limits (SANS:1929,2004)	75(a) 50(b)	40(c) 30(d)
Australian standards	50(e)	-
European Community (EC)	50(f)	40(g)
World Bank (General Environmental Guidelines)	(h)	(h)
United Kingdom	50(i)	40(j)
United States EPA	150(k)	50(l)
World Health Organisation	50(m)	20(m)

Notes:
(a) Limit value. Permissible frequencies of exceedance, margin of tolerance and date by which limit value should be complied with not yet set.
(b) Target value. Permissible frequencies of exceedance and date by which limit value should be complied with not yet set.
(c) Limit value. Margin of tolerance and date by which limit value should be complied with not yet set.
(d) Target value. Date by which limit value should be complied with not yet set.
(e) Australian ambient air quality standards. (http://www.deh.gov.au/atmosphere/airquality/standards.html). Not to be exceeded more than 5 days per year. Compliance by 2008.
(f) EC Directive, 2008/50/EC (http://ec.europa.eu/environment/air/quality/legislation/directive.htm). Already in force since 1 January 2005. Not to be exceeded more than 35 times per calendar year.
(g) EC Directive, 2008/50/EC (http://ec.europa.eu/environment/air/quality/legislation/directive.htm). Already in force since 1 January 2005.
(h) World Bank Group, 2007. EHS Guidelines (http://www.ifc.org/ifcext/enviro.nsf/Content/EnvironmentalGuidelines). Guidelines state that pollutant concentrations do not reach or exceed relevant ambient quality guidelines and standards by applying national legislated standards, or in their absence, the current WHO Air Quality Guidelines, or other internationally recognized sources.
(i) UK Air Quality Objectives. www.airquality.co.uk/archive/standards/php. Not to be exceeded more than 35 times per year. Compliance by 31 December 2004
(j) UK Air Quality Objectives. www.airquality.co.uk/archive/standards/php. Compliance by 31 December 2004
(k) US National Ambient Air Quality Standards (www.epa.gov/air/criteria.html). Not to be exceeded more than once per year.
(l) US National Ambient Air Quality Standards (www.epa.gov/air/criteria.html). To attain this standard, the 3-year average of the weighted annual mean PM10 concentration at each monitor within an area must not exceed 50 µg/m³.
(m) WHO (2000) issued linear dose-response relationships for PM10 concentrations and various health endpoints with no specific guideline provided. WHO (2005) made available during early 2006 proposes several interim target levels (see Table 2-2 and 2-3).

Table 2-2: WHO air quality guideline and interim targets for particulate matter (annual mean) (WHO, 2005)

Annual Mean Level	PM10 (µg/m³)	PM2.5 (µg/m³)	Basis for the selected level
WHO interim target-1 (IT-1)	70	35	These levels were estimated to be associated with about 15% higher long-term mortality than at AQG
WHO interim target-2 (IT-2)	50	25	In addition to other health benefits, these levels lower risk of premature mortality by approximately 6% (2-11%) compared to WHO-IT1
WHO interim target-3 (IT-3)	30	15	In addition to other health benefits, these levels reduce mortality risks by another approximately 6% (2-11%) compared to WHO-IT2 levels.
WHO Air Quality Guideline (AQG)	**20**	**10**	These are the lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to PM2.5 in the American Cancer Society (ACS) study (Pope *et al.*, 2002 as cited in WHO 2005). The use of the PM2.5 guideline is preferred.

Table 2-3: WHO air quality guideline and interim targets for particulate matter (daily mean) (WHO, 2005)

Annual Mean Level	PM10 (µg/m³)	PM2.5 (µg/m³)	Basis for the selected level
WHO interim target-1 (IT-1)	150	75	Based on published risk coefficients from multi-centre studies and meta-analyses (about 5% increase of short-term mortality over AQG)
WHO interim target-2 (IT-2)*	100	50	Based on published risk coefficients from multi-centre studies and meta-analyses (about 2.5% increase of short-term mortality over AQG)
WHO interim target-3 (IT-3)**	75	37.5	Based on published risk coefficients from multi-centre studies and meta-analyses (about 1.2% increase of short-term mortality over AQG)
WHO Air Quality Guideline (AQG)	**50**	**25**	Based on relation between 24-hour and annual levels

* 99th percentile (3 days/year)
** for management purposes, based on annual average guideline values; precise number to be determined on basis of local frequency distribution of daily means

The South African National Standards for inhalable particulate matter of diameter <10 µm (as provided in a draft document on 24 October 2007) is given in Table 2-4 to Table 2-7.

Table 2-4: National Ambient Air Quality Standards – AQA Schedule 2

Averaging Period	Concentration (µg/m³)	Frequency of Exceedance	Compliance Date
24 hour	180	0	Immediate
1 year	60	0	Immediate

Table 2-5: National Ambient Air Quality Standards – Interim Level 1 at 99%

Averaging Period	Concentration (µg/m³)	Frequency of Exceedance	Compliance Date
24 hour	127	88	2012
1 year	50	0	2012

Table 2-6: National Ambient Air Quality Standards – Interim Level 2 at 99.5%

Averaging Period	Concentration (µg/m³)	Frequency of Exceedance	Compliance Date
24 hour	100	44	2017
1 year	45	0	2017

Table 2-7: National Ambient Air Quality Standards at 99.9%

Averaging Period	Concentration (µg/m³)	Frequency of Exceedance	Compliance Date
24 hour	75	9	2022
1 year	40	0	2022

2.2 Sulphur Dioxide

Sulphur dioxide is a colourless gas that is highly soluble in water (ATSDR, 1999; WHO, 2000). On inhalation, a large portion of sulphur dioxide is absorbed through the nasal mucosa (Speizer and Frank, 1966). Penetration to the alveoli is greater when inhaled through the mouth than through the nose (Calabrese *et al*, 1981).

The critical effect of sulphur dioxide is irritation of the upper respiratory tract. When exposed to large quantities of sulphur dioxide the outcome is burning of the nose and throat, breathing difficulties and severe airway obstruction. Long-term exposure of sulphur dioxide can affect human health with changes in lung function occurring (ATSDR, 1999). These changes may be in the form of damage to the epithelium of the airways followed by epithelial hyperplasia, a dose-related increase in goblet cells and hypertrophy of the submucosal glands (WHO, 2000). Sensitive populations (i.e. asthmatics) have been observed to be sensitive to respiratory effects at low concentrations of sulphur dioxide (ATSDR, 1999, Bethal *et al*, 1985, WHO, 2000). These effects are exacerbated through increased levels of exercise (Bethal *et al*, 1985).

Animal studies have also shown that exposure to high concentrations of sulphur dioxide have resulted in decreased respiration, inflammation of the airways and destruction of areas of the lung. No studies have clearly shown carcinogenic effects in human and animals (ATSDR, 1999).

Ambient air quality guidelines and standards issued for various countries and organisations for sulphur dioxide are given in Table 2-8.

Table 2-8: Ambient air quality guidelines and standards for sulphur dioxide for various countries and organisations

Authority	Maximum 10-minute Average (µg/m³)	Maximum 1-hourly Average (µg/m³)	Maximum 24-hour Average (µg/m³)	Annual Average Concentration (µg/m³)
SA standards (Air Quality Act)	500(a)	-	125(a)	50
RSA SANS limits (SANS:1929,2004)	500(b)	-	125(b)	50
Australian standards	-	524(c)	209 (c)	52
European Community (EC)	-	350(d)	125(e)	20(f)
World Bank (General Environmental Guidelines)	(g)	(g)	(g)	(g)
United Kingdom	266(h)	350(i)	125(j)	20(k)
United States EPA	-	-	365(l)	80
World Health Organisation	500(m)	350(m)	125(m)	50(m) 10-30(n)

Notes:
(a) No permissible frequencies of exceedance specified
(b) Limit value. Permissible frequencies of exceedance, margin of tolerance and date by which limit value should be complied with not yet set.
(c) Australian ambient air quality standards. (http://www.deh.gov.au/atmosphere/airquality/standards.html). Not to be exceeded more than 1 day per year. Compliance by 2008.
(d) EC Directive, 2008/50/EC (http://ec.europa.eu/environment/air/quality/legislation/directive.htm). Already in force since 1 January 2005. Limit to protect health (not to be exceeded more than 24 times per calendar year).
(e) EC Directive, 2008/50/EC (http://ec.europa.eu/environment/air/quality/legislation/directive.htm). Already in force since 1 January 2005. Limit to protect health (not to be exceeded more than 3 times per calendar year).
(f) EC Directive, 2008/50/EC (http://ec.europa.eu/environment/air/quality/legislation/directive.htm). Limited value to protect ecosystems.
(g) World Bank Group, 2007. EHS Guidelines (http://www.ifc.org/ifcext/enviro.nsf/Content/EnvironmentalGuidelines). Guidelines state that pollutant concentrations do not reach or exceed relevant ambient quality guidelines and standards by applying national legislated standards, or in their absence, the current WHO Air Quality Guidelines, or other internationally recognized sources.
(h) UK Air Quality Objective for 15-minute averaging period (www.airquality.co.uk/archive/standards/php). Not to be exceeded more than 35 times per year. Compliance by 31 December 2005.
(i) UK Air Quality Objective (www.airquality.co.uk/archive/standards/php). Not to be exceeded more than 24 times per year. Compliance by 31 December 2004.
(j) UK Air Quality Objective (www.airquality.co.uk/archive/standards/php). Not to be exceeded more than 3 times per year. Compliance by 31 December 2004.
(k) UK Air Quality Objective (www.airquality.co.uk/archive/standards/php). Compliance by 31 December 2000.
(l) US National Ambient Air Quality Standards (www.epa.gov/air/criteria.html). Not to be exceeded more than once per year.
(m) WHO Guidelines for the protection of human health (WHO, 2000).
(n) Represents the critical level of eco toxic effects (issued by WHO for Europe); a range is given to account for different sensitivities of vegetation types (WHO, 2000).

It should be noted that the WHO Air Quality Guidelines (AQG) for sulphur dioxide as published in 2000 have recently been revised (WHO, 2005). Although the 10-minute AQG (500 µg/m³) has remained unchanged, the previously published daily guideline has been significantly reduced from 125 µg/m³ to 20 µg/m³. The previous daily guideline was based on epidemiological studies. WHO (2005) makes reference to more recent evidence which suggests the occurrence of health risks at lower concentrations. Although WHO (2005) acknowledges the considerable uncertainty as to whether sulphur dioxide is the pollutant responsible for the observed adverse effects (may be due to ultra-fine particles or other correlated substances), it took the decision to publish a stringent daily guideline in line with

the precautionary principle. The WHO (2005) stipulates an annual guideline is not needed for the protection of human health, since compliance with the 24-hour level will assure sufficiently lower levels for the annual average. Given that the 24-hour WHO AQG (20 µg/m³) is anticipated to be difficult for some countries to achieve in the short term, the WHO (2005) recommends a stepped approach using interim goals as shown in Table 2-9.

Table 2-9: WHO air quality guidelines and interim guidelines for sulphur dioxide (WHO, 2005)

	24-hour Average Sulphur Dioxide (µg/m³)	**10-minute Average Sulphur Dioxide (µg/m³)**
WHO interim target-1 (IT-1) (2000 AQF level)	125	
WHO interim target-2 (IT-2)	50(a)	
WHO Air Quality Guideline (AQG)	**20**	**500**

(a) Intermediate goal based on controlling either (i) motor vehicle (ii) industrial emissions and/or (iii) power production; this would be a reasonable and feasible goal to be achieved within a few years for some developing countries and lead to significant health improvements that would justify further improvements (such as aiming for the guideline).

The South African National Standards for sulphur dioxide (as provided in a draft document on 24 October 2007) is given in Table 2-10 to Table 2-12.

Table 2-10: National Ambient Air Quality Standards – AQA Schedule 2 at 99%

Averaging Period	**Concentration (µg/m³)**	**Frequency of Exceedance**	**Compliance Date**
10 minute (calculated on running averages)	500	526	Immediate
1 hour	350	88	Immediate
24 hours	125	4	Immediate
1 year	50	0	Immediate

Table 2-11: National Ambient Air Quality Standards – Interim Level 1 at 99.5%

Averaging Period	**Concentration (µg/m³)**	**Frequency of Exceedance**	**Compliance Date**
10 minute (calculated on running averages)	500	263	2012
1 hour	350	44	2012
24 hours	125	2	2012
1 year	50	0	Immediate

Table 2-12: National Ambient Air Quality Standards – Interim Level 2 at 99.9%

Averaging Period	Concentration (µg/m³)	Frequency of Exceedance	Compliance Date
10 minute (calculated on running averages)	500	50	2017
1 hour	350	9	2017
24 hours	125	1	2017
1 year	50	0	Immediate

2.3 Nitrogen Dioxide

Nitrogen dioxide is an oxidised gas that forms from the oxidation of nitric oxide in the presence of ozone and UV-light. It is a reddish-brown gas and is relatively insoluble in water (Mukala, 1999).

The health effects of nitrogen dioxide are not well understood despite the extensive epidemiological studies that have been undertaken. Animal studies have suggested, however, that higher concentrations of nitrogen dioxide can cause susceptibility to bacterial lung infections and irreversible emphysema-like structural changes (Mukala, 1999). Long-term effects of nitrogen dioxide have also been associated with increased respiratory disorders and impaired lung function in children (EPA, 1993; Pershagen et al, 1995; WHO, 1995).

Sensitive population groups to nitrogen dioxide exposure include children, cigarette smokers and asthmatics (Mukala, 1999).

The standards and guidelines of most countries and organisations are given exclusively for nitrogen dioxide concentrations. South Africa's nitrogen dioxide standards are compared to various widely referenced foreign standards and guidelines in Table 2-13.

Table 2-13: Ambient air quality guidelines and standards for nitrogen dioxide for various countries and organisations

Authority	Instanta-neous Peak (µg/m³)	Maximum 1-hourly Average (µg/m³)	Maximum 24-hour Average (µg/m³)	Maximum 1-month Average (µg/m³)	Annual Average Concentra-tion (µg/m³)
SA standards (Air Quality Act)	941(a)	376(a)	188(a)	151(a)	94
RSA SANS limits (SANS:1929,2004)	-	200(b)	-	-	40(b)
Australian standards		226(c)			56
European Community (EC)	-	200(d)	-	-	40(e)

Authority	Instanta-neous Peak (µg/m³)	Maximum 1-hourly Average (µg/m³)	Maximum 24-hour Average (µg/m³)	Maximum 1-month Average (µg/m³)	Annual Average Concentra-tion (µg/m³)
World Bank (General Environmental Guidelines)	(f)	(f)	(f)	(f)	(f)
United Kingdom	-	200(h)	-	-	40(i) 30(j)
United States EPA	-	-	-	-	100(k)
World Health Organisation (2000, 2005)	-	200(l)		-	40(l)

Notes:
(a) No permissible frequencies of exceedance specified
(b) Limit value. Permissible frequencies of exceedance, margin of tolerance and date by which limit value should be complied with not yet set.
(c) Australian ambient air quality standards. (http://www.deh.gov.au/atmosphere/airquality/standards.html). Not to be exceeded more than 1 day per year. Compliance by 2008.
(d) EC Directive, 2008/50/EC (http://ec.europa.eu/environment/air/quality/legislation/directive.htm). Not to be exceeded more than 18 times per year. This limit is to be complied with by 1 January 2010.
(e) EC Directive, 2008/50/EC (http://ec.europa.eu/environment/air/quality/legislation/directive.htm). Already in force since 1 January 2005. Annual limit value for the protection of human health, to be complied with by 1 January 2010.
(f) World Bank Group, 2007. EHS Guidelines (http://www.ifc.org/ifcext/enviro.nsf/Content/EnvironmentalGuidelines). Guidelines state that pollutant concentrations do not reach or exceed relevant ambient quality guidelines and standards by applying national legislated standards, or in their absence, the current WHO Air Quality Guidelines, or other internationally recognized sources.
(g) UK Air Quality Provisional Objective for nitrogen dioxide (www.airquality.co.uk/archive/standards/php). Not to be exceeded more than 18 times per year. Compliance by 31 December 2005.
(h) UK Air Quality Provisional Objective for nitrogen dioxide (www.airquality.co.uk/archive/standards/php). Compliance by 31 December 2005.
(i) UK Air Quality Objective for NOx for protection of vegetation (www.airquality.co.uk/archive/standards/php). Compliance by 31 December 2000.
(j) US National Ambient Air Quality Standards (www.epa.gov/air/criteria.html).
(k) WHO Guidelines for the protection of human health (WHO, 2000). AQGs remain unchanged according to WHO (2005).

The South African National Standards for nitrogen dioxide (as provided in a draft document on 24 October 2007) is given in Table 2-14 to Table 2-17.

Table 2-14: National Ambient Air Quality Standards – AQA Schedule 2

Averaging Period	Concentration (µg/m³)	Frequency of Exceedance	Compliance Date
1 hour	376	0	Immediate
1 year	100	0	Immediate

Table 2-15: National Ambient Air Quality Standards – Interim Level 1 at 99%

Averaging Period	Concentration (µg/m³)	Frequency of Exceedance	Compliance Date
1 hour	288	88	2012
1 year	70	0	2012

Table 2-16: National Ambient Air Quality Standards – Interim Level 2 at 99.5%

Averaging Period	Concentration (µg/m³)	Frequency of Exceedance	Compliance Date
1 hour	244	44	2017
1 year	55	0	2017

Table 2-17: National Ambient Air Quality Standards at 99.9%

Averaging Period	Concentration (µg/m³)	Frequency of Exceedance	Compliance Date
1 hour	200	9	2022
1 year	40	0	2022

CHAPTER 3
DISPERSION SIMULATION AND EMISSIONS QUANTIFICATION METHODOLOGY

3.1 Dispersion Simulation Methodology

Dispersion models are useful tools to compute ambient concentrations as a function of source configurations, emission strengths and meteorological characteristics. With the use of this tool, the spatial and temporal patterns in the ground level concentrations arising from the emissions of various sources can thus be ascertained. Increasing reliance has been placed on ground level air pollution concentration estimates from models as the primary basis for environmental and health impact assessments, risk assessments and determining emission control requirements. Care was therefore taken in the selection of a suitable dispersion model for the task at hand. The US Environmental Protection Agency approved CALPUFF modelling suite was selected for use in the baseline assessment, comprising the CALMET meteorological model, the CALPUFF dispersion model and the CALPOST result-processing module (Figure 3-1) (Scire *et al*, 2000a).

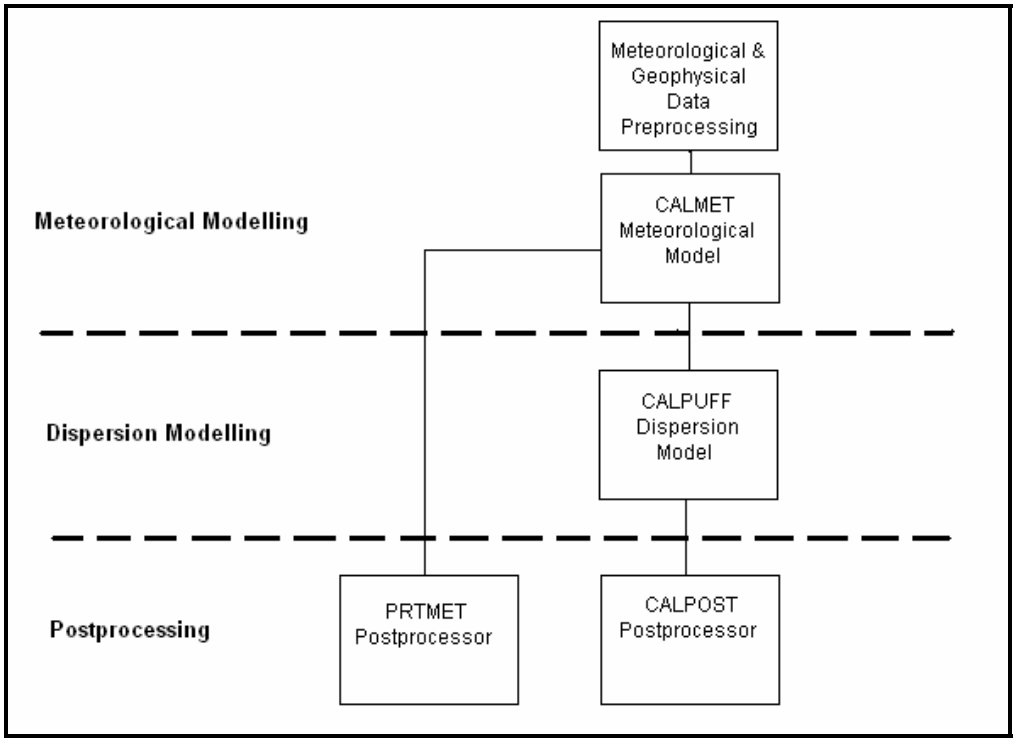


Figure 3-1: An overview of the CALMET/CALPUFF modelling system (after Scire *et al*, 2000a).

3.1.1 CALMET Meteorological Model

CALMET is a meteorological model which includes a diagnostic wind field generator, taking into account slope flows, kinematic terrain effects and terrain blocking effects. CALMET also includes a divergence minimisation procedure and a micrometeorology model for overland and overwater boundary layers (EPA, 1995a). Major features of the CALMET model are summarised in Table 3-1 and input data required for CALMET is given in Table 3-2 (Scire *et al*, 2000a).

Table 3-1: Major features of the CALMET meteorological model.

Module	Contents

Boundary Layer Module	- Overland boundary layer – Energy balance method
	- Overwater boundary layer – Profile method
	- Produces gridded fields of:
	  - Surface friction velocity
	  - Convective velocity scale
	  - Monon-Obukhov length
	  - Mixing height
	  - Pasquill-Gifford-Turner (PGT) Stability class
	  - Air temperature (3-D)
	  - Precipitation rate

Diagnostic Wind Field Module	- Slope flows - Kinematic terrain effects - Terrain blocking effects - Divergence minimisation - Produces gridded fields of U, V, W wind components - Inputs include domain-scale winds, observations and (optionally) coarse-grid prognostic model winds - Lambert conformal projection capability.

Table 3-2: A summary of source groups and parameters required as input data into the CALMET model.

Meteorological Data	Parameters
Surface meteorological data	Hourly observations of: - wind speed - wind direction - temperature - cloud cover - ceiling height - surface pressure - relative humidity - precipitation rates - precipitation type code
Upper air data	Twice-daily observed vertical profiles of:

Meteorological Data	Parameters
	- wind speed - wind direction - temperature - pressure - elevation
Overwater observations (optional)	- air-sea temperature difference - air temperature - relative humidity - over water mixing height - wind speed - wind direction - overwater temperature gradients above and below mixing height
Geophysical data	Gridded fields of: - terrain elevations - land use categories - surface roughness length (optional) - albedo (optional) - Bowen ratio (optional) - Soil heat flux constant (optional) - Anthropogenic heat flux (optional) - Vegetative leaf area index (optional)

The CALMET model operates in a terrain-following vertical coordinate system (Scire *et al*, 2000a):

$$Z = z - h_t$$

where,

Z - is the terrain-following vertical coordinate (m),
z - is the Cartesian vertical coordinate (m), and
h_t - is the terrain height

The vertical velocity, W, in the terrain-following coordinate system is defined as (Scire *et al*, 2000a):

$$W = w - u\frac{\partial h_t}{\partial x} - v\frac{\partial h_t}{\partial y}$$

where,

w - is the physical vertical wind component (m/s) in Cartesian coordinates,
u,v - are the horizontal wind components

The CALMET diagnostic wind field model has a two-step approach to the computation of the wind field. Step 1, an initial guess wind field is adjusted for:

- Kinematic effects of terrain

- Slope flows
- Blocking effects
- Three dimensional divergence minimisation

CALMET parameterises the kinematic effects of terrain using the methodology by Liu and Yocke (1980). The Cartesian vertical velocity, w, is quantified as follows:

$$w = (V.\Delta h_t)\exp(-kz)$$

where,

V - is the domain-mean wind,
z - is the vertical coordinate,
h_t - is the terrain height, and,
k - is a stability-dependent coefficient of exponential decay.

The exponential decay coefficient increases with increase in atmospheric stability (Scire *et al*, 2000a):

$$k = \frac{N}{|V|}$$

$$N = \left[\left(\frac{g}{\theta}\right)\frac{d\theta}{dz}\right]^{1/2}$$

where,

N - is the Brunt-Väisälä frequency (1/s) in a layer from the ground through a user-input height (m)
θ - is the potential temperature (K),
g - is the acceleration due to gravity (m/s²), and,
|V| - is the speed of the domain-mean wind

CALMET makes use of an empirical scheme to estimate the magnitude of slope flows in complex terrain. The slope flow vector is added to Step 1 of the gridded wind field, producing an adjusted Step 1 wind field (Scire *et al*, 2000a):

$$u_1' = u_1 + u_s$$

$$v_1' = v_1 + v_s$$

where,

(u_1,v_1) - are the components of Step 1 wind field (m/s) before considering slope flow effects,

(u_s,v_s) - are the slope flow wind components, and,

(u_1',v_1') - are the components of Step 1 wind field (m/s) after considering slope flow effects.

This slope flow parameterisation follows the methodology of Mahrt (1982), whereby it is assumed (for the derivation of the slope flow speed only) that the flow is steady, its depth is constant and the terrain slope is constant. Coriolus effects and cross-slope components are neglected. The slope flow is given as (Scire *et al*, 2000a):

$$S = S_e\left[1-\exp\left(-x/L_e\right)\right]^{1/2}$$

$$S_e = \left[hg\left(\Delta\theta/\theta\right)\sin\alpha/\left(C_D+k\right)\right]^{1/2}$$

$$L_e = h/\left(C_D+k\right)$$

where,

S_e - is the equilibrium speed of the slope flow,

L_e - is the equilibrium length scale,

x - is the distance to the crest of the hill,

$\Delta\theta$ - is the potential temperature deficit with respect to the environment,

θ - is the potential temperature of the environment,

C_D - is the surface drag coefficient,

h - is the depth of the slope flow,

α - is the angle of the terrain relative to the horizontal,

k - is the entrainment coefficient at the top of the slope flow layer, and,

g - is the gravitational acceleration constant (9.8 m/s²).

As the flow moves down slope, it is cooled by the local heat flux. The constant depth of the slope flow and sensible heat flux is determined using the assumptions of Briggs (1979).

The thermodynamic blocking effects of terrain on the wind flow are determined in terms of the local Froude number (Allwine and Whiteman, 1985):

$$Fr = \frac{V}{N\Delta h_t}$$

$$\Delta h_t = (h_{\max})_{ij} - (z)_{ijk}$$

where,

Fr - is the local Froude number,
V - is the wind speed (m/s) at the grid point,
N - is the Brunt-Väisälä frequency,
Δh_t - is an effective obstacle height (m),
$(h_{max})_{ij}$ - is the highest gridded terrain height within a radius of influence of the grid point (i,j), and,
$(z)_{ijk}$ - is the height of level k of grid point (i,j) above the ground.

Step 2 consists of four sub steps due to the introduction of observational data (Douglas and Kessler, 1988):

- Interpolation
- Smoothing
- O'Brien adjustment of vertical velocities
- Divergence minimisation

Observational data are excluded from the interpolation if the distance between the station and a particular grid point exceeds the maximum radius of influence specified (EPA, 1995b; Scire and Robe, 1997).

An inverse-distance method is utilised to introduce observational data into the Step 1 wind field (Scire *et al*, 2000a):

$$(u,v)_2' = \frac{\frac{(u,v)_1}{R^2} + \sum_k \frac{(u_{obs}, v_{obs})_k}{R_k^2}}{\frac{1}{R^2} + \sum \frac{1}{R_k^2}}$$

where,

$(u_{obs}, v_{obs})_k$ - are the observed wind components at station k,
$(u,v)_1$ - are the Step 1 wind components at a particular grid point,
$(u,v)_2'$ - are the initial Step 2 wind components,
R_k - is the distance from the observational station k to the grid point,
R - is a user defined weighting parameter for the Step 1 wind field.

The interpolation scheme allows data to be heavily weighted in the vicinity of the observed station.

Once observational data has been introduced to Step 1 wind data, the wind field is subject to smoothing to reduce resultant discontinuities in the wind field. Smoothing is undertaken using the following equation (Scire *et al*, 2000a):

$$\left(u_{i,j}\right)_2'' = 0.5u_{i,j} + 0.125\left[u_{i-1,j} + u_{i+1,j} + u_{i,j-1} + u_{i,j+1}\right]$$

where,

(ui,j)" - is the u wind component at grid point (i,j) after smoothing, and
(ui,j) - is the u wind component before smoothing

A similar equation is supplied for the v wind component.

Two methods are available for calculating vertical velocities in CALMET (Scire *et al*, 2000a):

- Method 1: vertical velocities are computed directly from the incompressible conservation of mass equation using the smooth horizontal and vertical wind components;
- Method 2: adjusts the vertical velocity profile so that the values at the top of the modelling domain are zero. The horizontal wind components are, hereafter, readjusted to be mass consistent with the new vertical velocity field.

Method 1 is calculated as follows:

$$\frac{du}{dx}'' + \frac{dv}{dy}'' + \frac{dw_1}{dz} = 0$$

where,

w_1 - is the vertical velocity in terrain-following coordinates, and
u",v" - are the horizontal wind components after smoothing.

This procedure, however, may lead to unrealistically large vertical velocities in the top layers of the grid (Godden and Lurmann, 1983). To avoid this problem, Method 2 is provided (a procedure suggested by O'Brien (1970) to adjust w_1:

$$w_2(z) = w_1(z) - \left(z / z_{top}\right) w_1\left(z = z_{top}\right)$$

The three-dimensional divergence in the wind field is minimised by making use of the procedure provided by Goodin *et al.* (1980). With the use of this procedure, the horizontal wind components (u,v) are iteratively adjusted for a fixed vertical velocity field so that at each grid point, the divergence is less than a user-specified maximum value.

$$\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}<\varepsilon$$

where,

u,v	-	are the horizontal wind components
w	-	is the vertical velocity in terrain following coordinates, and,
ε	-	is the maximum allowable divergence

The horizontal wind components are defined at the grid points, whereas the vertical velocities are defined at the vertical grid cell faces. Therefore, the divergence (D) at grid point (i,j,k) is:

$$D_{ijk}=\frac{w_{i,j,k+1/2}-w_{i,j,k-1/2}}{z_{k+1/2}-z_{k-1/2}}+\frac{u_{i+1,j,k}-u_{i-1,j,k}}{2\Delta x}+\frac{v_{i,j+1,k}-v_{i,j-1,k}}{2\Delta y}$$

where Δx and Δy are the sizes of the grid cell in the x and y direction respectively.

At each grid point, divergence is calculated. The u and v components at the surrounding cells are adjusted so that the divergence at the grid cell point is zero. The adjustments are as follows:

$$(u_{new})_{i+1,j,k}=u_{i+1,j,k}+u_{adj}$$

$$(u_{new})_{i-1,j,k}=u_{i-1,j,k}-u_{adj}$$

$$(v_{new})_{i,j+1,k}=v_{i,j+1,k}+v_{adj}$$

$$(v_{new})_{i,j-1,k}=v_{i,j-1,k}-v_{adj}$$

where the adjustment velocities (u_{adj}, v_{adj}) are:

$$u_{adj} = \frac{-D_{ijk}\Delta x}{2}$$

$$v_{adj} = \frac{-D_{ijk}\Delta y}{2}$$

It should be noted that as divergence is eliminated at a particular grid point, it is created at surrounding grid points. However, through an iterative procedure, the divergence is minimised to a threshold value (ε) throughout the grid.

3.1.2 CALPUFF Dispersion Model

CALPUFF is a non-steady-state Lagrangian Gaussian puff dispersion model which is able to simulate the effects of time- and space-varying meteorological conditions, and thus is able to predict the pollutant transport, transformation and eventual removal from the atmosphere. The CALPUFF model is suitable for application in modelling domains of 50 km to 200 km. The model contains modules for complex terrain effects, overwater transport, coastal interaction effects, building downwash, wet and dry removal and simple chemical transformation (EPA, 1995a). Major features of the CALPUFF model is summarised in Table 3-3 and input data required for CALPUFF is given in Table 3-4 (Scire *et al*, 2000b).

Table 3-3: Major features of the CALPUFF model

Feature	Contents
Sources types	- Point sources (constant or variable emissions) - Line sources (constant or variable emissions) - Volume sources (constant or variable emissions) - Area sources (constant or variable emissions)
Non-steady-state emissions and meteorological conditions	- Gridded 3-D fields of meteorological variables (winds, temperatures) - Spatially-variable fields of mixing height, friction velocity, convection velocity scale, Monon-Obukhov length, precipitation rate - Vertical and horizontally-varying turbulence and dispersion rates - Time-dependent source and emissions data
Efficient sampling functions	- Integrated Puff formulation - Elongated Puff (slug) formulation
Dispersion coefficient (σ_y,σ_z) options	- Direct measurements of σ_v and σ_w - Estimated values of σ_v and σ_w based on the similarity theory - Pasquill-Gifford (PG) dispersion coefficients (rural areas) - McElroy-Pooler (MP) dispersion coefficients (urban areas) - CTDM dispersion coefficients (neutral/stable)
Vertical wind shear	- Puff splitting - Differential advection and dispersion

Feature	Contents
Plume rise	- Partial penetration - Buoyant and momentum rise - Stack tip effects - Vertical wind shear - Building downwash effects
Building downwash	- Huber-Snyder method - Schulman-Scire method
Subgrid scale complex terrain	- Dividing streamline, H_d: - Above H_d, puff flows over the hill and experiences altered diffusion rates - Below H_d, puff deflects around the hill, splits and warps around the hill
Interface to the Emissions Production Model (EPM)	- Time-varying heat flux and emissions from controlled burns and wildfires
Dry Deposition	- Gases and particulate matter - Three options: - Full treatment of space and time variations of deposition with a resistance model - User-specified diurnal cycles for each pollutant - No dry deposition
Overwater and coastal interaction effects	- Overwater boundary layer parameters - Abrupt change in meteorological conditions, plume dispersion at coastal boundary - Plume fumigation - Option to introduce subgrid scale Thermal Internal Boundary Layers (TIBLs) into coastal grid cells
Chemical transformation options	- Pseudo-first-order chemical mechanism for sulphur dioxide, SO_4, NO_x, HNO_3 and NO_3 (MESOPUFF II method) - User-specific diurnal cycles of transformation rates - No chemical conversion
Wet removal	- Scavenging coefficient approach - Removal rate a function of precipitation intensity and precipitation type
Graphical User Interface	- Point-and-click module setup - Enhanced error checking of model inputs - On-line Help files

Table 3-4: Summary of input data used by the CALPUFF dispersion model using the CALMET meteorological model

Input Data	Contents
Geophysical data (CALMET.DAT)	Gridded fields of: - surface roughness lengths (z_0) - land use categories - terrain elevations - leaf area indices
Meteorological data (CALMET.DAT)	Gridded fields of: - u,v,w wind components (3-D) - air temperature (3-D) - surface friction velocity (u_*)

Input Data	Contents
	- convective velocity scale (w_*) - mixing height (z_i) - Monon-Obukhov length (L) - PGT stability class - Precipitation rate Hourly values of the following parameters at surface meteorological stations: - air density (ρ_a) - air temperature - short-wave solar radiation - relative humidity - precipitation type
Restart Data (RESTARTB.DAT)	Model puff data generated from a previous run (allows continuation of a pervious model run)
Emissions Data (CALPUFF.INP, PTEMARB.DAT, BAEMARB.DAT, VOLEM.DAT, LNEMARB.DAT)	Point source emissions: - Source and emissions data for point sources with constant or cyclical emission parameters (CALPUFF.INP) - Source and emissions data for point sources with arbitrary-varying emission parameters (PTMARB.DAT) Area source emissions: - Emissions and initial size, height and location for area sources with constant or cyclical emission parameters (CALPUFF.INP) - Gridded emissions data for buoyant area sources with arbitrary-varying emission parameters (BAEMARB.DAT) Volume source emissions: - Emissions, height, size and location of volume sources with constant or cyclical emission parameters (CALPUFF.INP) - Emissions data for volume sources with arbitrary-varying emission parameters (VOLEM.DAT) Line source emissions: - Source and emissions data, height, length, location, spacing and orientation of buoyant line sources with constant or cyclical emission parameters (CALPUFF.INP) - Emissions data for buoyant line sources with arbitrary-varying emission parameters (LNEMARB.DAT)
Deposition Velocity Data (VD.DAT)	Deposition velocity for each user-specified species for each hour of a diurnal cycle
Ozone Monitoring Data (OZONE.DAT)	Hourly ozone measurements at one or more monitoring stations
Chemical Transformation Data (CHEM.DAT)	Species-dependent chemical transformation rates for each hour of a diurnal cycle
Hill Data (HILL.DAT)	Hill shape and height parameters in CTDMPLUS format for use in the sub-grid scale complex terrain module (CTSG)
CTSG Receptors (HILLRCT.DAT)	Receptor locations and associated hill ID in CTDMPLUS format
Subgrid Scale Coastal Boundary Data (COASTLN.DAT)	File containing X,Y coordinates of subgrid scale coastlines to be treated by CALPUFF
Boundary Data for Diagnostic Mass Flux Option (FLUXBDY.DAT	File containing X,Y coordinates of boundaries used to evaluate hourly mass transport

The CALPUFF (puff-based) dispersion model has numerous features as discussed in Table 3-3 and contains complex algorithms for the computation of the dispersion of pollutants taking into consideration the:

- Atmospheric turbulence (with the use of methods provided by Arya (1984), Briggs (1985), Caughey (1981), Draxler (1976), Gifford (1976), Hanna *et al*. (1977), Heffter (1965), Hicks (1985), Nieuwstadt (1984), Panofsky *et al.* (1977) and Weil (1985));
- Buoyancy (with the use of methods provided by Pasquill (1976) and Irwin (1979));
- Initial plume size;
- Puff-splitting
- Convective boundary layer (with the use of methods provided by Hanna *et al*. (1986), Hicks (1985) and Weil *et al.* (1997));
- Vertical puff stretching;
- Building downwash (with the use of algorithms provided by Huber and Snyder (1976), Huber (1977), Scire and Schulman (1980) and Schulman and Hanna (1986));
- Plume rise (with the use of methods provided by Briggs (1973), Briggs (1975), Hanna and Chang (1991), Hoult and Weil (1972) and Weil (1988)); and,
- Complex terrain.

In a simplistic review, puff models (such as the CALPUFF model) represent a continuous plume of pollutant material as a number of discreet packets with the basic equation for the contribution of a puff at a receptor given as (Scire *et al*, 2000b):

$$C = \frac{Q}{2\pi\sigma_x\sigma_y} g \exp\left[-d_a^2/\left(2\sigma_x^2\right)\right]\exp\left[-d_c^2/\left(2\sigma_y^2\right)\right]$$

$$g = \frac{2}{(2\pi)^{1/2}\sigma_z}\sum_{n=-\infty}^{\infty}\exp\left[-\left(H_e + 2nh\right)^2/\left(2\sigma_z^2\right)\right]$$

where,

C - is the ground-level concentration (g/m³)
Q - is the pollutant mass (g) in the puff
σ_x - is the standard deviation (m) of the Gaussian distribution in the along-wind direction
σ_y - is the standard deviation (m) of the Gaussian distribution in the cross-wind direction
σ_z - is the standard deviation (m) of the Gaussian distribution in the vertical direction
d_a - is the distance (m) from the puff centre to the receptor in the along-wind direction

d_c - is the distance (m) from the puff centre to the receptor in the cross-wind direction
g - is the vertical term (m) of the Gaussian equation
H - is the effective height (m) above the ground of the puff centre
h - is the mixed-layer height (m)

For a horizontal symmetric puff, with σx = σy, the puff equation can be simplified as follows (Scire *et al*, 2000b):

$$C(s) = \frac{Q(s)}{2\pi\sigma_y^2(s)} g(s) \exp\left[-R^2(s)/\left(2\sigma_y^2(s)\right)\right]$$

where,

R - is the distance (m) from the centre of the puff to the receptor, and,
s - is the distance (m) travelled by the puff

Integrating the above equation over the distance of puff travel, ds, during the sampling step, dt, gives the time averaged concentration, $\overline{C}$ (Scire et al, 2000b):

$$\overline{C} = \frac{1}{ds}\int_{s_0}^{s_0+ds} \frac{Q(s)}{2\pi\sigma_y^2(s)} g(s) \exp\left[-R^2(s)/\left(2\sigma_y^2(s)\right)\right] ds$$

where s_0 is the initial value of s at the start of the sampling step.

A systematic solution of this equation can be obtained if it is assumed that the puff distance descrepencies during the sampling step are in the R(s) and Q(s) terms. Assuming the trajectory segment is a straight line, and transforming s to a dimensionless trajectory variable (p) the radial distance to the receptor at (x_r,y_r) is (Scire et al, 2000b):

$$R(s) = \left[\left(x_1 - x_r + pdx\right)^2 + \left(y_1 - y_r + pdy\right)^2\right]^{1/2}$$

where,

p - is zero at the start of the trajectory segment (x_1,y_1)
p - is 1 at the end of the trajectory segment (x_1,y_1), and
dx, dy - are the incremental X and Y distances travelled by the puff ($dx=x_2-x_1$, and $dy=y_2-y_1$).

The exponential variation of Q, taking into account the removal and chemical transformation process, is expressed as a linear function of the sampling interval (Scire et al, 2000b):

$$Q(s) = Q(s_0) + p[Q(s_0 + ds) - Q(s_0)]$$

Transforming to p coordinates, the equation becomes (Scire et al, 2000b):

$$C = \frac{g}{2\pi\sigma_y^2}\left\{Q(s_0)\int_0^1 \exp\left[-R^2(p)/\left(2\sigma_y^2\right)\right]dp + \left[Q(s_0 + ds) - Q(s_0)\right]\int_0^1 p\exp\left[-R^2(p)/\left(2\sigma_y^2\right)\right]dp\right\}$$

The solution of the integrals of the above equation is expressed in terms of error functions and exponentials (Scire et al, 2000b):

$$\overline{C} = \frac{g}{2\pi\sigma_y^2}\{Q(s_0)I_1 + [Q(s_0 + ds) - Q(s_0)]I_2\}$$

where,

$$I_1 = \left[\frac{\pi}{2a}\right]^{1/2}\exp\left[\frac{b^2}{2a} - \frac{c}{2}\right]\left\{erf\left[\frac{a+b}{(2a)^{1/2}}\right] - erf\left[\frac{b}{(2a)^{1/2}}\right]\right\}$$

and,

$$I_2 = \frac{-bI_1}{a} + \frac{1}{a}\exp\left[\frac{b^2}{2a} - \frac{c}{2}\right]\left\{\exp\left[\frac{-b^2}{2a}\right] - \exp\left[\frac{-1}{2}\left(a + 2b = \frac{b^2}{a}\right)\right]\right\}$$

with reference to,

$$a = \left(dx^2 + dy^2\right)/\sigma_y^2$$

$$b = \left[dx(x_1 - x_r) + dy(y_1 - y_r)\right]/\sigma_y^2$$

$$c = \left[(x_1 - x_r)^2 + (y_1 - y_r)^2\right]/\sigma_y^2$$

The horizontal dispersion coefficient (σ_y) and the vertical term (g) are evaluated and held constant throughout the trajectory segment.

3.1.3 Model Accuracy

Comparisons between CALPUFF results, and results generated by the Industrial Source Complex Model Short Term version 3 (ISCST3) model, have shown that predictions form the CALPUFF model are generally more conservative (Strimaitis, *et al.*, 1998). From numerous investigations, modelled predictions from the ISC model is typically within a factor of 2 to 10 for areas of complex topography with a high incidence of calm wind conditions. When applied in flat or gently rolling terrain, the United States Environmental Protection Agency (US-EPA) (EPA, 1986) considers the range of uncertainty of the ISC to be -50% to 200%. Predicted average concentrations using CALPUFF has a greater correlation with observations in comparison to ISCST3 (Wang *et al.*, 2006). The accurate prediction of instantaneous peaks, however, are the most difficult with the CALPUFF and ISCST3 models becoming less accurate (Wang *et al.*, 2006). Instantaneous peak releases are therefore normally performed with more complicated dispersion models specifically fine-tuned and validated for the location. The duration of these short-term, peak concentrations are frequently limited to a few minutes and on-site meteorological data are then essential for accurate predictions.

CALPUFF has undergone sufficient testing to secure its accuracy for assessing impacts on air quality related studies. The public comments on the CALPUFF model have provided general consensus that the technical basis of the CALPUFF modeling system has merit and provides substantial capabilities to not only address long range transport, but to address transport and dispersion effects in complex wind situations. Commenters generally agreed that the CALPUFF modeling system has adequate accuracy for use in the 50 km to 200 km range, with some studies showing that acceptable results can be achieved on larger areas of 200 km to 300 km (EPA, 2003).

3.1.4 Dispersion Model Data Inputs for the Study Area

3.1.4.1 Receptor Locations and Modelling Domain

A modelling domain was defined in order to encapsulate the Vaal Airshed. The extent of this domain is demonstrated in Figure 1-1. The meteorology was modelled and the dispersion of pollutants simulated for the entire area covering ~120 km (east-west) by 135 km (north-south), with ambient ground-level concentrations and deposition levels being predicted for over 16 200 receptor points. The regular Cartesian receptor grid selected has a resolution of 1 000 m by 1 000 m. Discrete receptor points were specified for each of the monitoring station locations to facilitate the simulation of concentrations at these locations for application in the validation and calibration of the model.

3.1.4.2 Meteorological Data Inputs

CALMET was used to simulate the meteorological field within the study area, including the spatial variations – both in the horizontal and in the vertical - and temporal variations in the windfield and atmospheric stability. Upper air data required by CALMET include pressure, geopotential height, temperature, wind direction and wind speed for various levels. No upper air monitoring stations are located within the study area with the nearest SAWS station being located at Irene, City of Tshwane Metropolitan Municipality. Use was therefore made of ETA-model data for four locations as obtained from the SAWS. Twice daily data were obtained for five sounding levels. The initial guess field in CALMET was therefore determined as a combined weighing of surface winds at one Eskom monitoring station, one ArcelorMittal monitoring station, six Sasol monitoring stations and three SAWS stations, vertically extrapolated using Similarity Theory (Stull, 1997) and upper air winds. Eskom monitoring station included Makalu, with the Sasol monitoring sites for which data were obtained including Hospital, AJ Jacobs, Boiketlong, Leitrim, Steam Station 2 and Grootvlei. The SAWS stations used in the study were Johannesburg (OR Tambo), Vereeniging and Springs (Figure 4-8) (see Section 4.5 for a description on dispersion potential).

The CALMET meteorological model requires hourly average surface data as input; including wind speed, wind direction, ceiling height, cloud cover, temperature, relative humidity, pressure and precipitation. The data availability for each of the surface and upper-air stations used in the current study is given in Table 3-1.

Table 3-5: Data availability for surface data from industrial and South African Weather Service (SAWS) meteorological stations within the study area and calculated upper air from ETA modelled data obtained from the SAWS for the period 2004 to 2006.

Data	Station	Period		
		2004	2005	2006
Surface data (SAWS)	Johannesburg	98%	98%	98%
	Vereeniging	99%	96%	95%
	Springs	99%	100%	100%
Surface data (Eskom)	Makalu [(a)]	100%	-	-
Surface data (Sasol)	Hospital [(b)]	-	-	100%
	AJ Jacobs [(b)]	-	-	100%
	Steam Station 2 [(b)]	99%	99%	99%
	Boiketlong [(b)]	-	-	100%
	Leitrim [(b)]	99%	93%	96%
	Grootvlei	94%	84%	85%
Surface data	Jabavu	55%	62%	65%

Data	Station	Period		
		2004	2005	2006
(City of Johannesburg)	Orange Farm	62%	84%	84%
Surface data (ArcelorMittal)	ArcelorMittal	65%	89%	88%
Upper air data	ETA	88%	97%	96%

Notes:
(a) Makalu was decommissioned in December 2004.
(b) A problem was identified in the averaging wind speed and wind direction data from 10 minute to hourly averages. Unfortunately the 10 minute data was over written with the averaged data and was subsequently lost for the period 2004 and 2005 and was only available for October to December 2006 (pers comm. Ristoff van Zyl from Sasol).

A three dimensional meteorological data set for the region was output by the CALMET model for application in the CALPUFF model. This data set parameterised spatial (horizontal and vertical) and temporal variations in the parameters required to model the dispersion and removal of pollutants, including: vertical wind speed, wind direction, temperature, mixing depths, atmospheric stability, (etc.). Meteorological parameters were projected at various heights above the ground, viz.: 20m, 200m, 500m, 1500m, and 3000m. In projecting vertical changes in the windfield, temperature (etc.) it was possible to accurately parameterize the atmospheric conditions characteristic of within valley layers, transitional layers and atmospheric layers located above the terrain. The three-dimensional data set was generated for the base-case years selected (2004 to 2006) and comprised hourly averages for each parameter, thus providing information for each time interval required by the non-steady state CALPUFF dispersion model.

3.1.4.3 Source and Emissions Data Inputs

Point, area and volume sources (in the form of CALPUFF.INP files) were inputted into the CALPUFF model. Source parameter requirements for input into the CALPUFF model include stack height, stack diameter, exit temperature, exit velocity, elevation of stack base above sea level and source location. For fugitive emission sources, the dimensions of the source as well as the location are required. Emissions rates for each pollutant and source were also required as input to the model. The emissions data input in the dispersion simulations are provided in Chapter 6.

3.1.4.4 Chemical Transformation

CALPUFF allows for first order chemical transformation modelling to determine gas phase reactions for SO_x and NO_x. Chemical transformation rates were computed internally by the model using the RIVAD/ARM3 Scheme. This scheme allows for the separate modelling of nitrogen dioxide and nitric oxide, whereas the default MESOPUFF II Scheme only makes

provision for the combined modelling of NO_x. The RIVAD/ARM3 scheme treats the nitric oxide and nitrogen dioxide conversion process in addition to the nitrogen dioxide and total NO_3 and sulphur dioxide to SO_4 conversions, with equilibrium between gaseous HNO_3 and ammonium nitrate aerosol (Scire *et al*, 2000b). The scheme uses user-input ozone data (together with modelled radiation intensity) as surrogates for the OH concentration during the daytime when gas phase free radical chemistry is active. Measured ambient ozone concentrations were used for input into the dispersion model for the chemical transformation modelling.

3.2 Emissions Quantification Methodology

3.2.1 Industrial Sources

In order to obtain recent emissions data from industry, a detailed questionnaire was compiled and sent out to all identified industries within the Vaal Airshed (Liebenberg-Enslin *et al.*, 2007) (see Appendix A for example). Of all identified industries and mines, 51% responded with updated emissions information reflecting current operating conditions (as for 2006). Information for 37% of the remaining industries was obtained from the NEDLAC Dirty Fuels study conducted in 2004 and EIA information with 12% of the sources unaccounted for.

3.2.2 Domestic Fuel Burning

The numbers and spatial distribution of households using various fuel types were estimated based on energy use statistics and household numbers from the 2001 Census. A more recent study undertaken by the Bureau of Market Research at UNISA (2006) indicated that the African population for the Free State and Gauteng provinces has increased by 0.47% and 0.97% from 2001 to 2006, respectively. Thus there may be an under prediction for domestic fuel burning of less than 1% based on population predictions. Due to the 2001 Census data being outdated reference was also made to a study conducted by NOVA during 2003 – 2004 in Zamdela where coal burning households were surveyed. The aim of this study, however, was to determine the reduction in coal use due to the introduction of the Basa Njengo Magogo coal burning method. This information was therefore not useful in determining the actual amount of coal per household.

Typical monthly fuel use figures, given by Afrane-Okese (1998) for various house types, were used together with the numbers of households using the various fuel types to estimate the total quantities of fuels being consumed. Quantities of fuels used were estimated on a community-by-community basis and selected emission factors applied to calculate resultant emissions. The emission factors selected for use in the study are given in Table 3-6. Table 3-7 provides the estimated total amount of fuel used within the Vaal Airshed.

Table 3-6: Emission factors selected for use in estimating atmospheric emission occurring as a result of coal, paraffin and wood combustion by households.

Fuel	Emission Factors		
	SO_2 (g/kg)	NO (g/kg)	PM10 (g/kg)
Coal	11.6[(a)]	4[(d)]	12[(f)]
Paraffin	0.1[(b)]	1.5[(e)]	0.2[(e)]
Wood	0.2[(c)]	1.3[(c)]	17.3[(c)]

Notes:
(a) Based on sulphur content of 0.61% and assuming 95% of the sulphur is emitted.
(b) Based on sulphur content of paraffin (<0.01% Sulphur).
(c) Based on US-EPA emission factor for residential wood burning (EPA, 1996).
(d) Based on the AEC household fuel burning monitoring campaign (Britton, 1998) which indicated that an average of 150 mg/MJ of NO_x were emitted during cooking and space heating. Given a calorific value of 27 MJ/kg, the emission rate was estimated to be ~4 g/kg.
(e) US-EPA emission factors for kerosene usage (EPA, 1996).
(f) Initially taken to be 6 g/kg based on 2001 synopsis of studies pertaining to emissions from household coal burning (Scorgie *et al*., 2001). Results from simulations using this emission factor undertaken as part of the current study indicated that fine particulate concentrations within household coal burning areas are under predicted by a factor of two. This emission factor was therefore scaled to 12 g/kg in order to facilitate the more accurate simulation of airborne fine particulates within household coal burning areas.

Table 3-7: Sources of energy used by households within the Vaal Airshed (based of 2001 Census data and given as a percentage of total energy consumption).

Source	Lighting (%)	Cooking (%)	Heating (%)
Electricity	86	79	74
Gas	0.1	1	1
Paraffin	2	17	10
Wood	N/A	1	2
Coal	N/A	2	11
Animal dung	N/A	0.2	0.1
Solar	0.1	0.2	0.2
Other	0.1	0.1	2

N/A: Not Applicable

3.2.3 Mining Operations

In quantifying the fugitive emissions from the Sigma and New Vaal collieries, use was made of the US-EPA emission factors as no locally derived emission factors are available. The US-EPA has derived emission factors for numerous mining activities which have been summarised in the AP42 documents under Section 11.9 (Western Surface Coal Mining)[3].

[3] http://www.epa.gov/ttn/chief/ap42/

3.2.4 Wind Blown Dust from Eskom's Ash Dams and Dumps

The calculation of an emission rate for every hour of the simulation period was carried out using the ADDAS model. This model, developed by Airshed for specific use by Eskom in the quantification of fugitive emissions from its ash dumps, is based on the dust emission model proposed by Marticorena and Bergametti (1995). This model accounts for the variability in source erodibility through the parameterisation of the erosion threshold (based on the particle size distribution of the source) and the roughness length of the surface. In the quantification of wind erosion emissions, the model incorporates the calculation of two important parameters: (i) the threshold friction velocity of each particle size, and (ii) the vertically integrated horizontal dust flux, in the quantification of the vertical dust flux (i.e. the emission rate).

The location, dimensions and orientations of the ash dumps were taken from recent satellite imagery and topographical maps. Particle size distribution data from the Matimba ash dump (Scorgie et al, 2006) (Table 3-8) were used in the emission estimates given that no site-specific data in this regard could be obtained.

Table 3-8: Particle size distribution for the typical materials found on the ash dumps (as obtained from measured data from the Matimba Power Station operations).

Ash	
µm	**Fraction of Total Mass**
600	0.0472
404.21	0.0269
331.77	0.0296
272.31	0.0336
223.51	0.0404
183.44	0.0503
150.57	0.0609
123.59	0.0687
101.44	0.0728
83.26	0.0739
68.33	0.072
56.09	0.0669
46.03	0.0607
37.79	0.0537
31.01	0.0471
25.46	0.0407
17.15	0.0628
14.08	0.0528
7.78	0.0285
3.53	0.0105

3.2.5 Vehicle Emissions

In estimating petrol-driven vehicle emissions the following steps were followed:

- The petrol-driven vehicle fleets were characterised based on the vehicle sales for 2000 (obtained from Anton Moldan of SA Petroleum Industry Association). The vehicle sales for 2000 comprise detailed information on petrol-driven vehicles sold between including: engine capacity and catalytic converters (etc.).

- A more recent national vehicle population data base was obtained from the National Transport Information System (NATIS) for the period of 2005 to supplement the spatially-resolved 2000 engine capacity data obtained from SA Petroleum Industry Association.

- Annual leaded and unleaded petrol sales data, obtained from South African Petroleum Industry Association (SAPIA) per magisterial district for 2004 (Table 3-9), obtained from SAPIA data per magisterial district for 2006, were used to estimate the total vehicle kilometers travelled using fuel consumption rates suited to each engine capacity class and general fuel type. (Petrol consumption rates range from 7.7 to 15.1 litres per 100 km) (Wong, 1999).

- Locally developed emission factors published by Wong (1999) were applied taking into account variations in such factors for different energy capacities. Emission factors used are given in Table 3-10 and Table 3-11. Emissions were calculated by multiplying the emission factors by the total vehicle kilometers travelled (VKT) estimated on the basis of the 2006 fuel sales data.

Table 3-9: Leaded and unleaded petrol sales within the Vaal Airshed during 2006 as obtained from Anton Moldan, South African Petroleum Industry Association.

Magisterial District	2006 Fuel Sales within the Vaal Airshed (Litres/Annum)	
	Lead Replacement Petrol	Unleaded Petrol
Alberton	63 103 689	74 761 516
Benoni	68 445 049	75 322 346
Boksburg	58 772 808	82 142 120
Brakpan	29 951 228	27 698 022
Brits	25 778 315	32 799 595
Bronkhorstspruit	15 904 413	20 043 790
Balfour	5 251 026	10 780 033
Cullinan	6 274 607	4 764 748
Frankfort	4 043 998	3 288 779
Germiston	84 113 076	133 712 749
Heilbron	3 143 949	2 255 120
Heidelberg (Tvl)	11 857 863	17 615 396
Johannesburg	415 893 559	542 370 272
Krugersdorp	45 169 509	52 356 568

Magisterial District	2006 Fuel Sales within the Vaal Airshed (Litres/Annum)	
	Lead Replacement Petrol	Unleaded Petrol
Kempton Park	103 944 224	131 702 687
Koppies	2 106 858	5 112 227
Nigel	12 470 450	10 911 712
Pretoria	335 171 318	511 348 121
Parys	5 208 162	5 155 609
Potchefstroom	25 182 024	31 663 236
Randfontein	21 604 667	18 588 473
Roodepoort	74 087 410	128 281 483
Randburg	122 602 264	345 380 532
Sasolburg	67 316 725	34 720 763
Springs	37 170 449	35 894 568
Vanderbijlpark	46 132 668	46 130 541
Vereeniging	54 879 358	74 082 905
Westonaria	20 725 082	13 111 435
Wonderboom	42 239 158	55 318 351

Table 3-10: Emission factors for non-catalytic converter equipped petrol-driven vehicles used for the estimation of vehicle emissions

Pollutant	Units	Highveld	
		Leaded Petrol	Unleaded Petrol
THC	g/km	1.79	1.63
NO_X	g/km	1.99	2.15
CO	g/km	16.13	10.70
CO_2	g/km	188.00	190.00
SO_2	g/km	0.05	0.04
CH_4	g/km	0.06	0.04
NMTOC	g/km	1.74	1.59
1,3 Butadiene	g/km	0.02	0.03
Benzene	g/km	0.03	0.02
Formaldehyde	mg/km	14.57	16.50
Acetaldehyde	mg/km	4.93	11.30
Lead	g/km	0.02	
N_2O	mg/km	5.00	5.00

Sources: Wong (1999), Copert (2000) for lead and N_2O

Table 3-11: Emission factors for catalytic converter equipped petrol-driven vehicles used for the estimation of vehicle emissions

Pollutant	Units	Highveld	
		Leaded Petrol	Unleaded Petrol
THC	g/km	0.54	1.03
NO_X	g/km	0.86	0.93
CO	g/km	3.63	4.30
CO_2	g/km	257.00	243.00
SO_2	g/km	0.01	0.02

Pollutant	Units	Highveld	
		Leaded Petrol	Unleaded Petrol
CH4	g/km	0.03	0.05
NMTOC	g/km	0.51	0.98
1,3 Butadiene	g/km	0.00	0.00
Benzene	g/km	0.02	0.02
Formaldehyde	mg/km	3.47	3.60
Acetaldehyde	mg/km	4.93	8.00
Lead	g/km	0.02	
N_2O	mg/km	5.00	5.00

Source: Wong (1999), Copert (2000) for lead and N_2O

In estimating diesel-driven vehicle emissions the following steps were followed:

- Average percentages of light commercial vehicles (LCVs) and medium and heavy commercial vehicles (M&HCVs) within the national diesel vehicle fleet were obtained from the NATIS 2005 vehicle population data for Gauteng, Free State, Mpumalanga and the North West Province.

- Diesel consumption rates were obtained for LCVs, MCVs and HCVs for highveld applications from Stone (2000) and Wong (1999). Such rates varied from 10.5 to 24.4 litres per 100 km.

- Annual diesel sales data, obtained from SAPIA per magisterial district for 2006 (Table 3-12), were used to estimate the total vehicle kilometres travelled using fuel consumption rates suited to each vehicle weight category.

- Locally developed emission factors published by Stone (2000) were applied taking into account variations in vehicle weight categories (highveld factors) (Table 3-13). Emissions were calculated by multiplying the emission factors by the total vehicle kilometres travelled (VKT) estimated on the basis of the 2006 fuel sales data.

Table 3-12: Diesel sales within the Vaal Airshed during 2006 as obtained from Anton Moldan, South African Petroleum Industry Association.

Magisterial District	2006 Fuel Sales within the Vaal Airshed (litres/annum)
	Diesel
Alberton	142 600 629
Benoni	65 286 343
Boksburg	59 905 659
Brakpan	36 071 165
Brits	62 528 175
Bronkhorstspruit	23 156 394
Balfour	12 229 861

Magisterial District	2006 Fuel Sales within the Vaal Airshed (litres/annum)
	Diesel
Cullinan	6 609 371
Frankfort	10 388 670
Germiston	141 789 939
Heilbron	3 935 819
Heidelberg (Tvl)	19 335 318
Johannesburg	558 673 261
Krugersdorp	85 876 185
Kempton Park	126 789 531
Koppies	16 598 418
Nigel	28 909 287
Pretoria	463 496 496
Parys	8 196 844
Potchefstroom	26 888 137
Randfontein	24 793 638
Roodepoort	53 546 946
Randburg	123 332 507
Sasolburg	137 603 263
Springs	25 346 532
Vanderbijlpark	54 671 269
Vereeniging	74 281 995
Westonaria	17 179 230
Wonderboom	35 050 176

Table 3-13: Highveld emission factors for diesel-driven vehicles used in the quantification of vehicle emissions for the Vaal Airshed.

Pollutant	Units	Sources: Wong (1999)	Source: Stone (2000)
		Diesel – LCVs	Diesel - M&H
THC	g/km	1.010	1.010
NOX	g/km	11.680	11.680
CO	g/km	3.540	3.540
CO_2	g/km	739.000	739.000
SO_2	g/km	1.540	1.540
CH_4	g/km	0.147	0.088
NMTOC	g/km	0.863	0.922
1,3 Butadiene	g/km	0.007	0.004
Benzene	g/km	0.008	0.000
Formaldehyde	mg/km	0.016	0.016
Acetaldehyde	mg/km	0.010	0.010
Particulates	g/km	0.640	0.640
N_2O[(a)]	mg/km	30.000	30.000
FUEL CONSUMPTION (l/km)		0.239	0.244

(a) Use was made of Coppert emission factors for the estimation of N_2O emissions given the absence of local emission factors for this pollutant

CHAPTER 4
REGIONAL CLIMATE AND ATMOSPHERIC DISPERSION POTENTIAL OVER THE VAAL AIRSHED

The meteorological characteristic of a site governs the transport (viz. wind speed and wind direction) and dispersion (viz. turbulence and mixing height of lower boundary layer) of pollutants in the atmosphere (Pasquill and Smith, 1983; Godish, 1990). The extent to which pollution will accumulate or disperse in the atmosphere is dependent on the vertical (defined by the stability of the atmosphere and the depth of the surface mixing layer) and horizontal (a function of the wind field) components of motion. The speed of the wind field in turn will determine the distance the plume will travel before it reaches ground level and the rate of plume dilution (Shaw and Munn, 1971; Pasquill and Smith, 1983; Preston-Whyte and Tyson, 1989, Oke, 1990).

Variations in spatial, diurnal and seasonal wind field and stability changes are functions of atmospheric processes (Goldreich and Tyson, 1988). It is therefore necessary to consider processes at macro- and meso-scales in order to accurately parameterise the atmospheric dispersion potential of a particular area. Macro-scale ventilation characteristics of an area are determined by the general circulation, and thus synoptic systems that dominate, within the region. Meso-scale processes include thermo-topographically induced circulations.

4.1 General Synoptic Circulations that Influence Weather over Southern Africa

The general circulation over southern Africa is influenced by systems that originate in the tropics in the north, and temperate latitudes to the south. The high pressure systems or subtropical high pressure cells also influence the general circulation over the southern hemisphere (The Standard Encyclopaedia of Southern Africa, 1971; Preston-Whyte and Tyson, 1989; Garstang et al, 1996; Tyson, 1997) (Figure 4-1).

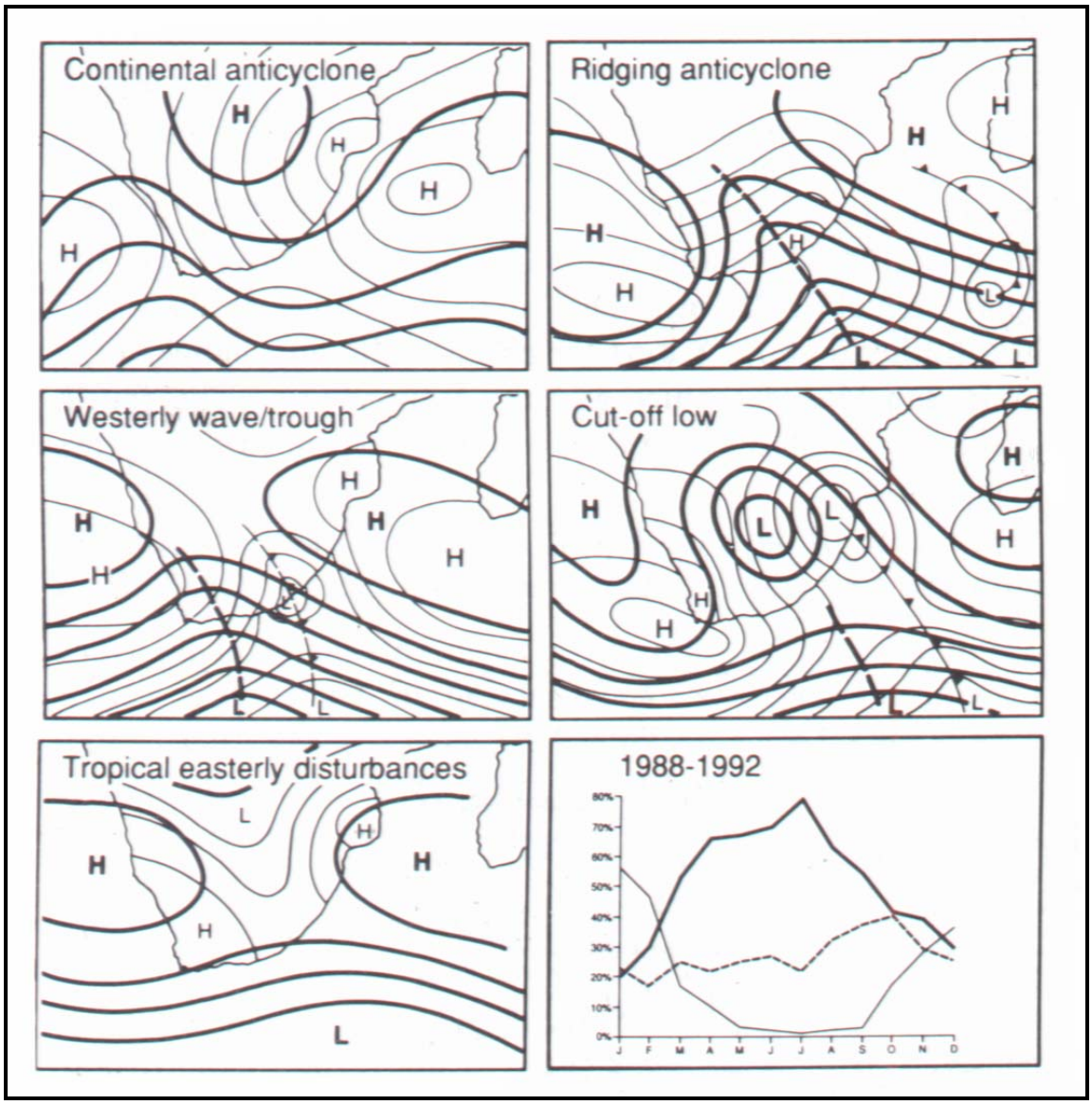


Figure 4-1: Major synoptic circulation types affecting southern Africa and their monthly frequencies of occurrence over a five year period (after Preston-Whyte and Tyson, 1988 and Garstang et al., 1996).

4.1.1 Subtropical Systems

The mean circulation over southern Africa is dominated by anticyclonic systems, creating highly stable atmospheric conditions (Taljaard, 1955; The Standard Encyclopaedia of Southern Africa, 1971; Tyson et al., 1976; Preston-Whyte et al., 1977; Tyson et al., 1988; Preston-Whyte and Tyson, 1989; Cosijn and Tyson, 1996, Tyson et al., 1996c; Tyson and Gatebe, 2001) with a 70% frequency of occurrence in the middle of winter (July) (Tyson et al., 1996c). These systems are deep and tilt towards the northwest with height. The semi-

permanent anticyclonic systems that influence the circulation over southern Africa consist of the South Atlantic Anticyclone, South Indian Anticyclone and Continental High. In winter the anticyclonic systems intensify and move northward with the migration of the Inter-Tropical Convergence Zone (The Standard Encyclopaedia of Southern Africa, 1971; Preston-Whyte and Tyson, 1989). The South Atlantic and South Indian anticyclones move ~6° north in winter (Preston-Whyte and Tyson, 1989). The South Indian Anticyclone fluctuates more on a longitudinal scale than the Atlantic Anticyclone (The Standard Encyclopaedia of Southern Africa, 1971) with the South Indian Anticyclone migrating as much as 24° west during winter and the South Atlantic Anticyclone moving ~13° east (Preston-Whyte and Tyson, 1989). In summer, the Continental High is observed to weaken and move southward (The Standard Encyclopaedia of Southern Africa, 1971).

Stable conditions with low wind speeds reduce mixing and thus dispersion of pollutants in the atmosphere.

4.1.2 Tropical Systems

Tropical disturbances occur as easterly waves and lows. Easterly waves are semi-stationary and form in deep easterly currents in the vicinity of the easterly jet. The axes of the systems are not displaced with height with convergence occurring east of the trough and divergence above the flow at ~ 500 hPa. This results in strong uplift and rainfall. In unstable conditions and associated northerly winds, rainy periods will occur east of the trough over wide areas (Preston-Whyte and Tyson, 1989). The unstable atmospheric conditions enhance the dispersion of pollutants form emission sources. The pollutant concentrations are thus diluted before coming down to ground level.

Easterly lows are associated with convergence at the surface (as with easterly waves) but divergence occurs higher up in the troposphere (Preston-Whyte and Tyson, 1989).

Surface troughs are usually associated with moist air to the northeast and dry air to the southwest, with thunderstorms occurring in the convergence zone (Preston-Whyte and Tyson, 1989; The Standard Encyclopaedia of Southern Africa, 1971). Thus the storms occur in two opposing currents, viz. a warm humid surface current and a cool subsiding southwestern current at a height of 4 km. The primary thermal surface convection initiates the instability of the atmosphere, while the convergence of the surface air over the southwestern air feeds the instability and results in heavy thundershower activity (The Standard Encyclopaedia of Southern Africa, 1971).

4.1.3 Temperate Systems

Temperate systems are made up of westerly waves, cut-off lows, southerly meridional flow, ridging anticyclones, west coast troughs and cold fronts (Preston-Whyte and Tyson, 1989).

4.1.3.1 Westerly Waves

Westerly wave systems slope westward with height with convergence occurring at the surface to the rear of the trough and divergence ahead of the trough line. Although the systems may bring about rainfall, this will normally occur over coastal regions and seldom extend over the interior (Preston-Whyte and Tyson, 1989).

4.1.3.2 Cut-Off Lows

Cut-off lows are an intense form of a westerly wave. These systems are unstable and slope westward with height with strong convergence and vertical motion (aiding in the dispersion potential of pollutants). With these characteristics, cut-off lows are associated with flood producing rains over South Africa (Preston-Whyte and Tyson, 1989).

4.1.3.3 Southerly Meridional Flow

This system is a surface circulation pattern over the south of the subcontinent. The system has a strong pressure gradient with a high to the west and a low to the east. This results in a region of upper level divergence overlying an area of convergence west of the cold front. The resultant vertical motion gives rise to light rainfall over coastal regions and the Lowveld (Preston-Whyte and Tyson, 1989).

4.1.3.4 Ridging Anticyclones

Ridging anticyclones are associated with westerly waves in the upper atmosphere (500 hPa). They develop due to the steep pressure gradient over the Indian Ocean and adjacent inland areas, promoting strong advection of moist unstable air over land (aiding in the dispersion potential of pollutants). Weakening inland pressure gradient and meso-scale orographic forcing with upper level divergence results in wide spread uplift and general rainfall over the eastern regions of southern Africa (aiding in wet deposition of pollutants within the atmosphere) (Preston-Whyte and Tyson, 1989).

4.1.3.5 West Coast Troughs

West coast troughs are systems that occur due to a surface trough over the west coast and an upper level westerly wave to the west of the continent. Surface convergence and upper level divergence allows for upward vertical; motion (aiding in the dispersion potential of pollutants) and thus general rainfall over the central and western regions of southern Africa (aiding in wet deposition of pollutants within the atmosphere) (Preston-Whyte and Tyson, 1989).

4.1.3.6 Cold Fronts

Cold fronts (also known as mid-latitude frontal depressions) are systems that occur together with westerly waves and cut-off lows, and therefore cannot be seen to occur in isolation (Preston-Whyte and Tyson, 1989). Frontal depressions form in the westerlies and move eastwards towards the sub-continent (The Standard Encyclopaedia of Southern Africa, 1971). Pre-frontal conditions are associated with northwesterly air flow with post-frontal associated with southwesterly. The systems result in sharp decreases in temperature and generally occur in winter. Pre-frontal conditions give rise to Berg Wind conditions due to the occurrence of Coastal Lows that precede the front. Coastal Lows result in the movement of air from the interior to coastal areas increasing in temperature with the adiabatic lapse rate as it descends the escarpment. Convection occurs to the rear of the front and rainfall generally occurs as a result over the coastal areas (The Standard Encyclopaedia of Southern Africa, 1971; Preston-Whyte and Tyson, 1989). As the cold air circulates over land, the continental warm air will undercut the cold air forcing it to rise. This causes a natural inversion layer to develop between the two layers of air. If sources of pollutant emissions are below this inversion, the pollutants will be trapped within this layer. Higher wind speeds associated with this temperate system, however, will aid in the dispersion potential of pollutants (Preston-Whyte and Tyson, 1989).

4.2 Persistent Elevated Inversions

The impact of synoptic systems and weather disturbances on the dispersion potential of the atmosphere is dependent on the occurrences of elevated inversions (Figure 4-2). Elevated inversions restrict the vertical dispersion of pollutants by reducing the height by which pollutants are able to mix while confining horizontal transport to between layers (Tyson et al., 1996a; Tyson et al., 1996c; Freiman and Tyson, 2000; Tyson and Gatebe, 2001). These elevated inversions also play an important role in the long-range and re-circulated transport of pollutants.

Persistent stable discontinuities (representing the predominant type of elevated inversion over South Africa) develop due to the dominant anticyclonic activities over the subcontinent (Tyson et al., 1996a; Tyson et al., 1996b; Tyson, 1997). The subsiding air that is characteristic of the anticyclonic activity warms up adiabatically with temperatures in excess of the mixed boundary layer. The interface between the mixed boundary layer and the subsiding air is characterised by elevated inversions. These persistent stable discontinuities are consistent over large distances and have very little diurnal variation (Tyson et al., 1996c).

Persistent elevated inversions over the plateau occur in the middle to upper troposphere at ~700 hPa (~3 km), ~500 hPa (~5 km) and ~ 300 hPa (~7 km), with a forth inversion present at ~800hPa over coastal areas (Diab, 1975; Cosijn, 1996; Cosijn and Tyson, 1996; Tyson et al., 1996c; Tyson, 1997; Tyson and Gatebe, 2001). The spatial, circulation type and seasonal distribution of these absolute stable layers is illustrated in Figure 2-2. These features are generally shallow with depths varying between a minimum of 51 hPa (for the ~

800 hPa layer) to a maximum of 66 hPa (for the 300 hPa layer) and seldom more than 1 km on average (Cosijn and Tyson, 1996).

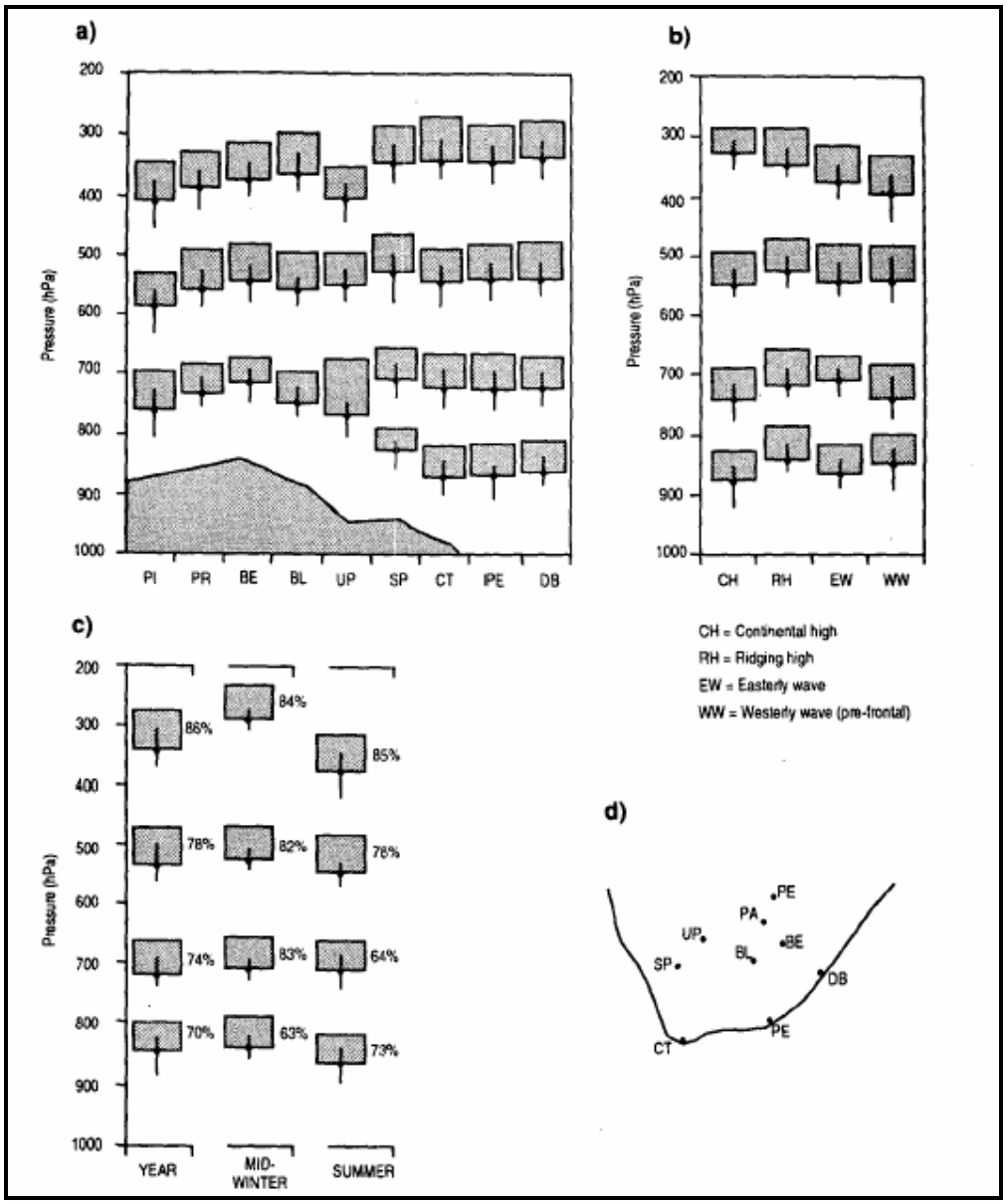


Figure 4-2: The occurrence of absolutely stable layers over South Africa by circulation type and time of year. Absolutely stable layers are indicated in block shading, showing base heights (with 95% confidence limits) and depths (horizontal dimension is arbitrary) (a) for spatial distribution across South Africa, (b) by circulation type, and (c) by time of year. (d) Locations of stations. The results are based on the analysis of a total of 2925 radiosonde ascents taken over the period 1986-92 (Tyson et al., 1996c).

The ~800, ~700 and ~500 hPa elevated inversions show little variation in mean base height of occurrence and depth throughout the year. During winter the 500 hPa layer is slightly more frequent and a little higher over the eastern areas. During summer, this layer is slightly higher over the west (Cosijn and Tyson, 1996). The ~700 hPa layer is slightly more frequent in winter, but the seasonal contrast in occurrence and depth throughout the year is slight. The ~ 800 hPa layer is least frequent in winter. Of all the layers, the elevated inversion at ~300 hPa is the most constantly present and provides the largest seasonal change in height, with the layer being highest in winter and lowest in summer (Cosijn and Tyson, 1996).

Circulation changes do not rapidly affect the occurrence of elevated inversions due to the circulation over the area being mainly anticyclonic in nature (Preston-Whyte and Tyson, 1989; Cosijn and Tyson, 1996, Cosijn, 1996; Freiman and Tyson, 2000). Even with the passage of a cold –front, the layer persists, with pre-frontal conditions tending to lower the base of the elevated inversion, and so reducing the mixing depth (Cosijn and Tyson, 1996, Cosijn, 1996; Preston-Whyte and Tyson, 1989). Following the passage of the front, a gradual rise in the mixing depth occurs over the interior (Cosijn, 1996; Preston-Whyte and Tyson, 1989). It is generally only with the passage of deep and unstable systems or with deep and vigorous cumulus convection, associated with westerly and easterly wave disturbances, that the formation of inversions is hindered or that the inversion layers are destroyed (Cosijn, 1996; Preston-Whyte and Tyson, 1989; Freiman and Tyson, 2000). These conditions occur for ~18% of the days in a year, producing ~ 86% of the rainfall over the Highveld (Cosijn and Tyson, 1996). However, although the elevated inversion layers will dissipate locally, the general spatial and temporal trends of these layers will not alter significantly (Cosijn and Tyson, 1996; Freiman and Tyson, 2000).

The 500hPa elevated inversion is the most persistent stable layer (Freiman and Tyson, 2000; Tyson and Gatebe, 2001) and may on occasion prevail without disruption for 40 days over South Africa during winter and early spring (Freiman and Tyson, 2000; Tyson and Gatebe, 2001). The 500 hPa absolutely stable layer controls the distribution of pollutants over South Africa and marks the top of the haze layer both in summer and in winter (Freiman and Tyson, 2000; Tyson and Gatebe, 2001).

4.3 Trans-Boundary Transportation of Air Masses over Southern Africa

The two main transport modes of air masses consist of direct transport, in which air masses are advected directly from the subcontinent to the oceans beyond, and re-circulated transport, in which air masses re-circulates to the point of origin (Tyson et al., 1996a, Tyson et al., 1996c) (Figure 4-3). Direct transport is made up of the four cardinal compass directions, viz. westerly, easterly, northerly and southerly. Westerly transport (within the Natal Plume) is influenced by the westerly waves (Fishman, 1991; Pickering et al., 1994; Krishnamurti et al., 1993; Benkovitz et al., 1994; Tyson et al., 1996a, Tyson et al., 1996b) moving air from the highveld to the Indian Ocean at north-to-central Kwa-Zulu Natal or southern Mozambique (Tyson et al., 1996a). Air transported in the Natal Plume takes place at high levels of ~525 hPa (Tyson et al., 1996a). Easterly transport takes place by means of

easterly waves to move air masses to the Atlantic Ocean. Air masses that move towards the Atlantic Ocean are transported in the Angolan Plume at low levels due to the subsidence over the western subcontinent and South Atlantic Ocean. Northerly and southerly transport moves air masses to equatorial Africa and to the South Indian Ocean respectively (Tyson et al., 1996a).

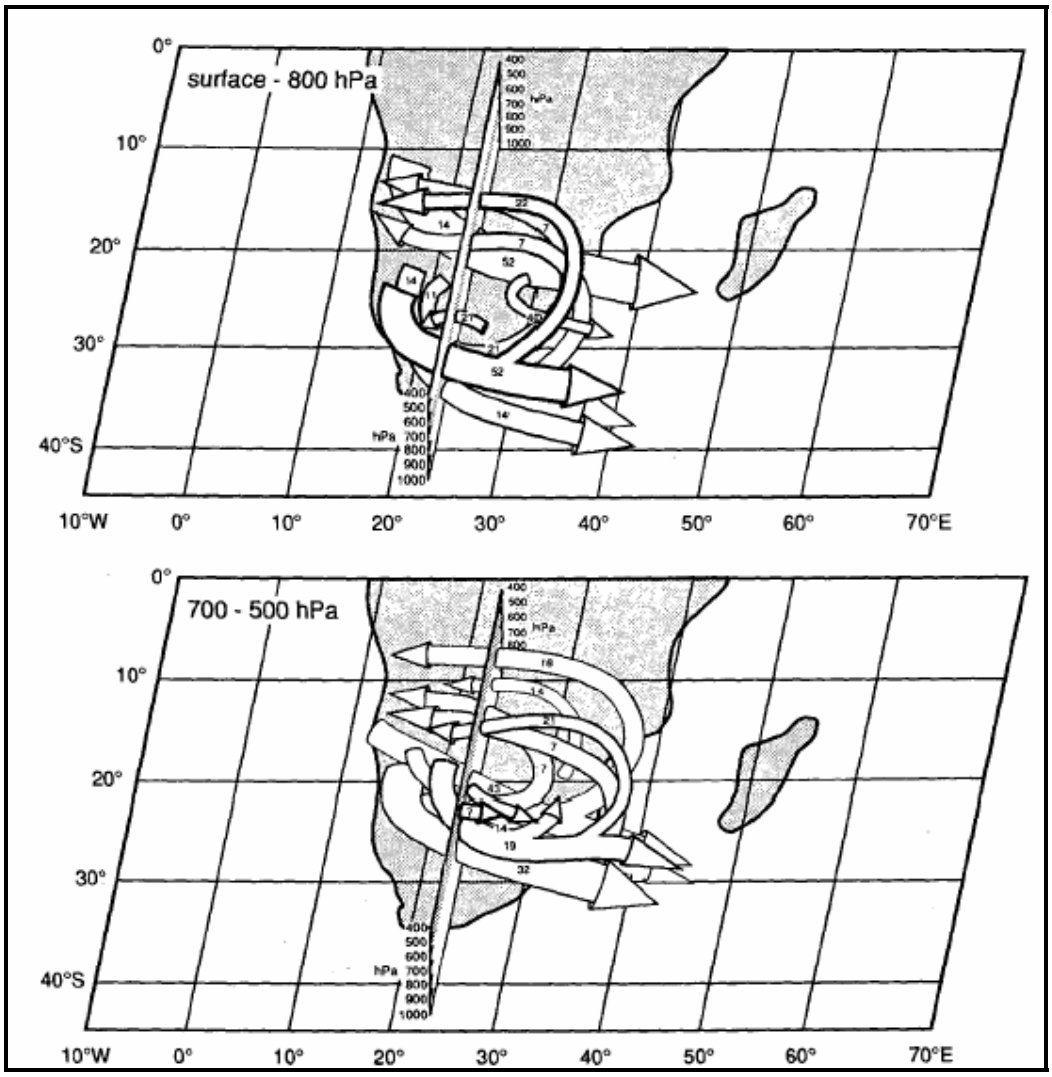


Figure 4-3: Schematic representation of major low-level transport trajectory models likely to result easterly or westerly exiting of material from southern African or in recirculation over the subcontinent (Tyson et al, 1996c).

Re-circulated transport is confined to levels of less than 200 hPa and is mainly anticyclonic (Tyson et al., 1996a). Local and regional recirculation extends over the highveld and surrounding neighbouring countries, such as Mozambique, Zimbabwe and Botswana (Tyson et al., 1996a; Tyson and Gatebe, 2001). Analysis of trajectory fields undertaken by Tyson et

al. (1996c) has revealed that air masses emanating from a particular point of origin follow anticyclonic curving streams with radii of 500 – 700 km. The recirculation vortex is evident from the surface to the persistent stable layer of 500 hPa. Above 500 hPa, due to the influence of the circumpolar westerlies, recirculation diminishes rapidly and transport patterns become more zonal. Local and sub-continental re-circulation over the interior makes up for ~44% of total air mass transportation (Tyson et al., 1996c; Tyson and Gatebe, 2001) with a recirculation time frame of 2-9 days (Tyson et al., 1996a). Up to a quarter of re-circulated air masses are observed to re-circulate a second time (Tyson et al., 1996c). Thus, the greatest impact of pollutants on neighbouring countries is under re-circulating air and prolonged residence time (Tyson et al., 1996a).

More than 75% of all air circulating over the southern African continent exits to the Indian Ocean, either by direct or re-circulated transportation (Tyson and Gatebe, 2001).

4.4 Thermo-Topographic Influences

Due to the persistence of anticyclonic activity over the southern African continent, conditions are typically, to large extent, free of cloud, thus maximising daytime insolation. Similarly, clear nights result in maximum nocturnal cooling at the surface. The result is the generation of local and meso-scale thermo-topographic wind systems (Tyson, 1967; Tyson and Preston-Whyte 1972; Tyson et al., 1988; Preston-Whyte and Tyson, 1989; Annegarn et al., 1993; Held et al., 1994; Piketh, 1995).

4.4.1 Urban Boundary Layer

The urban boundary layer is a complex three-dimensional structure (Rotach *et al.*, 2002) as shown in Figure 4-4. The main origin of the urban boundary layer (and its differences to the natural forming boundary layer) is its modified surface roughness elements (i.e. buildings, tress, etc.).

Horizontally, the urban environment is made up of changes in the roughness and thermal surface properties (viz. heat capacity and albedo). These changes in surfaces may lead to the formation of internal boundary layers (Raupach *et al.*, 1991) (Figure 4-4a).

Vertically, the lowest distinct layer is the urban canopy layer that ranges from the ground up to the average height of roughness elements (i.e. buildings and trees) (Figure 4-4c). Within the urban canopy layer, the micro scale environments of street canyons develop (ideally when straight buildings of equal height on either side of a street exist) (Raupach *et al.*, 1991).

The urban canopy layer forms part of the roughness sub layer (Figure 4-4b) (Raupach et al., 1991) with the inertial sub layer above (Tennekes and Lumley, 1972).

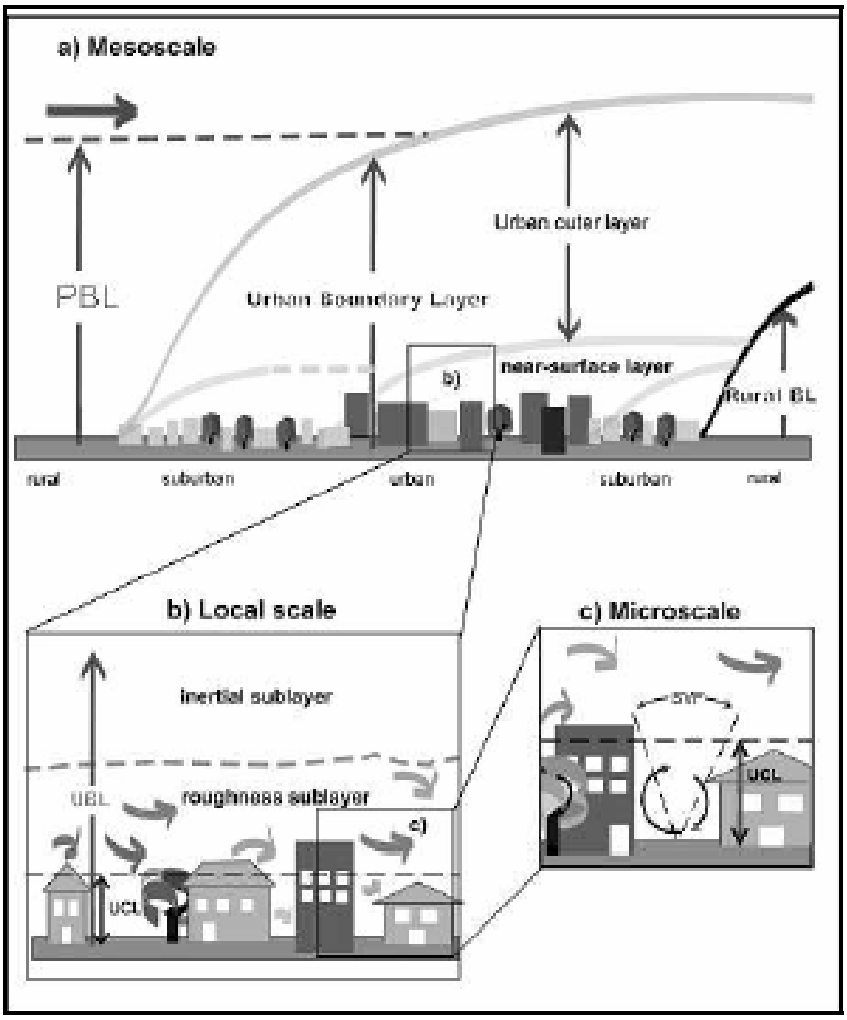


Figure 4-4: Sketch of the urban boundary layer structure indicating the various (sub) layers and their names (from Rotach *et al.*, 2004, modified after Oke, 1987). An unstable daytime urban boundary layer is shown.

Due to the characteristic urban boundary layer, pollution domes may form due to the collection of pollution below the inversion (Barry and Chorley, 1992) (Figure 4-5a). Figure 4-5b, shows a section of an urban plume. Fumigation is when an inversion lid prevents upward dispersion and downward lofting occurs above the temperature inversion at the top of a rural boundary layer dispersing pollution upwards.

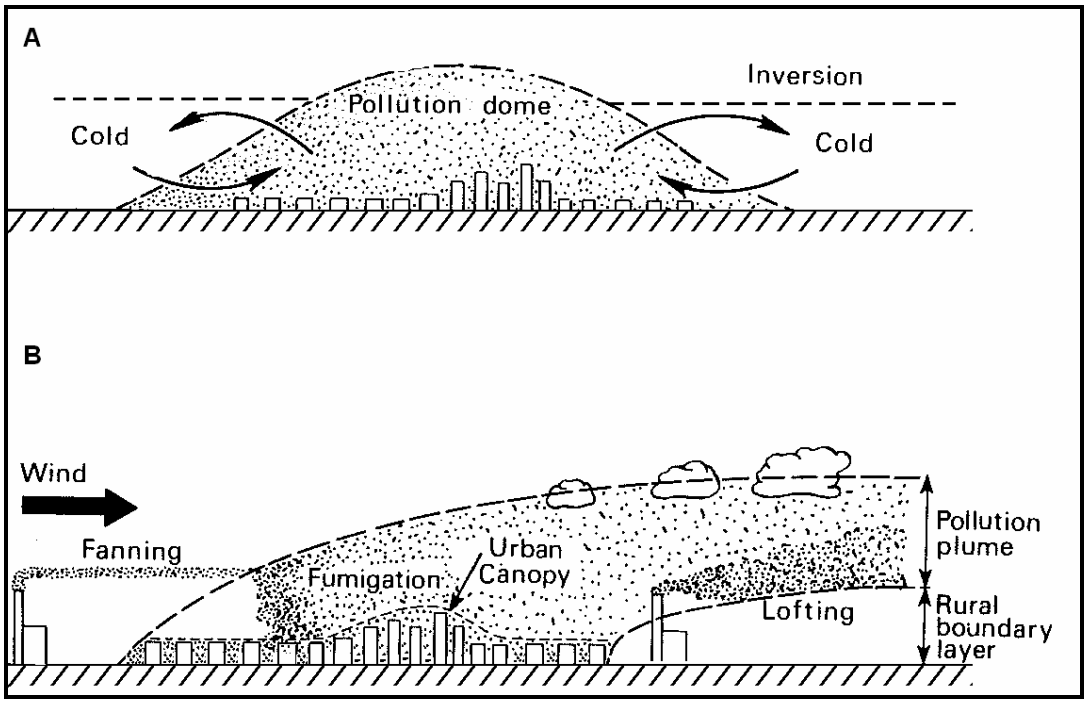


Figure 4-5: Configurations of urban pollution. (a) Urban pollution dome and (b) urban pollution plume in a stable environment (i.e. early morning following a clear night). Fanning is indicative of vertical atmospheric stability (after Barry and Chorley, 1992).

4.4.2 Valley Atmospheres

The differential heating of slopes gives rise to anabatic (up-valley) flow during the day and katabatic (down-valley) flow during the night. In order to compensate for the valley flow, a return current develops above the near-surface flows known as the “anti-wind” (Figure 4-6). A third distinct layer then completing the valley circulation is the gradient wind just above the anti-wind (Preston-Whyte and Tyson, 1989; Stull, 1997).

The near-valley flow is characterised by moderate wind speed of 1-5m/s. During the dissipation of anabatic winds and the development of katabatic flow, brief periods of calm conditions occur (Stull, 1997).

During night-time conditions, cold descending air accumulates within the valley with the upper slopes remaining warmer. This results in a layer of warm air above cooler air which in turn creates a valley inversion. The warmer air migrates upslope until the colder air completely covers the valley. Thus the valley inversion occurs from the ground upwards, replacing the turbulent mixing layer and resulting in low level stability (Preston-Whyte and Tyson, 1989; Stull, 1997) (Figure 4-7). Due to the combination of the stable layer near the surface and the elevated inversion, pollutants within the valley become suppressed. In turn, the gradual development of a mixing layer beneath the valley inversion results in fumigation

conditions with the valley inversion acting as a lid trapping the pollution. Maximum ground level pollutant concentrations therefore develop in the early morning and at night due to the dissipation and development of valley inversions (Rautenbach, 2006).

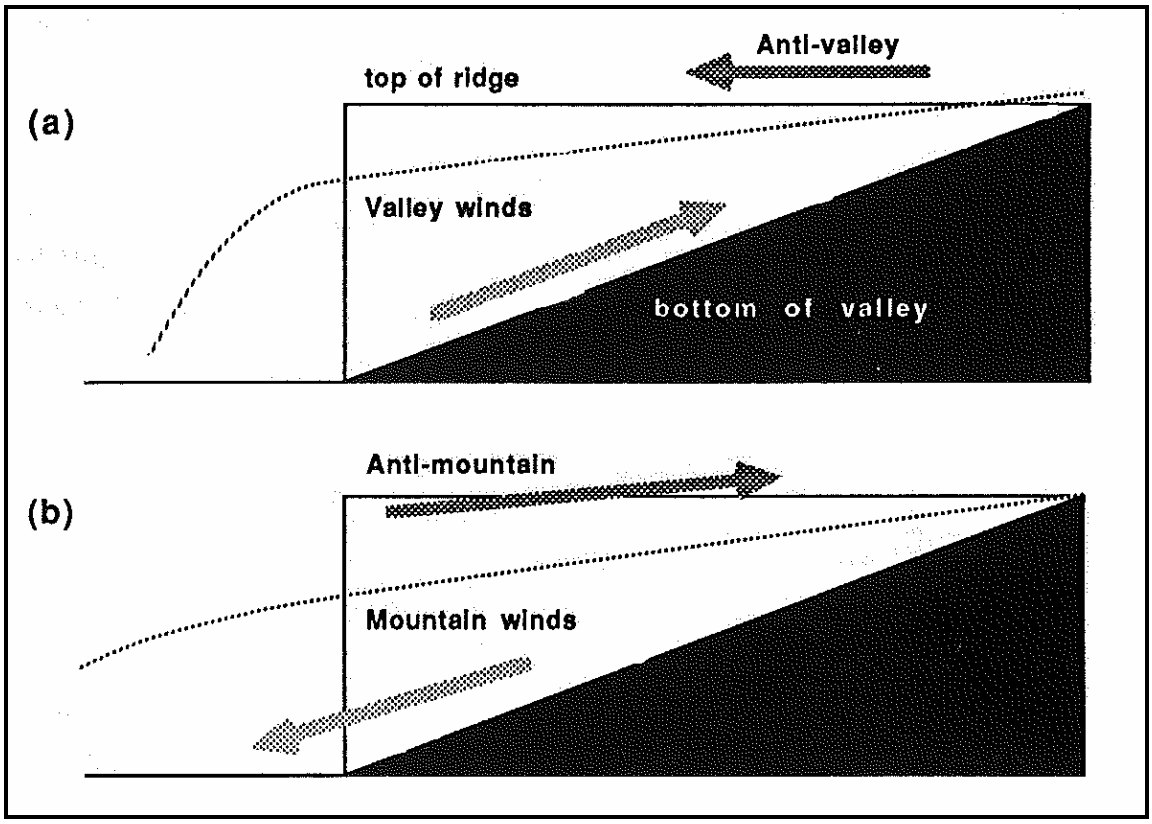


Figure 4-6: Along-valley winds: (a) daytime valley and anti-valley winds; and (b) night time mountain and anti-mountain winds (after Stull, 1997).

During day-time conditions, surface heating of the valley due to incoming solar radiation results in low-level mixing and anabatic flow up the valley sides. The subsiding air in turn heats adiabatically as the valley inversion subsides until a well mixed atmosphere fills the valley (Preston-Whyte and Tyson, 1989; Rautenbach, 2006). Due to the well mixed layer, the potential for vertical and horizontal dispersion of pollutants is improved (Rautenbach, 2006).

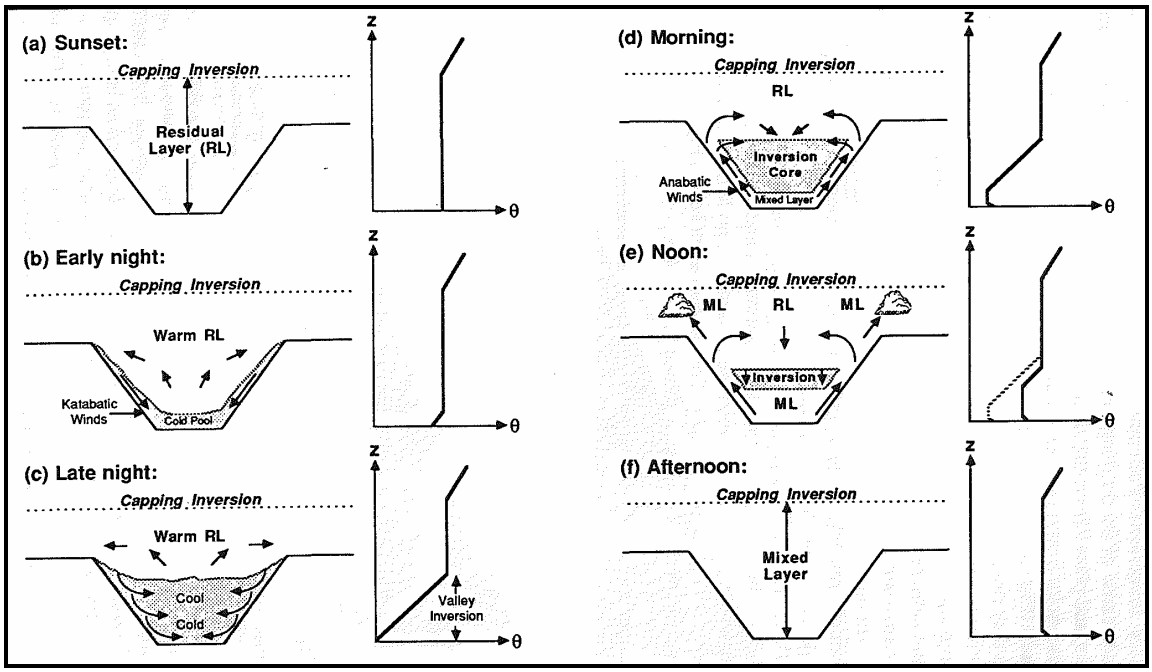


Figure 4-7: Idealised evolution of the cross-valley circulations during a diurnal cycle. Potential temperature profile corresponds to sounding made from the centre of the valley (after Stull, 1997).

4.5 Meso-scale Ventilation and Site-specific Dispersion Potential.

The analysis of hourly average meteorological data is necessary to facilitate a comprehensive understanding of the ventilation potential of the site, and to provide the input requirements for the dispersion simulations. A comprehensive data set for three years of detailed hourly average wind speed, wind direction and temperature data are needed for the dispersion simulations (as specified by the US-EPA for CALMET/CALPUFF suite models). The period covered included January 2004 to December 2006.

Surface meteorological data was obtained from the South African Weather Service (SAWS) stations of Vereeniging, Johannesburg (OR Tambo Airport) and Springs and the monitoring stations of the City of Johannesburg (COJ). In addition use was made of the meteorological data supplied by various industries in the Vaal Airshed including Sasol, ArcelorMittal Steel Vanderbijlpark Steel and Eskom (only for 2004 since it was decommissioned). Upper air meteorological data was obtained from SAWS ETA data model. The information from these stations was used to simulate a three-dimensional wind field for the study area, taking into account the land use and topographical data.

A summary of all the meteorological stations used for the current assessment are provided in Table 4-1, stating the parameters measured and the operational status of each station amongst other information. The locations of these stations are reflected in Figure 4-8.

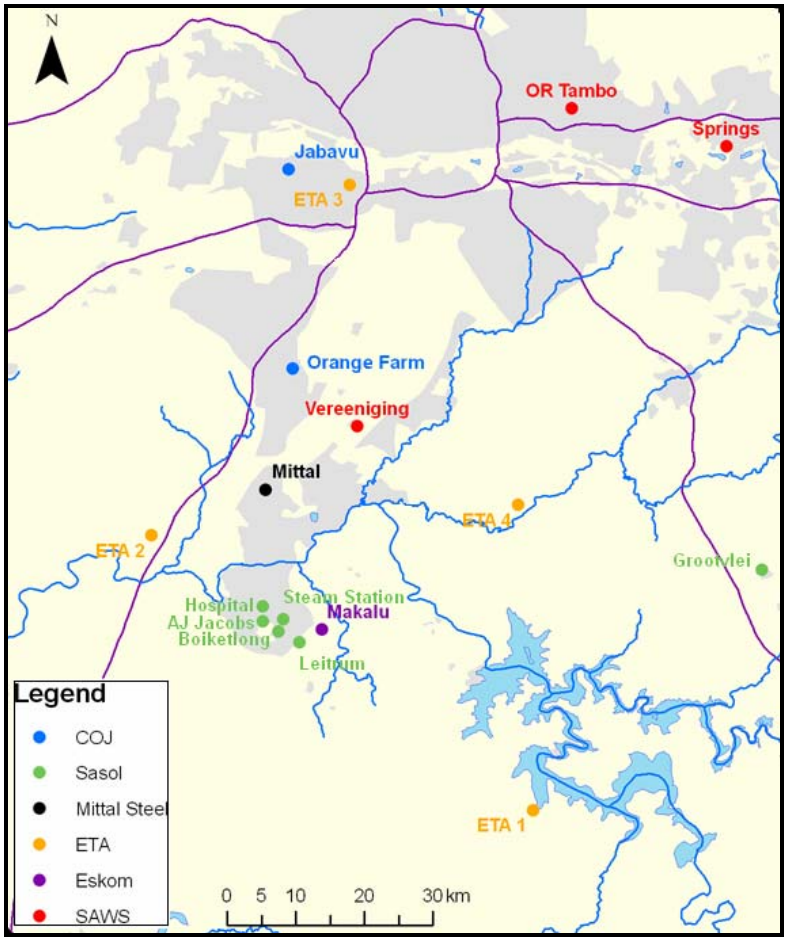


Figure 4-8: Locations of surface meteorological stations operated by industry, government and the SAWS and calculated ETA data points within the study area for which data were obtained for the study.

Table 4-1: Evaluation of meteorological stations operated by the SAWS, industry and various spheres of Government

Monitoring Agency	Station Name	Longitude (°E)	Latitude (°S)	Status	Monitoring Period	Parameters Measured	Averaging Period	Type of Equipment	SANAS Accredited - Yes/No
COJ	Jabavu	27.872	-26.253	Active	2004 - Present	Wind speed, Wind direction, Temperature, Relative humidity, Pressure, Rainfall	10 min intervals	Met One	No
	Orange Farm	27.867	-26.480	Active	2004 - Present	Wind speed, Wind direction, Temperature, Relative humidity, Pressure, Rainfall	10 min intervals	Met One	No
Eskom	Makalu	27.903	-26.835	Decom-mission-ed	1984 - 2004	Wind speed, Wind direction, Temperature, Relative humidity, Sigma Theta	Hourly	RM Young	Yes
ArcelorMittal Steel (MSVS)	Station 620	27.822	-26.673	Active	2005 - Present	Wind speed, Wind direction, Temperature	10 min intervals	RM Young	No
	Station 350	27.834	-26.655	Active	2005 - Present	Wind speed, Wind direction, Temperature	10 min intervals	RM Young	No
	Caravan (mobile)	27.788	-26.645	Active	2006 - Present	Wind speed, Wind direction, Temperature	10 min intervals	RM Young	No
Sasol	AJ Jacobs	27.826	-26.823	Active	2003 - Present	Wind speed, Wind direction	10 min intervals	RM Young	Yes
	Boiketlong	27.846	-26.836	Active	2003 - Present	Wind speed, Wind direction	10 min intervals	RM Young	Yes
	Grootvlei	28.479	-26.754	Active	-	Wind speed, Wind direction, Temperature	10 min intervals	RM Young	Yes

Monitoring Agency	Station Name	Longitude (°E)	Latitude (°S)	Status	Monitoring Period	Parameters Measured	Averaging Period	Type of Equipment	SANAS Accredited - Yes/No
	Hospital	27.826	-26.803	Active	2003 - Present	Wind speed, Wind direction	10 min intervals	RM Young	Yes
	Steam Station	27.853	-26.820	Active	2003 - Present	Wind speed, Wind direction, Temperature, Humidity, Pressure, Rainfall, Solar Radiation	10 min intervals	RM Young	Yes
	Leitrim	27.871	-26.850	Active	2003 - Present	Wind speed, Wind direction, Temperature, Humidity	10 min intervals	RM Young	Yes
SAWS	OR Tambo International Airport	28.230	-26.150	Active	1960 - Present	Wind speed, Wind direction, Temperature, Humidity, Pressure, Rainfall, Ceiling Height, Cloud Cover	5 min intervals	-	-
	Springs	28.433	-26.200	Active	1993 - Present	Wind speed, Wind direction, Temperature, Humidity, Pressure, Rainfall	5 min intervals	-	-
	Vereeniging	27.950	-26.567	Active	1993 - Present	Wind speed, Wind direction, Temperature, Humidity, Pressure, Rainfall	5 min intervals	-	-

Notes: COJ - City of Johannesburg, SAWS - South African Weather Services

Parameters that characterise the meso-scale ventilation potentials of an area include: (i) wind speed, (ii) wind direction, (iii) ambient air temperature (which in turn is a function of solar radiation), (iv) precipitation and (v) mixing depth.

4.5.1 Local Wind Field

Wind is an important parameter in the transportation, dispersion and eventual removal of pollutants. The stronger the wind speed, the more rapid the dilution of pollutants and thus the lower the concentrations at ground level. Conversely, the lower the wind speeds, the less dilution of pollutant and thus the higher the concentrations at ground level.

The wind roses provided for the monitoring stations consist of sixteen cardinal wind directions, with the frequency of wind indicated with the dotted circles. Each circle indicates a 5% frequency of occurrence. The figure indicated in the centre of each circle is the percentage calm conditions (wind speeds of <1m/s).

Period average wind roses are reflected in Figure 4-9 with the day-time and night-time average wind roses provided in Figure 4-10 and 4-11, respectively. The wind roses are provided for the SAWS stations (OR Tambo, Springs and Vereeniging) and the two stations owned by the City of Johannesburg (namely Jabavu and Orange Farm) for the period 2004 to 2006. In addition data for three year period received from ArcelorMittal Steel and the Sasol Grootvlei station are also included. The Eskom Makalu station was decommissioned in December 2004 and the other five Sasol stations had only three months of data available (October to December 2006) due to technical problems experienced with the averaging of the 10-minute data (Personal Communication, Ristoff van Zyl from Sasol, 2007).

The spatial and annual variability in the wind field is clearly evident in the wind roses. OR Tambo station located furthest north, and to the northeast of the study area, has prevailing northerly winds with strong wind speeds (5-10 m/s) occurring for ~5% of the period. Springs located approximately 20 km east-southeast of OR Tambo reflects a different airflow pattern with dominant easterly winds and fairly low wind speeds supported by frequent calm conditions. Jabavu is situated in the northern outskirts of the study area reflecting weak winds on average with a slight dominance of northeasterly winds. The number of calm conditions is very high at 53%. Orange Farm on the other hand is located ~25 km directly south of Jabavu and generally has strong winds primarily from the northwest to west-southwest directions. The Vereeniging station has a slight resemblance of the OR Tambo airflow with prevailing northwesterly and northerly winds. Wind speeds recorded at Vereeniging have a higher frequency of lower wind speeds (1-3 m/s) with high incidences of calm conditions (24%). Grootvlei located on the eastern side of the study area and ArcelorMittal Steel station located almost on the same latitude but ~75 km to the west reflects similar wind fields. Both stations have almost no airflow from the north with the prevailing wind fields from the northeast. Frequent winds are also detected from the west-southwest and easterly sector. The main difference between these two stations is the highest percentage calms (35%) that occur at the Grootvlei station in comparison to the ArcelorMittal

Steel station (9%). Makalu (for the period 2004) reflects frequent high wind speeds (between 5 m/s and 10 m/s) mainly from the east and north-northwest. The five Sasol stations are all located in close proximity to each other within a radius of ~8 km. Steam Station, Leitrim and Boiketlong reflect similar flow patterns (northwesterly and easterly) with moderate wind speeds. AJ Jacobs, located within Sasolburg, has a different dominant wind direction from the northeasterly flow at the Hospital station reflecting very low and infrequent winds (see Figure 4-9).

Diurnal airflow for the area, as presented in Figure 4-10, reflects similar patterns than for period averages. In general all the stations with prevailing northwesterly airflow indicate an increase in winds from this sector during the day. At ArcelorMittal Steel and Grootvlei an increase in airflow from the southwest is also noted. AJ Jacobs (Sasol station) also indicates an increase in northwesterly winds during the day. The general daytime airflow shows lower incidences of calm conditions.

Night-time conditions are characterised by lower wind speeds and higher incidences of calm conditions. These are clearly reflected in the various wind roses provided in Figure 4-11. Only Springs and AJ Jacobs have lower incidences of calm conditions than during the daytime conditions. The wind speeds, however, have decreased significantly at both stations for night-time conditions. In general, airflow from the southwest decreases during the night with a slight increase in winds from the easterly to northeasterly sectors observed.

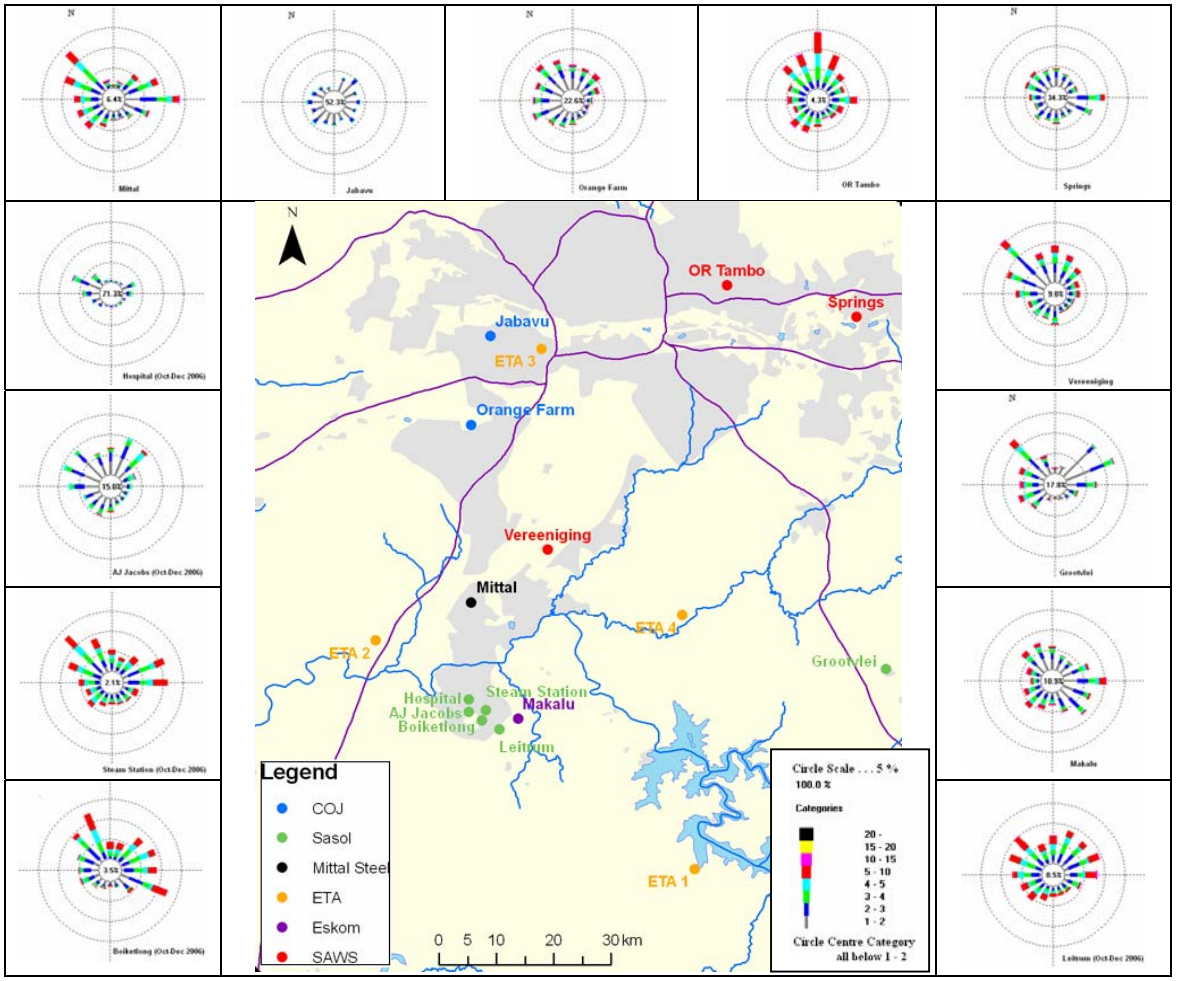


Figure 4-9: Period average wind roses for various monitoring stations operated by industry, various spheres of government and SAWS within the study area for the period 2004 to 2006 (with the exception of the Makalu monitoring station that has been assessed for the period 2004 (due to it being decommissioned) and the five Sasol monitoring stations that were only assessed for October to December 2006 as this was the only data available for the study).

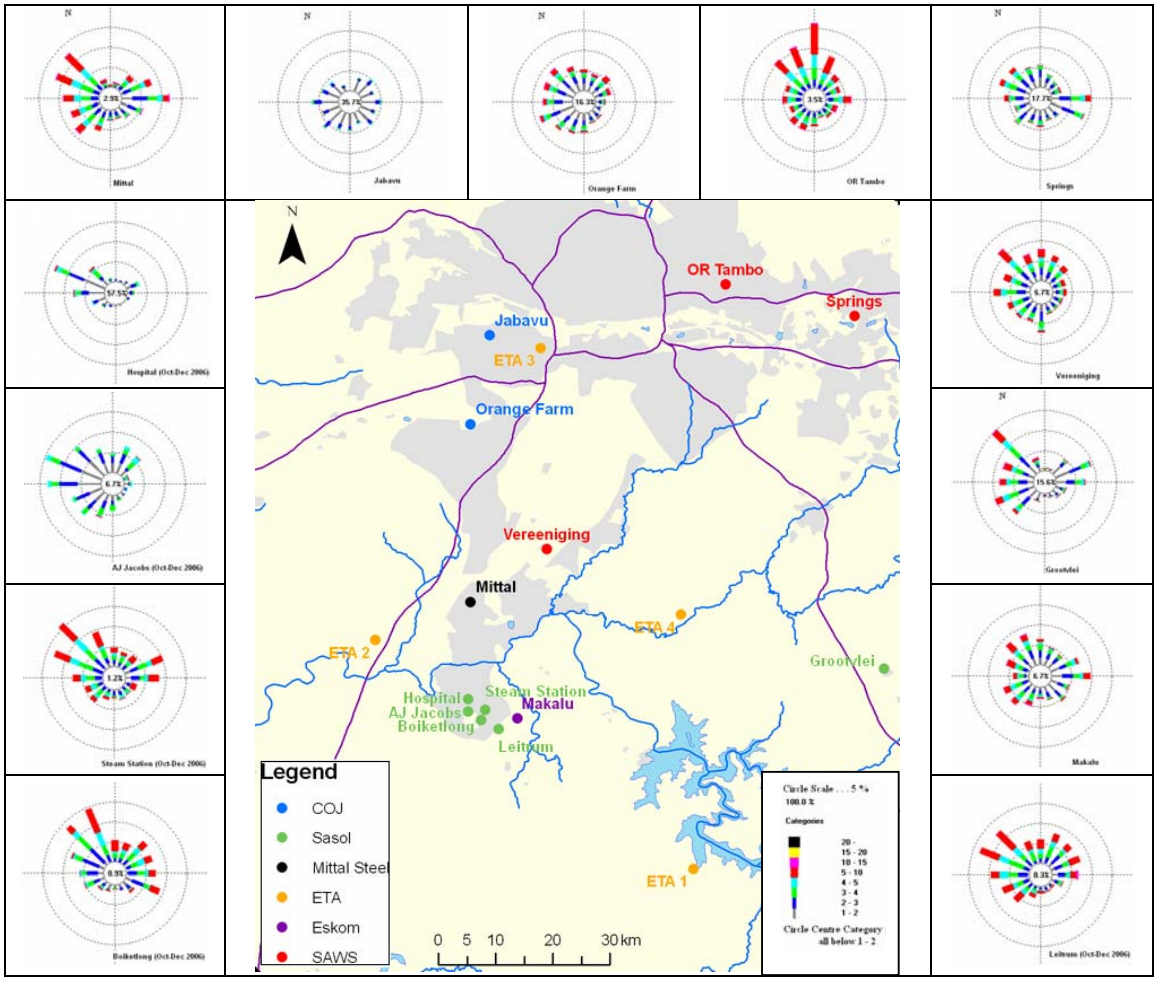


Figure 4-10: Day-time average wind roses for various monitoring stations operated by industry, various spheres of government and SAWS within the study area for the period 2004 to 2006 (with the exception of the Makalu monitoring station that has been assessed for the period 2004 (due to it being decommissioned) and the five Sasol monitoring stations that were only assessed for October to December 2006 as this was the only data available for the study).

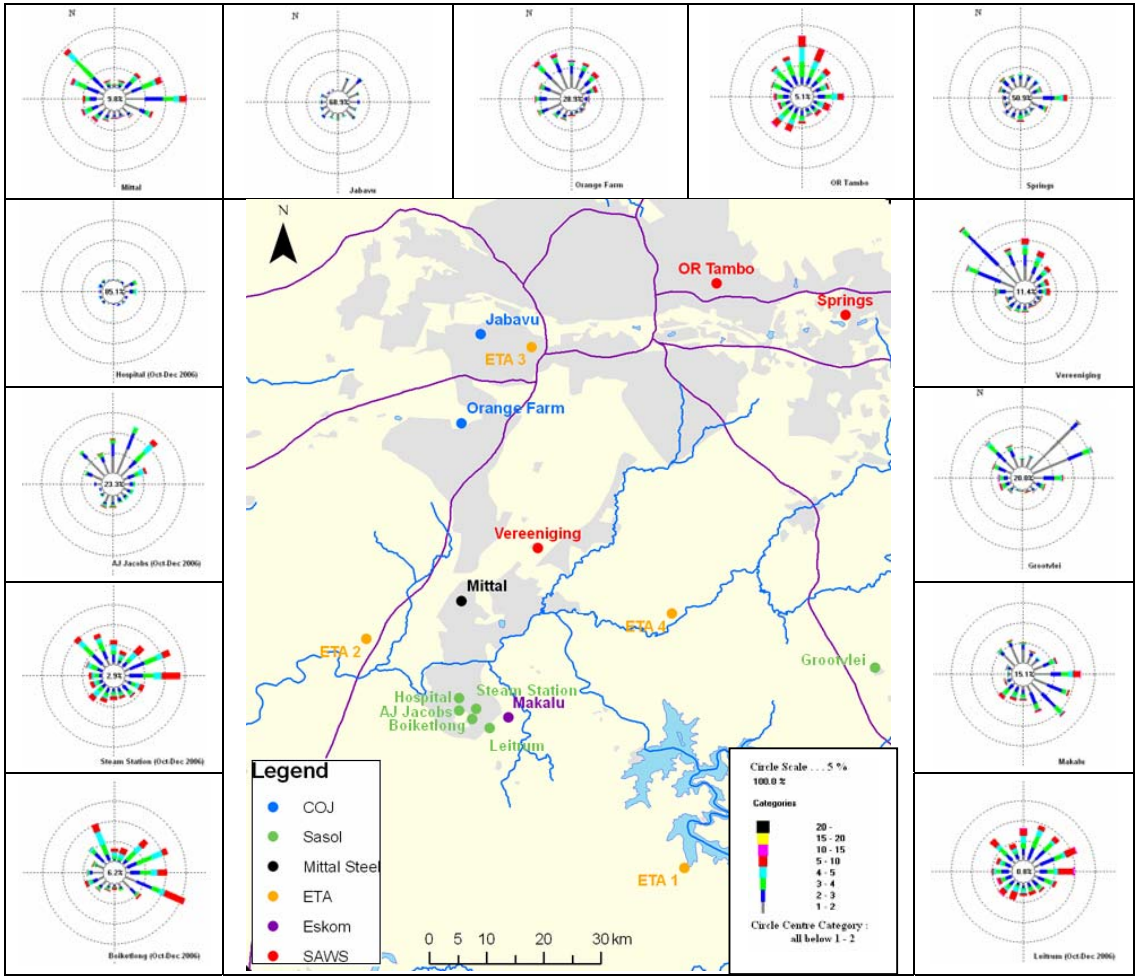


Figure 4-11: Night-time average wind roses for various monitoring stations operated by industry, various spheres of government and SAWS within the study area for the period 2004 to 2006 (with the exception of the Makalu monitoring station that has been assessed for the period 2004 (due to it being decommissioned) and the five Sasol monitoring stations that were only assessed for October to December 2006 as this was the only data available for the study).

4.5.2 Temperature Trends

Air temperature is an important parameter for the development of the mixing and inversion layers. It also determines the effect of plume buoyancy as the larger the temperature difference between ambient air and the plume, the higher the plume will rise. This in turn will affect the rate of dissipation of pollutants before it reaches ground level.

Long-term monthly temperatures for the SAWS monitoring stations in the study area are given in Table 4-2. The maximum temperatures occur during December, January and February with the minimum temperatures occurring during June and July. The mean monthly temperatures range between 10.3°C – 20.0°C for Johannesburg and 9.1°C – 21.9°C for Vereeniging.

Table 4-2: Long-term minimum, maximum and mean temperatures measured at SAWS stations over the study area (as obtained from the SAWS: WB42 – Climate Statistics).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum												
JHB	25.5	25.1	24.1	21.6	19.2	16.7	16.9	19.5	22.9	23.9	24.3	25.1
Ver	27.9	27.4	26.3	23.2	20.7	17.7	18.5	21.4	24.9	26.0	26.6	27.7
Mean												
JHB	20.0	19.6	18.7	15.9	13.1	10.3	10.3	12.7	16.1	17.5	18.4	19.5
Ver	21.9	21.3	19.9	16.4	12.6	9.1	9.3	12.4	16.7	18.9	20.2	21.3
Minimum												
JHB	14.6	14.2	13.2	10.1	7.0	3.9	3.7	5.8	9.2	11.1	12.5	13.8
Ver	15.9	15.2	13.6	9.6	4.4	0.4	0.2	3.4	8.6	11.8	13.8	15.0

Notes:
JHB (Johannesburg) had a monitoring period from 1975 to 2004 at OR Tambo airport
Ver (Vereeniging) had a monitoring period from 1961 to 1990

The mean monthly temperatures measured during 2006 (Table 4-3) provide similar ranges of 9.9°C – 20.5°C for Johannesburg (OR Tambo) and 9.0°C – 21.9°C for Vereeniging. At Johannesburg, maximum temperatures are below 25°C with minimums reaching below 5°C during June. Vereeniging measures maximum temperatures in exceedance of 25°C during summer (January – February and October to December) and minimum temperatures of below 5°C in winter (May to July). Springs, unfortunately does not have a long-term temperature record for comparison but measured mean monthly temperatures range between 8.4°C – 20.8°C during the period of 2006. Makalu was decommissioned in December 2004. Therefore the measured temperature for Makalu during the period 2004 was assessed for comparison. The mean temperature ranges for the period were 8.8°C – 22.7°C. A minimum temperature of 2.8°C was measured at Leitrim and Steam Station and 1.4°C was measured at Grootvlei during June 2006. The maximum recorded temperature of 29.7°C (Leitrim), 28.2°C (Steam Station), and 28.9°C (Grootvlei) occurred during December with a mean temperature range of 10.7°C - 23.0°C (Leitrim), 10.4°C – 22.5°C (Steam Station) and 8.2°C – 20.4°C (Grootvlei). The mean temperature ranges for Jabavu and Orange Farm was 10.3°C – 21.9°C and 11.5°C – 21.9°C respectively. The mean temperature range for ArcelorMittal Steel monitoring station was 9.8°C – 21.3°C.

Table 4-3: Minimum, maximum and mean temperatures measured at various monitoring stations operated by industry, various spheres of government and SAWS within the study area for the period 2006.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum												
JHB	22.8	23.3	20.9	20.1	16.7	16.6	18.4	16.8	21.9	24.6	23.2	25.1
Ver	25.6	25.2	23.1	22.0	18.1	18.5	20.7	18.5	24.3	26.9	25.4	27.3
Spr	23.7	23.6	20.9	21.2	17.7	17.6	19.5	18.0	23.1	26.1	23.9	25.8
Jab	21.9	25.2	23.5	20.5	17.9	17.7	19.9	18.5	24.2	26.8	25.5	27.9
OF	26.3	25.4	24.4	23.5	20.0	19.9	20.1	19.1	25.0	27.4	25.8	28.0
Lei	26.1	27.1	23.3	24.1	20.2	20.4	22.3	20.1	26.2	28.5	27.2	29.7

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SS	25.4	25.8	22.9	22.0	17.9	18.9	20.2	18.9	24.9	27.5	26.1	28.2
Mitt	23.6	24.4	21.5	20.7	17.4	17.9	19.9	17.2	23.0	26.2	24.7	26.8
GV	24.8	24.6	22.3	21.0	17.5	17.0	18.5	20.3	24.6	26.0	26.7	28.9
MA	31.1	29.4	27.5	27.8	29.0	23.2	22.2	26.4	27.8	29.9	33.2	30.2
Mean												
JHB	19.3	19.1	16.7	15.4	11.1	9.9	12.3	11.0	15.6	19.3	18.6	20.5
Ver	21.2	20.7	17.8	15.5	10.0	9.0	11.4	11.3	16.3	20.3	19.8	21.9
Spr	19.9	19.5	15.7	14.3	9.4	8.4	10.1	10.4	15.2	19.4	18.4	20.8
Jab	21.9	20.5	18.3	14.6	11.3	10.3	12.5	11.9	17.0	20.2	19.9	21.6
OF	21.0	20.3	18.0	16.6	12.4	11.5	12.5	12.4	17.6	20.5	19.8	21.9
Lei	21.4	21.7	17.4	16.9	11.5	10.7	12.6	12.1	17.2	20.9	20.9	23.0
SS	20.8	20.6	17.9	16.1	10.8	10.4	12.0	11.4	17.2	21.1	20.6	22.5
Mitt	19.9	20.0	17.2	15.8	10.4	9.8	12.6	11.0	16.2	19.7	19.3	21.3
GV	20.4	19.9	16.8	14.9	9.6	8.2	10.0	11.7	16.6	19.2	20.0	18.1
MA	22.3	21.0	19.1	16.9	13.6	9.4	8.8	14.2	15.7	19.7	22.7	21.7
Minimum												
JHB	16.2	15.9	13.3	11.1	6.1	4.3	7.2	6.1	9.4	14.2	14.1	16.4

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ver	17.3	16.5	13.7	9.6	3.1	0.8	3.4	5.0	8.2	13.8	14.3	17.0
Spr	16.6	15.9	11.3	8.3	2.4	0.9	1.8	3.8	6.7	13.3	13.2	16.2
Jab	21.9	16.7	14.2	8.8	4.8	3.8	6.1	5.8	9.8	14.6	14.5	15.9
OF	16.5	16.2	13.4	11.4	5.9	5.0	6.1	7.1	10.1	14.3	14.2	16.3
Lei	17.0	17.2	13.1	11.0	4.7	2.8	4.6	5.7	8.2	13.8	14.8	17.3
SS	17.0	16.4	14.0	10.7	4.1	2.8	4.6	4.8	9.2	14.8	15.2	17.9
Mitt	16.2	16.1	13.7	11.1	3.6	2.4	5.5	5.3	8.6	13.5	13.9	17.1
GV	16.4	16.0	12.7	9.8	3.3	1.4	3.0	5.0	9.7	13.1	14.3	15.9
MA	15.2	14.0	12.8	8.4	2.0	-1.3	-1.3	3.6	5.3	10.4	13.1	14.3

Notes:
JHB: Johannesburg
Ver: Vereeniging
Spr: Springs
Jab: Jabavu
OF: Orange Farm
Lei: Leitrim
SS: Steam Station
Mitt: MittalSteel
GV: Grootvlei
MA: Makalu

Diurnal and seasonal temperature profiles are clearly evident over the study area for the period 2006 (Figure 4-12 and Figure 4-13 respectively). As the earth cools during night-time, the air in direct contact with the earth's surface is forced to cool accordingly. The coldest temperatures occur between 06:00 and 08:00, which is just after sunrise. As the sun rises, the incoming solar radiation warms the surface of the earth, which in turn will heat up the layer of air directly above to reach a maximum at approximately 15:00 in the afternoon.

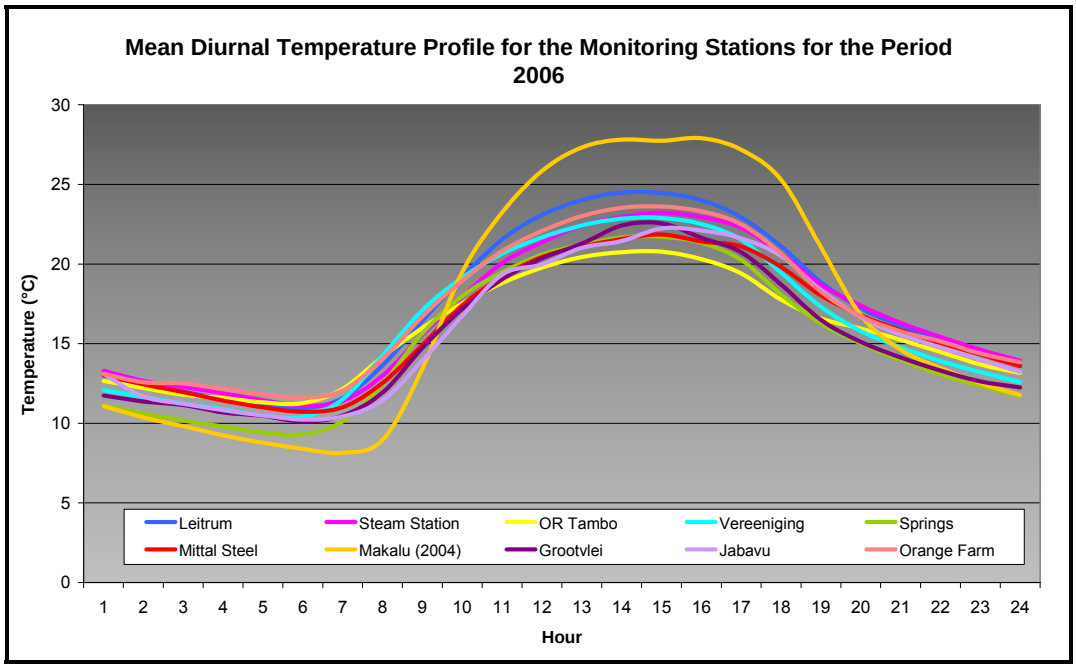


Figure 4-12: Mean diurnal temperature variations measured at various monitoring stations operated by industry, various spheres of government and SAWS within the study area for the period 2006.

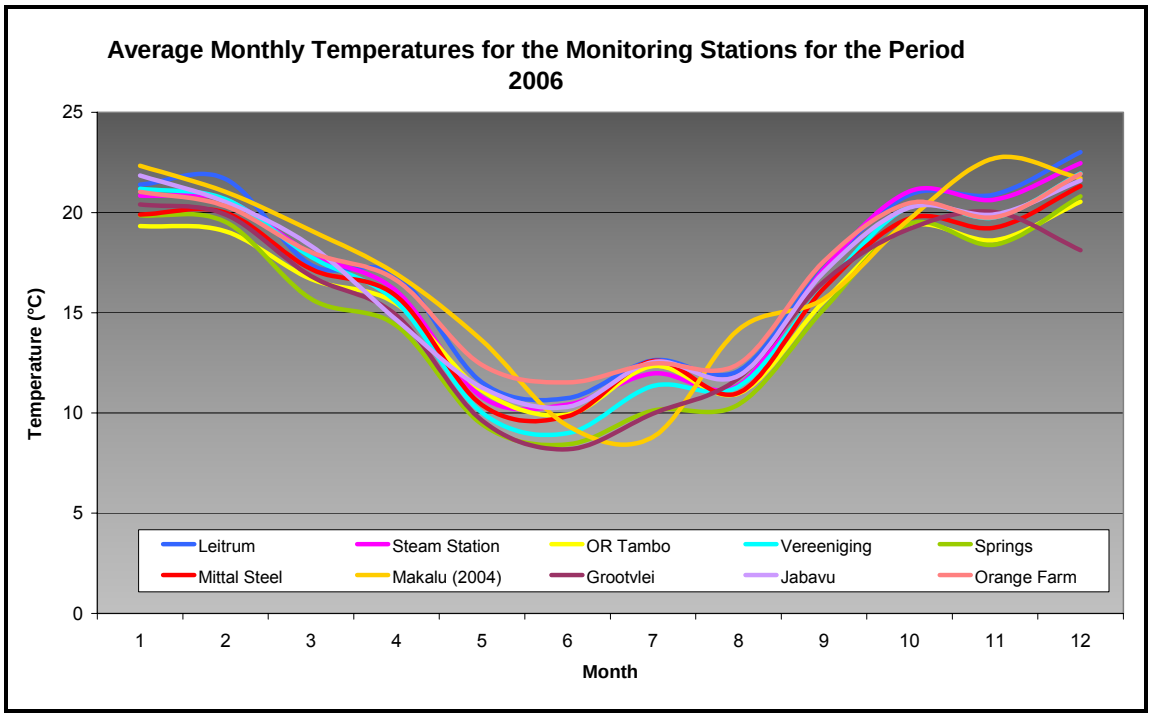


Figure 4-13: Average monthly temperatures measured at various monitoring stations operated by industry, various spheres of government and SAWS within the study area for the period 2006.

4.5.3 Precipitation

Precipitation can have a beneficial effect by washing pollutant particles from the air and helping to minimize particulate matter formed by activities such as construction and some industrial processes. Precipitation, however, can also act on pollutants in the air to create more dangerous secondary pollutants, such as the substances responsible for acid rain. The rainfall monitoring stations over the study area that were obtained for assessment consist of 3 SAWS stations.

Mean monthly rainfall for the monitoring stations are summarised in Table 4-4. The long-term rainfall records varied were provided for a length of 30 years (as obtained from the South African Weather Services: WB42 – Climate Statistics).

It can be observed from the long-term record from Johannesburg and Vereeniging that November to February is the main rainy season, with mean monthly rainfall ranging between 3 mm and 134 mm. The long-term rainfall showed highest rainfall occurring in January for both stations. The annual average long-term rainfall ranges from 671 mm at Vereeniging to 751 mm at Johannesburg. The dry season extends from about June to August.

During 2004, Vereeniging (Figure 4-15) measured below (27%) long-term average rainfall (27%). For the period 2005, all stations had below average rainfall from 12% at Vereeniging to 27% at Johannesburg (Figure 4-14). The period 2006 was an exceptionally wet year, with all stations measuring above long-term average rainfall (Johannesburg (50%) and Vereeniging (105%)).

At Springs the annual precipitation was measured at 364 mm and 425 mm for the period 2005 and 2006 respectively (Figure 4-16).

Table 4-4: Monthly rainfall figures (mm) for the meteorological monitoring stations within the study area.

Month	Springs	Johannesburg	Vereeniging
Long-term monthly rainfall figures (mm) (SAWS: WB42) [(1)(2)]			
January	-	134	125
February	-	114	74
March	-	100	68
April	-	36	56
May	-	18	14
June	-	8	8
July	-	3	5
August	-	8	10
September	-	28	25
October	-	79	72
November	-	104	95
December	-	118	119
Annual	**-**	**751**	**671**
Monthly rainfall figures (mm) for the period 2004 [(3)]			
January	-	171.0	123.4
February	-	206.6	85.0
March	-	114.8	24.8
April	-	48.8	26.8
May	-	0.0	0.0
June	-	0.6	3.0
July	-	16.2	12.6
August	-	0.2	23.8
September	-	0.0	0.0
October	-	14.6	28.2
November	-	49.4	27.6
December	-	203.6	126.4
Annual	**-**	**825.8**	**481.6**
Monthly rainfall figures (mm) for the period 2005[(3)]			
January	85.0	154.8	173.2
February	39.0	73.2	40.8
March	49.0	102.0	121.6
April	50.0	88.6	73.4
May	3.0	1.6	5.3
June	0.0	0.0	0.0

Month	Springs	Johannesburg	Vereeniging
July	0.0	0.0	0.0
August	4.0	0.0	0.2
September	4.0	0.0	0.2
October	12.0	0.0	12.6
November	75.0	100.0	93.8
December	43.0	72.6	58.6
Annual	**364.0**	**592.8**	**579.7**
Monthly rainfall figures (mm) for the period 2006[3]			
January	58.0	353.2	306.0
February	73.0	301.2	206.0
March	68.0	149.2	179.6
April	16.0	68.4	66.6
May	7.0	4.0	21.2
June	0.0	0.0	0.0
July	0.0	0.0	0.0
August	26.0	62.8	44.4
September	3.0	1.6	7.6
October	31.0	42.2	56.4
November	73.0	110.8	247.6
December	70.0	127.2	215.2
Annual	**425.0**	**1220.6**	**1350.6**

Notes:

1. JHB (Johannesburg) had a monitoring period from 1975 to 2004 at OR Tambo airport

2. Ver (Vereeniging) had a monitoring period from 1961 to 1990

3. The monitoring station at Johannesburg is at the OR Tambo airport

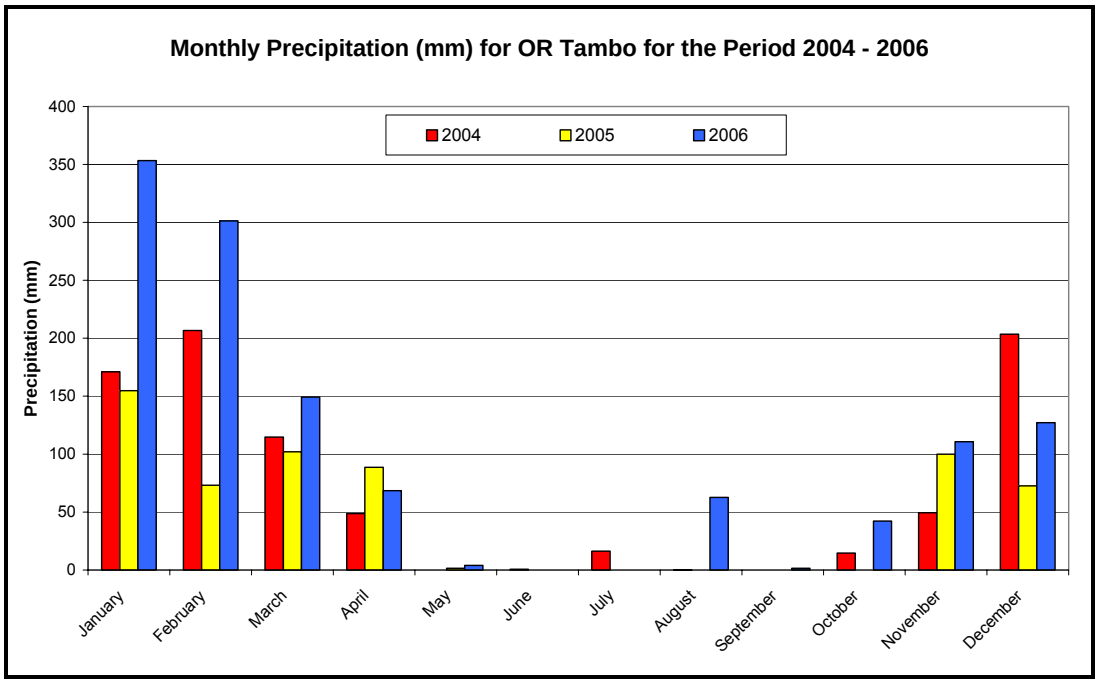


Figure 4-14: Monthly measured rainfall for the SAWS meteorological station of Johannesburg (OR Tambo) for the period 2004 – 2006.

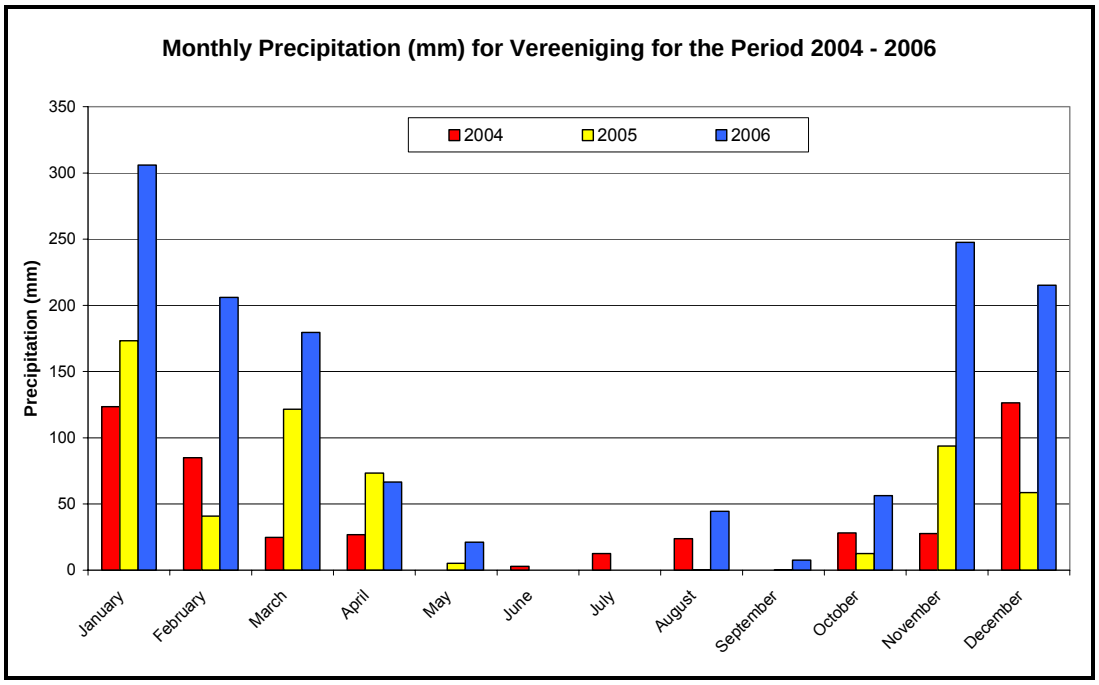


Figure 4-15: Monthly measured rainfall for the SAWS meteorological station of Vereeniging for the period 2004 – 2006.

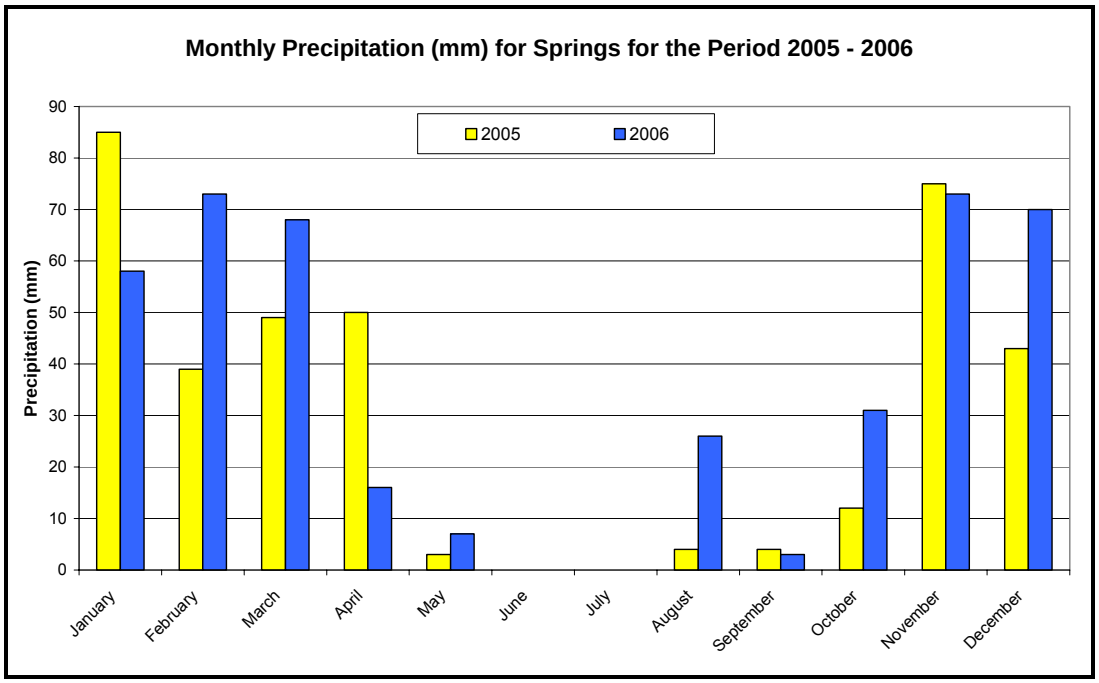


Figure 4-16: Monthly measured rainfall for the SAWS meteorological station of Springs for the period 2005 – 2006.

4.5.4 Relative Humidity

Relative humidity is an inverse function of ambient air temperature. As the ambient air temperature increases, so the relative humidity in the atmosphere will decrease. This is clearly observed in the diurnal trend in Figure 4-17.

Relative humidity will increase during the night to reach a maximum just after sunrise (07:00). This coincides with coldest observed ambient air temperatures (Figure 4-12). As the air temperature begins to increase, the relative humidity decreases to reach a minimum during the warmest part of the day (14:00 to 15:00). The maximum measured relative humidity for the period 2004 to 2006 ranged from 96% - 100% with the minimum ranging from 0% - 12%.

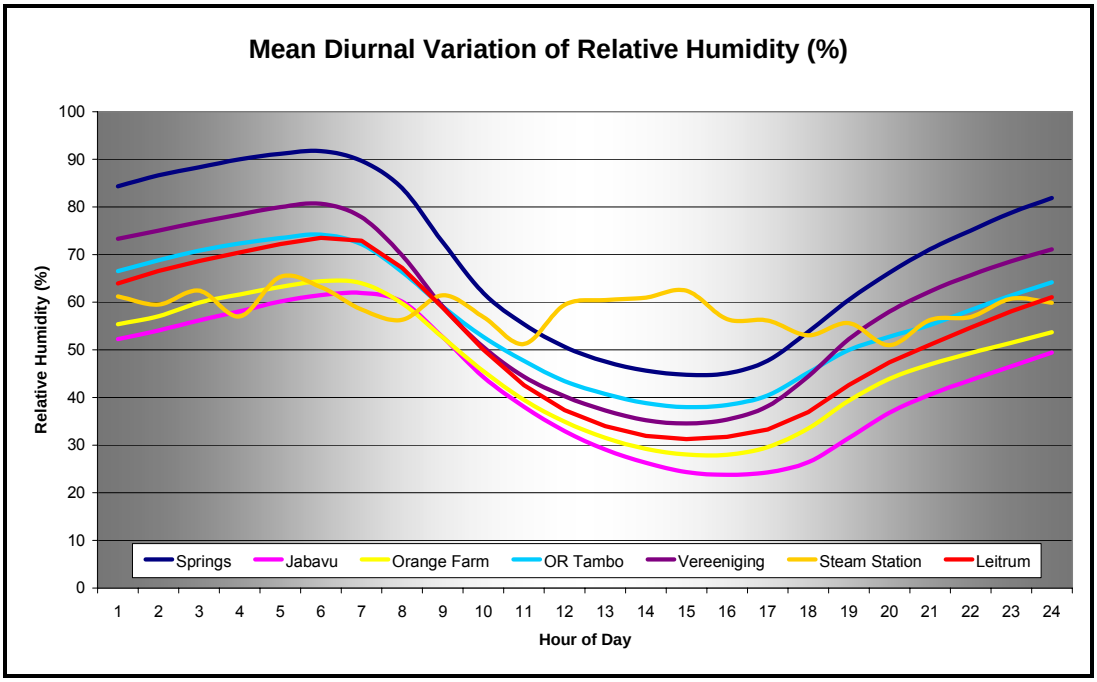


Figure 4-17: Mean diurnal variation of relative humidity measured at various monitoring stations operated by industry, various spheres of government and SAWS within the study area for the period 2004 -2006.

Mean monthly relative humidity values for the monitoring stations over the study area are summarised in Figure 4-18. As with temperature, the mean monthly relative humidity values decrease during the dryer winter months (May to September) and increase during the wetter summer months (January to April and October to December). The mean monthly relative humidity range is 24% - 61% (Jabavu), 28% - 63% (Orange Farm), 31% - 72% (Leitrim), 35% - 80% (Vereeniging), 38% - 73% (OR Tambo) and 45% - 91% (Springs).

The relative humidity for Steam Station seams to be suspicious as it does not follow the general diurnal and monthly trends. The trend may be due to the influence of the closely located Sasol Power Station, in which case the relative humidity would not be reflective of ambient conditions.

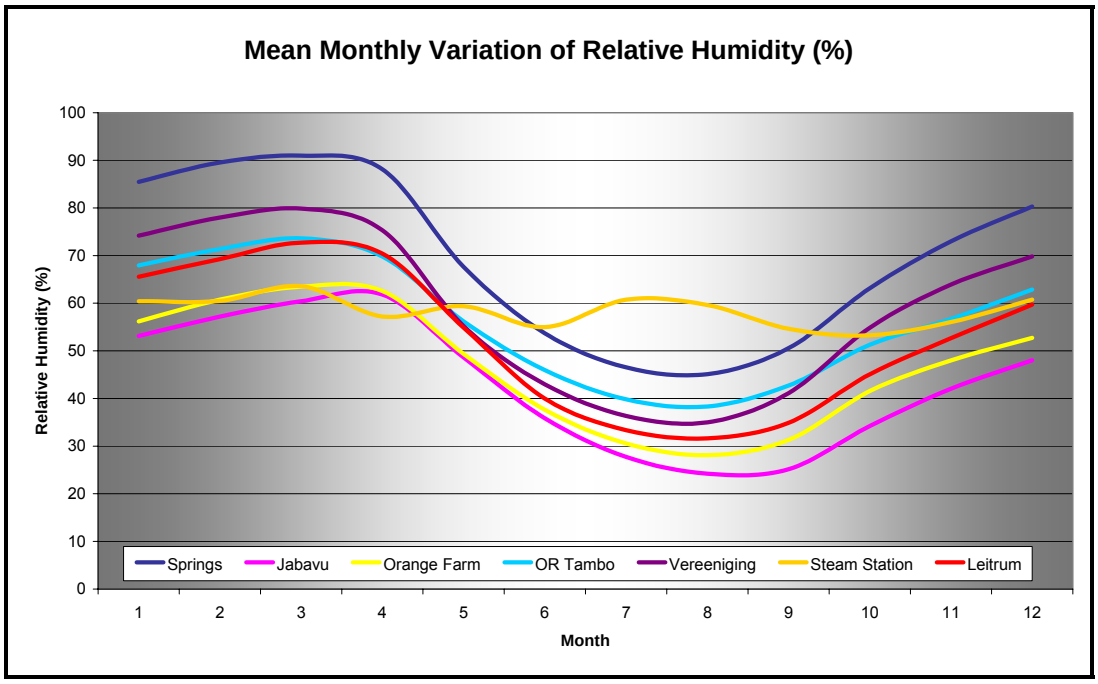


Figure 4-18: Mean monthly variation of relative humidity measured at various monitoring stations operated by industry, various spheres of government and SAWS within the study area for the period 2004 -2006.

4.5.5 Incoming Solar Radiation (Insolation)

Solar radiation was measured at the Sasol monitoring station (Steam Station). Incoming solar radiation determines the rate of development and dissipation of the mixing layer. It increases from sunrise (06:00) to reach a maximum at midday (12:00 – 13:00) and then decreases till sunset (19:00) (Figure 4-19). The maximum solar radiation measured at Steam Station was 1251 W/m² (13:00).

Monthly solar radiation reaches a maximum during January (280 W/m²) and a minimum during June (185 W/m²) (Figure 4-20).

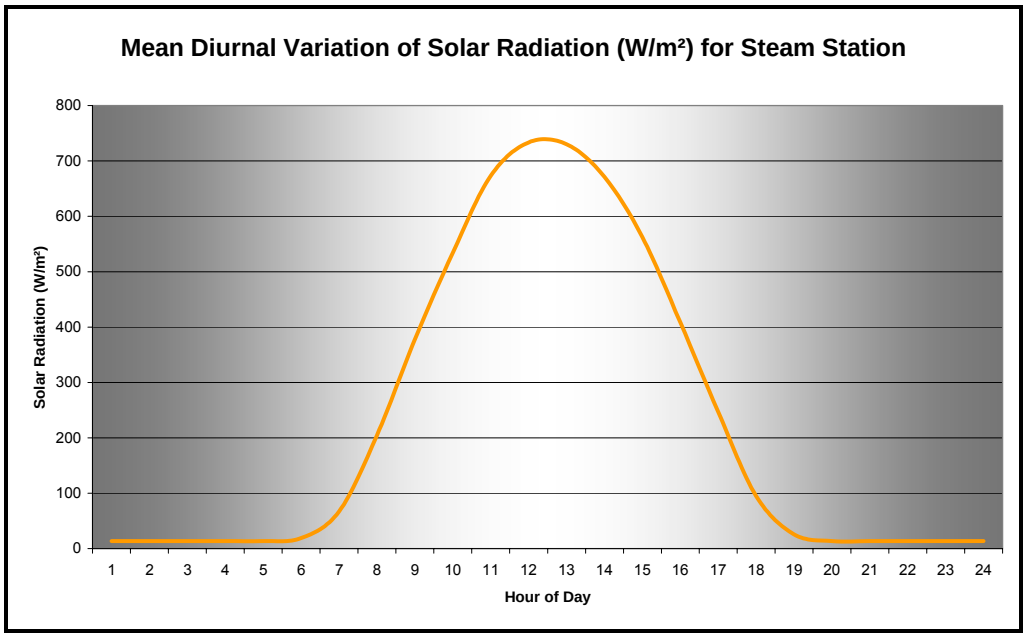


Figure 4-19: Mean diurnal variation of solar radiation measured at the Sasol monitoring station (Steam Station) for the period 2004 -2006.

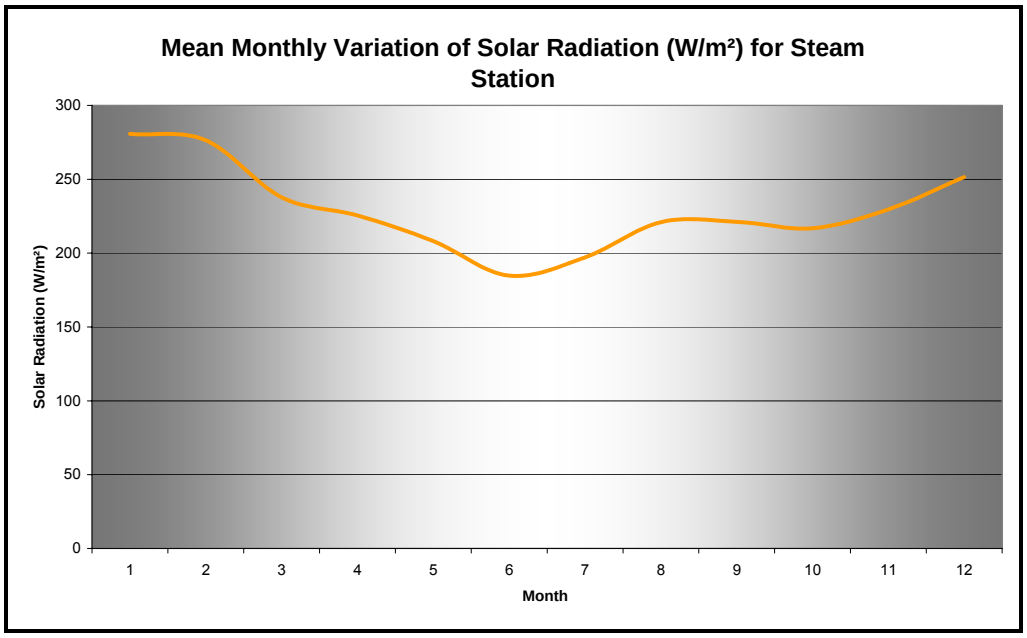


Figure 4-20: Mean monthly variation of solar radiation measured at the Sasol monitoring station (Steam Station) for the period 2004 -2006.

4.5.6 Surface Pressure Levels

Surface pressure was measured at the SAWS stations for the period 2004 – 2006 (Figure 4-21). The average pressure for the various stations was 845 hPa (Springs), 855 hPa (Vereeniging) and 834 hPa (OR Tambo). The highest surface pressure is observed at Vereeniging due to its lower altitude, with the lowest surface pressure observed at OR Tambo.

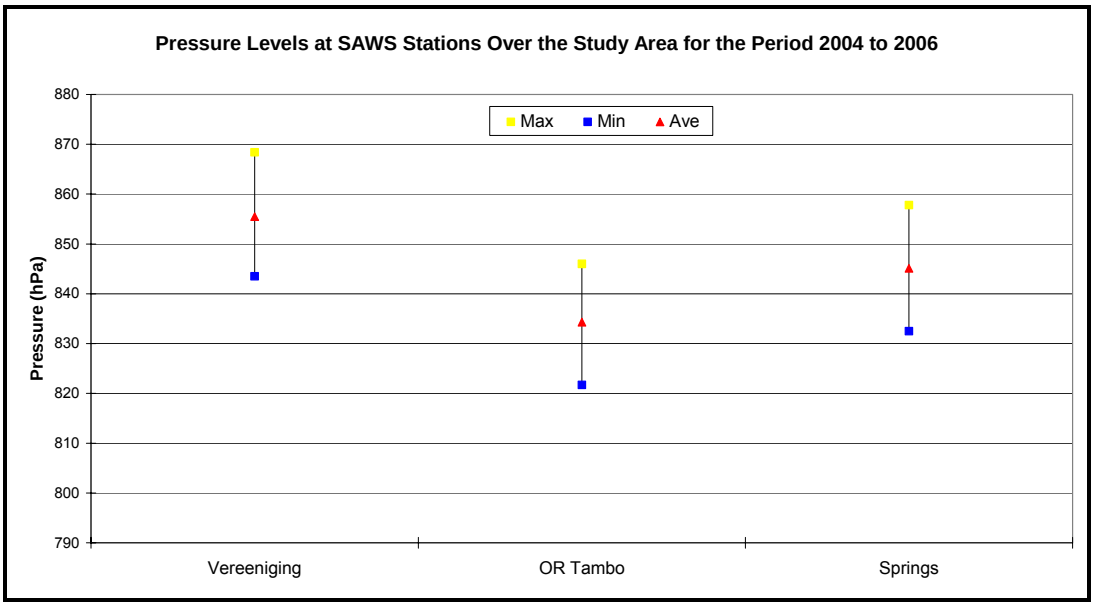


Figure 4-21: Measured surface pressure levels from SAWS monitoring stations over the study area for the period 2004 - 2006.

CHAPTER 5
MEASURED AMBIENT AIR QUALITY WITHIN THE STUDY AREA

In the analysis of ambient air quality monitoring data, use was made of all data to which a reasonable level of accuracy could be attached for the period 2004 - 2006. Data were obtained from industry- and government-run monitoring stations. A list of the sampling stations and pollutants measured is given in Table 5-1. The locations of the various monitoring stations are illustrated in Figure 5-1.

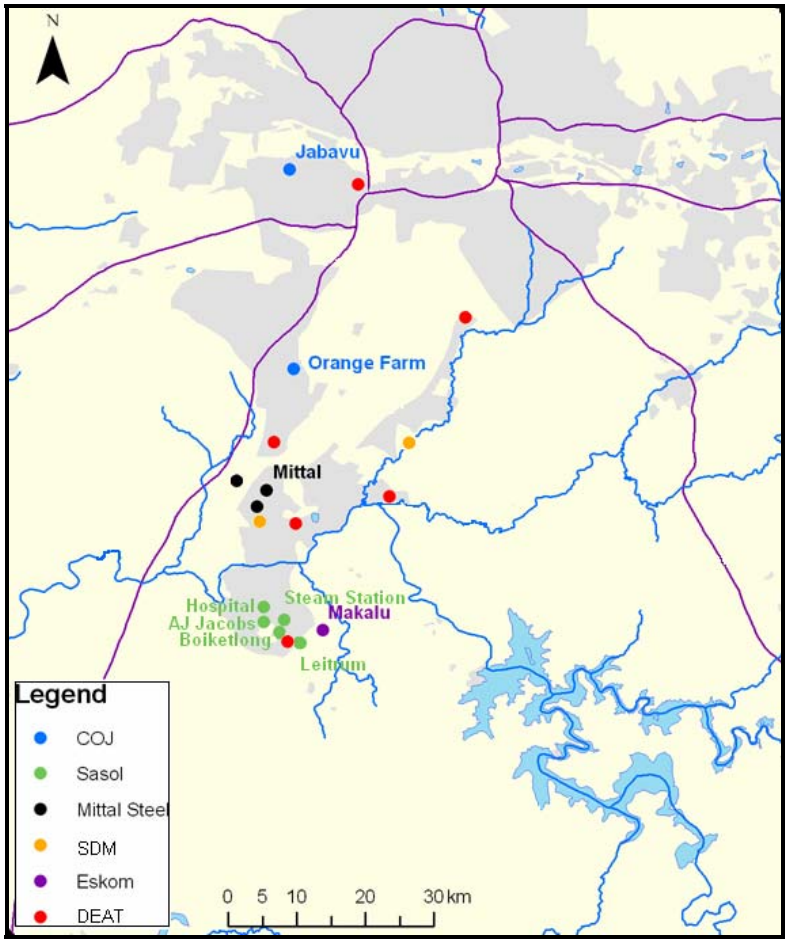


Figure 5-1: Location of Ambient Air Quality Monitoring Stations (including stations owned by City of Johannesburg (COJ), Sedibeng District Municipality (SDM), Department of Environmental Affairs and Tourism (DEAT) and Industry).

Table 5-1: Evaluation of monitoring stations operated by industry and various spheres of Government (after Liebenberg-Enslin *et al.*, 2007).

Monitoring Agency	Station Name	Longitude (°E)	Latitude (°S)	Status	Monitoring Period	Pollutants Measured	Averag-ing Period	Calibration		Type of Equip-ment	SANAS Accredited - Yes/No
								Frequency	Undertaken by		
COJ	Jabavu	27.872	-26.253	Active	2004 - Present	PM10, SO_2	10 min intervals	Quarterly	Climatology Research Group	Thermo	No
	Orange Farm	27.867	-26.480	Active	2004 - Present	PM10, SO_2	10 min intervals	Quarterly	Climatology Research Group	Thermo	No
Eskom	Makalu	27.903	-26.835	Decom-mission-ed	1984 - 2004	NO, NO_2, O_3, PM10, SO_2	Hourly	3 months	Eskom	Thermo, Dasibi and Monitor Labs	Yes
ArcelorMittal Steel (MSVS)	Station 620	27.822	-26.673	Active	2005 - Present	CO, NO_2, O_3, PM10, H_2S, SO_2	10 minutes	3 months	C&M Engineers	API, Opsis Open Path	No
	Station 350	27.834	-26.655	Active	2005 - Present	CO, NO_2, O_3, PM10, H_2S, SO_2	10 minutes	3 months	C&M Engineers	API, Opsis Open Path	No
	Caravan (mobile)	27.788	-26.645	Active	2006 - Present	CO, NO_2, O_3, PM10, H_2S, SO_2	10 minutes	3 months	C&M Engineers	API	No
Sasol [(1)]	AJ Jacobs	27.826	-26.823	Active	2003 - Present	SO_2, H_2S, NO, NO_2, NO_X	10 min intervals	2 x per months, external SANAS calibration done annually	Sasol	API, Opsis, Opsis Open Path, API	Yes

Monitoring Agency	Station Name	Longitude (°E)	Latitude (°S)	Status	Monitoring Period	Pollutants Measured	Averag-ing Period	Calibration		Type of Equip-ment	SANAS Accredited - Yes/No
								Frequency	Undertaken by		
	Boiketlong	27.846	-26.836	Active	2003 - Present	H2S, SO_2	10 min intervals	2 x per months, external SANAS calibration done annually	Sasol	API, Opsis, Opsis Open Path, API	Yes
	Hospital	27.826	-26.803	Active	2003 - Present	H2S, SO_2	10 min intervals	2 x per months, external SANAS calibration done annually	Sasol	API, Opsis, Opsis Open Path, API	Yes
	Steam Station	27.853	-26.820	Active	2003 - Present	NOx, O_3, PM10, H_2S, SO_2, NH_3, CH_4, Non-Methane	10 min intervals	2 x per months, external SANAS calibration done annually	Sasol	API, Opsis, Opsis Open Path, API	Yes
	Leitrim	27.871	-26.850	Active	2003 - Present	BTEX, CO, NO_2, O_3, PM10, SO_2	10 min intervals	2 x per months, external SANAS calibration done annually	Sasol	API, Opsis, Opsis Open Path, API	Yes

Notes: COJ - City of Johannesburg, DEAT - Department of Environmental Affairs and Tourism, SDM – Sedibeng District Municipality
(1) Sasol monitoring stations were accredited in 2004

Sasol operate five monitoring stations, viz. AJ Jacobs, Sasolburg Hospital, Boiketlong, Leitrim and Steam Station (Figure 5-2). Hospital and AJ Jacobs monitoring stations are located within Sasolburg, Boiketlong and Leitrim to the north and east of Zamdela residential area respectively and Steam Station, within the Sasolburg Chemical Industrial Complex.

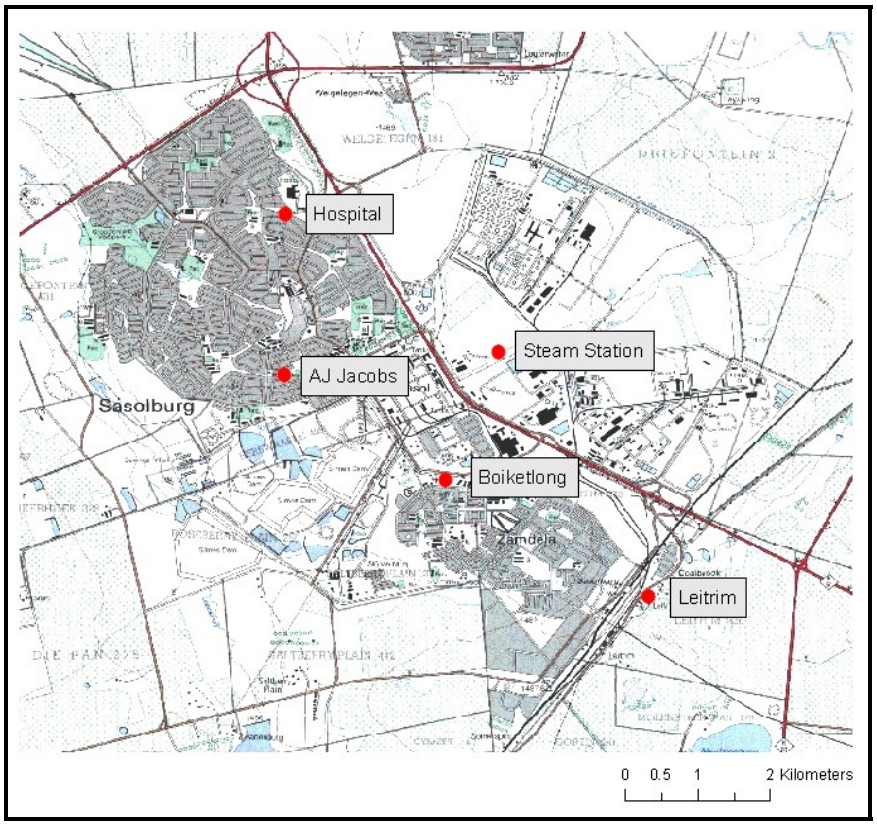


Figure 5-2: Location of the Sasol ambient monitoring stations within the study area (after Liebenberg-Enslin *et al*, 2007).

ArcelorMittal Steel Vanderbijlpark Steel (MSVS) operate two ambient monitoring stations, viz. Station 350 and Station 620, on the plant boundary, and a mobile station, viz. Caravan (Figure 5-3).

The department of Environmental Affairs and Tourism has recently (February – March 2007) established and commissioned six ambient monitoring stations in and around the Vaal Triangle. These stationed are located in Diepkloof (Soweto), Kliprivier, Sebokeng, Sharpville, Three Rivers and Zamdela. However, due to the limited data available, this information was not assessed in the current study.

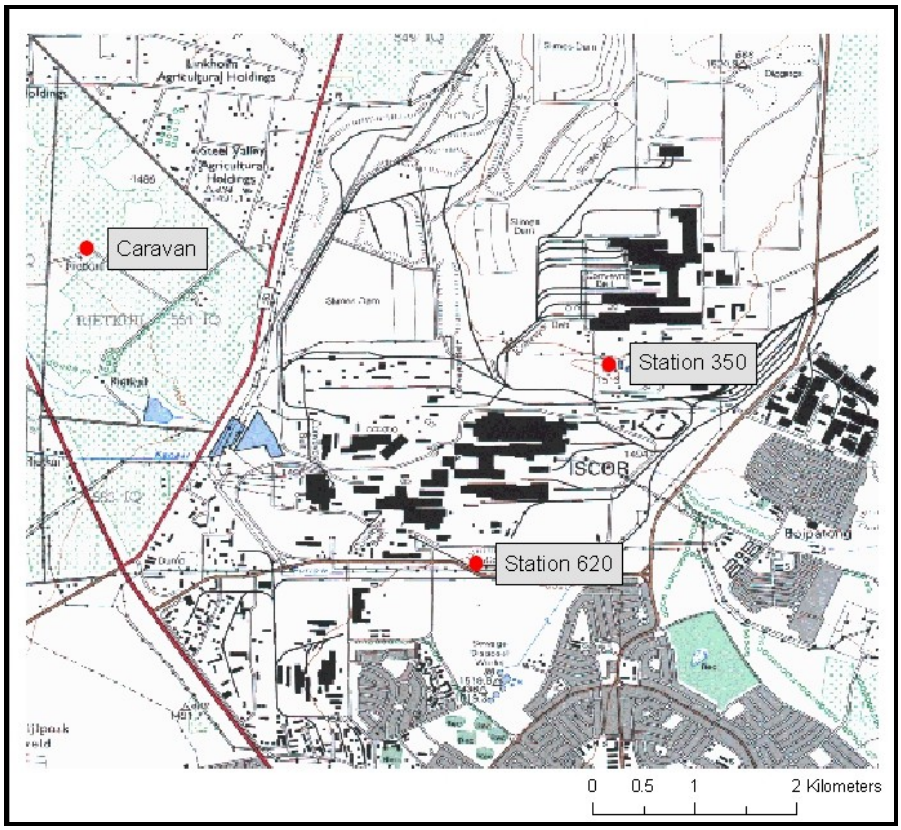


Figure 5-3: Location of the ArcelorMittal Steel Vanderbijlpark Steel ambient monitoring stations (after Liebenberg-Enslin *et al*, 2007).

As the criteria pollutants of sulphur dioxide, nitrogen dioxide, and inhalable particulate matter were quantified for the current assessment, only ambient monitored data for these pollutants has been discussed in the following sections.

5.1 Data Availability

The data availability of the monitoring stations for the period 2004 – 2006 is given in Table 5-2. It should be noted that a minimum data availability of 80% is required to achieve data quality assurance.

Table 5-2: Data availability for monitoring stations in the Vaal Airshed operated by industry and various spheres of Government (after, Liebenberg-Enslin *et al*, 2007) [(1)].

Monitoring Agency	Station	Data Availability (%)		
		2004	2005	2006
Inhalable Particulate Matter				
City of Johannesburg	Jabavu	89	**60**	**73**
	Orange Farm	**79**	**70**	**79**
ArcelorMittal Steel Vanderbijlpark Steel	Station620	-	**67**	**24**
	Station 350	-	**75**	**24**
	Caravan	-	-	**70**
Sasol	AJ Jacobs	-	-	-
	Boiketlong	-	-	-
	Hospital	-	-	-
	Leitrim	99	93	99
Eskom	Makalu	80	-	-
Sulphur Dioxide				
City of Johannesburg	Jabavu	85	**62**	**73**
	Orange Farm	88	83	83
ArcelorMittal Steel Vanderbijlpark Steel	Station620	-	**77**	86
	Station 350	-	96	**70**
	Caravan	-	-	**69**
Sasol	AJ Jacobs	100	100	99
	Boiketlong	99	100	99
	Hospital	100	100	99
	Leitrim	91	93	99
Eskom	Makalu	99	-	-
Nitrogen Dioxide				
City of Johannesburg	Jabavu	-	-	-
	Orange Farm	-	-	-
ArcelorMittal Steel Vanderbijlpark Steel	Station620	-	**77**	86
	Station 350	-	96	**74**
	Caravan	-	-	**75**
Sasol	AJ Jacobs	-	100	99
	Boiketlong	-	-	-
	Hospital	-	-	-
	Leitrim	91	93	99
Eskom	Makalu	98	-	-

(1) Data with less than 80% availability is given in bold.

5.2 Ambient Particulate Concentrations

Elevated levels of airborne particulates are known to occur over the Vaal Triangle. This subsection aims to provide an overview of the extent of such concentrations and to reflect on diurnal trends which are able to assist in determining the nature of sources contributing to such concentrations.

The monitored particulate matter for the period 2004 – 2006 is given in Table 5-3, with the frequency of exceedance of the SANS daily limit (proposed SA standard) given in Table 5-4. Monitored data , shows elevated inhalable particulate concentrations over the Vaal Airshed with daily and annual (with the exception of Makalu) ground level concentrations exceeding the SANS limits (proposed SA standards)at all monitoring stations.

Table 5-3: Monitored inhalable particulate matter at ambient stations operated by industry and various spheres of government within the Vaal Airshed (after Liebenberg-Enslin *et al*, 2007) [(1)].

Monitoring Agency	Station	Monitored PM10 Concentrations (µg/m³)		
		2004	2005	2006
Highest Hourly [(2)]				
City of Johannesburg	Jabavu	785	820	932
	Orange Farm	996	993	933
ArcelorMittal Steel Vanderbijlpark Steel	Station620	-	347	217
	Station 350	-	376	217
	Caravan	-	-	594
Sasol	AJ Jacobs	-	-	-
	Boiketlong	-	-	-
	Hospital	-	-	-
	Leitrim	999	942	947
Eskom	Makalu	647	-	-
Highest Daily [(3)]				
City of Johannesburg	Jabavu	**291**	**232**	**215**
	Orange Farm	**228**	**252**	**233**
ArcelorMittal Steel Vanderbijlpark Steel	Station620	-	**210**	**125**
	Station 350	-	**221**	**173**
	Caravan	-	-	**212**
Sasol	AJ Jacobs	-	-	-
	Boiketlong	-	-	-
	Hospital	-	-	-
	Leitrim	**275**	**314**	**294**
Eskom	Makalu	**145**	-	-
Annual Average [(4)]				
	Jabavu	-	**88**	**66**

Monitoring Agency	Station	Monitored PM10 Concentrations (µg/m³)		
		2004	2005	2006
City of Johannesburg (5)	Jabavu	-	**88**	**66**
	Orange Farm	-	**78**	**66**
ArcelorMittal Steel Vanderbijlpark Steel	Station620	-	**103**	**54**
	Station 350	-	**91**	**52**
	Caravan	-	-	**96**
Sasol	AJ Jacobs	-	-	-
	Boiketlong	-	-	-
	Hospital	-	-	-
	Leitrim	**53**	**105**	**41**
Eskom	Makalu	34	-	-

Notes:
(1) Exceedances of the SANS limits (proposed SA standards) is given in bold.
(2) No inhalable particulate limits/ standards are available for an hourly averaging period.
(3) The SANS daily limit for inhalable particulates is 75 µg/m³.
(4) The SANS annual limit for inhalable particulates is 40 µg/m³.
(5) Annual average not calculated for 2004 for Jabavu and Orange Farm as monitoring commenced in the second half of 2004.

Table 5-4: Measured frequency of daily inhalable particulate exceedance of the SANS limit of 75 µg/m³ (proposed SA standard) at various monitoring stations operated by industry and various spheres of government within the study area (after Liebenberg-Enslin *et al*, 2007).

Monitoring Agency	Station	Frequency of exceedance (days)		
		2004	2005	2006
City of Johannesburg (1)	Jabavu	90	184	154
	Orange Farm	154	182	196
ArcelorMittal Steel Vanderbijlpark Steel	Station620	-	188	24
	Station 350	-	168	56
	Caravan	-	-	180
Sasol	AJ Jacobs	-	-	-
	Boiketlong	-	-	-
	Hospital	-	-	-
	Leitrim	84	162	50
Eskom	Makalu	24	-	-

(1) Frequency of exceedance for Jabavu and Orange Farm were based on the City of Johannesburg guideline of 50 µg/m³.

Figure 5-4 provides the diurnal profile of the monitored inhalable particulate concentrations over the Vaal Airshed. Areas of domestic fuel burning activities (i.e. Jabavu and Orange Farm) have a distinct diurnal profile with increases in concentrations in the early morning (06:00 – 10:00) and evening (17:00 – 21:00). Peak pollutant concentrations from industry monitoring stations are noted to occur between 10:00 and 16:00. This diurnal trend is

generally indicative of ground level concentrations occurring due to elevated stack, with the plume typically being "brought to ground" during periods of atmospheric instability. Such vertical turbulence due to convective mixing occurs during the daytime.

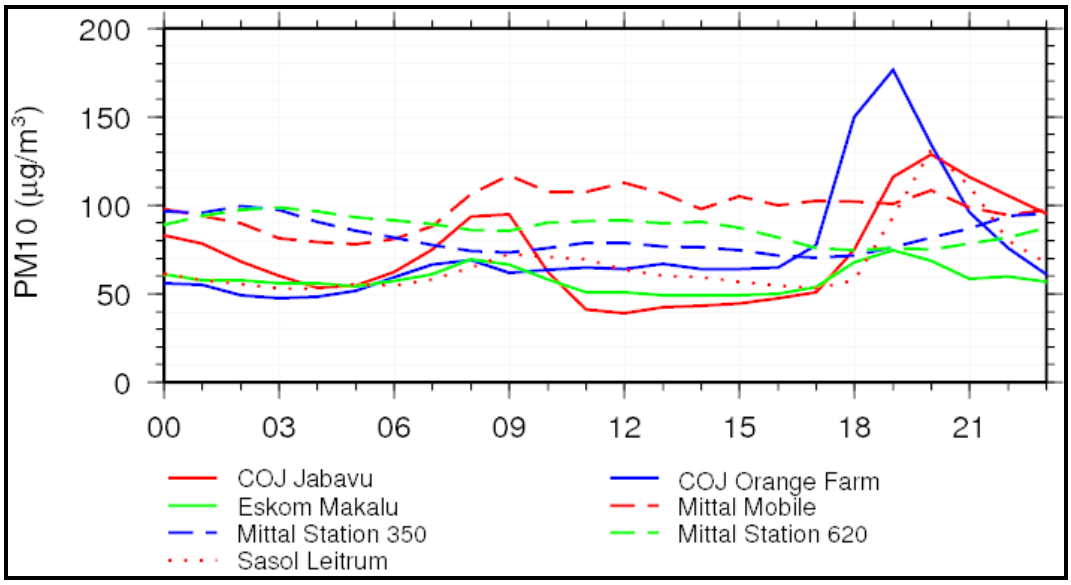


Figure 5-4: Diurnal profile of monitored inhalable particulate ground level concentrations at various monitoring stations operated by industry and government within the study area (after Liebenberg-Enslin *et al*, 2007).

Key findings in terms of ambient particulate concentrations (based on ambient monitored data within the Vaal Airshed for the period 2004 – 2006) are as follows:

- *Exceedances of current inhalable particulate SA standards and significant exceedances of the proposed inhalable particulate SA standards (SANS limits) have been measured to occur over the Vaal Airshed.*

- *In/ adjacent to domestic fuel burning areas (viz. Jabavu, Orange Farm and Leitrim) average annual inhalable particulate concentrations were found to range from 66 to 105 µg/m³ with maximum daily inhalable particulate concentrations in the order of 215 to 314 µg/m³.*

- *Maximum daily inhalable particulate levels were observed to be in the range of 125 to 221 µg/m³ in industrial areas (viz. Station 620, Station 350, Caravan and Makalu), with annual average concentrations of 34 to 103 µg/m³.*

The main conclusions to be drawn are that ambient inhalable particulate concentrations continue to be elevated across the Vaal Triangle region. Such concentrations represent a significant health risk.

5.3 Ambient Sulphur Dioxide Concentrations

The highest monitored sulphur dioxide ground level concentrations over the Vaal Airshed is given in Table 5-5 with the frequency of exceedance of SA standards (and SANS limits) given in Table 5-6. Short-term (hourly) sulphur dioxide concentrations at all monitoring stations (with the exception of Caravan) exceeded the SA standards for the period 2004 – 2006. At the domestic fuel burning areas of Jabavu and Orange Farm, the highest daily monitored concentrations exceeded the SA standards for the period 2005 – 2006 and 2006 respectively. Despite apparent reductions in sulphur dioxide levels in the Sasolburg industrial area, exceedances of SA standard for daily average concentrations continue to occur at the Sasol monitoring stations of AJ Jacobs and Boiketlong (for the period 2004 – 2006).

Table 5-5: Monitored sulphur dioxide concentrations at ambient stations operated by industry and government within the Vaal Airshed (after Liebenberg-Enslin *et al*, 2007) [(1)].

Monitoring Agency	Station	Monitored Sulphur Dioxide Concentrations (µg/m³)		
		2004	2005	2006
Highest Hourly [(2)]				
City of Johannesburg	Jabavu	**401**	**1350**	**2032**
	Orange Farm	**530**	**1069**	**2109**
ArcelorMittal Steel Vanderbijlpark Steel	Station620	-	**512**	**754**
	Station 350	-	**698**	**793**
	Caravan	-	-	190
Sasol	AJ Jacobs	**752**	**754**	**788**
	Boiketlong	**1865**	**773**	**1310**
	Hospital	**737**	**665**	**557**
	Leitrim	**566**	**523**	**666**
Eskom	Makalu	**624**	-	-
Highest Daily [(3)]				
City of Johannesburg	Jabavu	74	**185**	**149**
	Orange Farm	107	76	**140**
ArcelorMittal Steel Vanderbijlpark Steel	Station620	-	114	109
	Station 350	-	110	116
	Caravan	-	-	53
Sasol	AJ Jacobs	**271**	**205**	**197**
	Boiketlong	**155**	**183**	**190**
	Hospital	**145**	**164**	119

Monitoring Agency	Station	Monitored Sulphur Dioxide Concentrations (µg/m³)		
		2004	2005	2006
	Leitrim	106	108	113
Eskom	Makalu	124	-	-
Annual Average (4)				
City of Johannesburg (5)	Jabavu	-	27	27
	Orange Farm	-	13	15
ArcelorMittal Steel Vanderbijlpark Steel	Station620	-	38	31
	Station 350	-	28	23
	Caravan	-	-	11
Sasol	AJ Jacobs	39	35	37
	Boiketlong	37	41	43
	Hospital	36	33	27
	Leitrim	26	29	32
Eskom	Makalu	21	-	-

Notes:
(1) Exceedances of the SANS limits (also current SA standards) is given in bold.
(2) The SANS hourly limit for sulphur dioxide is 350 µg/m³.
(3) The SANS daily limit for sulphur dioxide is 125 µg/m³.
(4) The SANS annual limit for sulphur dioxide is 50 µg/m³.
(5) Annual average not calculated for 2004 for Jabavu and Orange Farm as monitoring commenced in the second half of 2004.

Table 5-6: Measured frequency of hourly and daily sulphur dioxide exceedance of the SANS limit of 350 µg/m³ and 125 µg/m³ respectively (proposed SA standard) at various monitoring stations operated by industry and government within the Vaal Airshed (after Liebenberg-Enslin *et al*, 2007).

Monitoring Agency	Station	Frequency of exceedance		
		2004	2005	2006
Hourly Exceedance				
City of Johannesburg	Jabavu	1	2	22
	Orange Farm	11	1	25
ArcelorMittal Steel Vanderbijlpark Steel	Station620	-	5	5
	Station 350	-	3	4
	Caravan	-	-	0
Sasol	AJ Jacobs	53	48	59
	Boiketlong	50	83	91
	Hospital	20	36	18
	Leitrim	5	31	12
Eskom	Makalu	16	-	-
Daily Exceedance				
City of Johannesburg	Jabavu	0	1	3
	Orange Farm	0	0	6
ArcelorMittal Steel	Station620	-	0	0
	Station 350	-	0	0

Monitoring Agency	Station	Frequency of exceedance		
		2004	2005	2006
Vanderbijlpark Steel	Caravan	-	-	0
Sasol	AJ Jacobs	6	7	9
	Boiketlong	3	8	8
	Hospital	2	3	0
	Leitrim	0	0	0
Eskom	Makalu	0	-	-

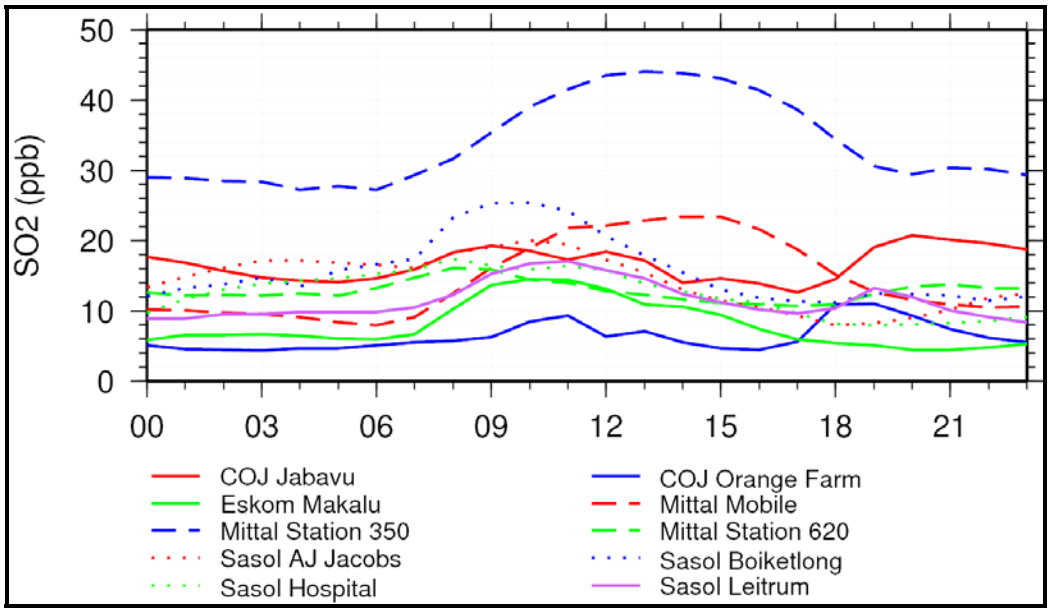


Figure 5-5: Diurnal profile of monitored sulphur dioxide ground level concentrations from various monitoring stations operated by industry and government within the Vaal Airshed (after Liebenberg-Enslin *et al*, 2007).

Distinct diurnal trends in sulphur dioxide concentrations are noted to occur (Figure 5-5). Concentration peaks observed during the morning at AJ Jacobs, Hospital, Boiketlong, Leitrim and Makalu are associated with emissions from tall stacks in the region. During the night-time the plumes from elevated sources emitting above or within the surface inversion layer are unable to penetrate to ground level. The dissipation of the surface inversion from the base upwards due to day-time convection and the entrainment and down-mixing of plumes from elevated plumes results in the peak concentrations noted.

Within domestic fuel burning areas, such as Jabavu, Orange Farm and Leitrim, bi-modal peaks occur in the diurnal trends. The first peak is observed to occur at 09:00 – 10:00 and the second at 19:00. The Leitrim site is primarily influenced by low level domestic fuel burning emissions and industrial emissions in the area.

Key findings in terms of ambient sulphur dioxide concentrations are as follows:

- *Maximum hourly average sulphur dioxide concentrations of between 512 µg/m³ and 2109 µg/m³ have been recorded to occur at the monitoring stations within the Vaal Airshed.*

- *Maximum daily concentrations of between 53 µg/m³ and 271 µg/m³ have been recorded at the monitoring stations within the Vaal Airshed for the period 2004 – 2006.*

- *A general increase in short-term sulphur dioxide ground level concentrations have been observed from the period 2005 to 2006 at all monitoring station within the Vaal Airshed.*

5.4 Ambient Nitrogen Dioxide Concentrations

The highest measured nitrogen dioxide ground level concentrations for the period 2004 – 2006 is given Table 5-7 and the frequency of hourly exceedances of the SANS limit (proposed SA standard) is given in Table 5-8. Few exceedances of the proposed SA hourly standard are observed with Leitrim recording 5 (in 2004), Station 620 recording 1 (in 2005 and 2006) and AJ Jacobs recording 1 (in 2006).

Table 5-7: Monitored nitrogen dioxide concentrations at ambient stations operated by industry and government within the Vaal Airshed (after Liebenberg-Enslin *et al*, 2007) [(1)].

Monitoring Agency	Station	Monitored Nitrogen Dioxide Concentrations (µg/m³)		
		2004	2005	2006
Highest Hourly [(2)]				
City of Johannesburg	Jabavu	-	-	-
	Orange Farm	-	-	-
ArcelorMittal Steel Vanderbijlpark Steel	Station 620	-	**241**	**294**
	Station 350	-	158	134
	Caravan	-	-	53
Sasol	AJ Jacobs	-	198	**227**
	Boiketlong	-	-	-
	Hospital	-	-	-
	Leitrim	**583**	143	120
Eskom	Makalu	100	-	-
Highest Daily [(3)]				
City of Johannesburg	Jabavu	-	-	-
	Orange Farm	-	-	-

Monitoring Agency	Station	Monitored Nitrogen Dioxide Concentrations (µg/m³)		
		2004	2005	2006
ArcelorMittal Steel Vanderbijlpark Steel	Station 620	-	64	71
	Station 350	-	67	81
	Caravan	-	-	37
Sasol	AJ Jacobs	-	79	87
	Boiketlong	-	-	-
	Hospital	-	-	-
	Leitrim	122	57	72
Eskom	Makalu	55	-	-
Annual Average (4)				
City of Johannesburg (5)	Jabavu	-	-	-
	Orange Farm	-	-	-
ArcelorMittal Steel Vanderbijlpark Steel	Station620	-	31	28
	Station 350	-	32	33
	Caravan	-	-	6
Sasol	AJ Jacobs	-	28	28
	Boiketlong	-	-	-
	Hospital	-	-	-
	Leitrim	28	23	27
Eskom	Makalu	16	-	-

Notes:
(1) Exceedances of the SANS limits (proposed SA standards) is given in bold.
(2) The SANS hourly limit for nitrogen dioxide is 200 µg/m³.
(3) No SANS daily limit is available for nitrogen dioxide.
(4) The SANS annual limit for nitrogen dioxide is 40 µg/m³.
(5) Annual average not calculated for 2004 for Jabavu and Orange Farm as monitoring commenced in the second half of 2004.

Table 5-8: Measured frequency of hourly nitrogen dioxide exceedance of the SANS limit of 200 µg/m³ (proposed SA standard) at various monitoring stations operated by government and industry within the Vaal Airshed (after Liebenberg-Enslin *et al*, 2007).

Monitoring Agency	Station	Frequency of hourly exceedance		
		2004	2005	2006
City of Johannesburg	Jabavu	-	-	-
	Orange Farm	-	-	-
ArcelorMittal Steel Vanderbijlpark Steel	Station620	-	1	1
	Station 350	-	0	0
	Caravan	-	-	0
Sasol	AJ Jacobs	-	0	1
	Boiketlong	-	-	-
	Hospital	-	-	-
	Leitrim	5	0	0

Monitoring Agency	Station	Frequency of hourly exceedance		
		2004	2005	2006
Eskom	Makalu	0	-	-

Distinct diurnal profile in measured nitrogen dioxide ground level concentrations is observed with peaks occurring in the morning at 06:00 (at the Station 350, Station 620, AJ Jacobs and Leitrim monitoring stations) and 09:00 (at the monitoring stations of Makalu and Caravan) and in the evening 19:00. This diurnal pattern may be due to the diurnal trend of vehicle and domestic fuel burning activity.

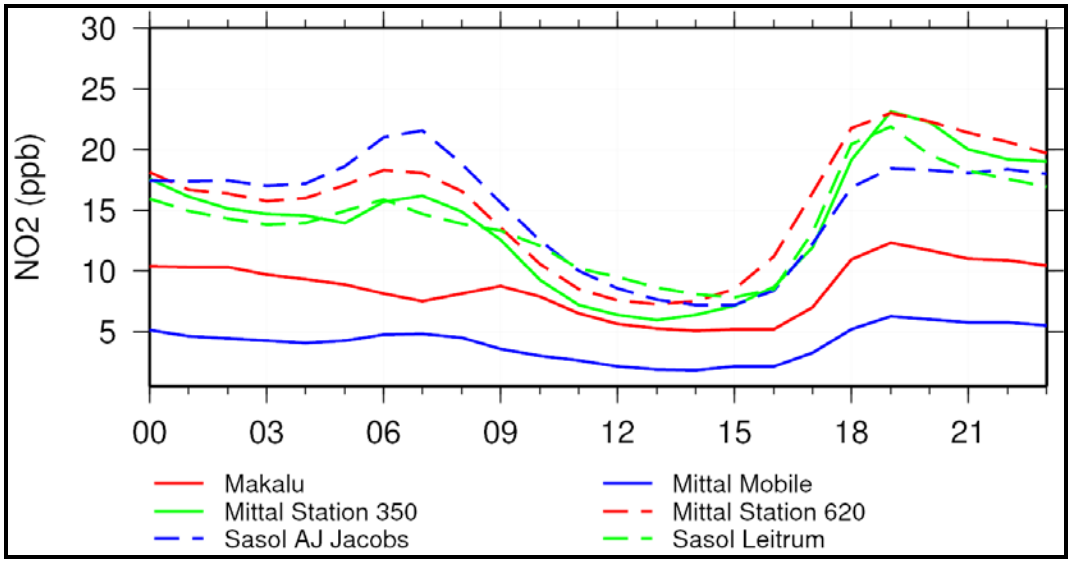


Figure 5-6: Diurnal profile of monitored nitrogen dioxide ground level concentrations from various monitoring stations operated by industry and government within the Vaal Airshed (after Liebenberg-Enslin *et al*, 2007).

Key findings in terms of ambient nitrogen dioxide concentrations are as follows:

- *Maximum hourly average nitrogen dioxide concentrations of between 53 µg/m³ and 583 µg/m³ have been recorded to occur at the monitoring stations within the Vaal Airshed.*

- *Few hourly exceedances of the SANS limit (proposed SA standard) is observed over the period 2004 – 2006, with less than 2 exceedances observed for the period 2006.*

CHAPTER 6
EMISSIONS INVENTORY FOR THE STUDY AREA

The identification and quantification of existing sources of emissions in the region, together with the characterisation of ambient pollutant concentrations is fundamental to the assessment of the potential for cumulative impacts given the existing operations and their associated emissions. Sources of air pollution within the study area and pollutants associated with such source types are identified with the aim of understanding which pollutants may be of importance in terms of cumulative impact potentials.

Sources of emissions are generally placed into categories with the most frequent distinctions being made between mobile and stationary sources, industrial and non-industrial sources, point and area sources and regulated and unregulated sources.

An emissions inventory for the study area was established for sources where information was available (viz, industry) or where emission factors could be utilised to quantify sources.

Sources which contribute to ambient air pollutant concentrations within the study region include:

- Stack, vent and fugitive emissions from industrial operations;
- Fugitive emissions from mining operations, including mechanically generated dust emissions and gaseous emissions from blasting and spontaneous combustion of exposed coal seams;
- Vehicle entrainment of dust from paved and unpaved roads;
- Vehicle tailpipe emissions;
- Domestic fuel burning (particularly use of coal, wood and paraffin);
- Biomass burning (viz., veld fires); and,
- Various other fugitive dust sources, such as agricultural activities and wind erosion of open areas.

Atmospheric emissions were quantified and simulated for the following sources during the current study:

- Gaseous and particulate emissions from industrial operations;
- Domestic fuel burning (particularly coal, wood and paraffin used by informal communities/settlements);
- Fugitive emissions from open cast coal mining operations;
- Wind-blown dust emissions from ash dumps; and
- Vehicle tailpipe emissions.

The extent and spatial location of atmospheric emissions from vehicle entrainment, biomass burning and spontaneous combustion that may contribute significantly to air pollution concentrations in certain parts of the study area could not be accurately quantified and were therefore omitted from the simulations.

Pollutants that were assessed for the baseline study included the criteria pollutants of nitrogen dioxide, sulphur dioxide and inhalable particulates. These pollutants are stipulated in the South African Standards, with adequate data available from industries to be quantified.

6.1 Industrial Sources

Significant and potentially significant emitters within the Vaal Triangle are generally grouped within larger industrial sectors within Vanderbijlpark, Vereeniging, Sasolburg and Meyerton. The main contributing sources within these sectors include:

Vanderbijlpark - ArcelorMittal Steel Vanderbijlpark Steel, Vitro Building Products and Davesteel (Cape Gate) are significant sources of particulates. Other potentially significant sources include Africa Cables and Dorbyl Heavy Engineering.

Sasolburg - Significant sources of emissions include: the Sasol Chemical Industries Complex, Natref, Omnia Fertiliser, Safripol and Sigma Colliery.

Vereeniging - ArcelorMittal Vaal Works, Rand Water Board and the New Vaal Colliery represents the most significant sources of particulate emissions. Other sources include Brickveld Stene, Concord Foundry and Lime Distributers.

Meyerton - Based on the emission estimates the largest sources of industrial/mining related emissions within Meyerton include the industries of Metalloys and EMSA in addition to various ceramic processes, viz. Ocon Bricks and Vaal Potteries. The Glen Douglas Dolomite Quarry is the only known quarrying/mining activity in the area which could not be quantified due to insufficient available data.

The use of coal, coking coal and HFO by industries within the Vaal Triangle is responsible for a large portion of the total particulate emissions from the industrial / institutional / commercial fuel use sector. Much of the particulate emissions associated with coking coal are due to the production of this fuel. Coal represents the main fuel type used by the commercial and institutional sector although anthracite, diesel and wood are also used to a lesser extent. The most significant group contributing to fuel burning emissions from the industrial, commercial, institutional fuel burning sector within the Vaal Triangle include:

- Iron and steel industries - associated with 38% of the total particulate emissions from the industrial / institutional / commercial fuel use sector (includes ArcelorMittal Steel Vanderbijlpark Steel and ArcelorMittal Vaal Works).

- Chemical and petrochemical sector - associated with 12% of the total particulate emissions from this sector (includes Sasol Chemical Industries and NATREF which are located in Sasolburg).

- Power generation – associated with 19% of the total particulate emissions from the industrial / commercial sector (includes Lethabo Power Station).

Other groups include: brick manufacturers which use coal (e.g. Brickveld Stene, Ocon Bricks) and other industries (use coal and to a lesser extent HFO for steam generation). The contribution of fuel combustion (primarily coal) by institutions such as schools and hospitals is relatively small given the extent of emissions from other groups.

Emissions from the industrial sectors were quantified based on emissions data obtained from industries, data which were already in the public domain and emission estimates from emission factor application. Appendix B provides a complete list of industries and their emissions within the Vaal Airshed.

The area of interest extended beyond the Vaal Triangle to incorporate industrial activity within the Ekurhuleni Metropolitan Municipality so as to take into account cross boundary cumulative effects. Table 6-1 provides an overview of the information gathered. The spatial distribution of the industries within the Vaal Airshed is provided in Figure 6-1. The contribution of sulphur dioxide, inhalable particulate matter and oxides of nitrogen emissions from industrial sources is illustrated in Figures 6-2, 6-3 and 6-4 respectively.

It should be noted that total suspended particulate emissions from Sasol sources were provided for the assessment. As a conservative approach, the particulate matter from these stack sources were assumed to be of the inhalable particulate fraction.

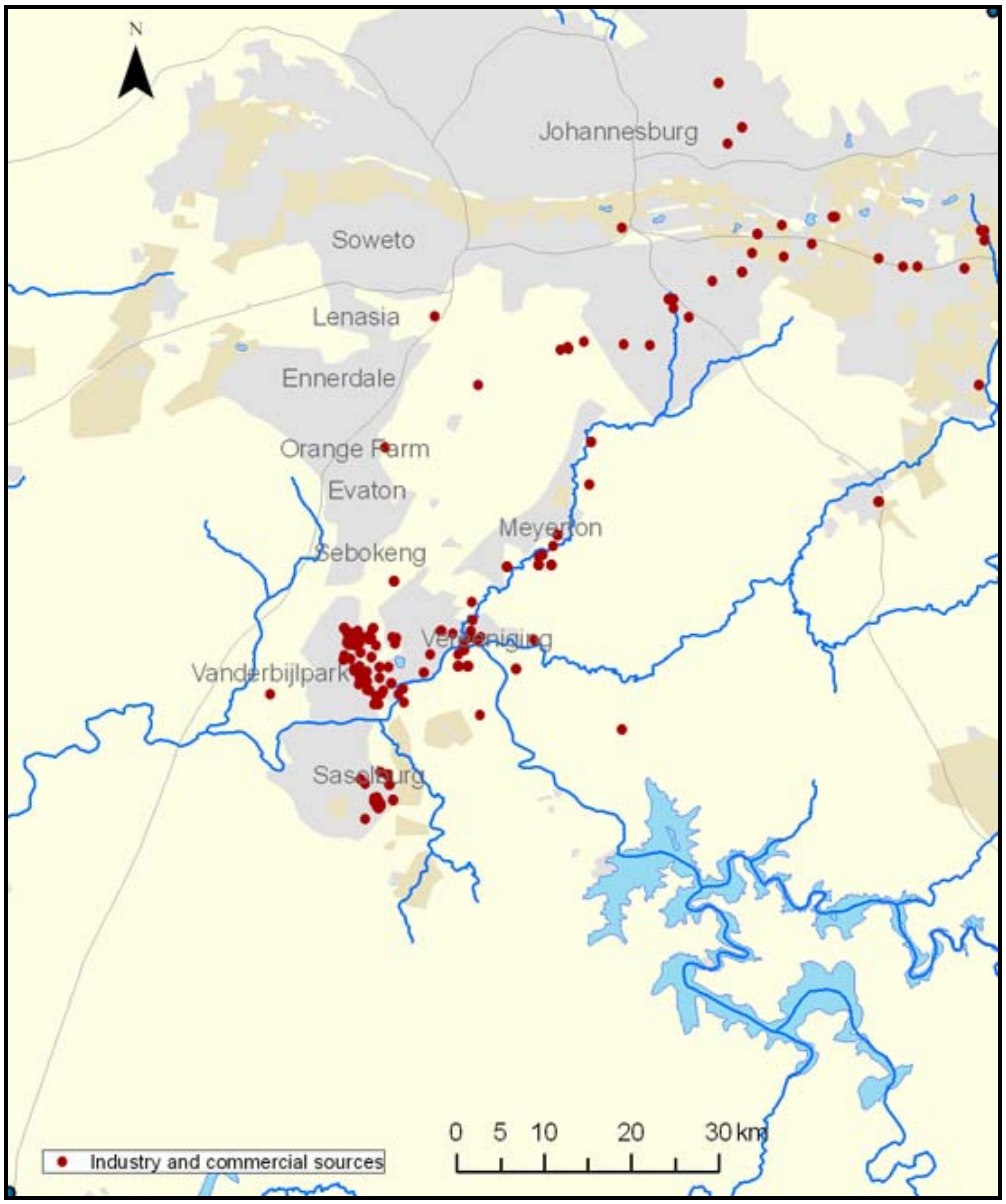


Figure 6-1: Location of the main industrial and mining activities within the Vaal Airshed that were quantified for the study.

Table 6-1: Industrial sources of atmospheric emissions within the Vaal Airshed and their associated emissions.

Industry Name	Returned (Yes)	Process Description	Pollutants			Comments
			NO_x	SO_2	PM	
A & I Brake & Clutch		Brake&Clutch Production-Asbestos Process	✓		✓	
Ab Brickworks (Pty) Ltd (Closed Down)		Brick Works		✓	▪	Closed Down
Aca		Brake&Clutch Production-Asbestos&Metal Recovery	✓		✓	
Acix Div Of Ncp-(Now Isegen Sa)		Plasticisers&Anhydrides		✓	✓	
Active Foundries		Bronze Ignot Casting Into Moulds			✓	
Aero Dry Cleaners	Yes (LM)	Dry Cleaning	✓	✓	✓	
Afcat (Now Sud-Chemie)	Yes	Metal Recovery And Phosphorous Process				Only Emits Po4
African Brick Lenasia		Clay Bricks Production	✓	✓	✓	
African Cables		Lead Process-Scrap Lead Recovery			✓	
African Detinning	Yes (LM)	Metal Recovery-Tin Scraps	✓	✓	✓	
African Pegmatite					✓	
African Zinc Mills		Milling Of Zinc In Ball Mills	✓	✓	✓	
Agricultural Research Council		Waste Incineration-Animal Carcasses And Biological Materials	✓	✓	✓	
Air Products	Yes (LM)	Acetylene Production From H2o&Calcium Carbide	✓	✓	✓	
Akulu Marchon		Produce H_2SO_3 Used In Soap Production		✓		
Albras Foundry		Melting Non-Ferrous Scrap Metal	✓	✓	✓	
Alfred Teves Eng Sa (Pty) Ltd		Brake Calisters			✓	
Alvoer (Pty) Ltd		Cattle Feedlot(Barley) Distribution			✓	
Ambijo Lounges		Wood Burning/Drying-Incinerator	✓	✓	✓	

Industry Name	Returned (Yes)	Process Description	Pollutants			Comments
			NO_x	SO_2	PM	
American Iron & Brass		Cast Iron Production			✓	
Analysis System Consultant (Ansynco Sa Cc)	Yes	Supply Installation Of On Line Analysers				No Emissions
Aquaplus	Yes					No Emissions
Bandag (Pty) Ltd			✓	✓	✓	
Besaans-Duplessis (Watt Rd)		Cast Iron Production			✓	
Blitz Concrete Works (Westongoud)		Concrete Products			✓	
Blue Armor					✓	
Bosworth			✓	✓	✓	
Brick & Clay (Nigel)		Brick And Clay Products		✓	✓	
Brickveld Stene		Bricks Production		✓	✓	
British American Tobacco		Tobacco Products	✓	✓	✓	
Britti Cc					✓	
Cargo Carriers	Yes	Transportation Of Cargo	✓	✓	✓	
Cas Ice Cream (Pty) Ltd		Ice Cream (Dairy)	✓	✓	✓	
Central Hotel		Waste Incinerator	✓	✓	✓	
Chamber Of Commerce		Waste Incinerator	✓	✓	✓	
Chubby Chick(Now Fourie's Poultry)		Meat Rendering			✓	
Claasens Tegniek		Waste Incinerator	✓	✓	✓	
Clover	Yes (LM)	Dairy Products	✓	✓	✓	
Concorde Foundry		Steel Products	✓	✓	✓	
Consol Glass (Pretoria)		Glass Manufacturing-Use Fluorspar	✓	✓	✓	
Consol Ltd (Wadeville)		Glass Manufacturing	✓	✓	✓	

Industry Name	Returned (Yes)	Process Description	Pollutants			Comments
			NO_x	SO_2	PM	
Consolidated Wire Industries		Galvanised Wire Products			✓	
Cord Chemicals		Sodium Carbonate And Silica Are Melted To Glass Then Dissolved To Sodium Silicate.		✓	✓	
Coverland Roof Tiles(Now Lafarge Roofing)		Clay Tiles			✓	
Craneware Ceramics	Yes	Bathroom Accessories	✓	✓	✓	Do Not Know Their Emissions
Cresent Packaging		Plastic	✓	✓	✓	
Crystal Papers		Paper Production	✓	✓	✓	
Davesteel (Cape Gate)		Steel Production From Scrap		✓	✓	
Df Malherbe	Yes (LM)	Waste Incinerator	✓	✓	✓	
Die Anker Skool	Yes (LM)	Waste Incinerator	✓	✓	✓	
Dimpho Foods	Yes	Fresh Food Processing				No Emissions
Dixon Battery Supplies (Pty)Ltd (Donaventa Holdings)	Yes	Automotive Battery Manufacturer			✓	Do Not Know Their Emissions
Dorbyl Heavy Engineering (Ptyltd	Yes	Manufacture Large Mining Items			✓	Do Not Know Their Emissions
Drie Riviere Primary		Waste Incinerator	✓	✓	✓	
Driefontein Gold Mine		Gold Mining		✓	✓	
Driehoek	Yes (LM)	Waste Incinerator	✓	✓	✓	
Drive In Dry Cleaners	Yes (LM)	Dry Cleaning	✓	✓	✓	
Drive-In Cleaners		Dry Cleaning	✓	✓	✓	
Eco Monitor Cc (Klipriver Forum)	Yes		▪	▪	▪	No Emissions

Industry Name	Returned (Yes)	Process Description	Pollutants			Comments
			NO_x	SO_2	PM	
Egoli Tissues			✓	✓	✓	
Emsa					✓	
Environ Drum (Pty) Ltd(Jhb Drum Reconditioning)		Reconditioned Drums			✓	
Era Stene		Brick Manufacturing	✓	✓	✓	
Escort		Animal Reduction-Cooking Pig Waste Products To Make Carcass Meal			✓	
Eskom	Yes	Power Generation	✓	✓	✓	
Eu & La Sheepskin		Leather Tanning			✓	
Everite Building Products(Everite Limited)		Asbestos Sheets	✓	✓	✓	
Everite Ltd (Klip River)		Asbestos Sheets	✓	✓	✓	
Excelsior Brickworks Edms Mpk		Brick Manufacturing		✓	✓	
First Garment Rental		Dry Cleaning	✓	✓	✓	
Flexilube		Refined Used Motor Oil			✓	
Frikkie Meyer	Yes (LM)	Waste Incinerator	✓	✓	✓	
Fry's Metals (Germiston)		Recovery Of Lead From Scrap			✓	
G Parkin Brick - Balfour		Brick Manufacturing	✓	✓	✓	
General Smuts High		Waste Incinerator	✓	✓	✓	
Geotech (Lower Wonderfonteinspruit Forum)	Yes	Consultants				No Emissions
Geotron Systems (Pty)Ltd						
Gillyfrost 3 (Pty)Ltd	Yes	Small Farmimg Operation			✓	Emissions Unknown
Grifo Foundry Cc		Ferrous&Non-Ferrous Castings		✓	✓	
Handhawer Primary		Waste Incinerator	✓	✓	✓	

Industry Name	Returned (Yes)	Process Description	Pollutants			Comments
			NO_x	SO_2	PM	
Hb Casting		Aluminium Castings	✓	✓	✓	
Heidelberg Hospital		Medical Waste Incineration			✓	
Hendrik Van Derbijl Primary	Yes (LM)	Waste Incinerator	✓	✓	✓	
Henkel			✓	✓	✓	
Historia Primary	Yes (LM)	Waste Incinerator	✓	✓	✓	
Hoer Tegnies		Waste Incinerator	✓	✓	✓	
Holfontein Steenwerke E/B		Brick Manufacturing	✓	✓	✓	
Ice Cold Bodies						
Impala Plat. (Ni/Cu) (Springs)		Platinum Mining&Refinery	✓	✓	✓	
Jhb. Mun Kelvin Power Station		Power Generation-Coal	✓	✓	✓	
Johan Heyns	Yes (LM)	Waste Incinerator	✓	✓	✓	
J & J Rubber Linings			✓	✓	✓	
Karan Beef	Yes	Cattle Feedlot			✓	Do Not Know Their Emissions
Karbochem	Yes	Rubber Latex		✓	▪	Do Not Know Their Emissions
Killarney Hotel	Yes (LM)	Waste Incinerator	✓	✓	✓	
King Food Corporation	Yes	Sorghum&Maize Milling(Steam Generation)			✓	Do Not Know Their Emissions
Kloof Gold Mine (Lower Wonderfonteinspruit Forum)		Gold Mining		✓	✓	
Kollegepark	Yes (LM)	Waste Incinerator	✓	✓	✓	
KrugerIn School		Waste Incinerator	✓	✓	✓	

Industry Name	Returned (Yes)	Process Description	Pollutants			Comments
			NO_x	SO_2	PM	
Kynoch Fertilizer (Pty)Ltd		Fertilizers	✓			
Langsley Ventures Cc						
Lime Distributors		Lime (Limestone) And Distribution	✓		✓	
Magistrate's Court	Yes (LM)	Waste Incinerator	✓	✓	✓	
Marievale Brickworks		Brick Manufacturing		✓	✓	
Mckeown Industries Sa (Pty)Ltd						
Mighty Products	Yes	Malt Manufacturers (Cereals)			✓	Emissions Unknown
ArcelorMittal Steel - Dunswart		Iron And Steel Making	✓	✓	✓	
ArcelorMittal Steel Sa Vanderbijlpark	Yes	Iron And Steel Making	✓	✓	✓	
ArcelorMittal Steel Sa Vereeniging		Iron And Steel Making	✓	✓	✓	Updated Emissions Inventory Will Be Available In June
Much Asphalt		Production Of Hot Premix Asphalt	✓	✓	✓	
Multispray	Yes (LM)	Spray Painted Automobiles			✓	
Nampak		Plastic, Paper, Glass & Metal Packagings	✓	✓	✓	
Naschem	Yes	Ammunition Manufacturing (Large Calibre)	✓	✓	✓	Emissions Unknown
Natalspruit Hospital		Waste Incineration	✓	✓	✓	
Natref	Yes	Crude Oil Refinery	✓	✓	✓	
Ncp (Chloorkop)-(Now Isegen)		Production Of Phthalic Anhydride	✓	✓	✓	
Ncp Tvl (Germiston)(Now Isegen)		Production Of Phthalic Anhydride	✓	✓	✓	
New Century Bricks		Brick Manufacturing	✓	✓	✓	

Industry Name	Returned (Yes)	Process Description	Pollutants			Comments
			NO_x	SO_2	PM	
New Vaal Colliery	Yes		✓	✓	✓	
Nkululeko Traders		Brick Manufacturing	✓	✓	✓	
Non-Ferrous Cast Products		Melting And Moulding Of Aluminium Products		✓	✓	
Noordhoek	Yes (LM)	Waste Incinerator	✓	✓	✓	
Oceanside Trading 456						
Ocon Bricks		Brick Manufacturing	✓	✓	✓	
Olifantsfontein Bricks		Brick Manufacturing	✓	✓	✓	
Oliver Lodge	Yes (LM)	Waste Incinerator	✓	✓	✓	
Omnia Fertiliser (Pty)Ltd	Yes	Fertilizer	✓		▪	
Oospark	Yes (LM)	Waste Incinerator	✓	✓	✓	
Overvaal High		Waste Incinerator	✓	✓	✓	
Pampino One		Waste Incinerator	✓	✓	✓	
Park Panel Beaters	Yes (LM)	Sanded And Sprayed Automobiles	✓	✓	✓	
Park Ridge Primary	Yes (LM)	Waste Incinerator	✓	✓	✓	
Petronet	Yes	Underground Pipeline Transportation				
Pfg Building Glass (Pty) Ltd		Flat Glass Manufacturing	✓	✓	✓	
Pinedene Primary	Yes (LM)	Waste Incinerator	✓	✓	✓	
Polifin Ltd - Midland Factory(Now Sasol Polymers)		Chemical Production	✓	✓	✓	
PPC (Pretoria)		Cement Production	✓		✓	
Premier Hollow Brick & Tile Co		Stock Brick Manufacturing	✓	✓	✓	
Pretoria Brickworks		Brick Manufacturing	✓	✓	✓	
Pretoria Kragsentrale(Pta-Wes)		Power Generation	✓	✓	✓	

Industry Name	Returned (Yes)	Process Description	Pollutants			Comments
			NO_x	SO_2	PM	
Pretoria Metal Pressing - Oos		Explosive Waste Recovery&Incineration		✓	✓	
Protein Products		Protein Products	✓	✓	✓	
Rand Water, Vereeniging	Yes	(Power Generation - Decommissioned End March 2006)	✓	✓	✓	
Rayton Bricks		Clay Brick Manufacturing	✓	✓	✓	
Riverside High		Waste Incinerator	✓	✓	✓	
Rosema Stene		Clay Brick Manufacturing	✓	✓	✓	
Rwb Blr			✓	✓	✓	
S Bothma & Seun Transport (Pty)Ltd		Bulk Transportation& Small Scale Sand Surface Mining			✓	
S.A. Breweries Ltd (Alberton)		Sorghum & Malt Products			✓	
Sabrix Boekenhoutkloof		Brick Manufacturing	✓	✓	✓	
Sabrix Vaal		Brick Manufacturing	✓	✓	✓	
Safripol	Yes	Polyethylene And Polypropylene	✓	✓	✓	
Samancor-Metalloys (Manganese)	Yes	Ferro Manganese Smelters			✓	
Sap	Yes (LM)	Waste Incinerator	✓	✓	✓	
Sappi Fine Papers (Springs)(Enstra Mill)		Pulp And Paper	✓	✓	✓	
Sasol	Yes	Chemical Manufacturing	✓	✓	✓	
Scaw Metals Ltd (Alberton)		Steel Scrap Melting To Produce Grinding Media		✓	✓	
Senmin	Yes	Mining Chemical Detergents				No Emissions
Shem Energy Paper Print Wood Association						

Industry Name	Returned (Yes)	Process Description	Pollutants			Comments
			NO_x	SO_2	PM	
Sigma Colliery					✓	
Slagment	Yes (LM)	Slag And Blended Cement	✓	✓	✓	
Smx Sasolburg (Sasol Nitro)		Chemical Manufacturing			✓	
South African Breweries		Sorghum And Malt Products			✓	
Sterkfontein Brick Works		Brick Manufacturing-Using Coal Duff (Mined On Site)	✓	✓	✓	
Sun Crest High	Yes (LM)	Waste Incinerator	✓	✓	✓	
Suncrush	Yes (LM)		✓	✓	✓	
Sunel Boerderye			✓	✓	✓	
Superior Casting Supplies/Pattern Makers		Iron Castings			✓	
Superp Dry Cleaners		Dry Cleaners	✓	✓	✓	
Supreme	Yes (LM)	▪	✓	✓	✓	Closed Down
Tanker Services	Yes (LM)	Fuel Storage&Transportation	✓	✓	✓	
Technical Manuf & Distrib		Iron Scrap Melting Into Fine Products			✓	
Tnt Panel Beaters	Yes (LM)	Sanded And Sprayed Automobiles	✓	✓	✓	
Tosa (Tubemakers Of Sa)		Zinc Galvanized Tubes And Fittings			✓	
Totius Primary	Yes (LM)	Waste Incinerator	✓	✓	✓	
Transvalia	Yes (LM)	Waste Incinerator	✓	✓	✓	
Uniresins			✓	✓	✓	
Unitaspark Primary School		Waste Incinerator	✓	✓	✓	
Vaal High	Yes (LM)	Waste Incinerator	✓	✓	✓	
Vaal Portugese Bakery	Yes (LM)	Bakery	✓	✓	✓	
Vaal Potteries		Ceramic Products	✓	✓	✓	
Vaal Technikon	Yes (LM)	Waste Incinerator	✓	✓	✓	
Vaalmed	Yes (LM)	Medical Waste Incinerator	✓	✓	✓	

Industry Name	Returned (Yes)	Process Description	Pollutants			Comments
			NO_x	SO_2	PM	
Van Leer Sa		Gas Cylinder Coating By Zinc Spray			✓	
Van Zyl Panelbeaters	Yes (LM)	Sanded & Sprayed Automobiles	✓	✓	✓	
Vanderbijlpark High	Yes (LM)	Waste Incinerator	✓	✓	✓	
Vereeniging Abbatoir		Meat Reduction	✓	✓	✓	
Vereeniging Crushers		Crushed Sand			✓	
Vereeniging High School		Waste Incinerator	✓	✓	✓	
Vereeniging Refr. (Springs)-(Verref)		Refractory Bricks	✓	✓	✓	
Verref Minerals		Pitch Bonded Refractory Bricks	✓	✓	✓	
Vesuvius		Treated Dolomite &Clay Bricks			✓	
Victoria Brick Pty Ltd		Clay Brick Manufacturing	✓	✓	✓	
Viljoen And Associates		Organic&Inorganic Soil Remedation Consultants				No Emissions
Vitro Building Products		Clay Products	✓	✓	✓	
Voorslag	Yes (LM)	Waste Incinerator	✓	✓	✓	
Vryheidsmonument Laerskool		Waste Incinerator	✓	✓	✓	
Wesbrix		Brick Manufacturing	✓	✓	✓	
Willies Confectionary	Yes (LM)		✓	✓	✓	
Yara						
Zimmerman And Jansen Sa					✓	
Zincor		Metallic Zinc & Sulphuric Acid		✓	✓	
Zwartkoppies Pumping Station		Steam Generation-Water Pumping Power	✓	✓	✓	

The red ticks ✓ are updated/ current information; the blue ticks ✓ indicate information obtained from the NEDLAG Dirty Fuels study (Scorgie et al, 2004); and the grey ticks ✓ are where emissions will exist but no information is available.
LM: Local Municipality

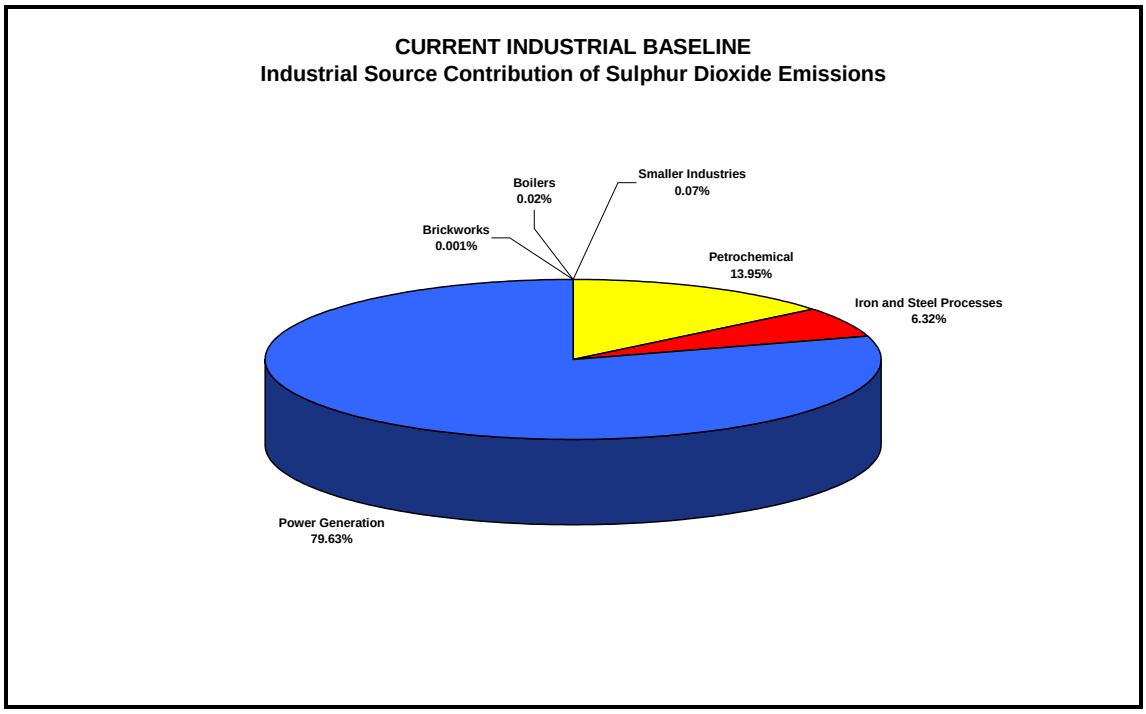


Figure 6-2: Total annual sulphur dioxide source emission distribution from industrial, commercial and institutional sources within the Vaal Airshed.

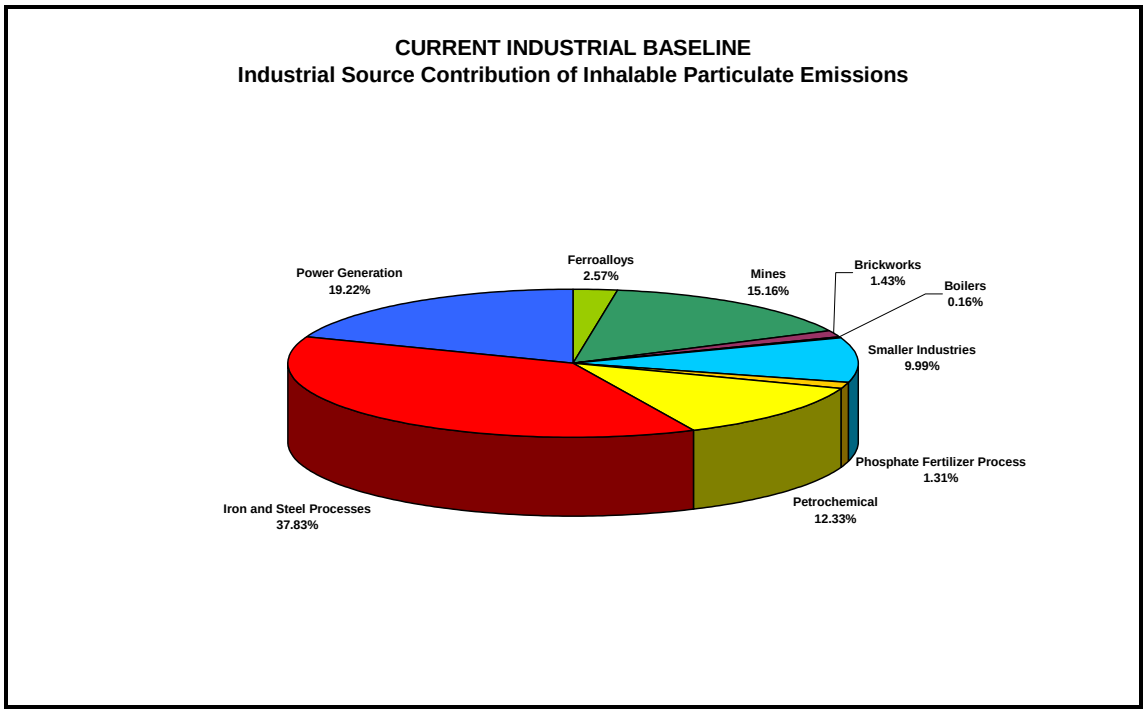


Figure 6-3: Total annual inhalable particulate source emission distribution from industrial, commercial and institutional sources within the Vaal Airshed.

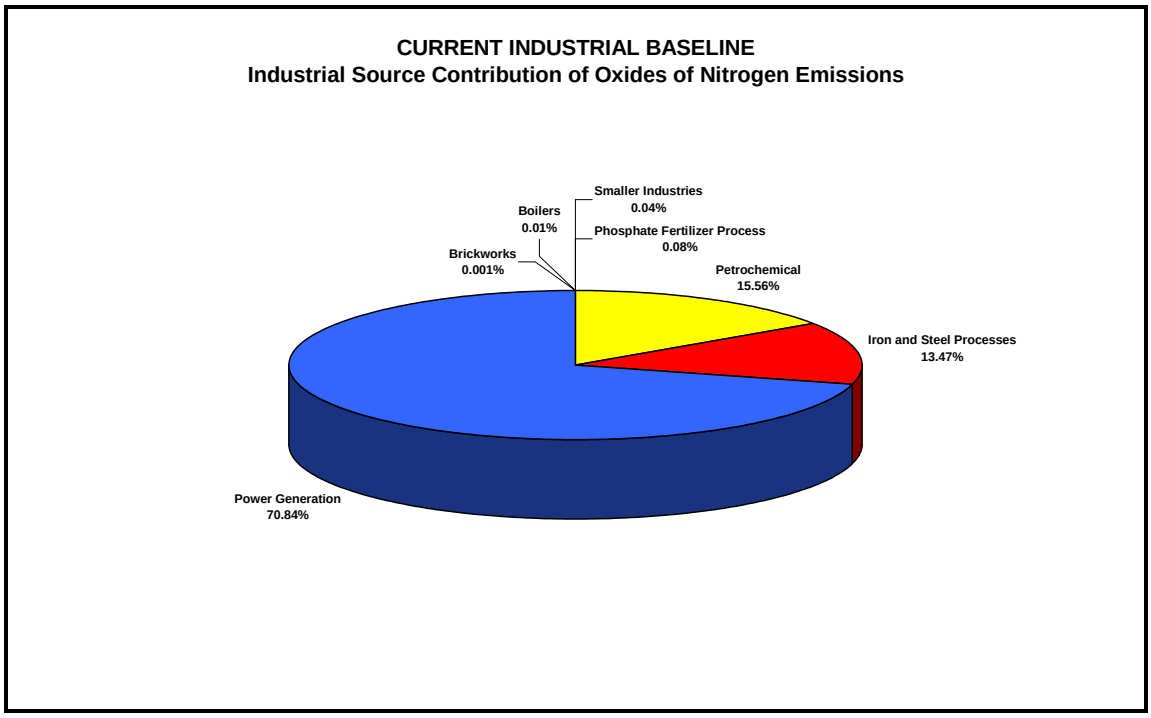


Figure 6-4: Total annual oxides of nitrogen emission distribution from industrial, commercial and institutional sources within the Vaal Airshed.

6.2 Domestic Fuel Burning

Although an intensive national electrification programme is in progress a large number of households continue to burn fuel to meet all or a portion of their energy requirements. The main fuels with air pollution potentials used by households within the Vaal Airshed are coal, wood and paraffin. These fuels continue to be used for primarily two reasons: (i) rapid urbanisation and the growth of informal settlements has exacerbated backlogs in the distribution of basic services such as electricity and waste removal, and (ii) various electrified households continue to use coal due particularly to its cost effectiveness for space heating purposes and its multi-functional nature (supports cooking, heating and lighting functions). The extent of household coal, wood and paraffin burning is illustrated in Figures 6-5, 6-6 and 6-7 respectively. The distribution patterns of fuel use are linked with the former townships and informal residential areas.

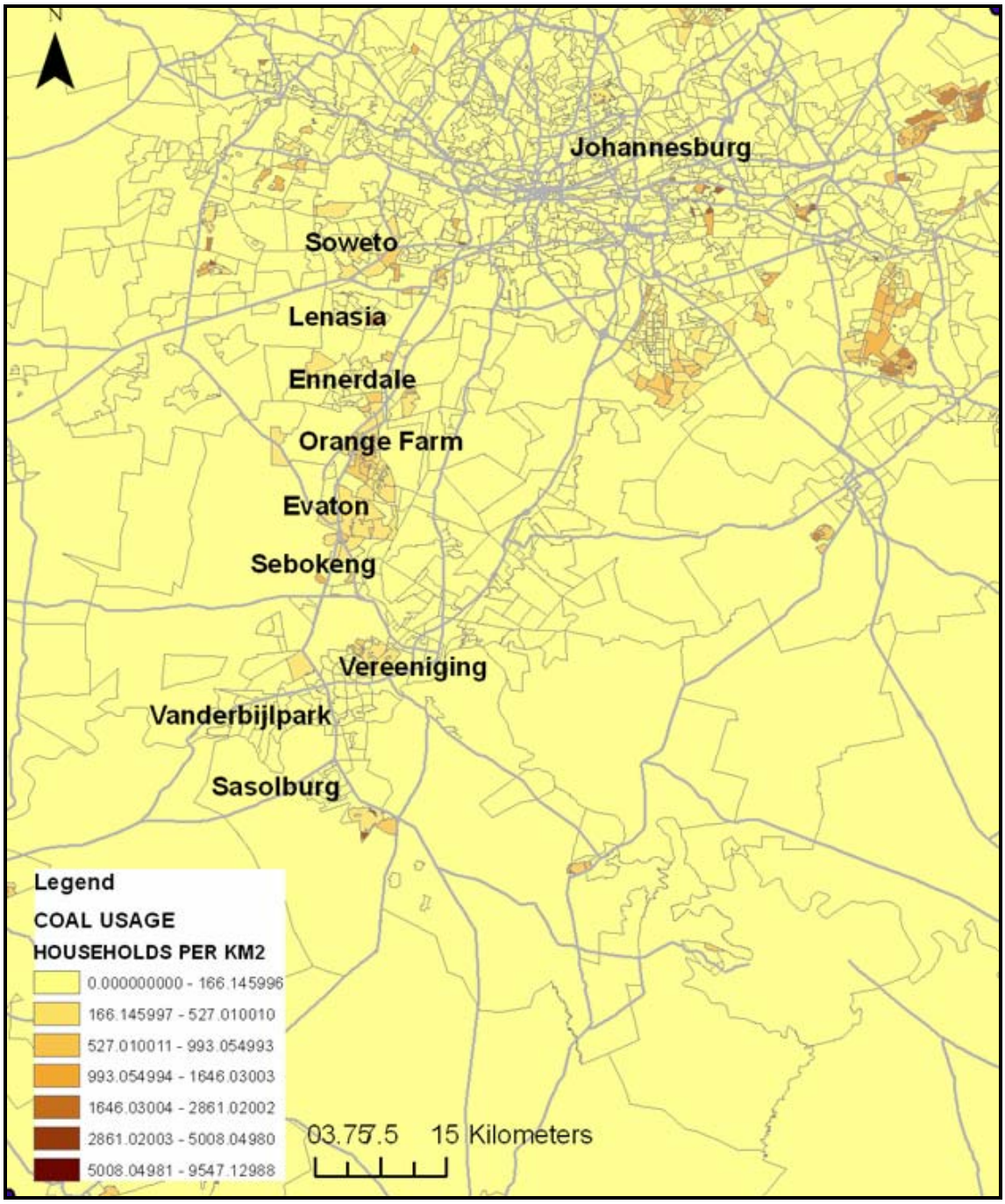


Figure 6-5: Spatial distribution of household coal burning within the Vaal Airshed (based on 2001 Census data).

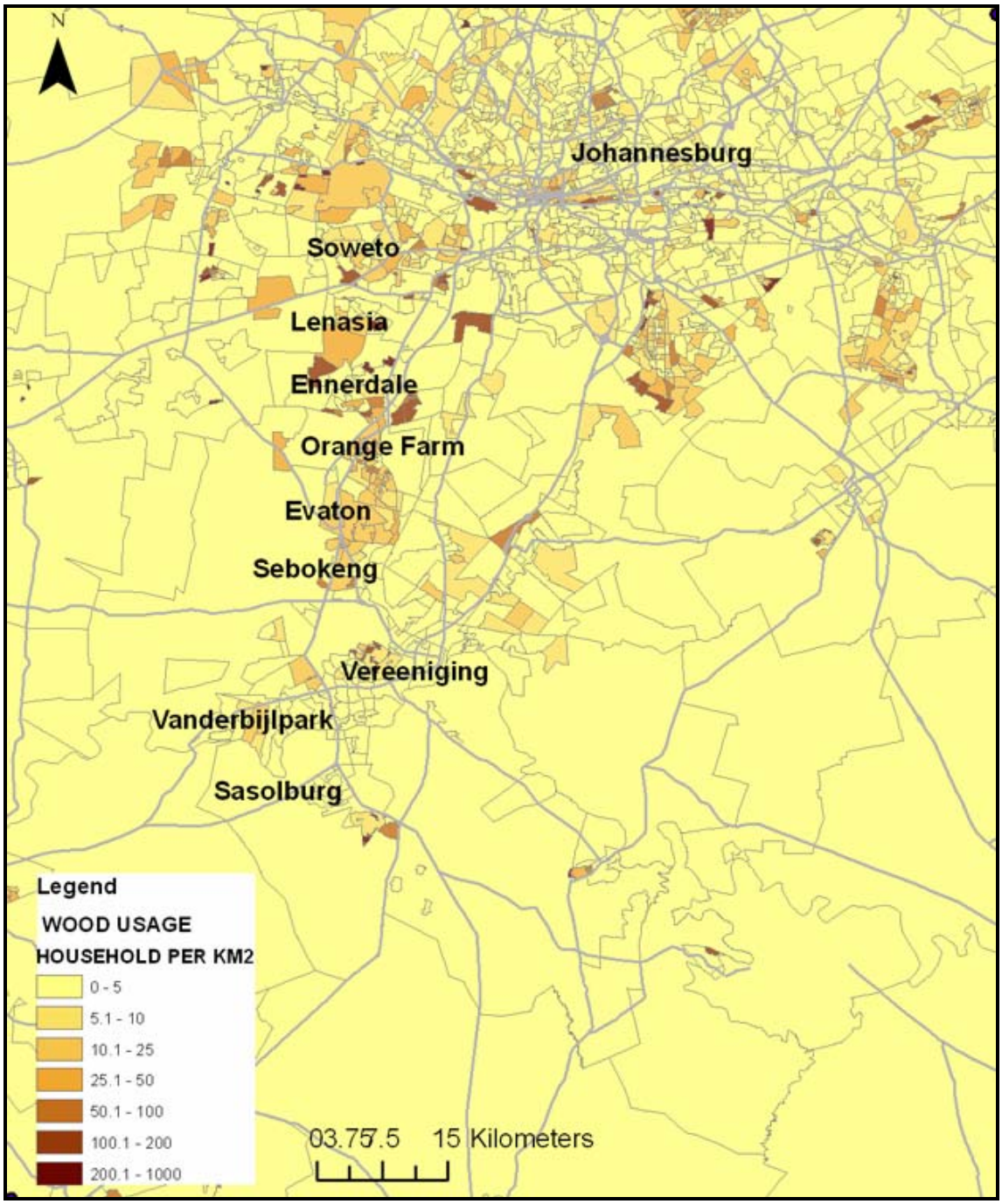


Figure 6-6: Spatial distribution of household wood burning within the Vaal Airshed (based on 2001 Census data).

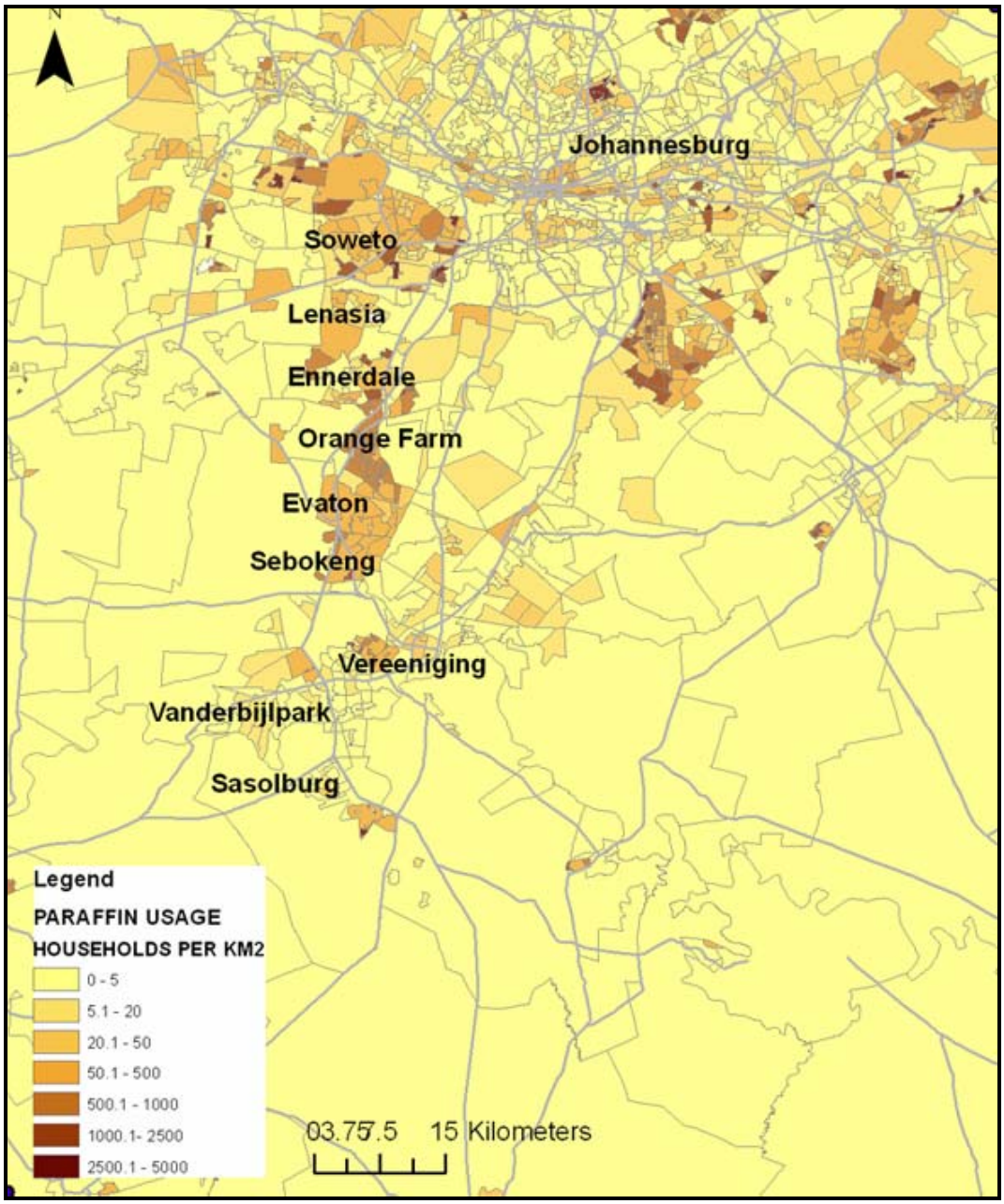


Figure 6-7: Spatial distribution of household paraffin burning within the Vaal Airshed (based on 2001 Census data).

Coal is relatively inexpensive and is easily accessible in the region due to the proximity of the region to coal mines and the well-developed local coal merchant industry. Coal burning emits a large amount of gaseous and particulate pollutants including sulphur dioxide, heavy metals, total and respirable particulates including heavy metals and inorganic ash, carbon monoxide, polycyclic aromatic hydrocarbons (a recognised carcinogen), and benzo(a)pyrene (Scorgie, 2006). Pollutants arising due to the combustion of wood include respirable

particulates, nitrogen dioxide, carbon monoxide, polycyclic aromatic hydrocarbons, particulate benzo(a)pyrene and formaldehyde (Scorgie, 2006). Wood burning is less widely used compared to coal burning. Although many of the wood burning residential areas tend to coincide with areas of coal burning there are some exceptions where only wood is burned, e.g. sections of Vereeniging and Vanderbijlpark. The main pollutants emitted from the combustion of paraffin are nitrogen dioxide, particulates, carbon monoxide and polycyclic aromatic hydrocarbons (Scorgie, 2006). The use of paraffin is of concern not only due to emissions from its combustion within the home, but also due to its use being associated with accidental poisonings (primarily of children), burns and fires.

The study area included the Emfuleni Local Municipality, Midvaal Local Municipality, Metsimaholo Local Municipality as well as the more distant Ekurhuleni Local Municipality, Mogale City Local Municipality and parts of the City of Johannesburg so as to take into consideration the cross boundary cumulative effect of this source. Total annual domestic fuel burning emissions calculated for the entire study area are summarised in Table 6-2.

Table 6-2: Estimated total annual domestic fuel burning emissions (in tons/annum) for the entire study area [(a)].

Sulphur Dioxide	Oxides of Nitrogen	Inhalable Particulate Matter
3 442	1 365	1 904

(a) Emissions estimated based on emission factors given in Table 6-2.

Emissions were calculated individually for a total of 65 area sources so as to accurately account for spatial distributions in fuel consumption intensities and hence emissions. The location of the 65 household fuel burning sources (burning coal, wood, and/or paraffin) in the study area is shown in Figure 6-8.

The demand for residential space heating, and hence the amount of fuel burning, has been found to be strongly dependent on the minimum daily temperature. Seasonal trends in space heating needs, and therefore in coal burning emissions, were estimated by calculating the quantity of "heating-degree-days" (HDD), i.e. the degrees below a minimum daily temperature of 8°C (Annegarn and Sithole, 1999) (Figure 6-9). Diurnal trends in fuel burning, documented in the local literature, were also taken into account in estimating temporal variations in household fuel burning emissions (Annegarn and Grant, 1999) (Figure 6-10).

Taking seasonal and diurnal variations in fuel use, and therefore emissions, into account it was estimated that the maximum emissions during an hour of peak burning (e.g. cold winter day, between 06:00 and 07:00 or 18:00 and 20:00) were a factor of 10 higher than an hourly emission rate taken as an average throughout the year.

Figure 6-8: Location of household fuel burning areas simulated for the baseline assessment of the Vaal Airshed.

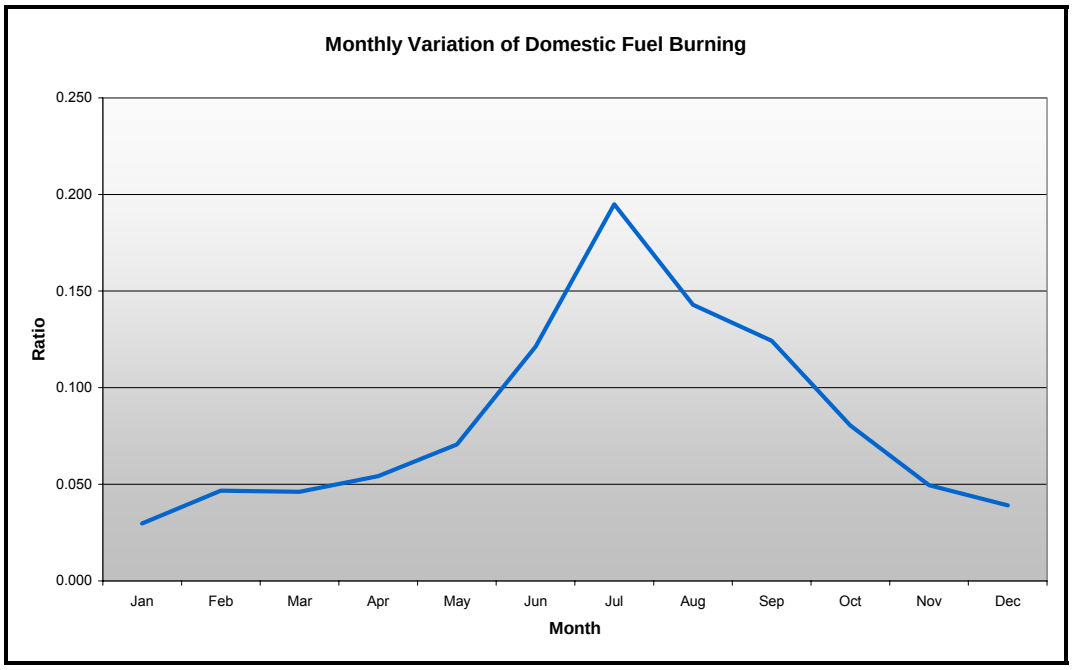


Figure 6-9: Monthly variations in domestic fuel burning activities that were taken into account during the simulation of this source (after Annegarn and Sithole, 1999).

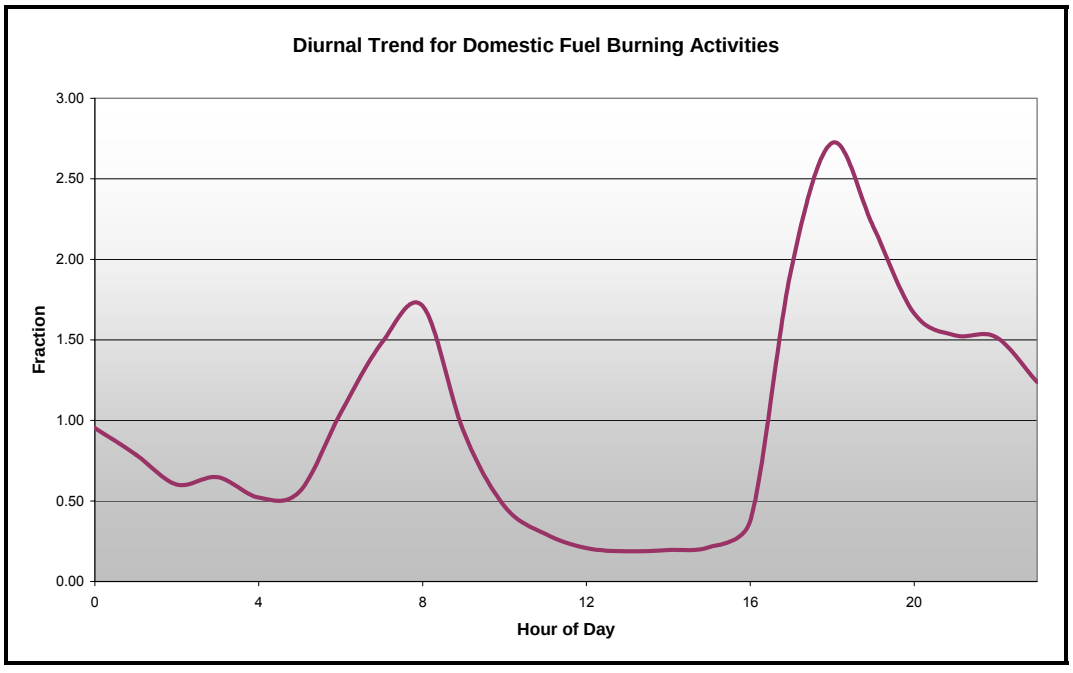


Figure 6-10: Diurnal variation in domestic fuel burning activities that were taken into account during the simulation of this source (after Annegarn and Grant, 1999).

6.3 Mining Operations

Mining operations within the Vaal Airshed almost exclusively include coal mining activities. Three mines are operational within the Study Area, namely New Vaal Colliery (in Vereeniging), Sigma Colliery (in Sasolburg) and Glen Douglas Dolomite Quarry (in Meyerton). Fugitive emissions from the Sigma and New Vaal opencast collieries were quantified for the baseline study (Table 6-5). Emissions emanating from the Glen Douglas Dolomite Quarry, however, could not be quantified due to insufficient available data.

Mining operations represent potentially significant sources of fugitive dust emissions, with particulate emissions being the main pollutant of concern. Fugitive dust sources associated with coal mining activities include drilling and blasting activities, materials handling activities, vehicle-entrainment by haul trucks, crushing and screening activities and wind-blown dust from stockpiles and exposed surfaces.

Typical operations associated with opencast mining operations include the pre-operational phase where the area is cleared by removal of vegetation, topsoil and overburden. The second phase is the operational phase usually including the movement of ore bearing rock or coal seam, and exposure of erodible surfaces prone to wind erosion. The final phase entails reclamation where the mined area is restored to its original state.

The initial operation entails the removal of topsoil and subsoil with large scrapers. The topsoil and subsoil is stored in storage piles which are later used for reclamation purposes. In the case of coal mines and quarries, drilling and blasting would be required. The blasted material is then removed by a shovel and truck operation (or in some cases by dragline operations) loading the material into haul trucks, and taking it out of the pit along graded haul roads to the tippler, or truck dump. Run of mine (ROM) material may sometimes be dumped onto a temporary storage pile and later re-handled by a front-end loader or bulldozer.

At most operations the material will undergo primary and sometimes secondary crushing and screening. These are large sources of dust if not controlled. The material may be transported to further processing operations by means of conveyors or front end loaders. The material could also be stored on storage piles which are prone to wind erosion if not enclosed.

Experience has shown that fugitive dust emissions due to on-site mining operations are typically only of concern within 3 km of the mine boundary. This is of course dependent on the dispersion potential of the site and the extent of the mining operations (including dust suppression methods. The most frequently used dust suppression methods in local mining operations include the wet suppression and the chemical stabilization of haul roads and storage piles.

Materials handling operations associated with the activities at the collieries include the transfer of material by means of tipping, loading and off-loading of trucks. The quantity of

dust that will be generated from such loading and off-loading operations will depend on various climatic parameters, such as wind speed and precipitation, in addition to non-climatic parameters such as the nature (i.e. moisture content) and volume of the material handled. Fine particulates are most readily disaggregated and released to the atmosphere during the material transfer process, as a result of exposure to strong winds. Increases in the moisture content of the material being transferred would decrease the potential for dust emissions, since moisture promotes the aggregation and cementation of fines to the surfaces of larger particles.

Significant emissions arise due to the mechanical disturbance of granular material from open areas and storage piles. Parameters which have the potential to impact on the rate of emission of fugitive dust include the extent of surface compaction, moisture content, ground cover, the shape of the storage pile, particle size distribution, wind speed and precipitation.

The quantity of dust emissions from unpaved roads varies linearly with the volume of traffic. In addition to traffic volumes, emissions also depend on a number of parameters which characterise the condition of a particular road and the associated vehicle traffic, including average vehicle speed, mean vehicle weight, silt content of road surface material and road surface moisture.

Table 6-3: Inhalable particulate emissions as quantified for various mining activities within the Vaal Airshed.

Mine	PM10 (tons/annum)
New Vaal Colliery	3 467
Sigma Colliery	1 087

6.4 Wind-blow Dust from Eskom's Ash Dams and Dumps

The emissions from the various ash dumps within the Vaal Airshed were taken from the Vaal South Environmental Impact Assessment undertaken by Airshed (Thomas and Scorgie, 2006). Parameters which have the potential to impact on the rate of emission include the extent of surface compaction, the particle size distribution, the moisture content of the material, the shape of the dam/dump, ground cover, wind speed and precipitation. Any factor that binds the erodible material, or reduces the erodible surface area, decreases the fugitive emissions from the source. High moisture content (due to precipitation or deliberate wetting) will increase the aggregation and cementation of fines, thus decreasing the potential for dust emissions. Similarly, surface compaction and ground cover will reduce the potential for dust generation. The shape of a dump has the potential to influence dust emissions through the modification of the airflow field. The particle size distribution of the material on the dump is important since it determines the rate of entrainment of material from the

surface, the nature of dispersion of the dust plume, and the rate of deposition, which may be anticipated (Burger, 1994; Burger et al., 1995).

6.5 Vehicle Emissions

Air pollution from vehicle emissions may be grouped into primary and secondary pollutants. Primary pollutants are those emitted directly into the atmosphere, and secondary, those pollutants formed in the atmosphere as a result of chemical transformation, such as hydrolysis, oxidation, or photochemical reactions. The significant primary pollutants emitted by motor vehicles include carbon dioxide, carbon monoxide, hydrocarbon compounds, sulphur dioxide, oxides of nitrogen and particulate matter. Secondary pollutants include nitrogen dioxide, photochemical oxidants (e.g. ozone), hydrocarbon compounds, sulphur acid, sulphates, nitric acid and nitrate aerosols (Copert, 2000). Emission estimates where undertaken for sulphur dioxide, nitric oxide, nitrogen dioxide and particulate matter for the current study.

The study area taken into consideration for this source extends beyond the Vaal Triangle (Emfuleni Local Municipality, Midvaal Local Municipality and Metsimaholo Local Municipality) to include Mogale City Local Municipality, Ekurhuleni Local Municipality and parts of City of Johannesburg. The study area was selected to take the highly congested traffic areas to the north of the Vaal Triangle into account which may add to the cumulative impact within the area.

The vehicle emissions were calculated per magisterial district within the study area (Table 6-4). These emissions were assigned to various national and regional routes (see Figure 6-11) by applying vehicle count data obtained from Mikros Traffic Monitoring (Pty) Ltd for the period 2004 to 2006. The remaining emissions data that could not be assigned to specific routes were then distributed over the remaining regional roads within the Vaal Airshed.

Table 6-4: Total annual tailpipe emissions due to vehicle activity calculated per magisterial area within the Vaal Airshed.

Magisterial Area	Emissions tons/annum			
	Sulphur Dioxide	Nitric Oxide	Nitrogen Dioxide	PM
Alberton	149	4 984	554	394
Balfour	12	413	46	30
Benoni	94	3 495	388	180
Boksburg	89	3 342	371	165
Brakpan	45	1 603	178	100
Brits	65	2 094	233	173
Bronkhorstspruit	25	858	95	58
Culinan	7	254	28	16

Magisterial Area	Emissions tons/annum			
	Sulphur Dioxide	Nitric Oxide	Nitrogen Dioxide	PM
Frankfort	9	276	31	26
Germiston	174	6 170	686	392
Heilbron	4	136	15	10
Heidelberg	20	710	79	48
Krugersdorp	94	3 220	358	237
Johannesburg	717	25 816	2 868	1 543
Kempton Park	169	6 132	681	350
Nigel	25	812	90	72
Roodepoort	104	4 137	460	148
Randburg	240	9 556	1 062	341
Pretoria	612	22 193	2 466	1 280
Sasolburg	118	3 711	412	342
Springs	35	1 345	149	63
Westonaria	23	860	96	47
Wonderboom	57	2 183	243	97
Koppies	9	305	34	25
Parys	10	350	39	24
Potch	22	977	109	16
Randfontein	23	894	99	36
Vereeniging	82	2 916	324	185
Vanderbijlpark	60	2 114	235	136

As the routes were assumed to be straight lines (see Figure 6-12), the length of the roads obtained were multiplied by a factor of 1.4 to accommodate the curved nature of these sources. In addition, based on vehicle emissions from the N4, it was calculated that 20% and 10% of the fuel usage from light and heavy commercial vehicles respectively, would be used outside the study area. As the routes within the Johannesburg magisterial districts are largely congested, emissions were assigned to the main national routes that pass over this area (i.e. the N4, N1, M1, N12, N17 and the N3). The remaining emissions were distributed over area sources assigned to built-up areas (see Figure 6-13).

The diurnal profile of vehicle activity was taken into account for regional and national routes for which vehicle count data was available (as obtained from Micros Traffic Monitoring). The diurnal profiles of the national routes are indicated in Figure 6-14. For roads without vehicle count data readily available, the hourly median was taken for the diurnal profile from all vehicle count data within the Vaal Airshed.

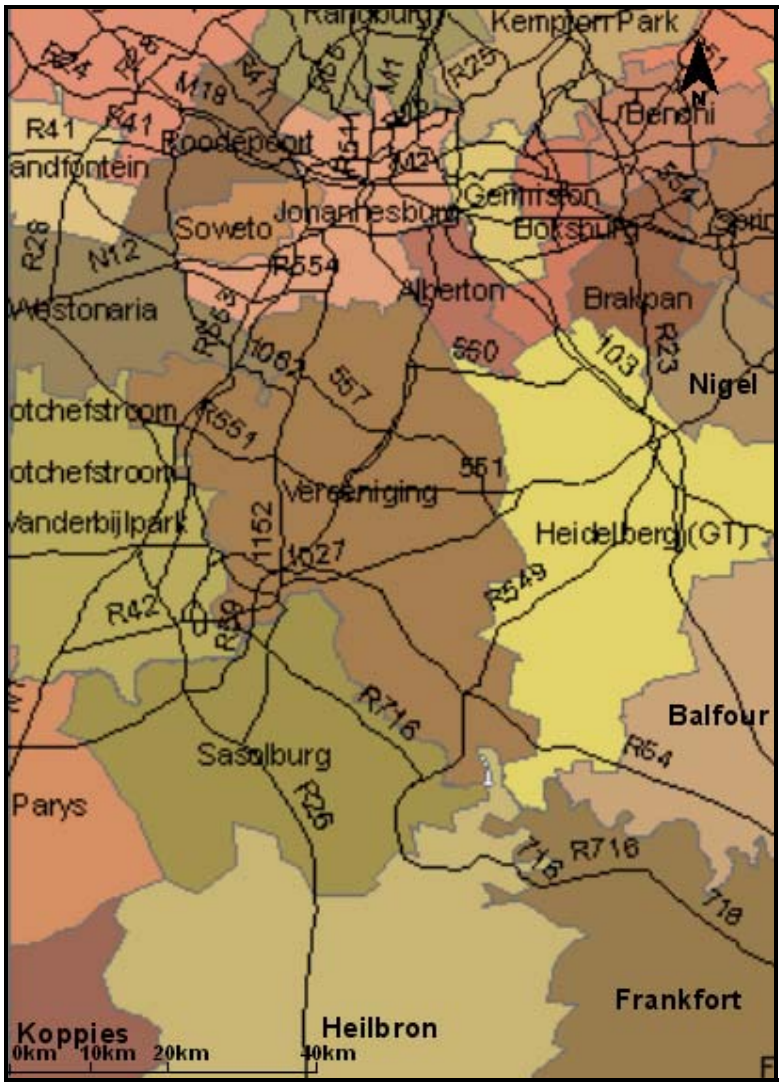


Figure 6-11: Layout of the regional and national road network and magisterial districts within the study area.

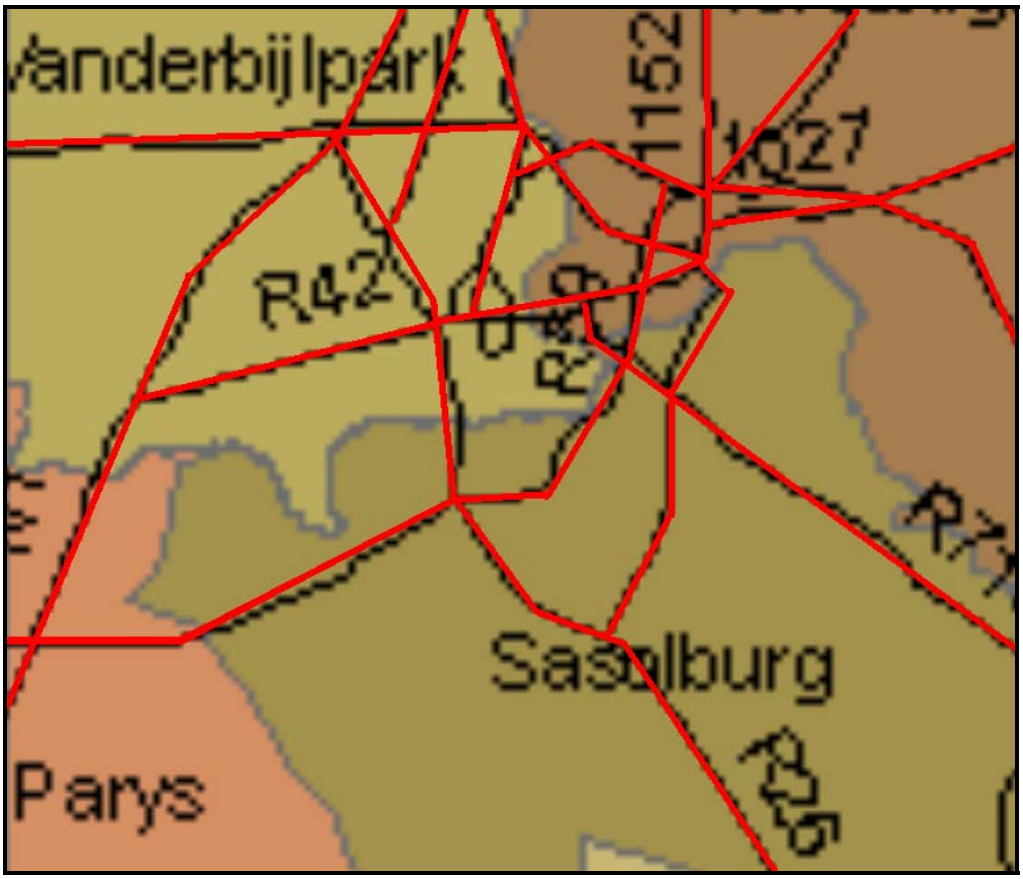


Figure 6-12: The layout of the road sources for the quantification of tailpipe emissions and identification of dispersion modelling areas.

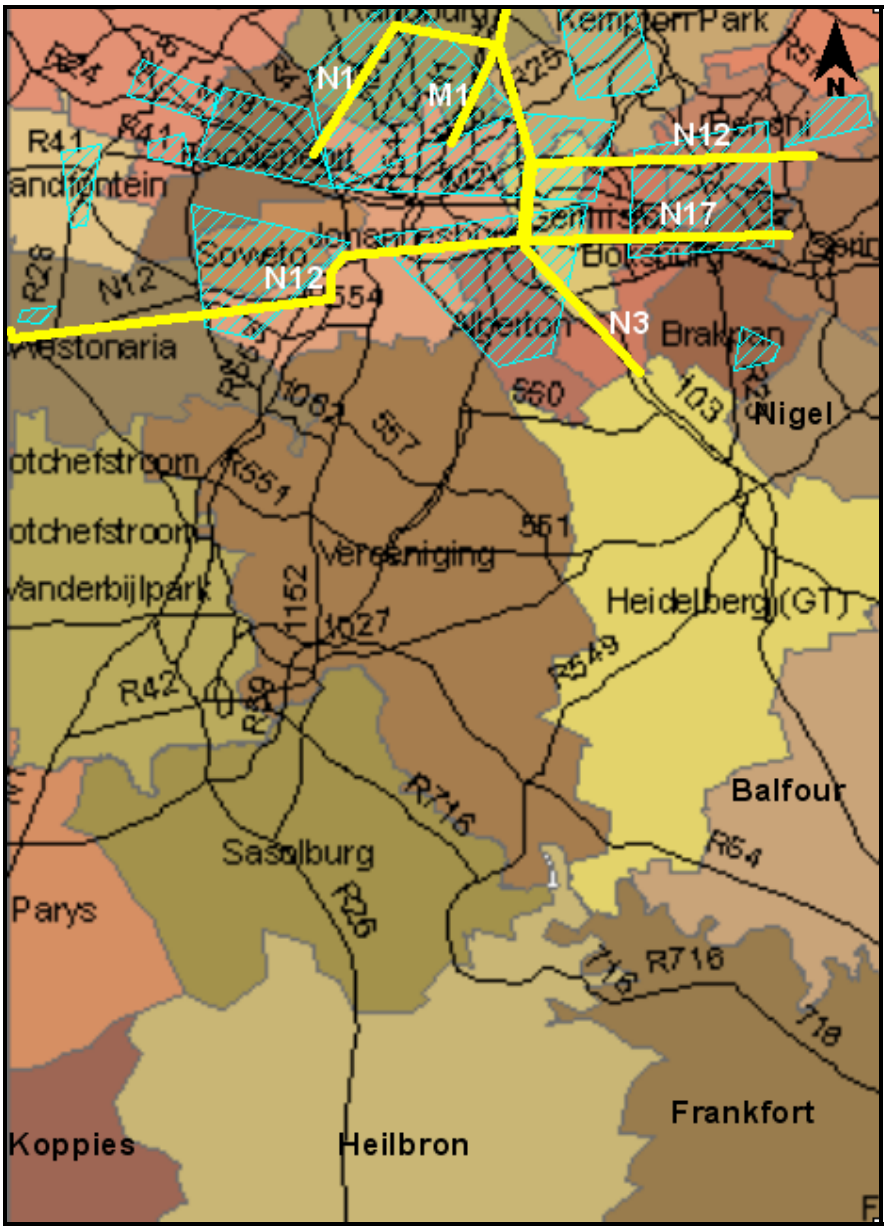


Figure 6-13: Spatial apportionment of vehicle emissions over the highly congested residential area of Johannesburg and surrounding areas.

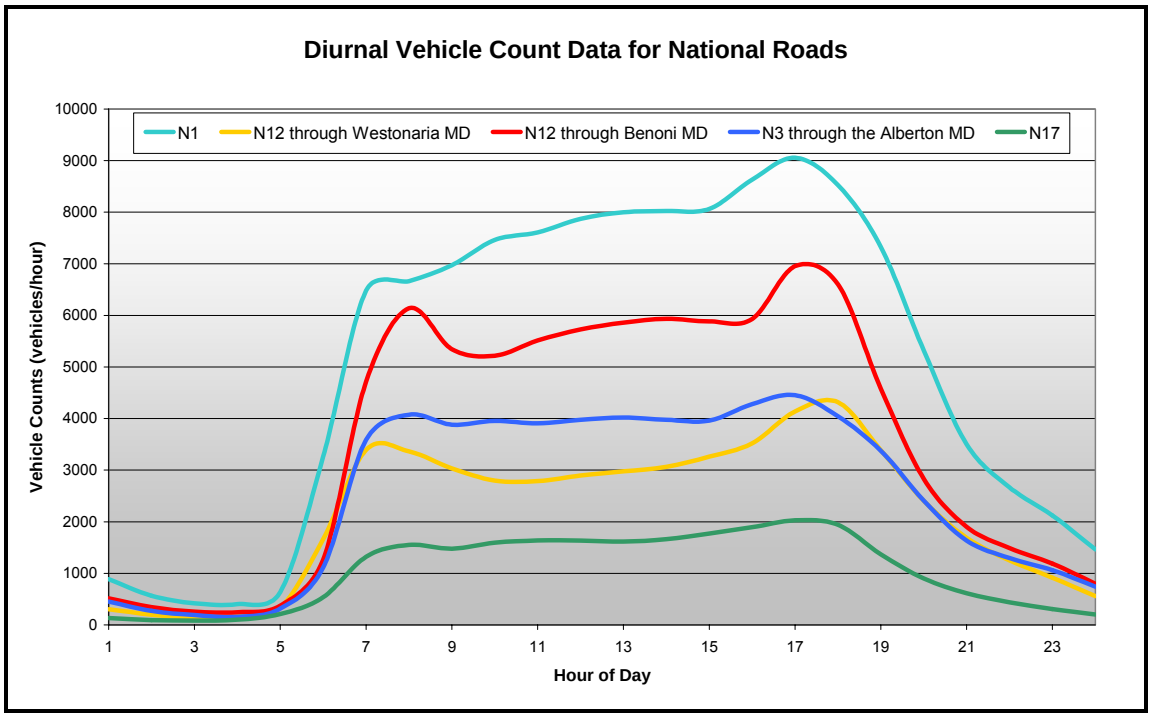


Figure 6-14: Diurnal profile of vehicles along national routes within the Vaal Airshed as obtained from vehicle count data (as obtained from Micros Traffic Monitoring).

6.6 Waste Treatment and Disposal Areas

Specific industrial activities are related to toxic emissions and waste disposal sites, i.e., landfills, waste water treatment works and waste incinerator facilities. Sufficient emissions and air quality data are, however, currently unavailable on which to base a comprehensive assessment of these sources.

6.6.1 Landfill operations

The majority of the waste collected by the local authority is disposed to landfill, usually within 10-20 km radius of the residential areas within which the waste was generated. At present, the Vaal Airshed has 12 regional disposal facilities as depicted in Table 6-13. Detailed landfill information, however, could not be obtained from the City of Johannesburg and Metsimaholo Local Municipality.

Table 6-5: Landfill operations located within the Vaal Airshed (after Liebenberg-Enslin *et al* (2007)).

Municipality	Name	Type
City of Johannesburg Metropolitan Municipality	Grootkoppies	
	Palm Springs	
Metsimaholo Local Municipality	Deneysville	
	Oranjeville	
	Sasolburg	
Emfuleni Local Municipality	Boitshepi	G:L:B+ (provisional)
	Palm Springs	G:S:B- or G:M:B- (provisional)
	Waldrift	G:L:B- (provisional)
	Zuurfontein	G:L:B- (provisional)
Midvaal Local Municipality	Vaal Marina	G:C:B- (expected)
	Henley on Klip	G:C:B- (expected)
	Walkerville / De Deur	G:C:B- (expected)

Notes:
G: General waste
C: Communal landfill (<25 tonnes/day)
S: Small landfill (>25 tonnes/day but <150 tonnes/day)
L: Large landfill (>500 tonnes/day)
B: is the Climatic Water Balance.
B- : A site is classified as B- if there is no significant leachate generation and only dry waste is disposed of
B+ : A site is classified as B+ if there is significant leachate generation and such leachate requires management.

All the waste disposal sites within the Vaal Airshed are predominantly used for general waste disposal, including domestic, commercial and industrial waste. It is unknown to what extent co-disposal of domestic and industrial/commercial hazardous waste occurs at the general waste sites. Limited information is available on the practical volumes and quantities of hazardous waste disposed at the landfill sites in Vaal Airshed, or on the volumes and masses of hazardous waste stored on-site by industrial operations.

6.6.2 Incinerator Operations

All identified incineration processes within the Vaal Airshed were included in the industrial source quantification. The emission rates of incinerator operations are a function of fuel usage, waste composition, incinerator design characteristics and operating conditions.

Gaseous emissions from incinerator operations may be grouped into: (i) criteria pollutants (viz. sulphur dioxide, oxides of nitrogen, carbon monoxide, lead and particulates), (ii) acid gases (viz. hydrogen chloride, hydrogen bromide and hydrogen fluoride), (iii) metal gases (viz. chromium, arsenic, cadmium, mercury, manganese, etc.), and (iv) dioxins and furans (viz. polychlorinated dibenzo-*p*-dioxins and dibenzo furans) (Scorgie, 2006).

Emissions due to incinerator operations have a greater sphere of influence than landfills and waste water treatment plants due to the elevated nature of the emission source and the larger quantities being released.

6.6.3 Waste Water Treatment Works

Insufficient information was available for waste water treatment facilities within the Vaal Airshed, to quantify these emission sources.

Pollutant sources of waste water treatment works include odourants such as hydrogen sulphide, mercaptans, ammonia and various fatty acids, as well as formaldehyde, acetone, toluene, ethyl benzene, xylenes and perchloroethylene (Scorgie, 2006).

Theoretical estimates of air pollutant emission rates emanating from sewer treatment facilities can be done by means of US-EPA emission factors. In order to calculate these emissions, however, detailed information regarding the process and the volumes treated is required.

6.7 Agriculture

Agricultural activities including field cultivation (with the principal crops being maize, sorghum and sunflower) and pastoral farming make up ~60% of the study area. These activities can be responsible for the emission of large quantities of particulates. Fallow fields in the dry winter months and ploughing and harvesting activities in the summer months result in the potential for fugitive dust.

Using data on agricultural land use and on the erosion potential of soils from the Department of Agriculture and US-EPA emission factors, van Nierop (1995) estimated total suspended particulates and inhalable particulate emissions due to agricultural activities as being 2886 tons/annum and 683 tons/annum respectively.

6.8 Railway Transport

Internationally, very few studies have been undertaken to accurately investigate these emissions, with emission estimates for the railway network in Europe having only been made in the last 10 years (Jorgensen and Sorenson, 1997). No emission factors are available locally for the calculation of emissions from railway transport.

Railway transport in the Vaal Triangle consists of electric, steam and diesel-powered locomotives. Diesel locomotives are generally used for the transportation of bulk material to and from industries. In order to calculate these emissions, reference may be made to the emission factors for railway traffic emissions estimated by the Department of Energy

Engineering at the University of Denmark (Jorgensen and Sorenson, 1997). However, detailed information, that was not available for the current assessment would be required including: inventory of train types (diesel, steam, electric), average train speed, number of passengers per seat (0-100%), topography of the distance travelled, slopes and hills, wind speed, number of cold starts (for diesel powered trains), average distance between train stations, and degree of reuse of braking energy.

6.9 Airport Emissions

Airports and airstrips within the Vaal Triangle include the Aerovaal Airport, Deneysville Landing Strip, Star Landing Ground and Vanderbijlpark Aerodrome. These airstrips/aircrafts accommodate infrequent small aircrafts, gliders, etc.

Although extensive studies have been undertaken in countries such as the United States to estimate airport emissions, local studies have been limited to air quality impact assessments for Cape Town and Johannesburg International Airports.

The extent of various pollutant emissions from the aircraft engine is depended on the mode of operation of the aircraft. The largest pollutant emitted from aircraft is oxides of nitrogen, with carbon monoxide forming the second largest emission. Other pollutants emitted consist of sulphur dioxide, total suspended particulates and volatile organic compounds. The extent of sulphur dioxide emissions is dependent on the sulphur dioxide content of the fuel. Carbon monoxide and hydrocarbon emissions are a result of incomplete or poor combustion and are generally greater during idle operations. Oxide of nitrogen emissions on the other hand are associated with the oxidation of atmospheric nitrogen during combustion processes and is generally greatest during take-off when the aircraft engine is producing maximum power (NPi, 2003).

Emission factors are available for the estimation of emissions of the various gaseous emissions from aircraft engines. Such factors are given in kg of pollutant per land-take-off cycle (LTO) and are refined for approach, taxi, take-off and climb-out operations. Emission factors are given for specific aircraft type with large variations in emissions from different aircraft types apparent (NPi, 2003).

Thus, in order to estimate emissions from aircraft engines and auxiliary power units, detailed information would need to be collated, including: inventory of aircraft types, average durations of taxi, take-off, approach and climb-out operations, sulphur content of fuels, (etc.). The estimation of evaporative emissions from fuel storage and handling would also require detailed information regarding storage conditions and handling operations. This information was not available for the current assessment. The emissions from this source, however, are expected to be low due to the infrequent traffic and small aircraft sizes at the Vaal Triangle airstrips/ airports.

6.10 Spontaneous Combustion

Spontaneous combustion occurs on discard dumps and underground. No known information is available in open literature for the quantification of spontaneous combustion emissions. However, in attempt to identify the occurrence of spontaneous combustion use has been made of satellite-based remote sensing products such as ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) which is a high resolution imaging instrument that is flying on the Terra satellite and MAS (Magical-Angle-Spinning) which is a new technique for high-resolution quadrupolar NMR.

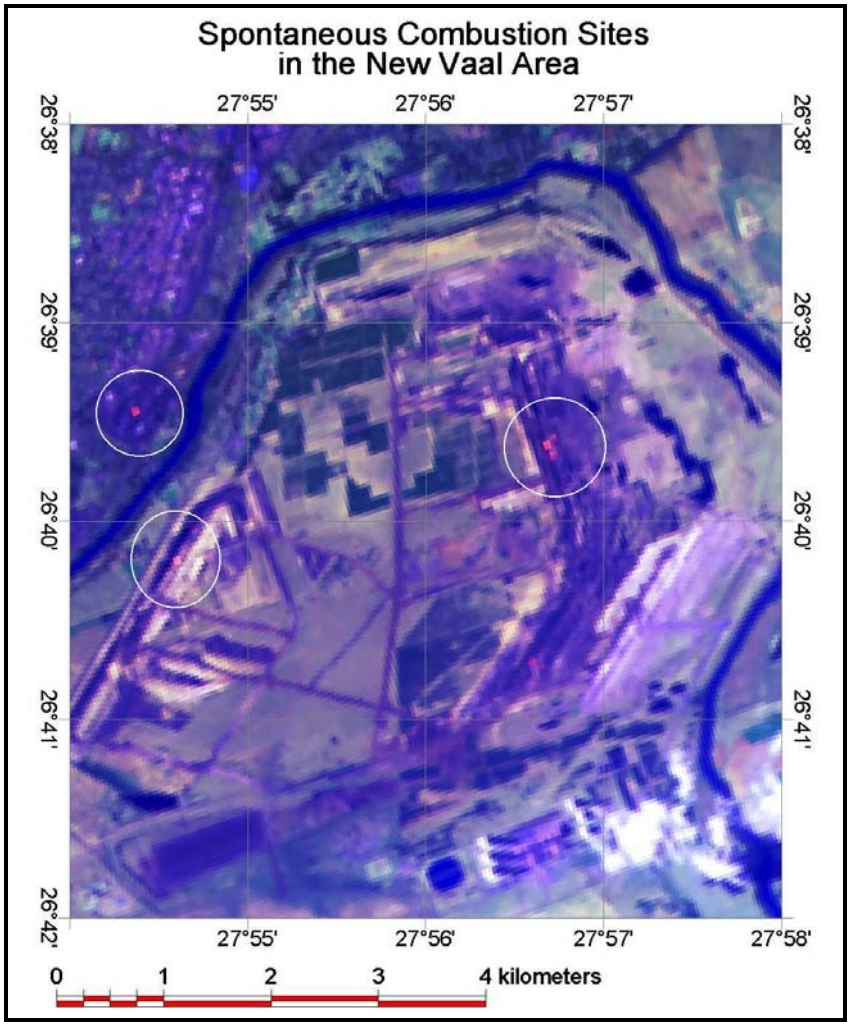


Figure 6-15: Spectral image for the New Vaal Colliery area, illustrating apparent incidences of spontaneous coal combustion sites as bright red areas (indicated by circles). The Lethabo Power Station is located at the bottom right of the image. (Work undertaken by Prof. Harold Annegarn and the Atmosphere and Energy Research Group, Wits University, 2002.)

Figure 6-15, provides a spectral image of the New Vaal Colliery area, illustrating areas of spontaneous combustion as bright red areas. The MAS bands which were used in the image consisted of 18, 12 and 1 corresponding to wavelengths 2.005, 1.75 and 0.465 respectively. This is the visible region of the spectrum.

Additional research into the occurrence, extent and duration of spontaneous combustion episodes is being conducted as part of the COALTECH 2020 initiative which aims to quantify greenhouse gas emissions arising due to this source. The research is however not sufficiently advanced as to provide a source of quantitative emission information.

6.11 Transboundary Sources

Dispersion of pollutants is influenced by large-scale circulations (as discussed in detail in Section 4.3). Pollutants from adjacent areas to the Vaal triangle as well as further afield may influence the air quality within the region. Similarly, the pollutants originating in the Vaal Triangle may impact the air quality of surrounding areas.

Source apportionment studies have identified four main source types of regional significance to the atmospheric aerosol loading, i.e. (i) aeolian crustal material consisting of mineral soil dust, (ii) marine aerosols from the two adjacent oceans (iii) biomass burning particles occurring mainly north of 20°S and (iv) aerosols from industrial emissions. These four sources groups have been identified in remote areas of South Africa (Piketh, 1995; Piketh *et al*., 1996; Salma *et al*., 1992; Maenhaut *et al*., 1996).

6.12 Summary of Emissions Quantified

The contribution of sulphur dioxide, inhalable particulate matter and oxides of nitrogen emissions from all quantified sources of emissions is illustrated in Figures 6-16, 6-17 and 6-18 respectively.

The main contributor to sulphur dioxide emissions is from power generation (~77%) with notable contributions from petrochemical (~13%) and iron and steel processes (~6%). The notable sources of inhalable particulate matter emissions within the study area are made up of industrial and non-industrial groups. The main contributors to the oxides of nitrogen emissions within the study area are vehicle exhaust (~44%) and power generation (38%).

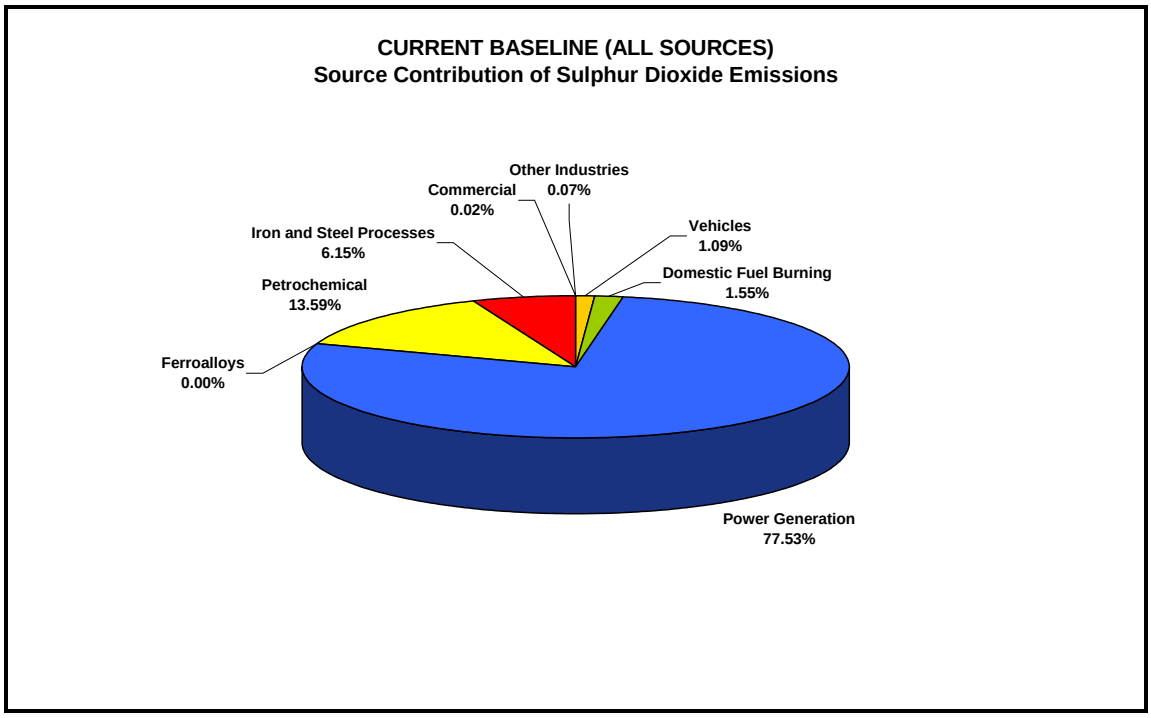


Figure 6-16: Total annual sulphur dioxide emission distribution from all quantified sources of emission within the Vaal Airshed.

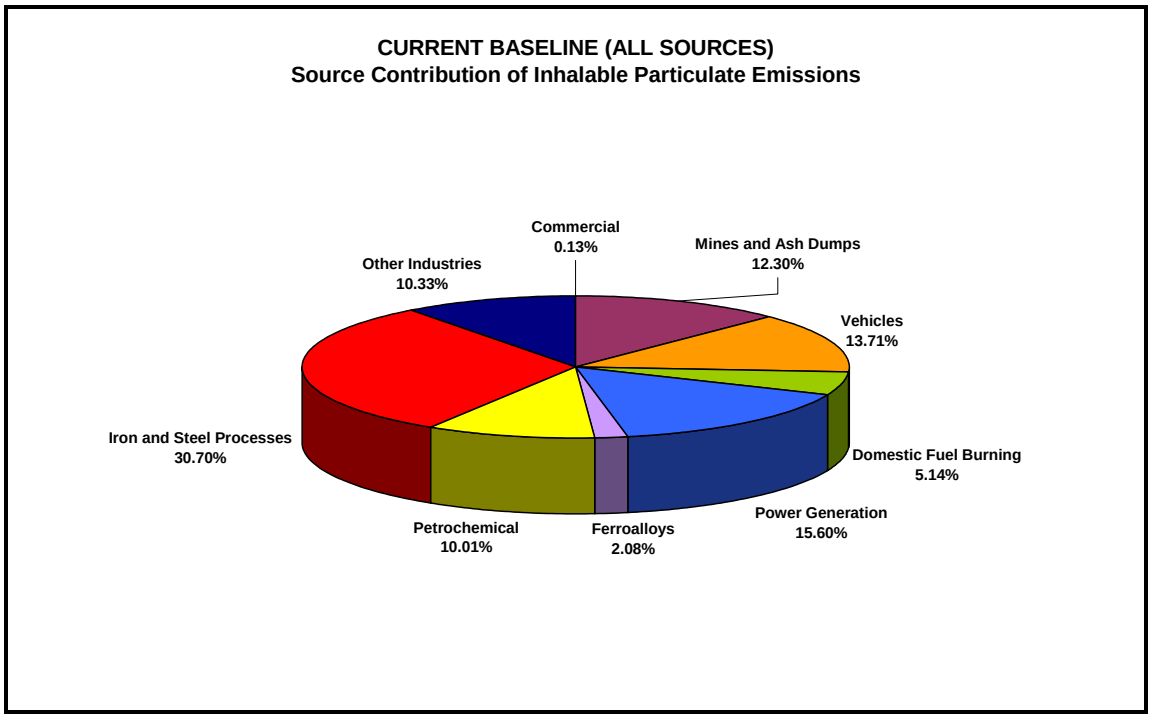


Figure 6-17: Total annual inhalable particulate emission distribution from all quantified sources of emission within the Vaal Airshed.

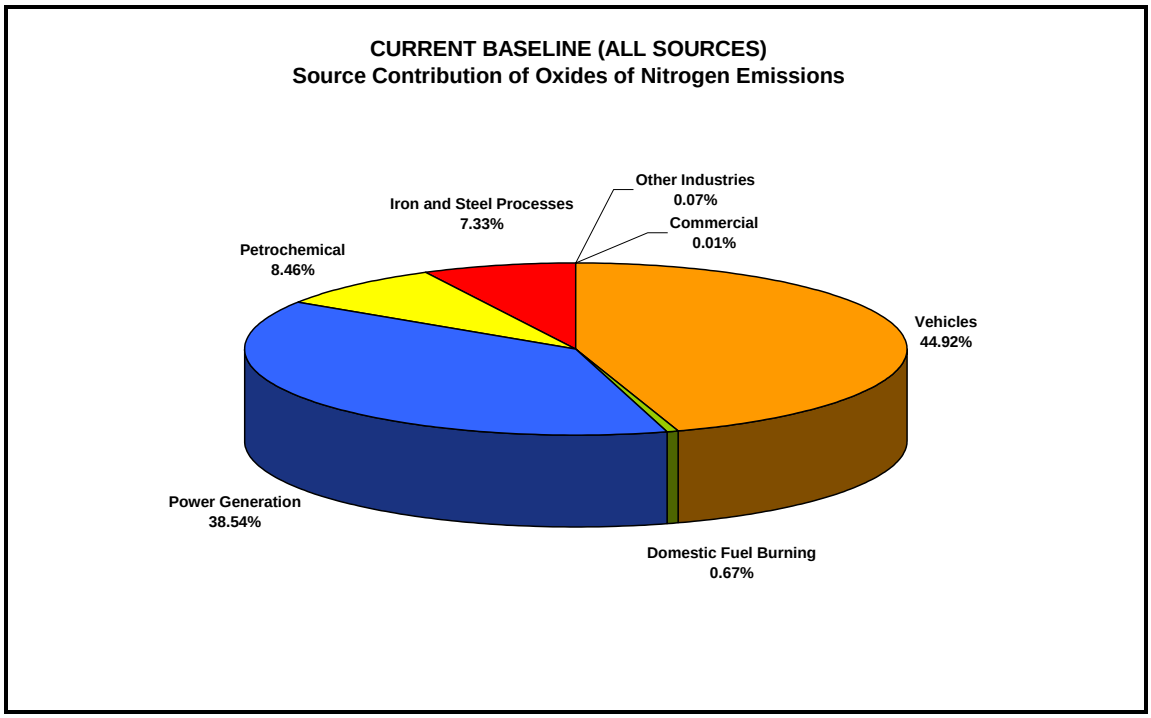


Figure 6-18: Total annual oxides of nitrogen emission distribution from all quantified sources of emission within the Vaal Airshed.

CHAPTER 7
DISPERSION SIMULATION AND IMPACT ASSESSMENT

7.1 Simulated Results

Simulations were undertaken to determine particulate matter, sulphur dioxide and nitrogen dioxide concentrations within the Vaal Airshed due to all quantifiable sources of emissions.

Isopleth plots reflecting hourly and daily averaging periods contain only the highest (99.99th and 99.7th percentile respectively) predicted ground level concentrations for that averaging period, over the entire period for which simulations were undertaken. *It is therefore possible that even though a high hourly or daily concentration is predicted to occur at certain locations, that this may only be true for one hour or day during the entire period.*

The plots provided for the baseline assessment is given in Table 7-1. Isopleth plots are only provided for averaging periods for which ambient air quality guidelines/standards are available.

Table 7-1: Isopleth plots presented in the current section.

Pollutant	Averaging period	Guideline/Standard (µg/m³)	Figure
Sulphur Dioxide	Highest hourly (4)	350 (1)(2)(3)	7-1
	Highest daily (5)	125 (1)(2)(3)	7-2
	Annual average	50 (1)(2)(3)	7-3
Nitrogen Dioxide	Highest hourly (4)	376 (1), 200 (2)(3)	7-4
	Highest daily (5)	188 (1)	7-5
	Annual average	94 (1), 40 (2)(3)	7-6
Inhalable Particulate Matter	Highest daily (5)	180 (1), 75 (2), 50 (3)	7-7
	Annual average	60 (1), 40 (2), 30 (3)	7-8

Notes:
(1) Current SA Standard as adopted by DEAT on 11 September 2005.
(2) Proposed SA standard (SANS limit)
(3) EC Limit
(4) 99.99th percentile
(5) 99.7th percentile

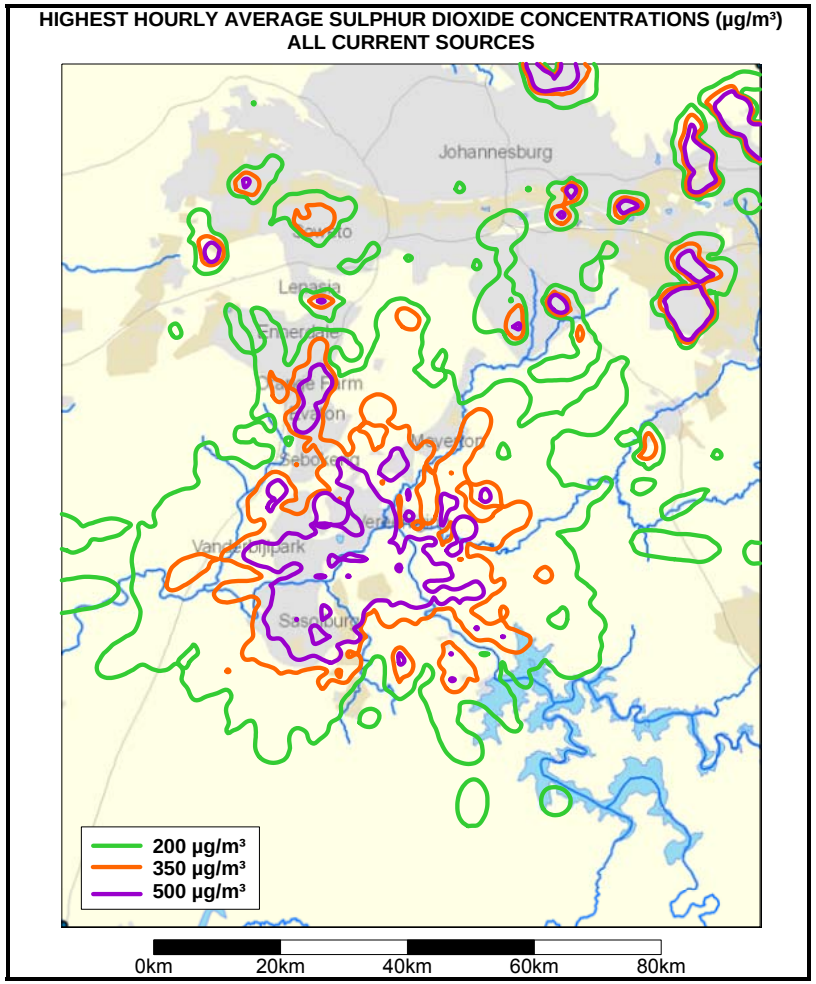


Figure 7-1: Highest hourly (99.99th percentile) predicted sulphur dioxide ground level concentrations (µg/m³) within the study area.

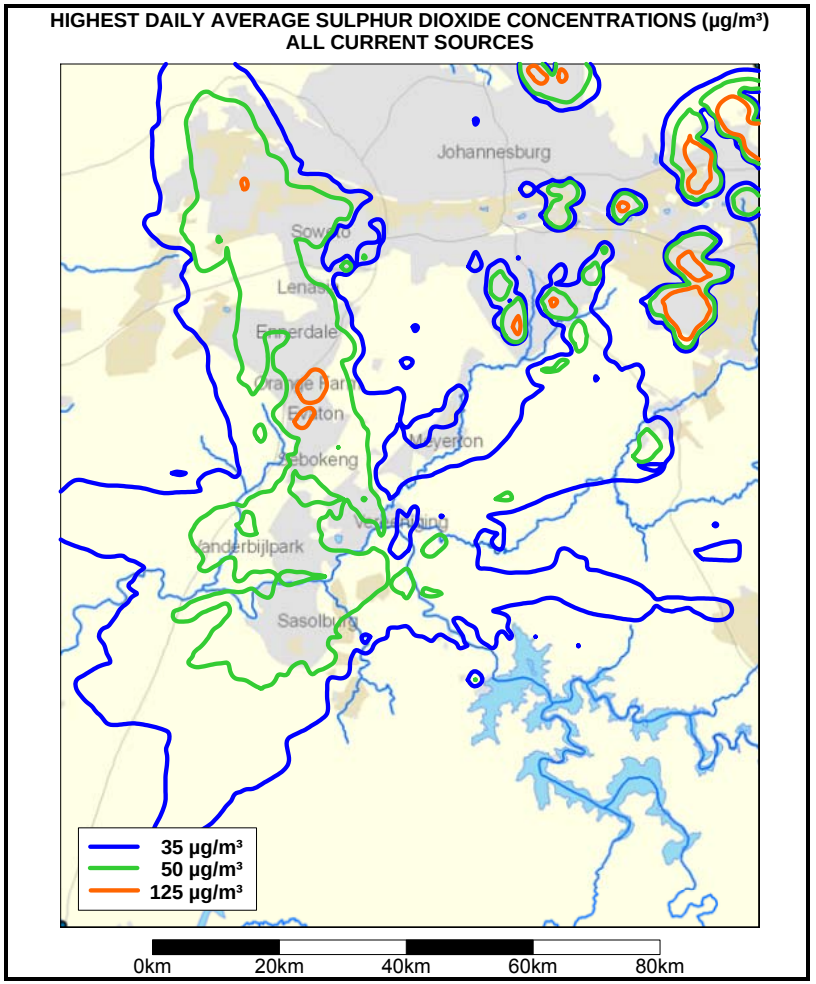


Figure 7-2: Highest daily (99.7th percentile) predicted sulphur dioxide ground level concentrations (µg/m³) within the study area.

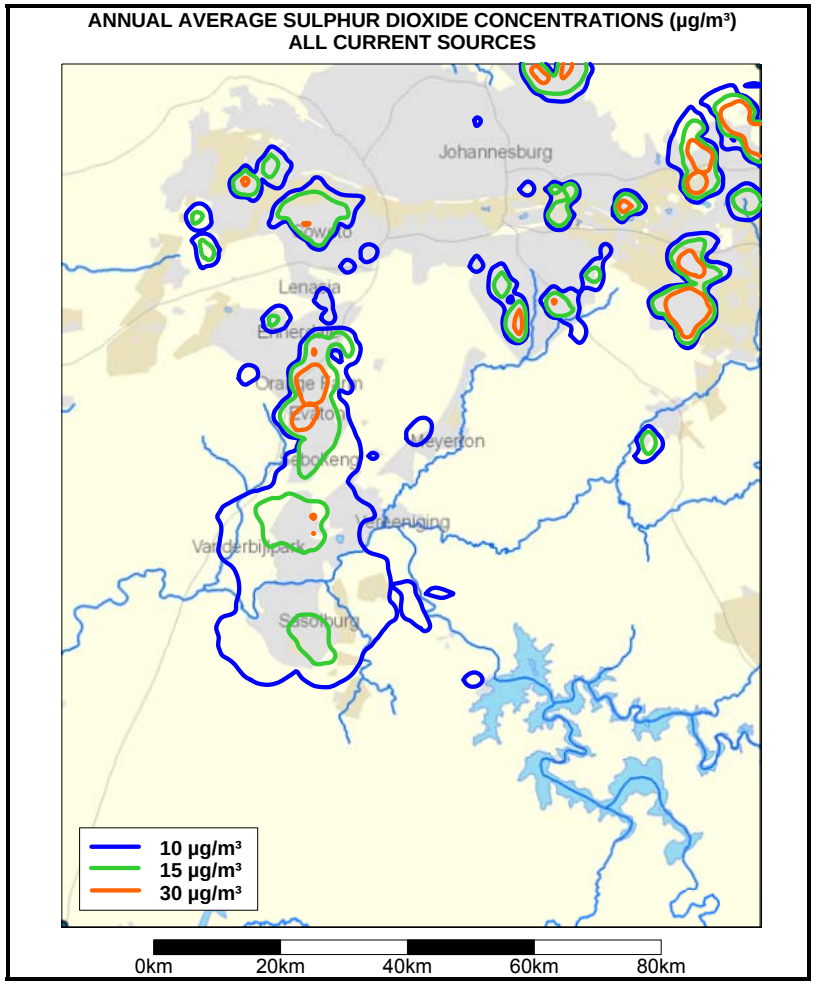


Figure 7-3: Annual average predicted sulphur dioxide ground level concentration (µg/m³) within the study area.

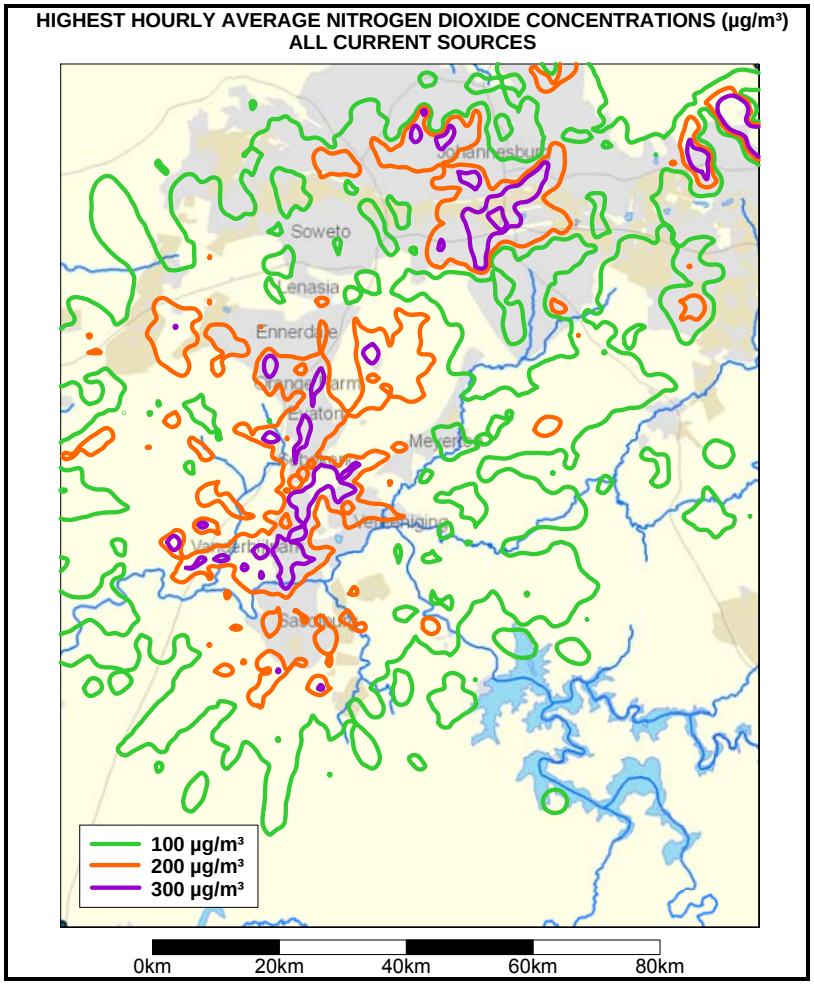


Figure 7-4: Highest hourly (99.99th percentile) predicted nitrogen dioxide ground level concentration (µg/m³) within the study area.

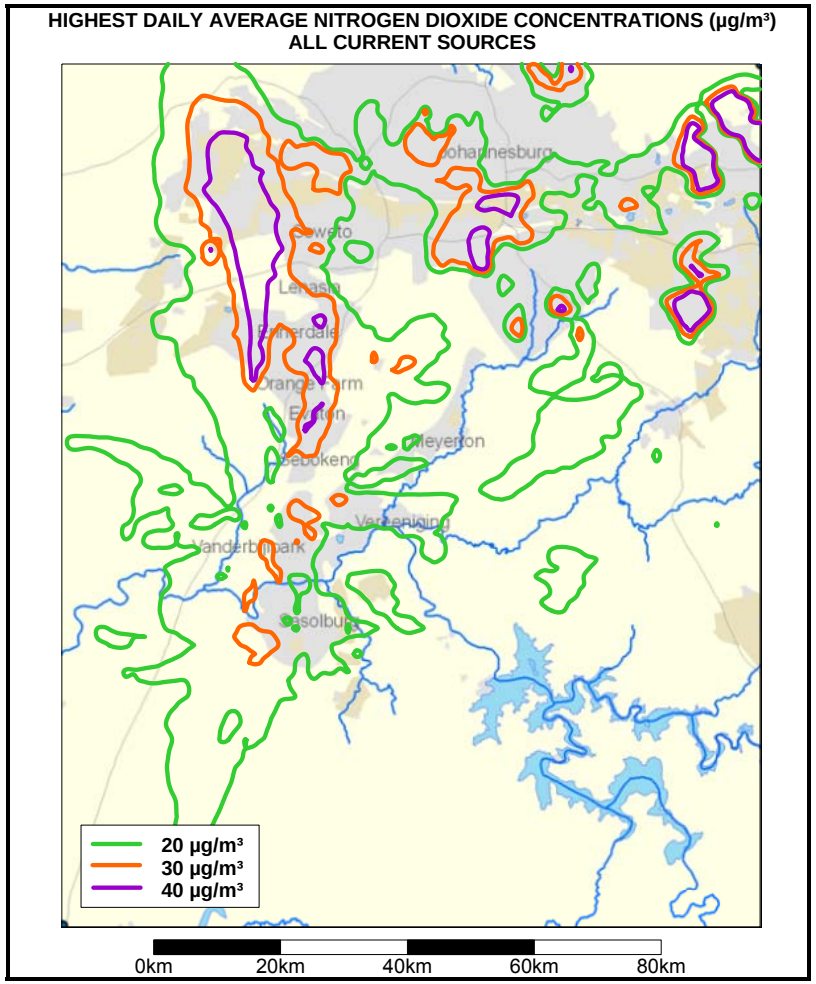


Figure 7-5: Highest daily (99.7th percentile) predicted nitrogen dioxide ground level concentration (µg/m³) within the study area.

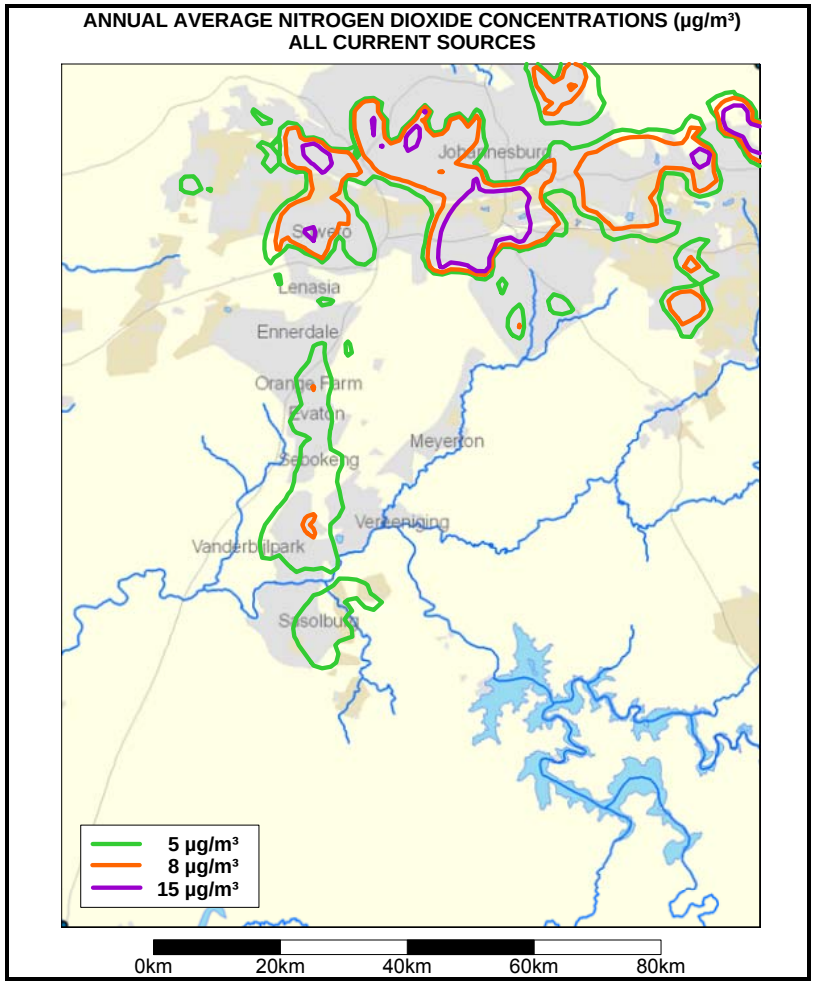


Figure 7-6: Annual average predicted nitrogen dioxide ground level concentration (µg/m³) within the study area.

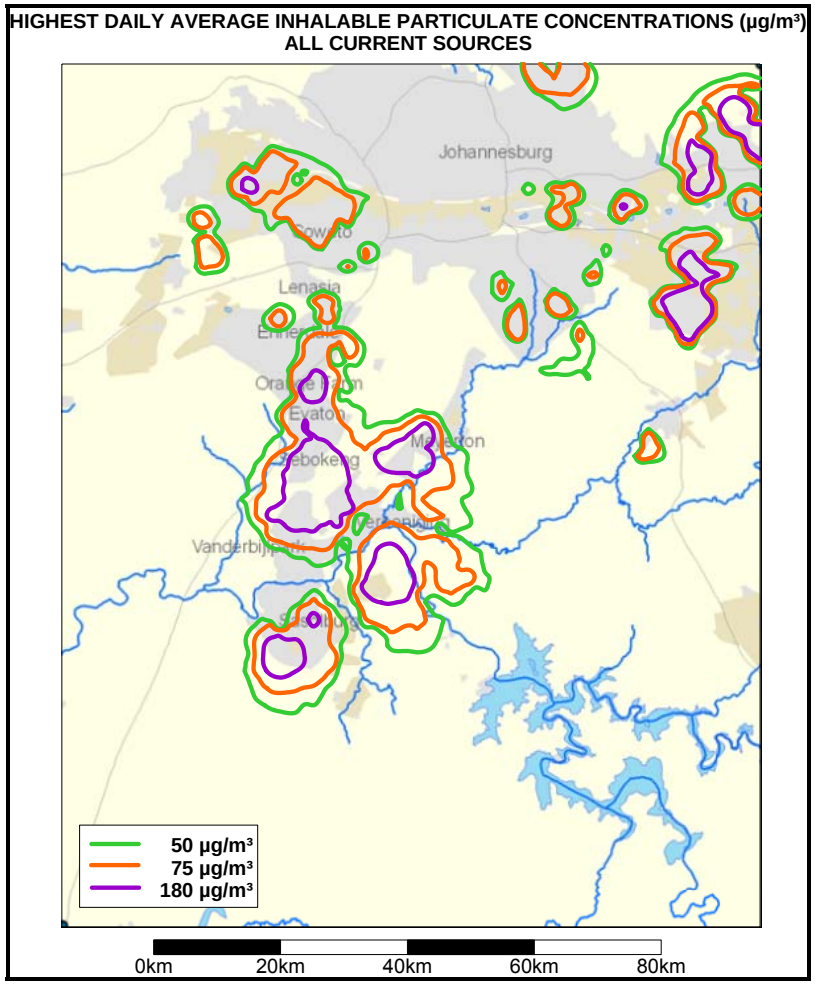


Figure 7-7: Highest daily (99.7th percentile) predicted inhalable particulate ground level concentration (µg/m³) within the study area.

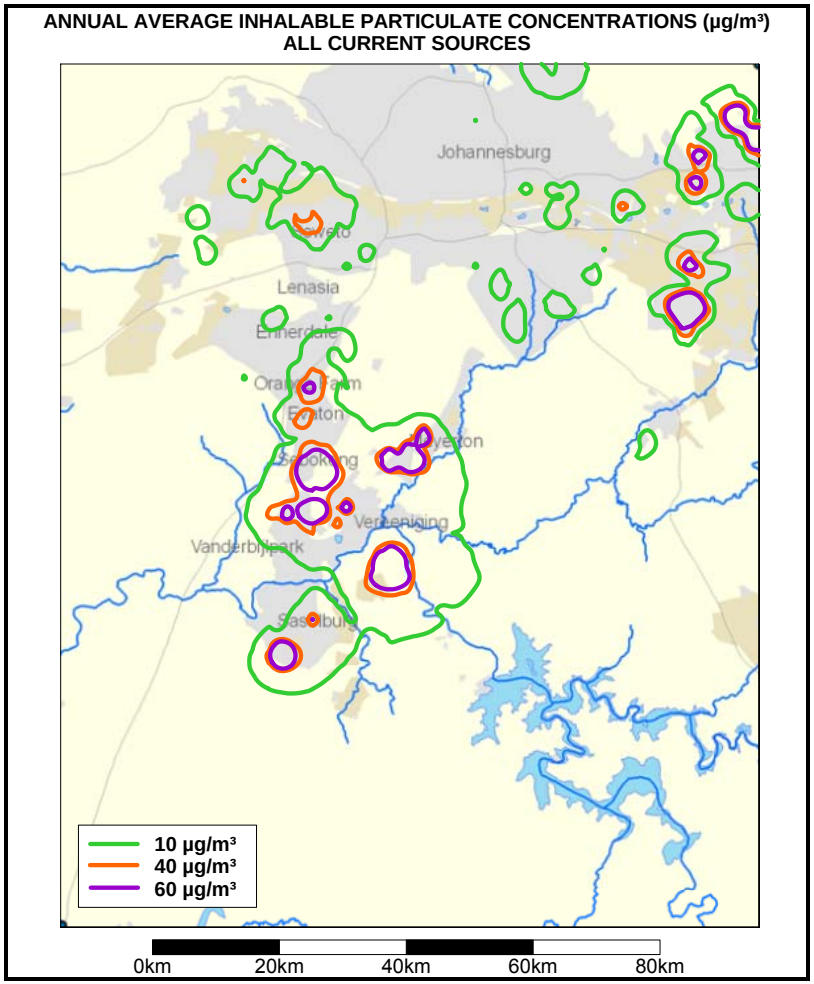


Figure 7-8: Annual average predicted inhalable particulate ground level concentration (µg/m³) within the study area.

7.2 Predicted Data Validation (Measured vs. Modelled)

Modelled sulphur dioxide, nitrogen dioxide and inhalable particulate concentrations simulated for current baseline conditions within the Vaal Airshed are compared to monitored concentrations (where data availability was >80%) in Table 7-2 to Table 7-4. Measured (99.99th percentile of hourly and 99.7th percentile daily concentrations) and modelled highest hourly (99.99th percentile), highest daily (99.7th percentile) and annual average air pollutant concentrations are given in the table for each of the monitoring stations. The ratio between measured and modelled concentrations is also presented. Given that the US-EPA gives the range of uncertainty in dispersion model results as being –50% to 200% only model predictions falling outside of this range when compared to monitored concentrations were flagged as being unrepresentative (i.e. modelled to monitored ratios of <0.5 or >2.0). Flagged values are indicated in bold print in the table. The measured and modelled frequencies of exceedance of air quality limits are compared in Table 7-5 to Table 7-6. Modelled and monitored air pollutant concentrations and modelled and measured frequencies of exceedance of air quality limits are depicted in Figures 7-9 to 7-20 for the three pollutants being investigated (Figures 7-9 to 7-13 for sulphur dioxide, Figure 7-14 to 7-17 for nitrogen dioxide, and Figure 7-18 to 7-20 for inhalable particulates).

7.2.1 Comparison of Measured and Modelled Sulphur Dioxide

The predicted ground level concentrations compared well with ambient measured sulphur dioxide levels for all averaging periods with the exception of the Sasol stations (i.e. modelled to monitored ratios of between 0.5 and 2.0). The predicted concentrations at the Sasol stations compared well for highest hourly and daily averaging periods, with the modelled predictions slightly under predicting on daily monitored concentrations, but still generally within the range of model uncertainty given by the US-EPA. On an annual averaging period, with the exception of the Leitrim monitoring station, the modelled concentrations under predict by 70% - 80%. The general model bias is to under predict on the medium- (daily) to long-term (annual) averaging periods.

7.2.2 Comparison of Measured and Modelled Nitrogen Dioxide

Modelled nitrogen dioxide concentrations compared generally well for highest hourly and daily averaging periods but under predicted for annual averaging periods for all monitoring stations.

Table 7-2: Comparison of monitored and modelled sulphur dioxide ground level concentrations for current baseline conditions within the Vaal Airshed.

Monitoring Agency	Station	Highest Hourly Average [1]			Highest Daily Average [2]			Annual Average		
		2004	2005	2006	2004	2005	2006	2004	2005	2006
Measured Sulphur Dioxide (µg/m³)										
City of Johannesburg	Orange Farm	-	237	395	-	-	64	-	13	15
ArcelorMittal Steel	Station 620	-	-	472	-	-	69	-	-	-
	Station 350	-	398		-	-	-	-	28	
Sasol	AJ Jacobs	546	701	621	109	104	110	39	36	37
	Boiketlong	515	664	1285	92	111	104	37	41	38
	Hospital	639	633	479	84	84	81	36	33	27
	Leitrim	477	461	947	70	78	153	26	31	32
Eskom	Makalu	581	-	-	59	-	-	20	-	-
Modelled Sulphur Dioxide (µg/m³)										
City of Johannesburg	Orange Farm	342	272	230	56	44	48	10	8	9
ArcelorMittal Steel	Station 620	457	430	389	86	128	111	20	22	23
	Station 350	432	366	406	64	44	48	20	18	20
Sasol	AJ Jacobs	609	688	626	63	65	64	12	7	10
	Boiketlong	498	444	696	61	44	56	13	11	11
	Hospital	453	296	669	53	47	54	10	6	8
	Leitrim	717	509	768	101	61	60	21	20	19
Eskom	Makalu	575	515	474	45	41	60	10	10	11
Ratio between Measured and Modelled Sulphur Dioxide Concentrations										
City of Johannesburg	Orange Farm	-	1.1	0.6	-	1.2	0.7	-	0.6	0.6
ArcelorMittal Steel	Station 620	-	-	0.8	-	-	1.6	-	-	0.8
	Station 350	-	0.9	-	-	0.7	-	-	0.6	
Sasol	AJ Jacobs	1.1	1.0	1.0	0.6	0.6	0.6	**0.3**	**0.2**	**0.3**
	Boiketlong	1.0	0.7	0.5	0.7	**0.4**	0.5	**0.3**	**0.3**	**0.3**

Monitoring Agency	Station	Highest Hourly Average [1]			Highest Daily Average [2]			Annual Average		
		2004	2005	2006	2004	2005	2006	2004	2005	2006
	Hospital	0.7	0.5	1.4	0.6	0.6	0.7	**0.3**	**0.2**	**0.3**
	Leitrim	1.5	1.1	0.8	1.4	0.8	**0.4**	0.8	0.6	0.6
Eskom	Makalu	1.0	-	-	0.8	-	-	0.5	-	-

Notes:
[1] 99.99th percentile
[2] 99.7th percentile

Table 7-3: Comparison of monitored and modelled nitrogen dioxide ground level concentrations for current baseline conditions within the Vaal Airshed.

Monitoring Agency	Station	Highest Hourly Average [1]			Highest Daily Average [2]			Annual Average		
		2004	2005	2006	2004	2005	2006	2004	2005	2006
Measured nitrogen dioxide (µg/m³)										
ArcelorMittal Steel	Station 620	-	-	274	-	-	48	-	-	28
	Station 350	-	140	-	-	55	-	-	29	-
Sasol	AJ Jacobs	-	181	161	-	63	54	-	28	28
	Leitrim	177	144	117	68	48	51	28	23	27
Eskom	Makalu	95	-	-	33	-	-	16	-	-
Modelled nitrogen dioxide (µg/m³)										
ArcelorMittal Steel	Station 620	291	124	296	31	22	21	6	5	6
	Station 350	145	130	169	26	23	26	6	5	6
Sasol	AJ Jacobs	256	149	243	31	25	25	6	4	4
	Leitrim	200	287	136	40	28	21	8	7	7
Eskom	Makalu	172	186	212	26	17	32	6	6	6
Ratio between Measured and Modelled nitrogen dioxide Concentrations										
ArcelorMittal Steel	Station 620	-	-	1.1	-	-	**0.4**	-	-	**0.2**
	Station 350	-	0.9	-	-	**0.4**	-	-	**0.2**	-
Sasol	AJ Jacobs	-	0.8	1.5	-	**0.4**	0.5	-	**0.1**	**0.2**
	Leitrim	1.1	**2.0**	1.2	0.6	0.6	**0.4**	**0.3**	**0.3**	**0.2**

Monitoring Agency	Station	Highest Hourly Average [1]			Highest Daily Average [2]			Annual Average		
		2004	2005	2006	2004	2005	2006	2004	2005	2006
Eskom	Makalu	1.8	-	-	0.8	-	-	**0.4**	-	-

Notes:
[1] 99.99th percentile
[2] 99.7th percentile

Table 7-4: Comparison of monitored and modelled inhalable particulate ground level concentrations for current baseline conditions within the Vaal Airshed.

Monitoring Agency	Station	Highest Hourly Average [1]			Highest Daily Average [2]			Annual Average		
		2004	2005	2006	2004	2005	2006	2004	2005	2006
Measured inhalable particulate (µg/m³)										
City of Johannesburg	Orange Farm	979	929	933	154	176	152		78	66
Sasol	Leitrim	998	905	947	168	254	153	53	105	41
Eskom	Makalu	605			97			34		
Modelled inhalable particulate (µg/m³)										
City of Johannesburg	Orange Farm	770	526	558	133	84	99	15	12	12
Sasol	Leitrim	1051	1014	1174	171	130	135	36	25	29
Eskom	Makalu	479	494	726	87	75	69	20	18	18
Ratio between Measured and Modelled inhalable particulate Concentrations										
City of Johannesburg	Orange Farm	0.8	0.6	0.6	0.9	0.5	0.6		**0.2**	**0.2**
Sasol	Leitrim	1.1	1.1	1.2	1.0	0.5	0.9	0.7	**0.2**	0.7
Eskom	Makalu	0.8			0.9			0.6		

Notes:
[1] 99.99th percentile
[2] 99.7th percentile

Table 7-5: Comparison of monitored and modelled sulphur dioxide frequencies of exceedance of air quality limits due to baseline conditions (Data availabilities given in brackets after measured frequencies.)

Monitoring Station	Frequencies of Exceedance (hours or days per year) of:											
	Hourly SO_2 air quality target of 350 µg/m³		Hourly SO_2 air quality target of 350 µg/m³		Hourly SO_2 air quality target of 350 µg/m³		Daily SO_2 air quality target of 125 µg/m³		Daily SO_2 air quality target of 125 µg/m³		Daily SO_2 air quality target of 125 µg/m³	
	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted
	2004		2005		2006		2004		2005		2006	
Orange Farm	Data <80%	0	1 (83%)	0	25 (83%)	0	Data <80%	0	0 (86%)	0	6 (88%)	0
Station 620	Data <80%	4	Data <80%	3	5 (86%)	1	Data <80%	0		2	0 (92%)	0
Station 350	NM	3	3 (96%)	1	4 (70%)	2	NM	0	0 (74%)	0	0 (79%)	0
AJ Jacobs	53 (100%)	6	48 (100%)	1	59 (99%)	6	6 (100%)	0	7 (100%)	0	9 (98%)	0
Boiketlong	50 (99%)	9	83 (100%)	1	91 (99%)	1	3 (99%)	0	8 (100%)	0	8 (99%)	0
Hospital	20 (100%)	2	36 (100%)	0	18 (99%)	7	2 (100%)	0	3 (100%)	0	0 (99%)	0
Leitrim	5 (91%)	6	31 (93%)	4	12 (99%)	2	0 (91%)	0	0 (95%)	0	0 (93%)	0
Makalu	16 (99%)	2	NM	3	NM	5	0 (100%)	0	NM	0	NM	0

NM – not measured

Table 7-6: Comparison of monitored and modelled nitrogen dioxide and inhalable particulate frequencies of exceedance of air quality limits due to baseline conditions (Data availabilities given in brackets after measured frequencies.)

Monitoring Station	Frequencies of Exceedance (hours or days per year) of:											
	Hourly NO_2 air quality target of 200 µg/m³		Hourly NO_2 air quality target of 200 µg/m³		Hourly NO_2 air quality target of 200 µg/m³		Daily PM10 air quality target of 75 µg/m³		Daily PM10 air quality target of 75 µg/m³		Daily PM10 air quality target of 75 µg/m³	
	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted
	2004		2005		2006		2004		2005		2006	
Orange Farm	NM	0	NM	1	NM	1	154 (87%)	8	182 (77%)	6	196 (88%)	6
Station 620	NM	1	0 (77%)	0	Data <80%	1	NM	51	Data <80%	99	Data <80%	105
Station 350	NM	0	0 (96%)	0	0 (74%)	0	NM	62	Data <80%	61	Data <80%	80
AJ Jacobs	NM	2	0 (100%)	0	1 (99%)	2	NM	6	NM	2	NM	4
Leitrim	5 (91%)	1	0 (93%)	1	0 (99%)	0	84 (80%)	37	162 (71%)	18	50 (99%)	25
Makalu	0 (98%)	0	NM	0	NM	1	24 (82%)	3	NM	2	NM	4

NM – not measured

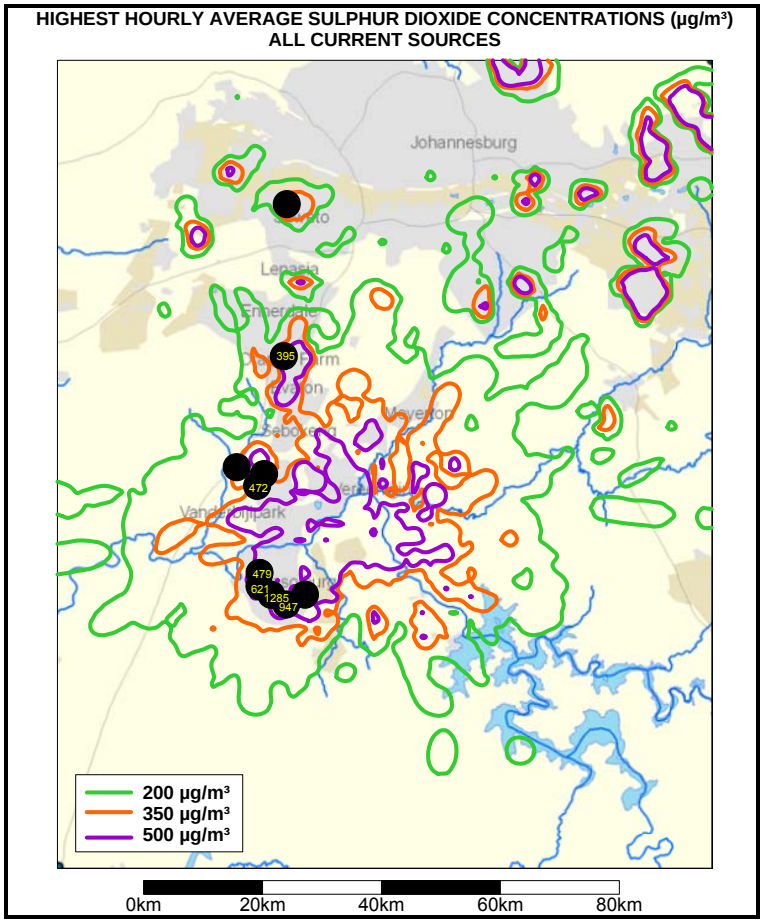


Figure 7-9: Comparison of simulated highest hourly (99.99th percentile) sulphur dioxide concentrations with measured highest hourly concentrations (for the period 2006) within the study area.

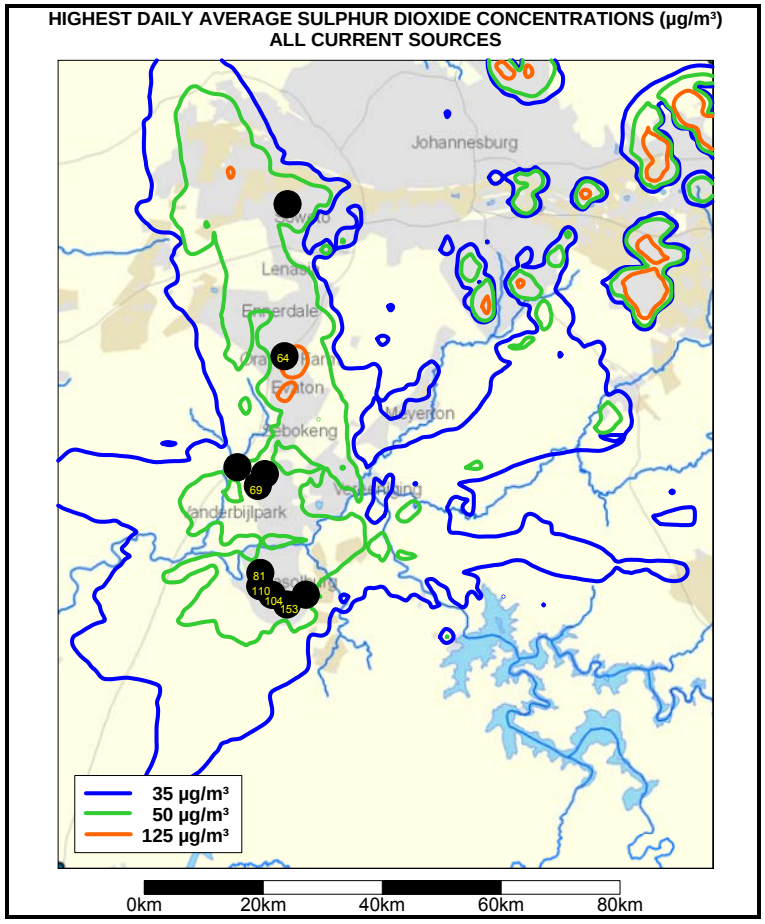


Figure 7-10: Comparison of simulated highest daily (99.7th percentile) sulphur dioxide concentrations with measured highest daily concentrations (for the period 2006) within the study area.

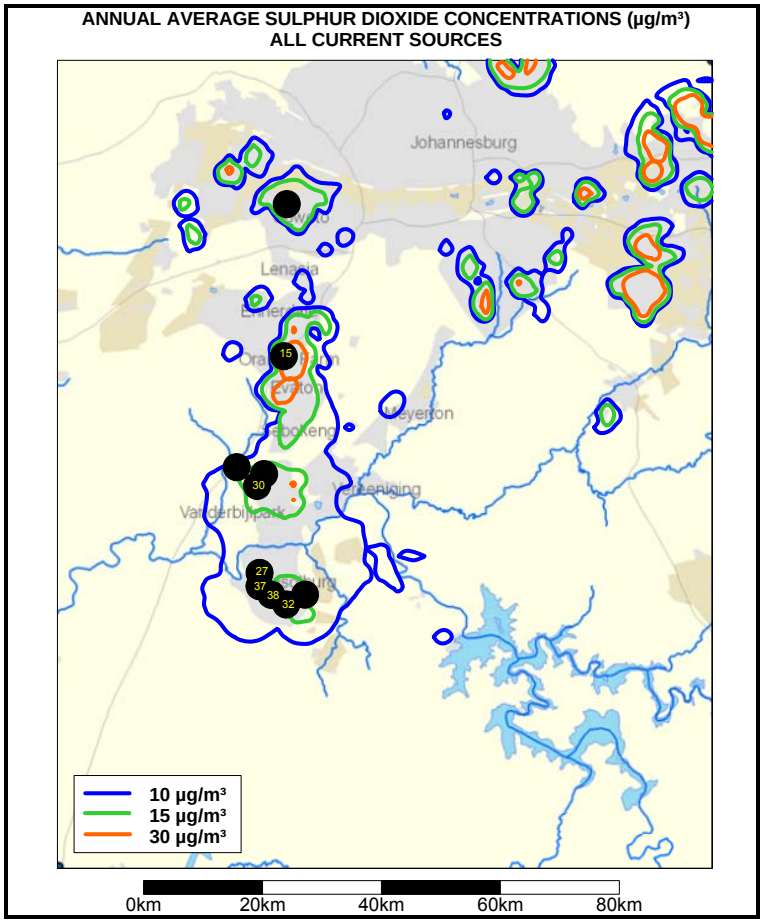


Figure 7-11: Comparison of simulated annual average sulphur dioxide concentrations with measured annual average concentrations (for the period 2006) within the study area.

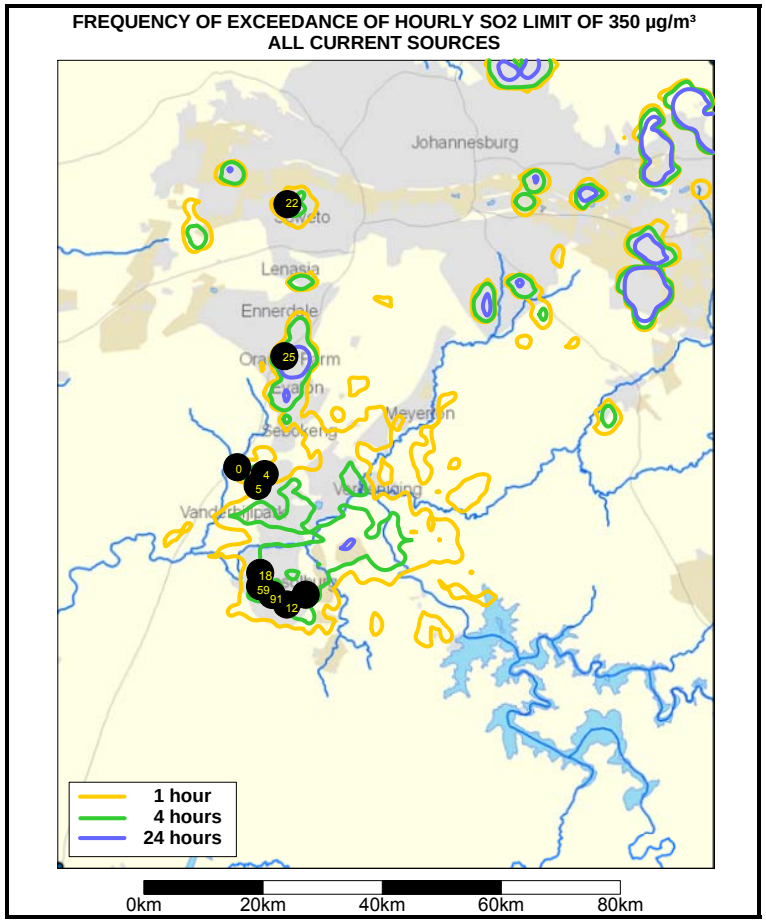


Figure 7-12: Comparison of simulated frequency of exceedance of the hourly sulphur dioxide SA standard of 350 µg/m³ with measured frequencies (for the period 2006) within the study area.

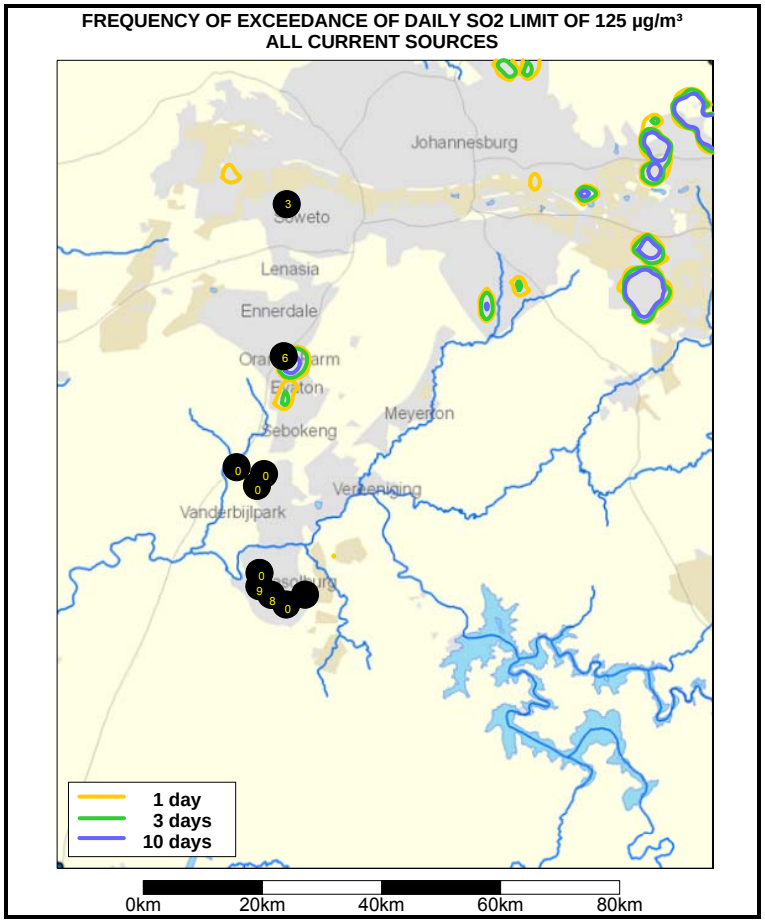


Figure 7-13: Comparison of simulated frequency of exceedance of the daily sulphur dioxide SA standard of 125 µg/m³ with measured frequencies (for the period 2006) within the study area.

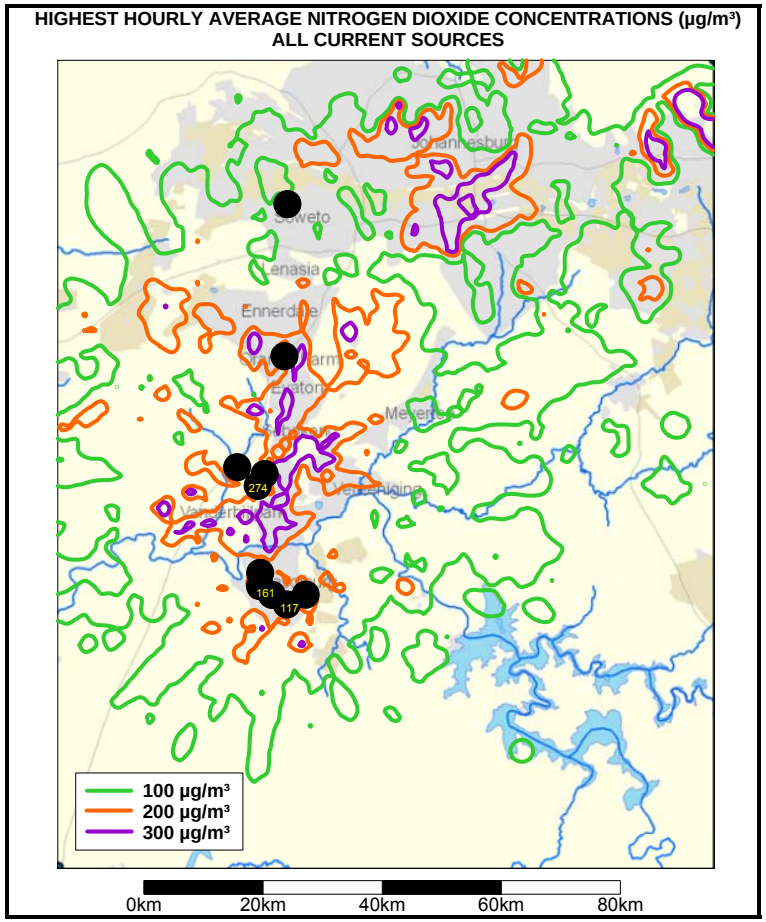


Figure 7-14: Comparison of simulated highest hourly (99.99th percentile) nitrogen dioxide concentrations with measured highest hourly concentrations (for the period 2006) within the study area.

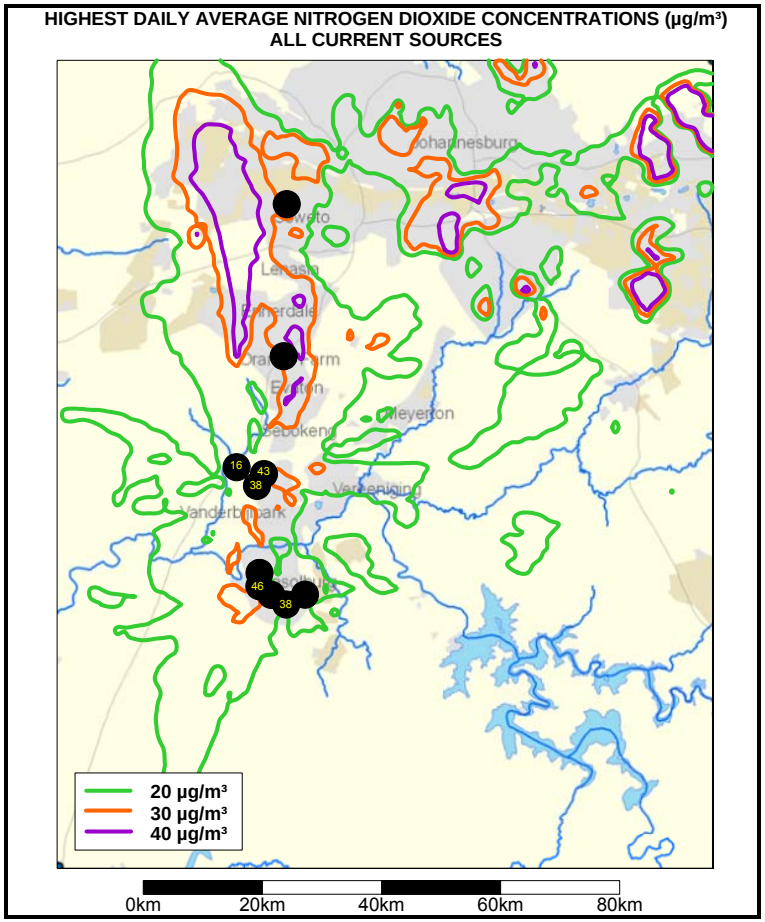


Figure 7-15: Comparison of simulated highest daily (99.7th percentile) nitrogen dioxide concentrations with measured highest daily concentrations (for the period 2006) within the study area.

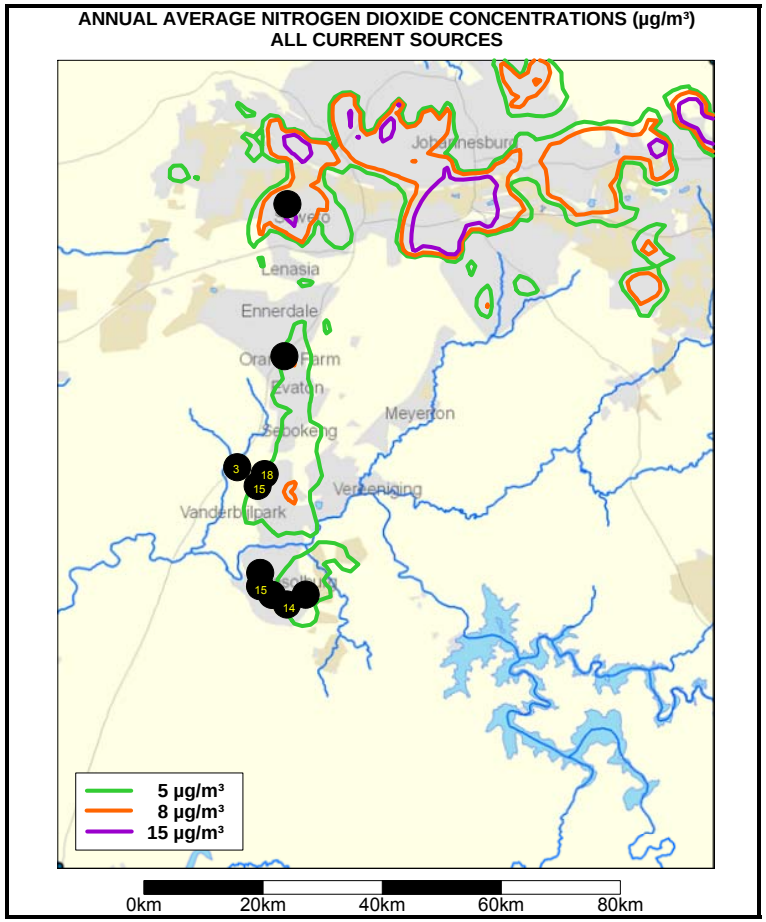


Figure 7-16: Comparison of simulated annual average nitrogen dioxide concentrations with measured annual average concentrations (for the period 2006) within the study area.

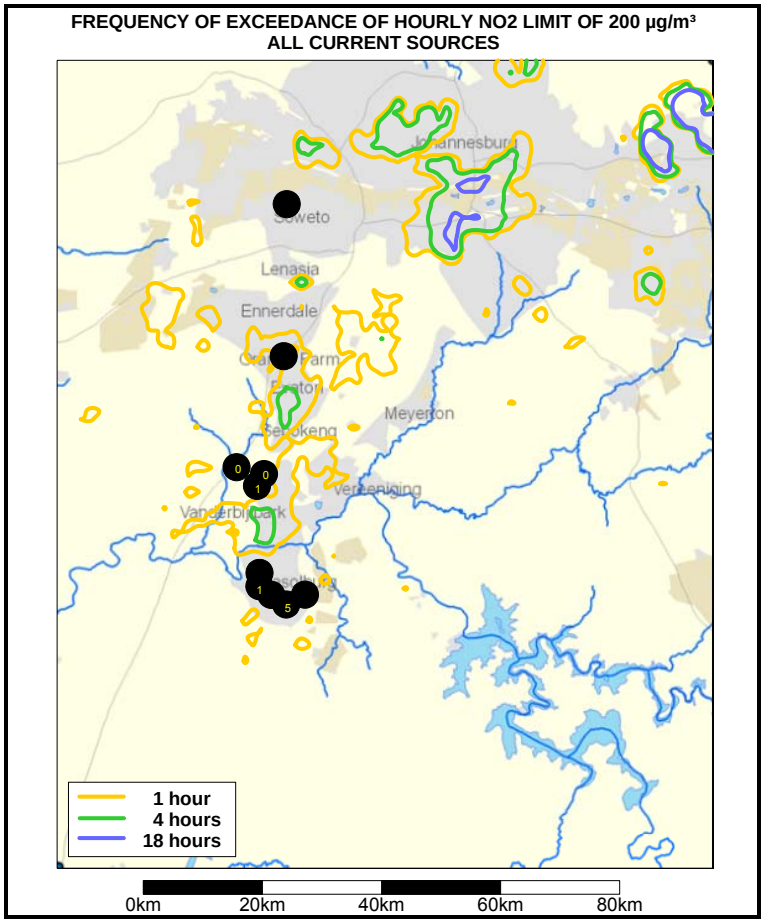


Figure 7-17: Comparison of simulated frequency of exceedance of the hourly nitrogen dioxide SANS limit (proposed SA standard) of 200 µg/m³ with measured frequencies (for the period 2006).

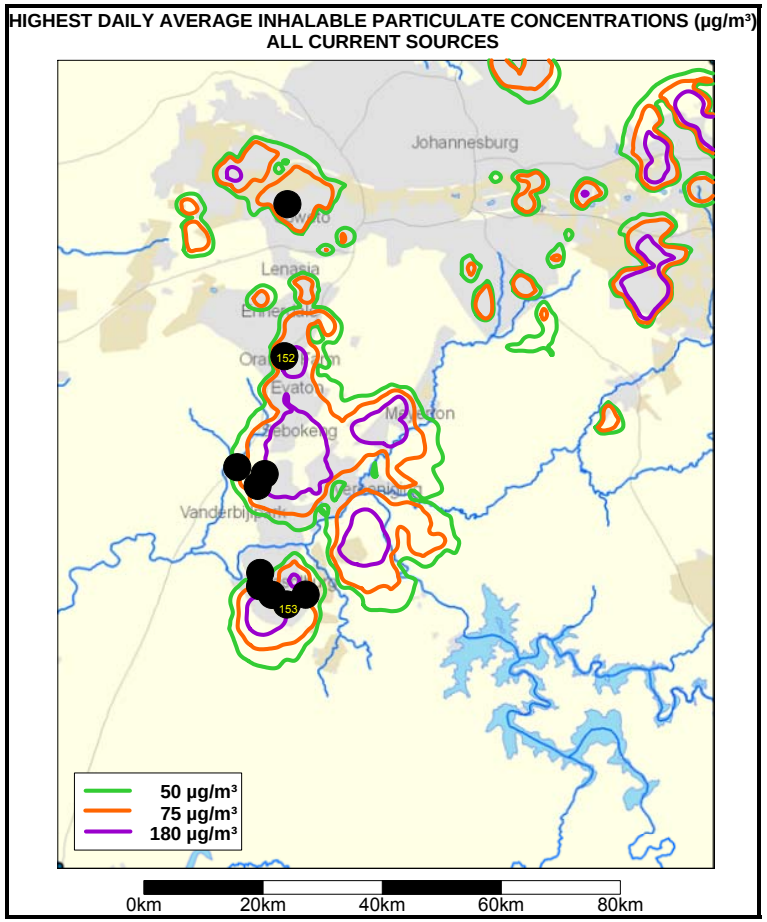


Figure 7-18: Comparison of simulated highest daily (99.7th percentile) inhalable particulate concentrations with measured highest daily concentrations (for the period 2006) within the study area.

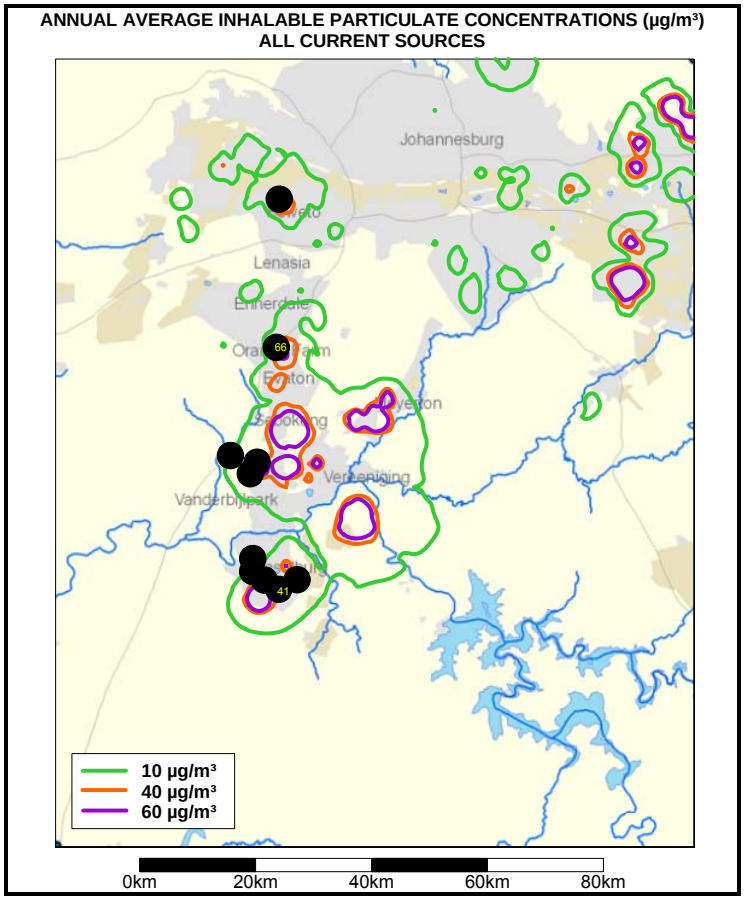


Figure 7-19: Comparison of simulated annual average inhalable particulate concentrations with measured annual average concentrations (for the period 2006) within the study area.

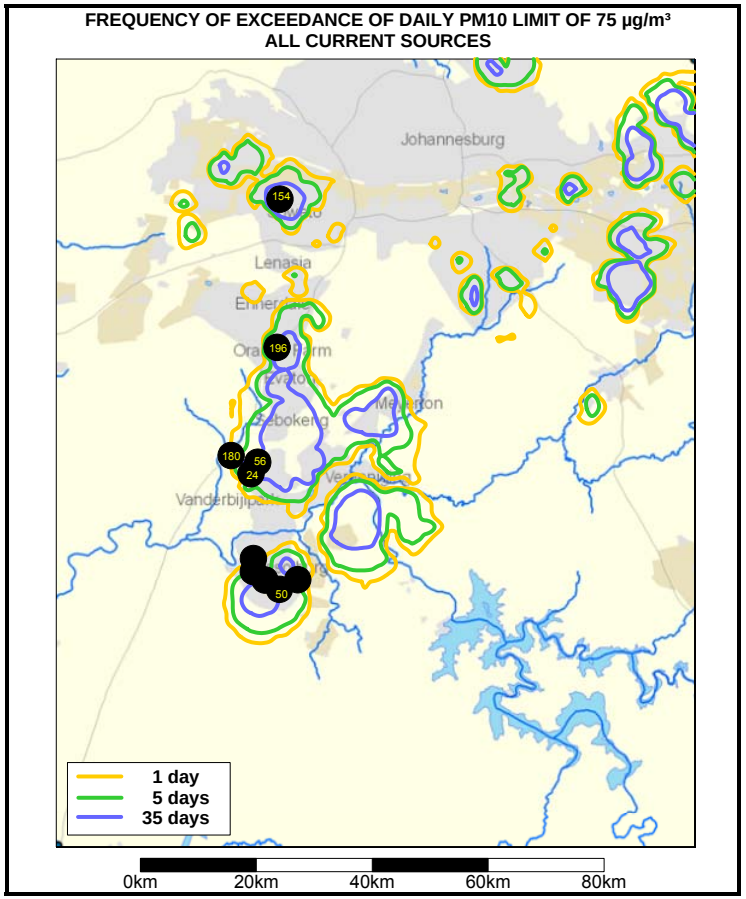


Figure 7-20: Comparison of simulated frequency of exceedance of the daily inhalable particulate SANS limit (proposed SA standard) of 75 µg/m³ with measured frequencies (for the period 2006) within the study area.

7.2.3 Comparison of Measured and Modelled Inhalable Particulate

At Orange Farm, the predicted ground level concentration compared well to monitored data for highest hourly and daily ground level concentrations, but under predicted on annual averages.

The predicted concentrations at the Leitrim monitoring station were comparative to monitored data with the exception of the annual averaging period of 2005.

Predicted ground level concentrations at Makalu correlated well for all averaging periods.

7.2.4 Summary of Measured versus Modelled Results

In general, a good correlation was found between modelled and monitored concentrations for the short and medium term exposures. This confirms that the model is interpreting the zones of impact correctly and the concentrations related to short-term health exceedance impacts. Over the long term (annual averages) the ground level concentrations were generally under predicted due to sources that could not be accounted for in the current study. These sources would include agricultural activities and biomass burning as well as sources outside the study area that would have an impact within the Vaal Airshed due to trans-boundary transportation of pollutants.

The hourly and daily frequency of SO_2 exceedances provided by the model is notably under predicting the monitored number of exceedances (especially at the Sasol monitoring stations). Similarly, the daily frequency of exceedances modelled is under predicted when compared to monitored exceedances for inhalable particulate concentrations. Spatially, however, the model has interpreted the areas of highest concentration exceedance fairly accurately.

7.3 Compliance with Ambient Air Quality Guidelines/Standards

In the comparison of simulated ambient pollutant concentrations due to the current activities within the Vaal Airshed, reference is made to the current SA standards as well as the SANS limits (proposed SA standards) and “best practice” EC limits.

In assessing compliance of current baseline operations attention is paid to cumulative air pollutant concentrations due to all quantified emissions within the Vaal Airshed. Where applicable, emphasis was placed on:

- the magnitude of the exceedance (i.e. extent to which pollutant concentrations exceed the permissible limit value);

- the frequency of exceedance (i.e. how many times, given as hours or days a year, air quality limit values are exceeded); and

- the spatial extent of exceedances (i.e. the area over which frequencies of exceedance are expected to occur.)

The dispersion results are represented in Table 7-7 as the highest (99.99th percentile for hourly averaging periods and 99.7th percentile for daily averaging periods) predicted cumulative concentrations in the Vaal Airshed in comparison to the relevant ambient air quality standards/limits. The table includes the predicted ground level concentrations and the relevant air quality standards/limits. Section 7.1 includes the isopleth plots indicating the concentration contours. It should be noted that the plots reflecting hourly and daily averaging periods contain second maximum predicted ground level concentrations, for those averaging periods, over the entire period for which simulations were undertaken. It is therefore possible that even though a high hourly or daily average concentration is predicted to occur at certain locations, that this may only be true for one hour or one day during the year.

Predicted air pollutant concentrations and frequencies of exceedance due exclusively to current conditions are summarised in Tables 7-7. The spatial extent of exceedances of sulphur dioxide, nitrogen dioxide and inhalable particulate limits are given in Figures 7-21, 7-22, 7-23 and 7-24, respectively.

Table 7-7: Predicted maximum air pollutant concentrations due to all source activity within the Vaal Airshed based on 2004, 2005 and 2006 meteorological conditions [h].

Sensitive Receptor	Pollutant	Averaging period	Predicted Maximum Concentrations (µg/m³)/ No. of exceedances	Current SA Standards (µg/m³)	SANS Limits (proposed SA standards) (µg/m³) / proposed frequency of exceedance	EC Limits (µg/m³) / allowable frequency of exceedance
Johannesburg [g]	Sulphur Dioxide	Calculated 10-minute average	**1560**	500	500	-
		Highest hourly average [a]	**1090**	350	350	350
		Highest daily average [b]	**243**	125	125	125
		Annual average	**55**	50	50	50
		Frequency of hourly exceedance of 350µg/m³ (hours/year)	**400**	-	88[c],44[d],9[e]	24
		Frequency of daily exceedance of 125µg/m³ (days/year)	**70**	-	4[c],2[d],1[e]	3
	Nitrogen Dioxide	Highest hourly average [a]	**500**	376	200	200
		Highest daily average [b]	100	188	-	-
		Annual average	28	94	40	40
		Frequency of hourly exceedance of 376µg/m³ (hours/year)	**12**	-	0[c]	-
		Frequency of hourly exceedance of 288µg/m³ (hours/year)	40	-	88[d]	-
		Frequency of hourly exceedance of 244µg/m³ (hours/year)	**80**	-	44[e]	-
		Frequency of hourly exceedance of 200µg/m³ (hours/year)	**240**	-	9[f]	18
	Inhalable Particulate Matter	Highest daily average [b]	**580**	180	75	50
		Annual average	**110**	60	40	40
		Frequency of daily exceedance of 180µg/m³ (days/year)	**55**	-	0[c]	-
		Frequency of daily exceedance of 127µg/m³ (days/year)	88	-	88[d]	-
		Frequency of daily exceedance of 100µg/m³ (days/year)	**120**	-	44[e]	-
		Frequency of daily exceedance of 75µg/m³ (days/year)	**170**	-	9[f]	-
		Frequency of daily exceedance of 50µg/m³ (days/year)	**230**	-	-	35

Sensitive Receptor	Pollutant	Averaging period	Predicted Maximum Concentrations (µg/m³)/ No. of exceedances	Current SA Standards (µg/m³)	SANS Limits (proposed SA standards) (µg/m³) / proposed frequency of exceedance	EC Limits (µg/m³) / allowable frequency of exceedance
Soweto	Sulphur Dioxide	Calculated 10-minute average	**644**	500	500	-
		Highest hourly average [a]	**450**	350	350	350
		Highest daily average [b]	85	125	125	125
		Annual average	25	50	50	50
		Frequency of hourly exceedance of 350µg/m³ (hours/year)	7	-	88[c],44[d],9[e]	24
		Frequency of daily exceedance of 125µg/m³ (days/year)	0	-	4[c],2[d],1[e]	3
	Nitrogen Dioxide	Highest hourly average [a]	160	376	200	200
		Highest daily average [b]	38	188	-	-
		Annual average	15	94	40	40
		Frequency of hourly exceedance of 376µg/m³ (hours/year)	0	-	0[c]	-
		Frequency of hourly exceedance of 288µg/m³ (hours/year)	0	-	88[d]	-
		Frequency of hourly exceedance of 244µg/m³ (hours/year)	0	-	44[e]	-
		Frequency of hourly exceedance of 200µg/m³ (hours/year)	0	-	9[f]	18
	Inhalable Particulate Matter	Highest daily average [b]	150	180	75	50
		Annual average	44	60	40	40
		Frequency of daily exceedance of 180µg/m³ (days/year)	0	-	0[c]	-
		Frequency of daily exceedance of 127µg/m³ (days/year)	10	-	88[d]	-
		Frequency of daily exceedance of 100µg/m³ (days/year)	25	-	44[e]	-
		Frequency of daily exceedance of 75µg/m³ (days/year)	**53**	-	9[f]	-
		Frequency of daily exceedance of 50µg/m³ (days/year)	**93**	-	-	35
Lenasia	Sulphur Dioxide	Calculated 10-minute average	**644**	500	500	-
		Highest hourly average [a]	**450**	350	350	350
		Highest daily average [b]	65	125	125	125
		Annual average	7	50	50	50
		Frequency of hourly exceedance of 350µg/m³ (hours/year)	20	-	88[c],44[d],9[e]	24
		Frequency of daily exceedance of 125µg/m³ (days/year)	0	-	4[c],2[d],1[e]	3

Sensitive Receptor	Pollutant	Averaging period	Predicted Maximum Concentrations (µg/m³)/ No. of exceedances	Current SA Standards (µg/m³)	SANS Limits (proposed SA standards) (µg/m³) / proposed frequency of exceedance	EC Limits (µg/m³) / allowable frequency of exceedance
	Nitrogen Dioxide	Highest hourly average [a]	200	376	200	200
		Highest daily average [b]	37	188	-	-
		Annual average	5.5	94	40	40
		Frequency of hourly exceedance of 376µg/m³ (hours/year)	0	-	0[c]	-
		Frequency of hourly exceedance of 288µg/m³ (hours/year)	0	-	88[d]	-
		Frequency of hourly exceedance of 244µg/m³ (hours/year)	0	-	44[e]	-
		Frequency of hourly exceedance of 200µg/m³ (hours/year)	7	-	9[f]	18
	Inhalable Particulate Matter	Highest daily average [b]	90	180	75	50
		Annual average	9	60	40	40
		Frequency of daily exceedance of 180µg/m³ (days/year)	0	-	0[c]	-
		Frequency of daily exceedance of 127µg/m³ (days/year)	0	-	88[d]	-
		Frequency of daily exceedance of 100µg/m³ (days/year)	0	-	44[e]	-
		Frequency of daily exceedance of 75µg/m³ (days/year)	5	-	9[f]	-
		Frequency of daily exceedance of 50µg/m³ (days/year)	10	-	-	35
Ennerdale	Sulphur Dioxide	Calculated 10-minute average	**715**	500	500	-
		Highest hourly average [a]	**500**	350	350	350
		Highest daily average [b]	100	125	125	125
		Annual average	25	50	50	50
		Frequency of hourly exceedance of 350µg/m³ (hours/year)	15	-	88[c],44[d],9[e]	24
		Frequency of daily exceedance of 125µg/m³ (days/year)	0	-	4[c],2[d],1[e]	3
	Nitrogen Dioxide	Highest hourly average [a]	360	376	200	200
		Highest daily average [b]	45	188	-	-
		Annual average	5.5	94	40	40
		Frequency of hourly exceedance of 376µg/m³ (hours/year)	0	-	0[c]	-
		Frequency of hourly exceedance of 288µg/m³ (hours/year)	1	-	88[d]	-
		Frequency of hourly exceedance of 244µg/m³ (hours/year)	1	-	44[e]	-

Sensitive Receptor	Pollutant	Averaging period	Predicted Maximum Concentrations (µg/m³)/ No. of exceedances	Current SA Standards (µg/m³)	SANS Limits (proposed SA standards) (µg/m³) / proposed frequency of exceedance	EC Limits (µg/m³) / allowable frequency of exceedance
		Frequency of hourly exceedance of 200µg/m³ (hours/year)	2	-	9[f]	18
	Inhalable Particulate Matter	Highest daily average [b]	160	180	75	50
		Annual average	38	60	40	40
		Frequency of daily exceedance of 180µg/m³ (days/year)	0	-	0[c]	-
		Frequency of daily exceedance of 127µg/m³ (days/year)	1	-	88[d]	-
		Frequency of daily exceedance of 100µg/m³ (days/year)	1	-	44[e]	-
		Frequency of daily exceedance of 75µg/m³ (days/year)	**40**	-	9[f]	-
		Frequency of daily exceedance of 50µg/m³ (days/year)	**80**	-	-	35
Orange Farm	Sulphur Dioxide	Calculated 10-minute average	**1073**	500	500	-
		Highest hourly average [a]	**750**	350	350	350
		Highest daily average [b]	**200**	125	125	125
		Annual average	45	50	50	50
		Frequency of hourly exceedance of 350µg/m³ (hours/year)	**100**	-	88[c],44[d],9[e]	24
		Frequency of daily exceedance of 125µg/m³ (days/year)	**18**	-	4[c],2[d],1[e]	3
	Nitrogen Dioxide	Highest hourly average [a]	360	376	200	200
		Highest daily average [b]	42	188	-	-
		Annual average	7.5	94	40	40
		Frequency of hourly exceedance of 376µg/m³ (hours/year)	0	-	0[c]	-
		Frequency of hourly exceedance of 288µg/m³ (hours/year)	1	-	88[d]	-
		Frequency of hourly exceedance of 244µg/m³ (hours/year)	1	-	44[e]	-
		Frequency of hourly exceedance of 200µg/m³ (hours/year)	3	-	9[f]	18
	Inhalable Particulate Matter	Highest daily average [b]	**280**	180	75	50
		Annual average	60	60	40	40
		Frequency of daily exceedance of 180µg/m³ (days/year)	**9**	-	0[c]	-
		Frequency of daily exceedance of 127µg/m³ (days/year)	30	-	88[d]	-
		Frequency of daily exceedance of 100µg/m³ (days/year)	42	-	44[e]	-

Sensitive Receptor	Pollutant	Averaging period	Predicted Maximum Concentrations (µg/m³)/ No. of exceedances	Current SA Standards (µg/m³)	SANS Limits (proposed SA standards) (µg/m³) / proposed frequency of exceedance	EC Limits (µg/m³) / allowable frequency of exceedance
		Frequency of daily exceedance of 75µg/m³ (days/year)	**70**	-	9[f]	-
		Frequency of daily exceedance of 50µg/m³ (days/year)	**120**	-	-	35
Evaton	Sulphur Dioxide	Calculated 10-minute average	**930**	500	500	-
		Highest hourly average [a]	**650**	350	350	350
		Highest daily average [b]	**130**	125	125	125
		Annual average	32	50	50	50
		Frequency of hourly exceedance of 350µg/m³ (hours/year)	30	-	88[c],44[d],9[e]	24
		Frequency of daily exceedance of 125µg/m³ (days/year)	**5**	-	4[c],2[d],1[e]	3
	Nitrogen Dioxide	Highest hourly average [a]	310	376	200	200
		Highest daily average [b]	40	188	-	-
		Annual average	6.5	94	40	40
		Frequency of hourly exceedance of 376µg/m³ (hours/year)	0	-	0[c]	-
		Frequency of hourly exceedance of 288µg/m³ (hours/year)	2	-	88[d]	-
		Frequency of hourly exceedance of 244µg/m³ (hours/year)	3	-	44[e]	-
		Frequency of hourly exceedance of 200µg/m³ (hours/year)	9	-	9[f]	18
	Inhalable Particulate Matter	Highest daily average [b]	**280**	180	75	50
		Annual average	50	60	40	40
		Frequency of daily exceedance of 180µg/m³ (days/year)	**10**	-	0[c]	-
		Frequency of daily exceedance of 127µg/m³ (days/year)	15	-	88[d]	-
		Frequency of daily exceedance of 100µg/m³ (days/year)	27	-	44[e]	-
		Frequency of daily exceedance of 75µg/m³ (days/year)	**55**	-	9[f]	-
		Frequency of daily exceedance of 50µg/m³ (days/year)	**100**	-	-	35
Sebo-keng	Sulphur Dioxide	Calculated 10-minute average	**544**	500	500	-
		Highest hourly average [a]	**380**	350	350	350
		Highest daily average [b]	80	125	125	125
		Annual average	22	50	50	50

Sensitive Receptor	Pollutant	Averaging period	Predicted Maximum Concentrations (µg/m³)/ No. of exceedances	Current SA Standards (µg/m³)	SANS Limits (proposed SA standards) (µg/m³) / proposed frequency of exceedance	EC Limits (µg/m³) / allowable frequency of exceedance
		Frequency of hourly exceedance of 350µg/m³ (hours/year)	5	-	88[c],44[d],9[e]	24
		Frequency of daily exceedance of 125µg/m³ (days/year)	0	-	4[c],2[d],1[e]	3
	Nitrogen Dioxide	Highest hourly average [a]	300	376	200	200
		Highest daily average [b]	32	188	-	-
		Annual average	6	94	40	40
		Frequency of hourly exceedance of 376µg/m³ (hours/year)	0	-	0[c]	-
		Frequency of hourly exceedance of 288µg/m³ (hours/year)	1	-	88[d]	-
		Frequency of hourly exceedance of 244µg/m³ (hours/year)	1	-	44[e]	-
		Frequency of hourly exceedance of 200µg/m³ (hours/year)	5	-	9[f]	18
	Inhalable Particulate Matter	Highest daily average [b]	**3151**	180	75	50
		Annual average	**456**	60	40	40
		Frequency of daily exceedance of 180µg/m³ (days/year)	**90**	-	0[c]	-
		Frequency of daily exceedance of 127µg/m³ (days/year)	**120**	-	88[d]	-
		Frequency of daily exceedance of 100µg/m³ (days/year)	**130**	-	44[e]	-
		Frequency of daily exceedance of 75µg/m³ (days/year)	**170**	-	9[f]	-
		Frequency of daily exceedance of 50µg/m³ (days/year)	**200**	-	-	35
Meyerton	Sulphur Dioxide	Calculated 10-minute average	**1002**	500	500	-
		Highest hourly average [a]	**700**	350	350	350
		Highest daily average [b]	30	125	125	125
		Annual average	7	50	50	50
		Frequency of hourly exceedance of 350µg/m³ (hours/year)	2	-	88[c],44[d],9[e]	24
		Frequency of daily exceedance of 125µg/m³ (days/year)	0	-	4[c],2[d],1[e]	3
	Nitrogen Dioxide	Highest hourly average [a]	200	376	200	200
		Highest daily average [b]	23	188	-	-
		Annual average	4	94	40	40
		Frequency of hourly exceedance of 376µg/m³ (hours/year)	0	-	0[c]	-

Sensitive Receptor	Pollutant	Averaging period	Predicted Maximum Concentrations (µg/m³)/ No. of exceedances	Current SA Standards (µg/m³)	SANS Limits (proposed SA standards) (µg/m³) / proposed frequency of exceedance	EC Limits (µg/m³) / allowable frequency of exceedance
		Frequency of hourly exceedance of 288µg/m³ (hours/year)	0	-	88[d]	-
		Frequency of hourly exceedance of 244µg/m³ (hours/year)	0	-	44[e]	-
		Frequency of hourly exceedance of 200µg/m³ (hours/year)	0	-	9[f]	18
	Inhalable Particulate Matter	Highest daily average [b]	**1095**	180	75	50
		Annual average	**200**	60	40	40
		Frequency of daily exceedance of 180µg/m³ (days/year)	**70**	-	0[c]	-
		Frequency of daily exceedance of 127µg/m³ (days/year)	**100**	-	88[d]	-
		Frequency of daily exceedance of 100µg/m³ (days/year)	**110**	-	44[e]	-
		Frequency of daily exceedance of 75µg/m³ (days/year)	**135**	-	9[f]	-
		Frequency of daily exceedance of 50µg/m³ (days/year)	**170**	-	-	35
Vereeniging	Sulphur Dioxide	Calculated 10-minute average	**1560**	500	500	-
		Highest hourly average [a]	**1090**	350	350	350
		Highest daily average [b]	60	125	125	125
		Annual average	10	50	50	50
		Frequency of hourly exceedance of 350µg/m³ (hours/year)	6	-	88[c],44[d],9[e]	24
		Frequency of daily exceedance of 125µg/m³ (days/year)	0	-	4[c],2[d],1[e]	3
	Nitrogen Dioxide	Highest hourly average [a]	350	376	200	200
		Highest daily average [b]	32	188	-	-
		Annual average	5.5	94	40	40
		Frequency of hourly exceedance of 376µg/m³ (hours/year)	0	-	0[c]	-
		Frequency of hourly exceedance of 288µg/m³ (hours/year)	1	-	88[d]	-
		Frequency of hourly exceedance of 244µg/m³ (hours/year)	1	-	44[e]	-
		Frequency of hourly exceedance of 200µg/m³ (hours/year)	3	-	9[f]	18
	Inhalable Particulate Matter	Highest daily average [b]	**420**	180	75	50
		Annual average	**90**	60	40	40
		Frequency of daily exceedance of 180µg/m³ (days/year)	**30**	-	0[c]	-

Sensitive Receptor	Pollutant	Averaging period	Predicted Maximum Concentrations (µg/m³)/ No. of exceedances	Current SA Standards (µg/m³)	SANS Limits (proposed SA standards) (µg/m³) / proposed frequency of exceedance	EC Limits (µg/m³) / allowable frequency of exceedance
		Frequency of daily exceedance of 127µg/m³ (days/year)	70	-	88[(d)]	-
		Frequency of daily exceedance of 100µg/m³ (days/year)	**72**	-	44[(e)]	-
		Frequency of daily exceedance of 75µg/m³ (days/year)	**80**	-	9[(f)]	-
		Frequency of daily exceedance of 50µg/m³ (days/year)	**115**	-	-	35
Vanderbijlpark	Sulphur Dioxide	Calculated 10-minute average	**1145**	500	500	-
		Highest hourly average [(a)]	**800**	350	350	350
		Highest daily average [(b)]	85	125	125	125
		Annual average	25	50	50	50
		Frequency of hourly exceedance of 350µg/m³ (hours/year)	8	-	88[(c)],44[(d)],9[(e)]	24
		Frequency of daily exceedance of 125µg/m³ (days/year)	0	-	4[(c)],2[(d)],1[(e)]	3
	Nitrogen Dioxide	Highest hourly average [(a)]	**488**	376	200	200
		Highest daily average [(b)]	36	188	-	-
		Annual average	8	94	40	40
		Frequency of hourly exceedance of 376µg/m³ (hours/year)	0	-	0[(c)]	-
		Frequency of hourly exceedance of 288µg/m³ (hours/year)	1	-	88[(d)]	-
		Frequency of hourly exceedance of 244µg/m³ (hours/year)	2	-	44[(e)]	-
		Frequency of hourly exceedance of 200µg/m³ (hours/year)	7	-	9[(f)]	18
	Inhalable Particulate Matter	Highest daily average [(b)]	**1095**	180	75	50
		Annual average	**180**	60	40	40
		Frequency of daily exceedance of 180µg/m³ (days/year)	**50**	-	0[(c)]	-
		Frequency of daily exceedance of 127µg/m³ (days/year)	88	-	88[(d)]	-
		Frequency of daily exceedance of 100µg/m³ (days/year)	**90**	-	44[(e)]	-
		Frequency of daily exceedance of 75µg/m³ (days/year)	**115**	-	9[(f)]	-
		Frequency of daily exceedance of 50µg/m³ (days/year)	**150**	-	-	35

Sensitive Receptor	Pollutant	Averaging period	Predicted Maximum Concentrations (µg/m³)/ No. of exceedances	Current SA Standards (µg/m³)	SANS Limits (proposed SA standards) (µg/m³) / proposed frequency of exceedance	EC Limits (µg/m³) / allowable frequency of exceedance
Sasolburg	Sulphur Dioxide	Calculated 10-minute average	**1545**	500	500	-
		Highest hourly average [(a)]	**1080**	350	350	350
		Highest daily average [(b)]	80	125	125	125
		Annual average	18	50	50	50
		Frequency of hourly exceedance of 350µg/m³ (hours/year)	10	-	88[(c)],44[(d)],9[(e)]	24
		Frequency of daily exceedance of 125µg/m³ (days/year)	0	-	4[(c)],2[(d)],1[(e)]	3
	Nitrogen Dioxide	Highest hourly average [(a)]	280	376	200	200
		Highest daily average [(b)]	32	188	-	-
		Annual average	6.5	94	40	40
		Frequency of hourly exceedance of 376µg/m³ (hours/year)	0	-	0[(c)]	-
		Frequency of hourly exceedance of 288µg/m³ (hours/year)	0	-	88[(d)]	-
		Frequency of hourly exceedance of 244µg/m³ (hours/year)	1	-	44[(e)]	-
		Frequency of hourly exceedance of 200µg/m³ (hours/year)	2	-	9[(f)]	18
	Inhalable Particulate Matter	Highest daily average [(b)]	**800**	180	75	50
		Annual average	**200**	60	40	40
		Frequency of daily exceedance of 180µg/m³ (days/year)	**80**	-	0[(c)]	-
		Frequency of daily exceedance of 127µg/m³ (days/year)	**120**	-	88[(d)]	-
		Frequency of daily exceedance of 100µg/m³ (days/year)	**122**	-	44[(e)]	-
		Frequency of daily exceedance of 75µg/m³ (days/year)	**150**	-	9[(f)]	-
		Frequency of daily exceedance of 50µg/m³ (days/year)	**180**	-	-	35

(a) 99.99th percentile
(b) 99.7th percentile
(c) Air Quality Act, Schedule 2, to be complied by immediately (as provided in the draft document on 24 October 2007). It should be noted that this document has not been finalised.
(d) National Ambient Air Quality Standard – interim level 1, to be complied by 2012 (as provided in the draft document on 24 October 2007). It should be noted that this document has not been finalised.

(e) National Ambient Air Quality Standard – interim level 2, to be complied by 2017 (as provided in the draft document on 24 October 2007). It should be noted that this document has not been finalised.
(f) National Ambient Air Quality Standard, to be complied by 2022 (as provided in the draft document on 24 October 2007). It should be noted that this document has not been finalised.
(g) Highest concentrations within Johannesburg within the study area.
(h) Exceedances of all relevant guidelines are provided in bold.

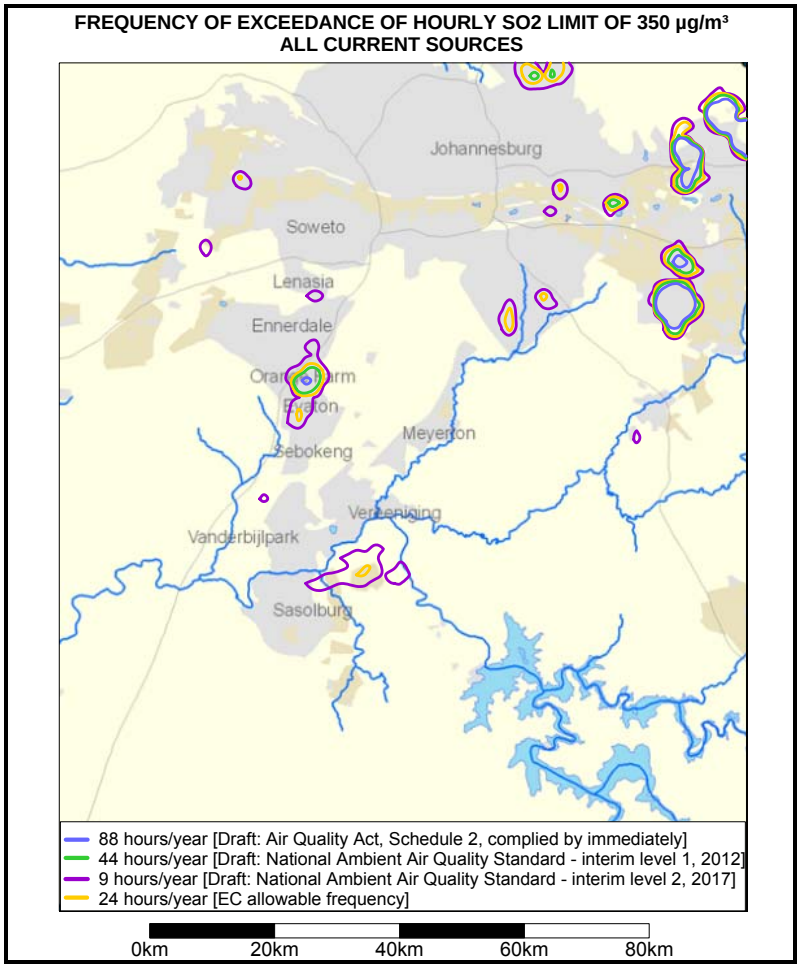


Figure 7-21: Hourly predicted exceedance of the SA standards for sulphur dioxide of 350 µg/m³ within the study area.

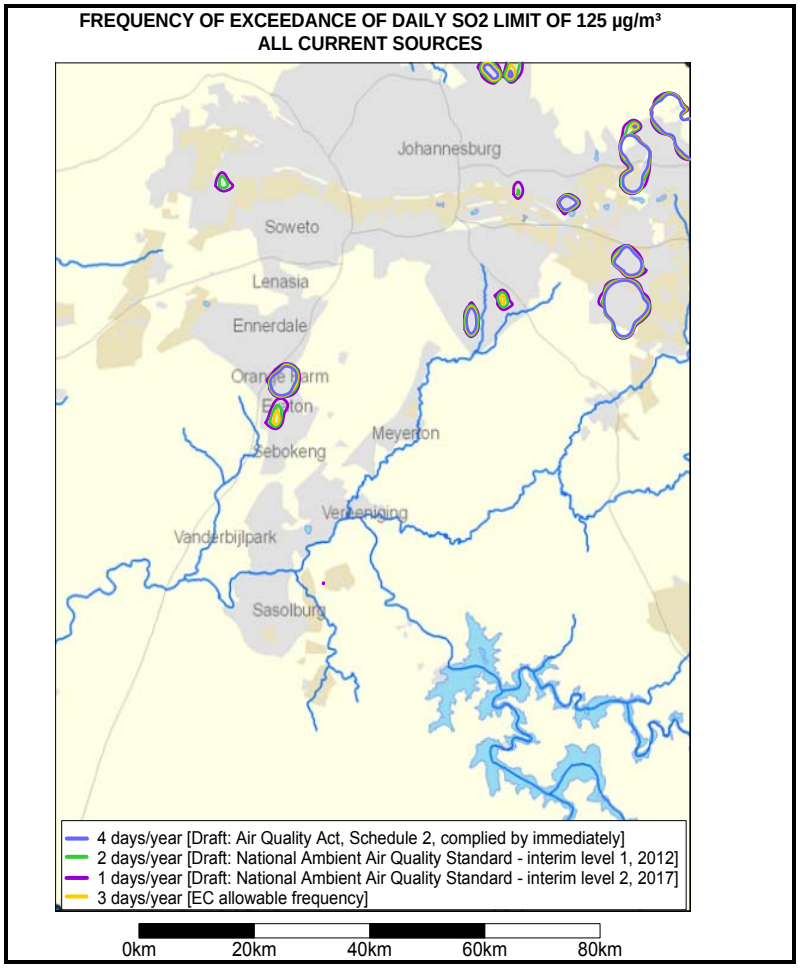


Figure 7-22: Daily predicted exceedance of the SA standards for sulphur dioxide of 125 µg/m³ within the study area.

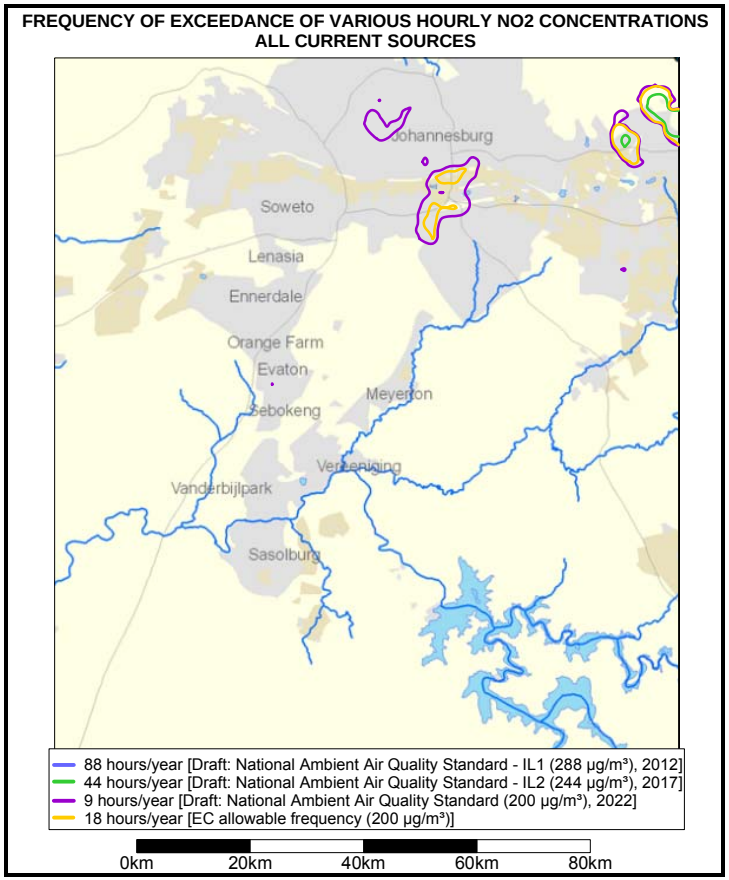


Figure 7-23: Hourly exceedance of various relevant standards/limits for nitrogen dioxide concentrations within the study area.

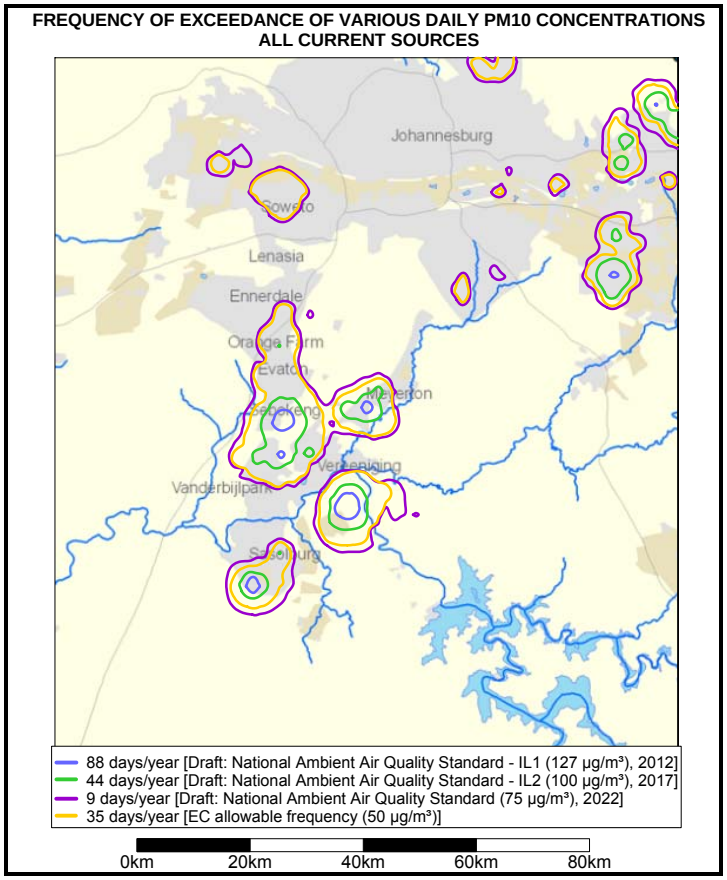


Figure 7-24: Daily exceedance of of various relevant standards/limits for inhalable particulate concentrations within the study area.

The main findings are as follows:

- **Sulphur Dioxide** – Sulphur dioxide short-term SA standards, SANS limits and EC limits are significantly exceeded due to current emitting sources in terms of the magnitude. However, when allowable frequency of exceedance is assessed, areas of Johannesburg, Orange Farm and Evaton are predicted to exceed the EC allowable hourly and daily frequency of 24 and 3 respectively as well as the proposed National Ambient Air Quality Standard allowable hourly and daily frequency of 9 and 1 respectively (as provided in the draft document (for discussion purposes only) on 24 October 2007).

- **Nitrogen dioxide** - Ambient hourly nitrogen dioxide SA standard, SANS limit and EC limit exceedances occur mainly over the built up areas of the Vaal Airshed (numbers of hourly exceedances over the Vaal Airshed, however, are within the limit permitted by the EC and proposed National Ambient SA Air Quality Standards (draft document on 24 October 2007) of 18 times and 9 times per year respectively (Figure 7-23)).

- **Inhalable particulates** – Ambient inhalable particulate daily SA standards, SANS limits and EC limits are significantly exceeded due to current emitting sources in terms of the magnitude, frequency and spatial extent of exceedance (Figure 7-24).

The main conclusion reached is that ***current baseline emissions are associated with significant non-compliance with relevant ambient inhalable particulate matter target levels***. Ambient short-term sulphur dioxide concentrations exceed the hourly target levels over large areas of the Vaal Airshed. The occurrences of these hourly exceedances are however, generally within the limit permitted by the EC and proposed National Ambient SA Air Quality Standards (draft document on 24 October 2007) with the exception of Johannesburg, Orange Farm and Evaton. Ambient nitrogen dioxide concentrations exceed the hourly target levels over the built up areas of the Vaal Airshed. The occurrences of these hourly exceedances are however, generally infrequent (within the limit permitted by the EC and proposed National Ambient SA Air Quality Standards (draft document on 24 October 2007) of 18 and 9 times per year respectively).

7.4 Priority Areas

Priority areas are identified based on the predicted ambient air concentrations from the priority pollutants and exposure potential.

The prioritisation of sources is ranked on the basis of impacts rather than the extent of their emissions. This ensures that the main contributing sources resulting in non-compliance with the Vaal Airshed ambient air quality targets and hence pose the greatest risk to human health and the environment, be addressed as priority. In addition, this will clearly define the problems within the area.

7.4.1 Exposure Potential of Predicted Ambient Air Concentrations

In order to determine the significance of the areas where the ambient air quality standards or Vaal Airshed ambient air quality objectives are exceeded, the predicted contours were superimposed onto the population density (based on 2001 Census). A synopsis of the findings of this analysis is presented in Table 7-8 for inhalable particulate matter, sulphur dioxide and nitrogen dioxide.

Table 7-8: Number of people residing in non-compliance [(a)] areas within Vaal Airshed exposed to sulphur dioxide, inhalable particulate and nitrogen dioxide concentrations.

Source Group	No. of Persons Residing within Vaal Airshed Predicted to Exceed the SANS limits (assessing the limits in conjunction with the proposed National Ambient Air Quality Standards, draft document 24 October 2007 [(b)])			
	9 exceedances of the SO_2 hourly 350 µg/m³ Limit	Single exceedance of SO_2 daily 125 µg/m³ Limit	9 exceedances of the NO_2 hourly 200 µg/m³ Limit	9 exceedances of PM10 daily 75 µg/m³ Limit
All quantifiable sources	52 936	3 930	0	860 584

(a) With accordance to the SANS limits (proposed SA standards)
(b) The draft document drafted on the 24 October 2004 was for discussion purposes only.

More than 860 000 people are currently exposed to more than 9 exceedances of the proposed inhalable particulate SA standards of 75 µg/m³. A total of ~53 000 people are exposed to more than 9 hourly SO_2 exceedances of the SA standard of 350 µg/m³ and ~4 000 people are exposed to more than a single daily exceedance of the SA sulphur dioxide standard of 125 µg/m³. Less than 9 hourly exceedances of the proposed SA nitrogen dioxide standards are currently predicted over the Vaal Airshed.

7.4.2 "Hot Spot" Areas

Although ambient monitoring data indicated the pollutants of concern and the ambient concentrations associated with these pollutants, monitoring stations are single points reflecting a specific geographic location. Dispersion modelling on the other hand is a useful tool in determining the zones of impact and the magnitude of the impact zone.

From predicted ground level concentrations through dispersion modelling, verified with ambient monitored data, the main pollutant of concern within the Vaal Airshed is inhalable particulates. Six priority areas were identified within the Vaal Airshed based on highest inhalable particulate concentration zones or "hotspots" (Figure 7-25). The areas were also

selected to correspond with impact zones due to acute exposures to sulphur dioxide and nitrogen dioxide.

The sensitive receptors together with the emissions sources and main pollutants of concern are provided in Table 7-9 for each of the identified priority zones.

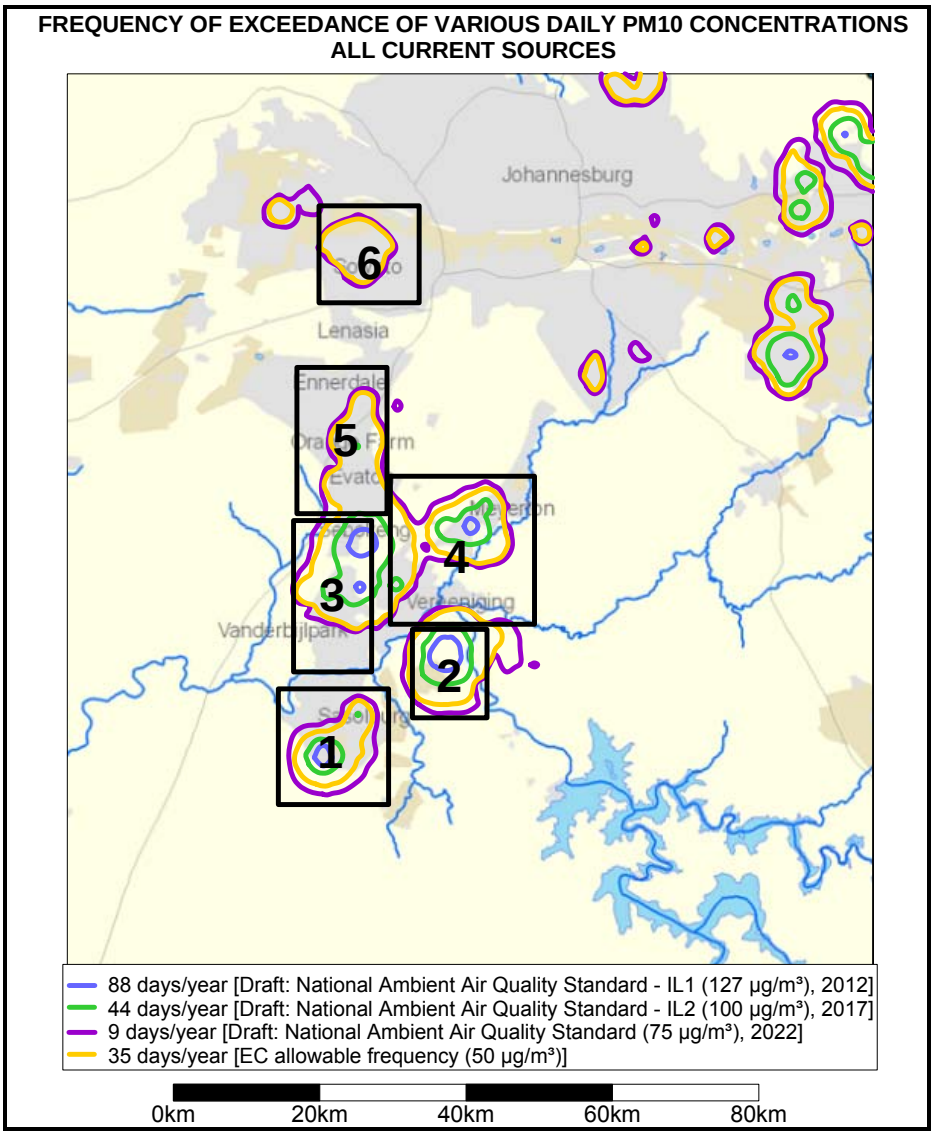


Figure 7-25: Six priority "hotspot" areas identified within the Vaal Airshed based on predicted inhalable particulate ground level concentrations.

Table 7-9: Priority "hotspot" zones within the Vaal Airshed indicating the sensitive receptors and the main contributing sources.

Hotspot Zone	Sensitive Receptors within Zone	Emission Sources within the Zone	Additional sources not quantified and included	Pollutants of concern	Figure indicating Hotspot Zone
1	Residential areas of Sasolburg, Zamdela and Coalbrook	Industrial activities (viz. Sasol, Omnia and Natref), mining activities (viz. Sigma Colliery) and domestic fuel burning	Agricultural activities and biomass burning	PM10, SO_2 NO_2, H_2S and VOCs	Figure 7-26
2	Located just south of the residential area of Vereeniging – no residential areas included in this zone but potential for environmental impacts	Mining activities (viz. New Vaal Colliery), power generation (viz. Lethabo Power Station) and other industrial activities	Agricultural activities and water treatment works which may result in odour impacts	PM10, SO_2, and NO_2.	Figure 7-27
3	Residential areas of Vanderbijlpark and Sebokeng	Industrial activities (viz. Iron and Steel process (ArcelorMittal and Davesteel), commercial boilers and other smaller industrial activities), and domestic fuel burning	Industrial activities just north of ArcelorMittal (viz. a ceramics manufacturing facility, a brickworks and a quarry), water treatment works, biomass burning and agricultural activities	PM10, SO_2, NO_2, odours, Ozone and VOCs	Figure 7-28
4	Residential areas of Vereeniging and Meyerton	Industrial activities (viz. ArcelorMittal Vaal Works, ArcelorMittal Klip Works, Metalloys, commercial boilers, and other small industrial activities) and domestic fuel burning	Agricultural activities and large areas of biomass burning	PM10, SO_2 NO_2, Ozone and VOCs	Figure 7-29
5	Residential areas of Orange Farm, Evaton and Ennerdale	Domestic fuel burning	Large areas of biomass burning	PM10, SO_2 NO_2 and VOCs	Figure 7-30
6	Residential area of Soweto	Domestic fuel burning	Wind blown dust from gold tailings dams	PM10, SO_2, NO_2 and VOCs	Figure 7-31

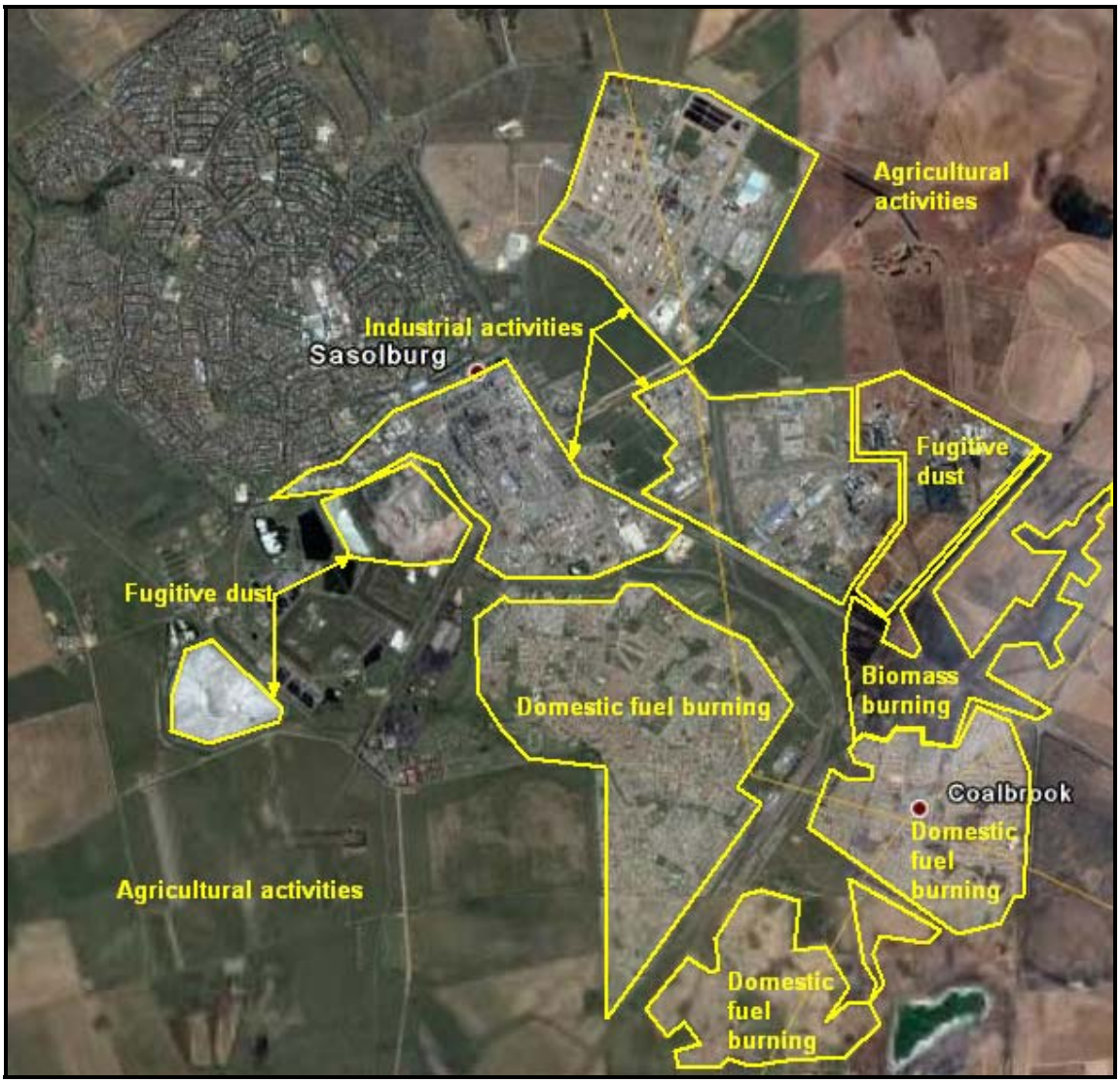


Figure 7-26: Sources of potential emissions within the identified priority "hotspot" zone 1 (including sensitive receptors of Sasolburg, Coalbrook and Zamdela) within the Vaal Airshed.

Figure 7-27: Sources of potential emissions within the identified priority "hotspot" zone 2 within the Vaal Airshed.

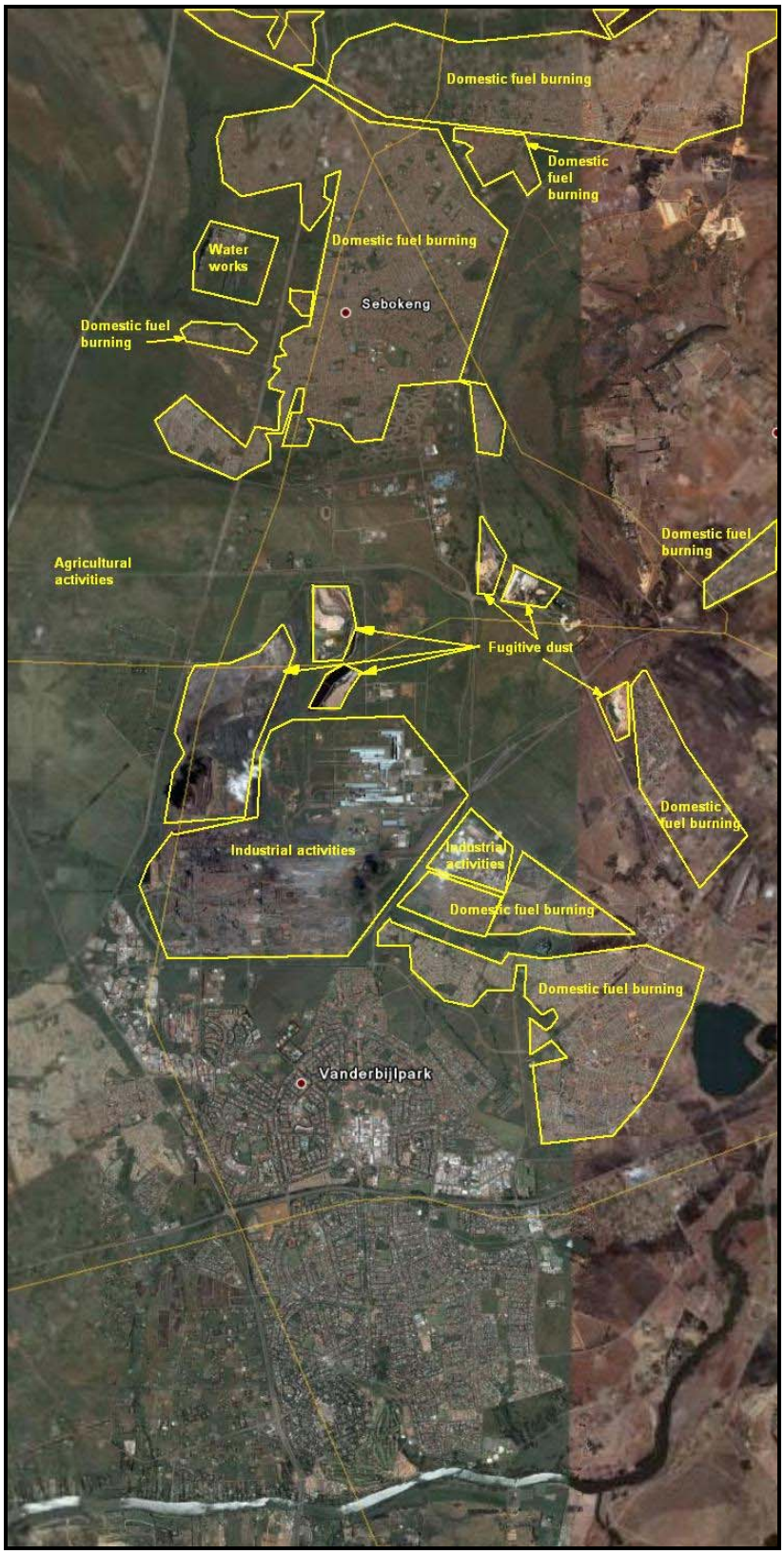


Figure 7-28: Sources of potential emissions within the identified priority "hotspot" zone 3 (including sensitive receptors of Vanderbijlpark and Sebokeng) within the Vaal Airshed.

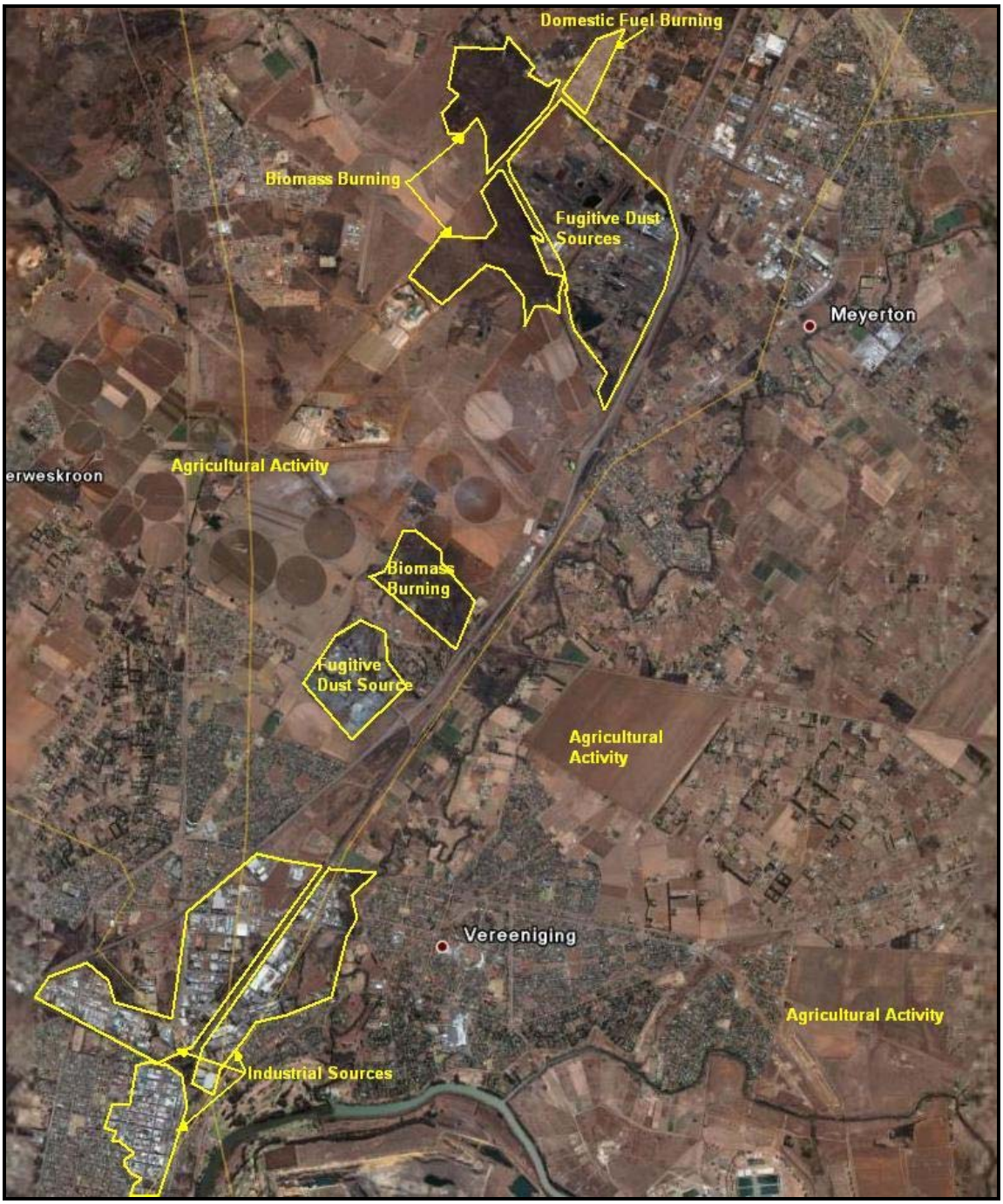


Figure 7-29: Sources of potential emissions within the identified priority "hotspot" zone 4 (including sensitive receptors of Vereeniging and Meyerton) within the Vaal Airshed.

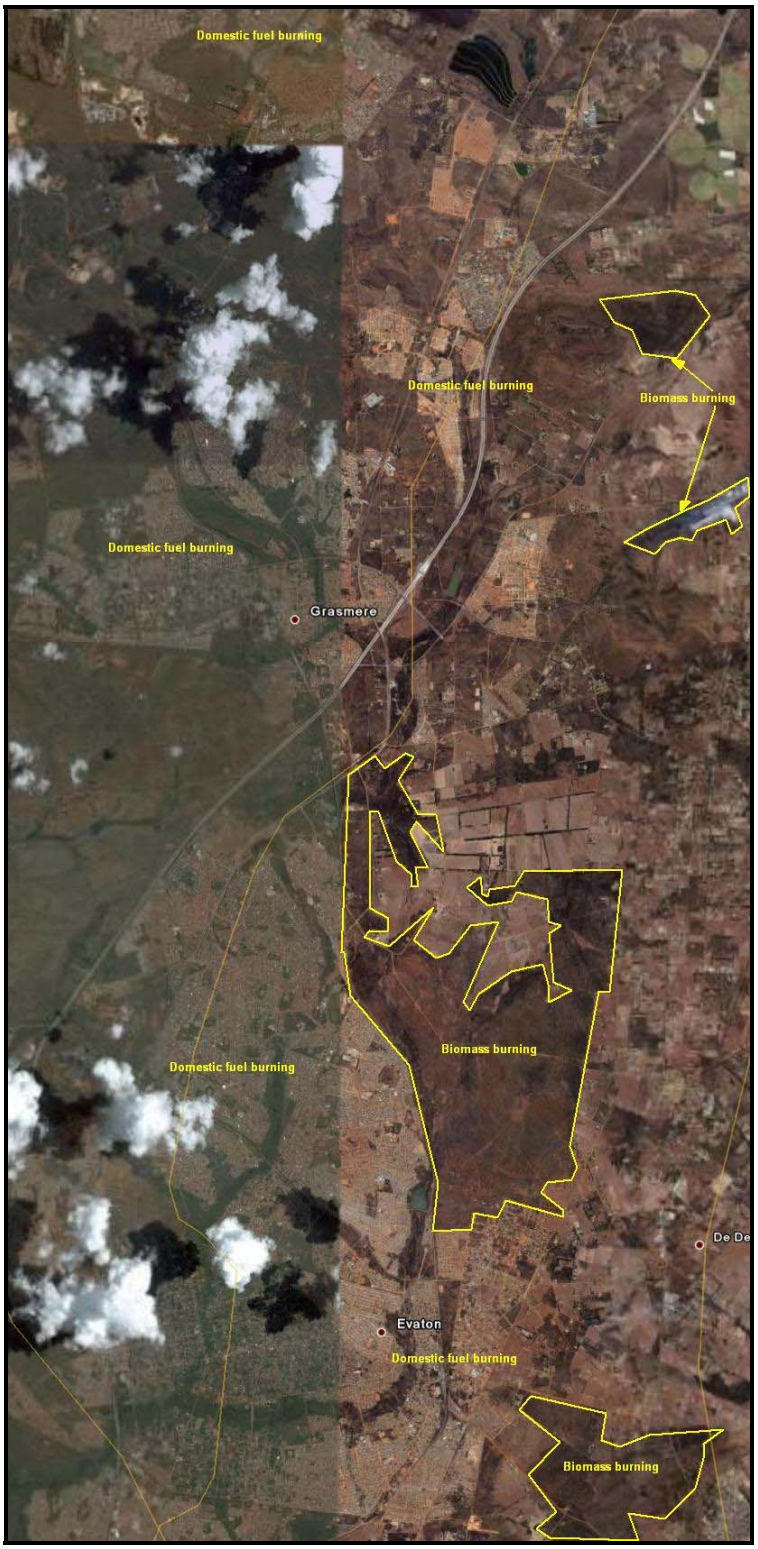


Figure 7-30: Sources of potential emissions within the identified priority "hotspot" zone 5 (including sensitive receptors of Orange Farm, Evaton and Ennerdale) within the Vaal Airshed.

Figure 7-31: Sources of potential emissions within the identified priority "hotspot" zone 6 (including the sensitive receptor of Soweto) within the Vaal Airshed.

The contributing emission sources as well as the long-term ground level concentrations per priority "hotspot" zone have been identified and are provided in Figure 7-33 to Figure 7-38. In order to assess the predicted ground level concentration contributions within the area, a number of discreet receptors within the zones were assessed (see Figure 7-32). The sources identified as contributing to ambient air quality consists of industrial activities, mining activities, domestic fuel burning and vehicle activities. It should be noted that the particulate emissions from Sasol were provided as total suspended particulates from their stack sources and as a conservative approach the total suspended particulates were assessed as inhalable particulate fraction.

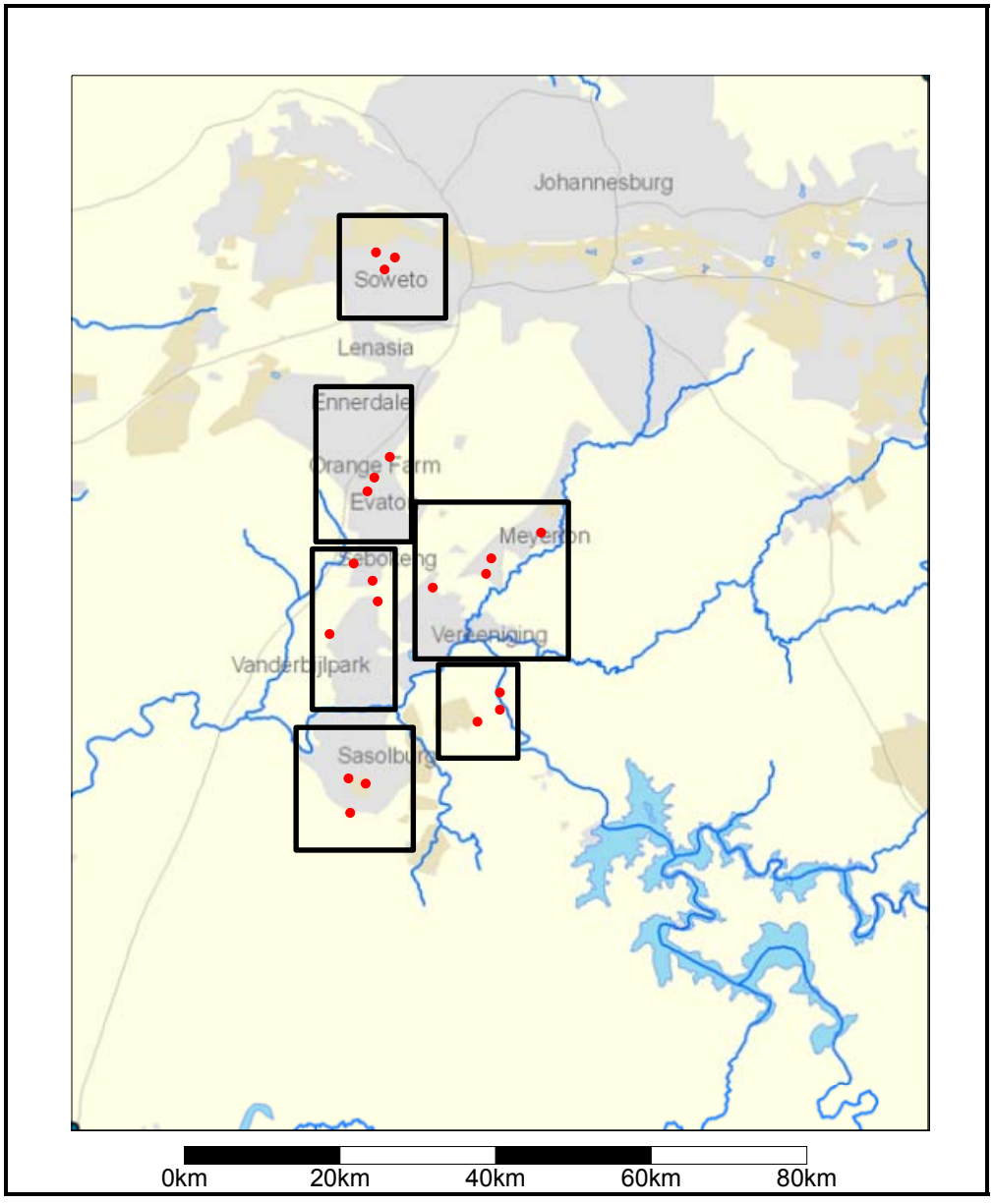


Figure 7-32: Receptors assessed for the long-term ground level concentrations

7.4.2.1 "Hot Spot" Zone 1 (Sasolburg, Coalbrook, Zamdela)

At priority "hotspot" zone 1 the main sources of emissions are petrochemical processes. For sulphur dioxide and oxides of nitrogen petrochemical processes contribute more than 90% of the emissions. For inhalable particulate emissions within the area, petrochemical processes contribute 70% and mining activities 18%. The main contributors of sulphur dioxide and nitrogen dioxide ground level concentrations in ranking order is a combination of petrochemical processes, power generation, iron and steel processes and domestic fuel burning. For inhalable particulate impacts the main contributing source is mining operations (>86%) (Figure 7-33).

7.4.2.2 "Hot Spot" Zone 2 (New Vaal, Eskom Area)

For priority "hotspot" zone 2, emissions are due primarily to power generation and mining activities in terms of inhalable particulates. Annual average ground level concentrations for sulphur dioxide and nitrogen dioxide are mainly from a combination of iron and steel processes, power generation, petrochemical processes and domestic fuel burning. Inhalable particulate ground level concentrations occur mainly due to small industries, fertilizer processes and mining activities (Figure 7-34).

7.4.2.3 "Hot Spot" Zone 3 (Vanderbijlpark, Sebokeng)

Priority "hotspot" zone 3 is situated in an area of elevated industrial activity. The main sources of emissions are from iron and steel processes (contributing more than 78% of sulphur dioxide, oxides of nitrogen and inhalable particulate matter) and vehicle activity (contributing 20% of inhalable particulates). For sulphur dioxide and nitrogen dioxide ground level concentrations, the main contributing sources in ranked order are iron and steel processes and then a combination of power generation, petrochemical processes and domestic fuel burning. For inhalable particulates, the main sources of annual ground level concentrations are iron and steel processes (50%) and other smaller industrial activities (45%) (Figure 7-35).

7.4.2.4 "Hot Spot" Zone 4 (Vereeniging, Meyerton)

The main sources of emissions within the priority "hotspot" zone 4 are vehicles to the contribution of sulphur dioxide and nitrogen dioxide. For inhalable particulate emissions the main contributing sources consist of smaller industrial activities (49%) and ferroalloy processes (39%). Nitrogen dioxide and sulphur dioxide annual ground level concentrations are due mainly to iron and steel processes with a combination of petrochemical processes, power generation, domestic fuel burning and vehicle activity (for oxides of nitrogen only)

contributing to a lesser extent. The inhalable particulate impacts are due mainly to (in ranking order); smaller industrial activities, ferroalloy processes, iron and steel processes and mining activities (Figure 7-36).

7.4.2.5 "Hot Spot" Zone 5 (Orange Farm, Evaton, Ennerdale)

Priority "hotspot" zone 5 consists of a lower income population group with the main source of inhalable particulate and sulphur dioxide emissions being domestic fuel burning. Vehicle tailpipe emissions contribute <70% of the nitrogen dioxide emissions in the area. The main source of long-term ground level concentrations are from domestic fuel burning for sulphur dioxide and inhalable particulates (>90%). Nitrogen dioxide ground level concentrations are made up of domestic fuel burning (58%), and to a lesser extent iron and steel processes (21%), power generation (9%), petrochemical processes (7%) and vehicle exhaust (5%) (Figure 7-37).

7.4.2.6 "Hot Spot" Zone 6 (Soweto)

Priority "hotspot" zone 6 is situated in an area of domestic fuel burning and vehicle activity. Long-term ground level concentrations are therefore mainly due to domestic fuel burning contributing >87% for sulphur dioxide and inhalable particulates and 32% for nitrogen dioxide. Other sources contributing to annual ground level concentrations are vehicle activity (59% for nitrogen dioxide and 10% for inhalable particulates) (Figure 7-38).

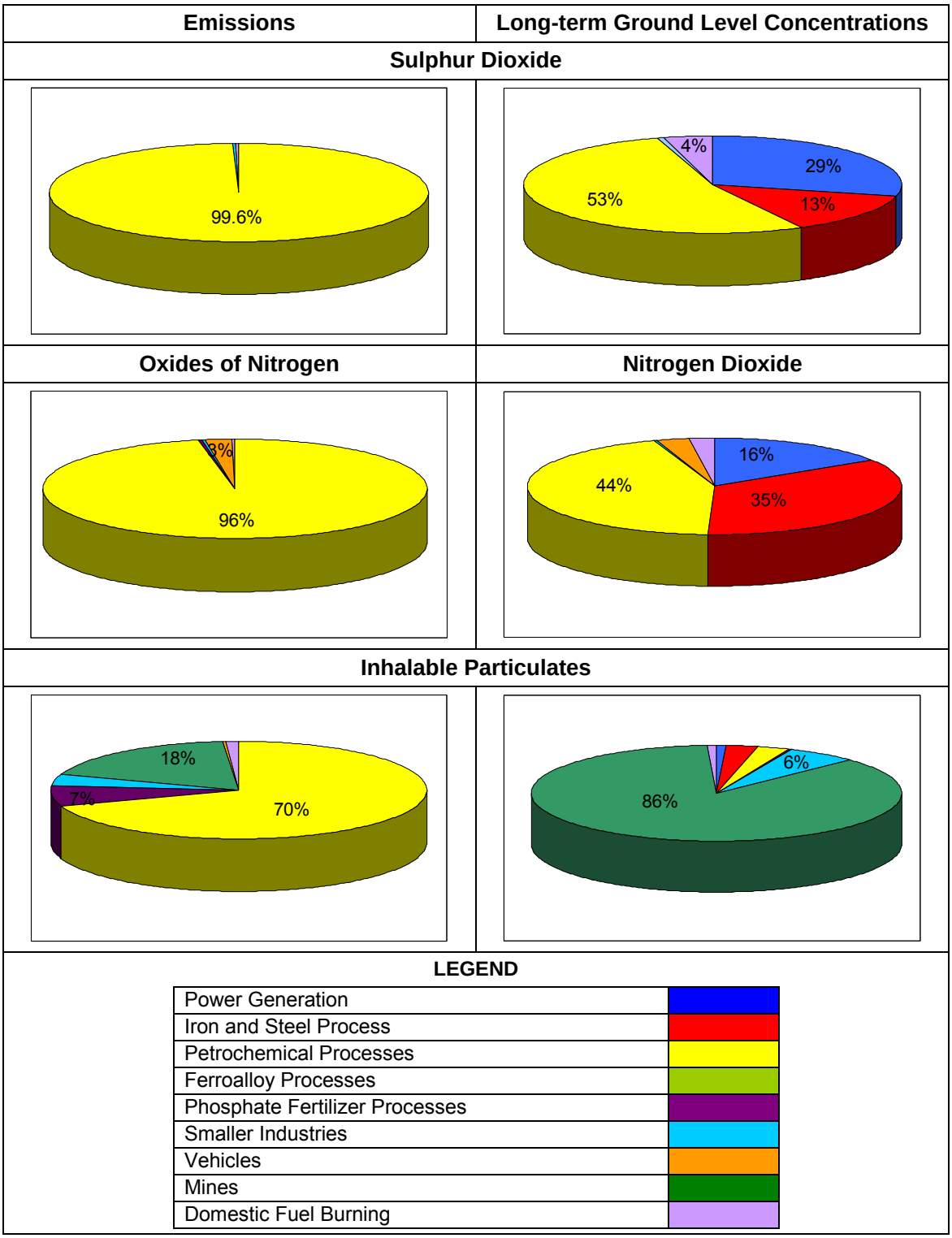
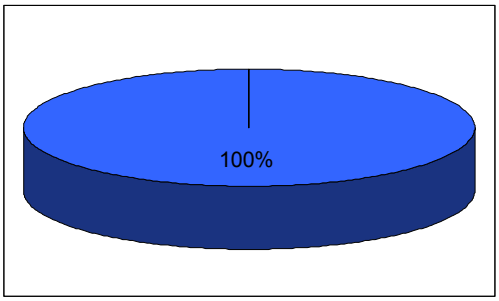
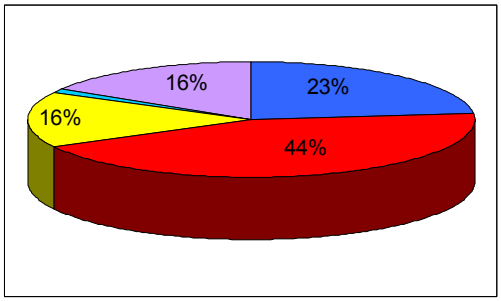
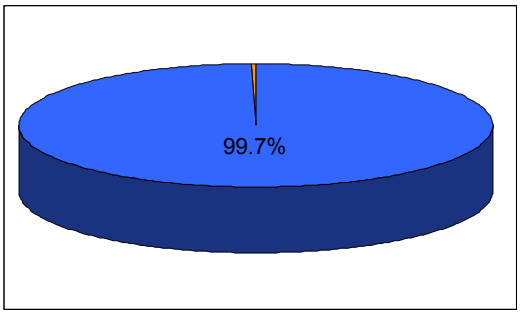
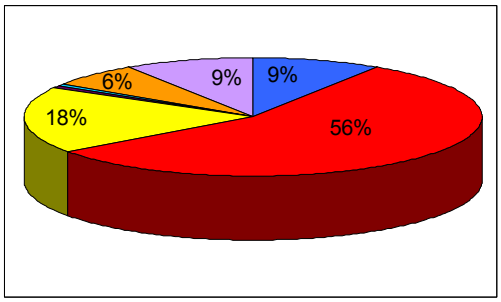
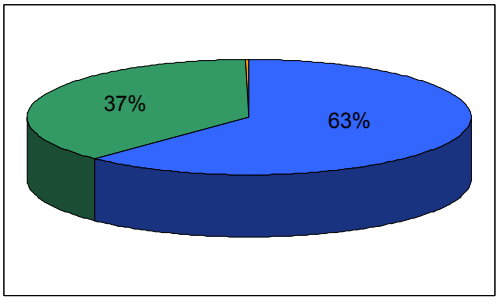
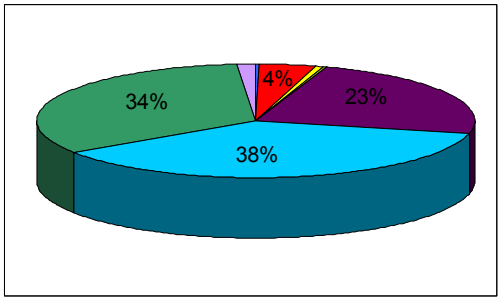


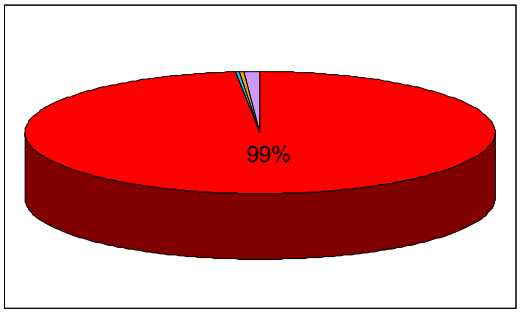
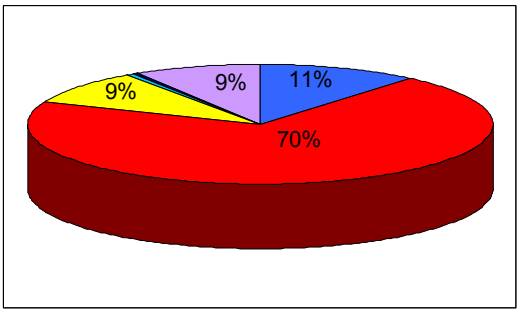
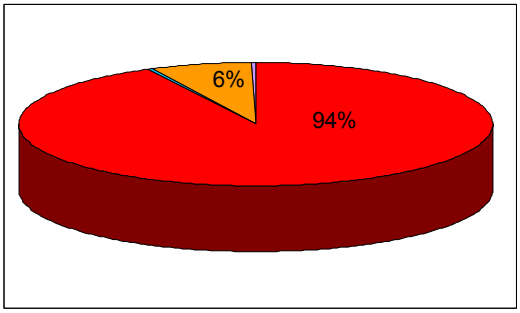
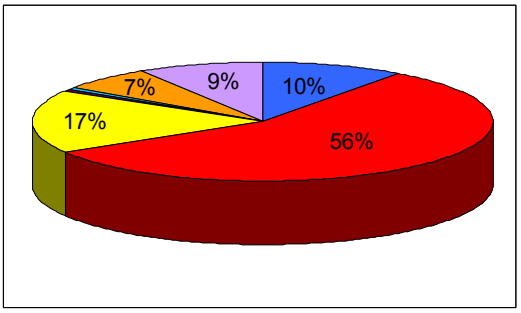
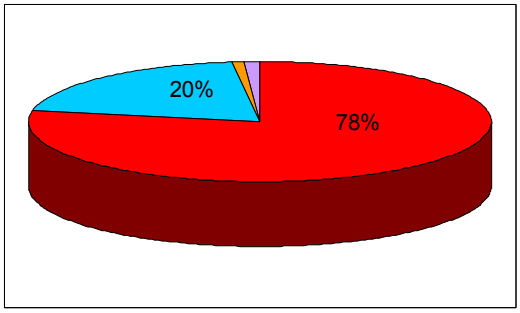
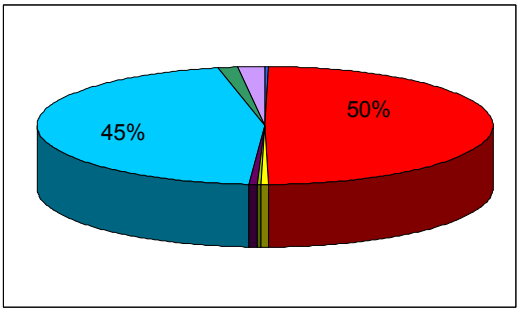
Figure 7-33: Predicted source contributions to total annual sulphur dioxide, nitrogen dioxide and inhalable particulate emissions and concentrations at various impact contribution for identified priority "hotspot" zone 1 (including sensitive receptors of Sasolburg, Coalbrook and Zamdela) within the Vaal Airshed.

Emissions	Long-term Ground Level Concentrations
Sulphur Dioxide	
	
Oxides of Nitrogen	**Nitrogen Dioxide**
	
Inhalable Particulates	
	

LEGEND

Power Generation	
Iron and Steel Process	
Petrochemical Processes	
Ferroalloy Processes	
Phosphate Fertilizer Processes	
Smaller Industries	
Vehicles	
Mines	
Domestic Fuel Burning	

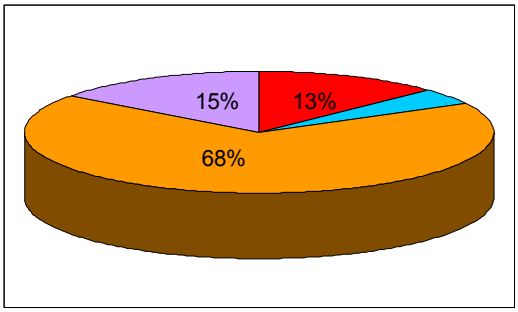
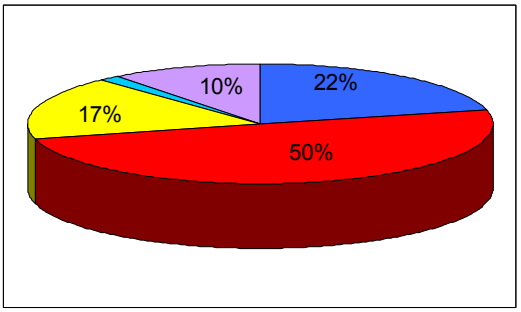
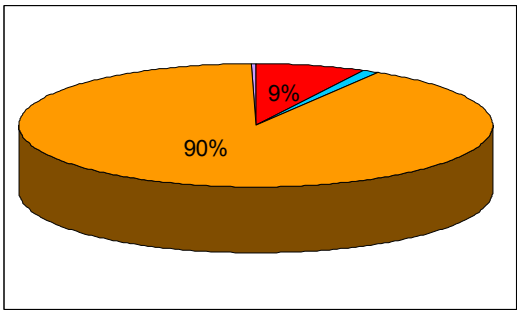
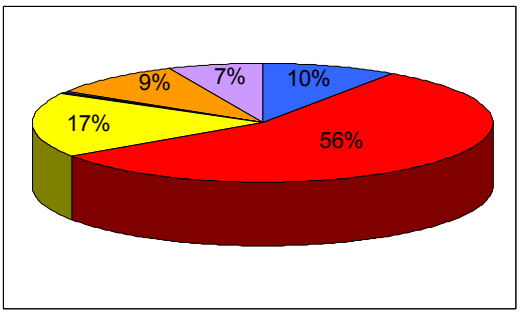
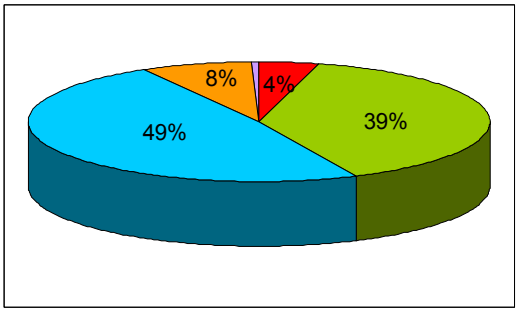
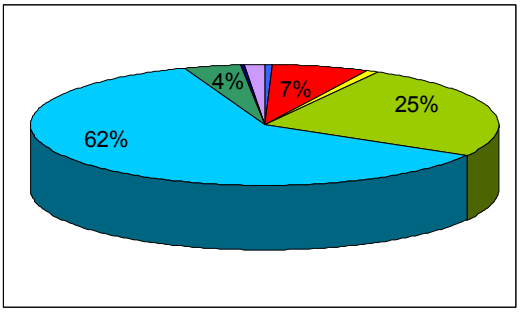
Figure 7-34: Predicted source contributions to total annual sulphur dioxide, nitrogen dioxide and inhalable particulate emissions and concentrations at various impact contribution for identified priority “hotspot” zone 2 within the Vaal Airshed.

Emissions	Long-term Ground Level Concentrations
Sulphur Dioxide	
	
Oxides of Nitrogen	**Nitrogen Dioxide**
	
Inhalable Particulates	
	

LEGEND

Power Generation	
Iron and Steel Process	
Petrochemical Processes	
Ferroalloy Processes	
Phosphate Fertilizer Processes	
Smaller Industries	
Vehicles	
Mines	
Domestic Fuel Burning	

Figure 7-35: Predicted source contributions to total annual sulphur dioxide, nitrogen dioxide and inhalable particulate emissions and concentrations at various impact contribution for identified priority "hotspot" zone 3 (including sensitive receptors of Vanderbijlpark and Sebokeng) within the Vaal Airshed.

Emissions	Long-term Ground Level Concentrations
Sulphur Dioxide	
	
Oxides of Nitrogen	**Nitrogen Dioxide**
	
Inhalable Particulates	
	

LEGEND

Power Generation	
Iron and Steel Process	
Petrochemical Processes	
Ferroalloy Processes	
Phosphate Fertilizer Processes	
Smaller Industries	
Vehicles	
Mines	
Domestic Fuel Burning	

Figure 7-36: Predicted source contributions to total annual sulphur dioxide, nitrogen dioxide and inhalable particulate emissions and concentrations at various impact contribution for identified priority "hotspot" zone 4 (including sensitive receptors of Vereeninging and Meyerton) within the Vaal Airshed.

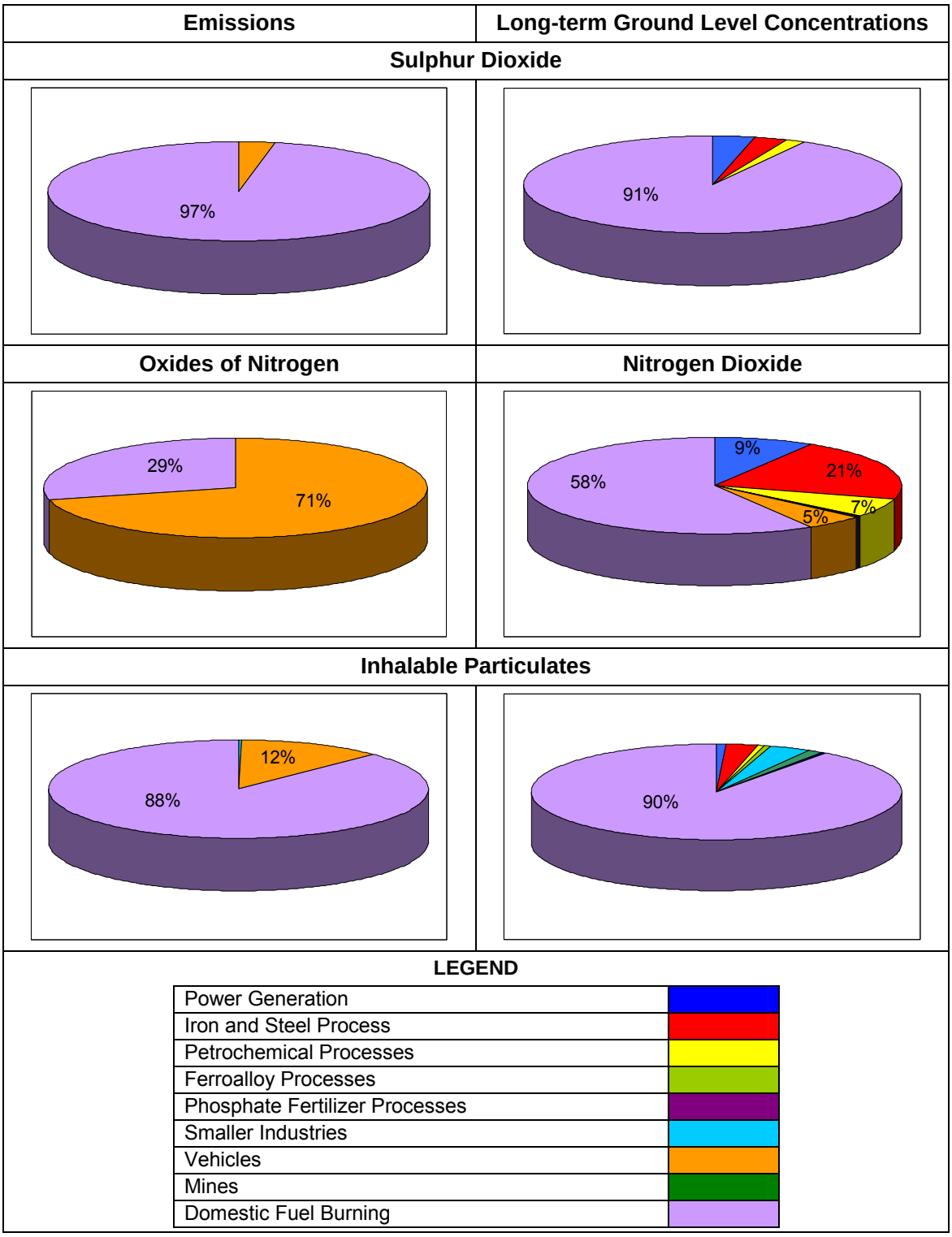


Figure 7-37: Predicted source contributions to total annual sulphur dioxide, nitrogen dioxide and inhalable particulate emissions and concentrations at various impact contribution for identified priority "hotspot" zone 5 (including sensitive receptors of Orange Farm, Evaton and Ennerdale) within the Vaal Airshed.

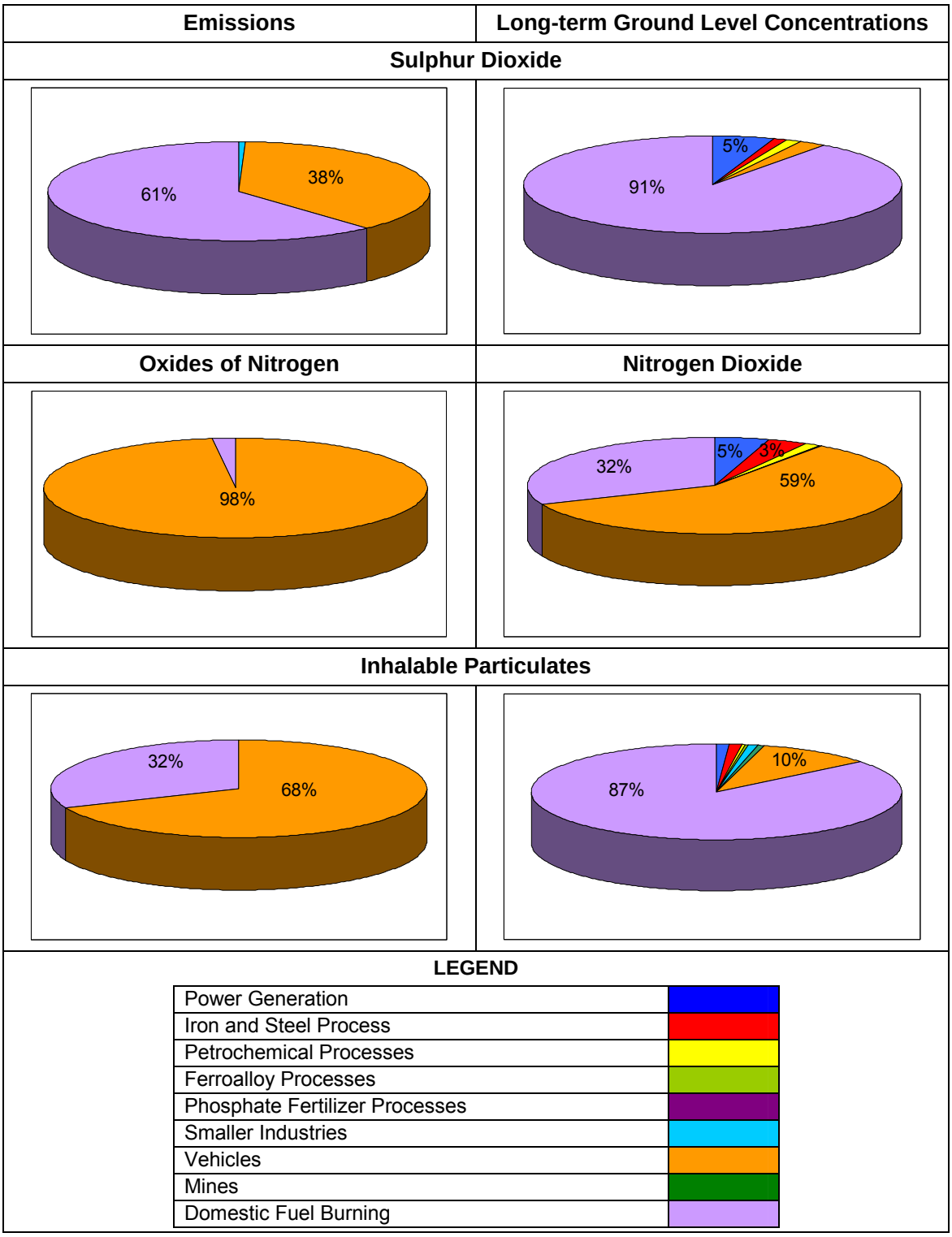


Figure 7-38: Predicted source contributions to total annual sulphur dioxide, nitrogen dioxide and inhalable particulate emissions and concentrations at various impact contribution for identified priority "hotspot" zone 6 (including sensitive receptors of Soweto) within the Vaal Airshed.

CHAPTER 8
CONCLUSIONS

8.1 Priority Pollutants within the Vaal Airshed

Pollutants in South Africa for which health based standards exists include particulate matter (both total suspended particulates and particulates with a diameter of less than 10 micrometer (inhalable particulate matter)), sulphur dioxide, oxides of nitrogen, ozone and lead. The proposed standards include carbon monoxide and benzene.

Based on the available monitoring data, the major findings of the air quality assessment indicate that:

- Particulate concentrations are elevated over most areas of the Vaal Triangle, particularly in residential areas where domestic fuel burning occurs and areas neighbouring major industrial operations.
- Sulphur dioxide concentrations are reduced in both the residential and industrial monitoring stations, although exceedances were recorded on several occasions at Jabavu, Orange Farm and in Sasolburg.
- Nitrogen dioxide concentrations are low in the Vaal Triangle, although a seasonal signature is observed in nitrogen dioxide concentrations. Nitrogen dioxide concentrations have a regional impact within the Vaal Triangle.
- Carbon monoxide concentrations are not considered to be significant in the Vaal Triangle.
- Ozone concentrations are elevated in areas surrounding major industrial operations with exceedances of the one hour average target recorded on numerous occasions. Ozone concentrations measured at Makalu are representative of known background concentrations in South Africa.

Based on predicted dispersion modelled data, the major findings of the air quality assessment indicate that:

- Sulphur dioxide short-term SA standards, SANS limits and EC limits are significantly exceeded due to current emitting sources in terms of the magnitude. However, when allowable frequency of exceedance is assessed, areas of Johannesburg, Orange Farm and Evaton are predicted to exceed the EC allowable hourly and daily frequency of 24 and 3 respectively as well as the proposed National Ambient Air Quality Standard allowable hourly and daily frequency of 9 and 1 respectively (as provided in the draft document (for discussion purposes only) on 24 October 2007).

- Ambient hourly nitrogen dioxide SA standard, SANS limit and EC limit exceedances occur mainly over the built up areas of the Vaal Airshed (numbers of hourly exceedances over the Vaal Airshed, however, are within the limit permitted by the EC and proposed National Ambient SA Air Quality Standards (draft document on 24 October 2007) of 18 times and 9 times per year respectively (Figure 7-23)).

- Ambient inhalable particulate daily SA standards, SANS limits and EC limits are significantly exceeded due to current emitting sources in terms of the magnitude, frequency and spatial extent of exceedance (Figure 7-24).

The main conclusion reached is that ***current baseline emissions are associated with significant non-compliance with relevant ambient inhalable particulate matter target levels***. Ambient short-term sulphur dioxide concentrations exceed the hourly target levels over large areas of the Vaal Airshed. Although the occurrences of these hourly exceedances are predicted to be within the limit permitted by the EC and proposed National Ambient SA Air Quality Standards (draft document on 24 October 2007) with the exception of Johannesburg, Orange Farm and Evaton, exceedances of the permitted EC limits and proposed SA Standards are measured at the Sasol monitoring stations (viz. 91 hourly and 8 daily exceedances at Boiketlong for the period 2006). Ambient nitrogen dioxide concentrations exceed the hourly target levels over the built up areas of the Vaal Airshed. The occurrences of these hourly exceedances are however, generally infrequent (within the limit permitted by the EC and proposed National Ambient SA Air Quality Standards (draft document on 24 October 2007) of 18 and 9 times per year respectively).

8.2 Priority Sources within the Vaal Airshed

Emission sources within the Vaal Airshed include a wide range of industries; a coal fired power station, household coal and wood combustion, vehicle emissions, filling stations, brickworks, mining operations and other sources such as waste disposal facilities, fugitive dust sources and biomass burning.

All of these sources to a larger and lesser extend contribute to inhalable particulate concentrations, with most of the industrial sources, the domestic fuel burning and vehicle tailpipe emissions contributing to sulphur dioxide and nitrogen dioxide ground level concentrations.

The main source contributions have been identified together with the priority areas and these are reflected in Table 8-1.

Table 8-1: Priority pollutants and their associated contributing sources and main impact areas within the Vaal Airshed.

Pollutant	Discussion
Suspended Particulate Concentrations (in the inhalable fractions)	
Levels (Particulate Matter)	Concentrations of inhalable particulates within domestic coal burning areas are well in excess of health guidelines. Significant health impacts and associated health costs have found to be associated with exposures to this pollutant. Ambient inhalable particulate levels within Soweto and Orange Farm measure frequent exceedances of the SANS limits (proposed SA standards) of 75 µg/m³. Fine particulate concentrations are elevated throughout much of the Vaal Airshed, even areas more remote from heavy industrial and domestic coal burning areas. Exceedances of the SANS limits (proposed SA standards) over the Vaal Airshed occurs on a frequent basis. A large portion of the Vaal Airshed is in non-compliance.
Main impact areas (Particulate Matter)	Domestic fuel burning areas - coincides with un-electrified areas (informal settlements, backyard shacks) and poorer electrified areas in former townships. Areas in close proximity to: large industries (particularly industries with smelting and/or combustion-related emissions), mines and quarries, busy unpaved roads, large exposed soil areas and agricultural activities, and open grass areas which frequently experience fires. Areas noted to be significantly impacted include Vanderbijlpark - particularly the northern suburbs, Bophelong, Boipatong, Sharpville, Vereeninging – particularly the western suburbs, Meyerton, Zamdela, the eastern suburbs of Sasolburg, Soweto and Orange Farm. Elevated throughout the Vaal Airshed even within non-fuel burning residential areas located fair distances from localised sources indicated above.
Sources (Particulate Matter)	Main sources of total airborne particulate concentrations in the fine fraction (<10µm in diameter) in ambient exposure areas - ranked: - Domestic fuel burning (primarily coal and to a lesser extent wood) - Fugitive soil dust including fugitive emissions from vehicle entrainment, industrial operations, wind erosion, mining activities, agricultural activities (etc.) - Industrial operations - particularly large industries undertaking smelting and fuel combustion related processes - Domestic fuel burning within Johannesburg transported into the region - Energy generation (fly ash) - Diesel-driven vehicle tailpipe emissions - Regional aged aerosol component due to pollution from distant sources being transported into the Region's airshed, specifically elevated power generation and industrial emissions located on the highveld and large-scale biomass burning to the north. Main sources of combustion-generated airborne particulate concentrations in the fine fraction (<10µm in diameter) in ambient exposure areas : - Domestic fuel burning - Industrial and energy generation processes Minor, localised and/or episodic sources of total particulates include: - Large-scale construction activities - Wild fires and tyre burning (can be significant contributors to acute exposures) - Spontaneous combustion

Pollutant	Discussion
Sulphur Dioxide	
Levels (Sulphur Dioxide)	Concentrations of sulphur dioxide within domestic coal burning areas are well in excess of health guidelines. Ambient sulphur dioxide levels within Soweto and Orange Farm measure frequent exceedances of the ambient hourly SA standards of 350 µg/m³. Sulphur dioxide concentrations are elevated throughout much of the Vaal Airshed, with ambient measured levels in exceedances of the hourly air quality targets at Soweto, Orange Farm, Sasolburg, and Vanderbijlpark were monitored data was available for analysis. A large portion of the Vaal Airshed is in non-compliance.
Main impact areas (Sulphur Dioxide)	Residential areas within Sasolburg located in close proximity to the Sasolburg industrial area are a key zone of impact. Hourly health target levels have been measured to be exceeded by up to a factor of 6 (hourly concentration of 2109 µg/m³ measured on the 19th of January 11:00 2006 in Orange Farm). Residential areas elsewhere located in close proximity to sulphur dioxide emitting industrial activities or within the impact zone of down-mixed plumes from elevated power station emissions. Such areas include: Zamdela, Three Rivers, Bedworth Park, Vereeniging, Vanderbijlpark and Boipatong. Domestic coal burning areas, and in particular Soweto, Orange Farm and Zamdela.
Sources (Sulphur Dioxide)	The main sources of ambient sulphur dioxide concentrations are likely to be: - industrial operations particularly chemical and petrochemical operations (e.g. Sasol, Natref) and operations with large-scale combustion-related processes (e.g. ArcelorMittal iron and steel plants, Rand Water Board, various brickworks including Ocon Brickworks) - Power generation. (The elevated release of Lethabo Power Station's emission, 275 m, significantly reduces the potential for high near ground sulphur dioxide concentrations. Down-mixing of the plume during turbulent atmospheric conditions does however provide the potential for intermittently increasing the ground level concentrations in certain areas.) Other minor, localised and/or episodic sources include: - Domestic and other (industrial, commercial) fuel burning appliances - Vehicle exhaust emissions, particularly diesel-powered vehicles
Nitrogen Dioxide	
Levels (Nitrogen Dioxide)	Exceedances of the hourly SANS limits (proposed SA standards) of 200 µg/m³ have been measured at the Sasol (AJ Jacobs) and ArcelorMittal (Station 620) monitoring stations. The occurrence of the hourly exceedances is however infrequent with 5 exceedances measured at AJ Jacobs and only 1 at Station 650.
Main impact areas (Nitrogen Dioxide)	Areas of impact are anticipated to be Vanderbijlpark, Boipatong Sebokeng and Orange Farm
Sources (Nitrogen Dioxide)	Primarily: - Vehicle tailpipe emissions - Industrial activities – power generation, petrochemical process, commercial boilers, etc. Other minor, localised and/or episodic sources include: - Domestic and other fuel burning appliances

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APPENDIX A

QUESTIONARE TO QUANTIFY INDUSTRIAL EMISSIONS WITHIN THE VAAL AIRSHED

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Request for Information Cover Letter:

15 December 2006

Dear Sir / Madam
Of: **INDUSTRY NAME**

Re: Request for Information for the Development of the Vaal Triangle Air Shed Priority Area Air Quality Management Plan (AQMP)

The Department of Environmental Affairs and Tourism (DEAT) has appointed Gondwana Environmental Solutions in association with Airshed Planning Professionals and Zitholele Consulting to assist government to develop an air quality management plan for the area known as the Vaal Triangle. The background information document to the project is included herewith.

This letter serves as a request for affected industry to participate in this project and to provide the data as outlined in the attached questionnaire. The scope of work to be undertaken by the consultants for the Department does not include the source quantification of all emissions and therefore great reliance is placed on industry for data that is reflective of their activities. In the event that data is not forwarded by the stipulated dates, available data as per the environmental impact assessment and/or environmental management plan; and the APPA permit conditions will be utilised where available. All data is to be forwarded to **Lerato Mudeme** or **Patricia Mashilo** by the **13th of February 2007.**

Your assistance in the completion of the attached questionnaire is highly appreciated.

Should you have any further queries pertaining to this project; please do not hesitate to contact us.

Kind regards

Hanlie Liebenberg-Enslin

Lerato Mudeme or **Patricia Mashilo**
Airshed Planning Professionals (Pty) Ltd
PO Box 5260, Halfway House, 1685
Tel: 011 805 1950
Fax: 011 805 7010
E-mail: lerato@airshed.co.za or patricia@airshed.co.za

Airshed Planning Professionals

GONDWANA ENVIRONMENTAL SOLUTIONS

ZITHOLELE CONSULTING

QUESTIONNAIRE:

INFORMATION REQUIRED FOR INCORPORATION INTO THE DEVELOPMENT OF AN AQMP FOR THE VAAL TRIANGLE PRIORITY AREA.

A. Facility and Contact Information		
Item ID.	**Aspect**	**Information Required**
A.1	**Name of Firm:**	
A.2	**Physical Address:**	
A.3	**Postal Address:**	
A.4	**Telephone Number:**	
A.5	**Fax Number:**	
A.6	**Name of Safety, Health and Environmental Official:**	
A.7	**Email Address:**	
A.8	**Name of emission control officer:**	
A.9	**Email Address:**	
A.10	**Name of alternate contact person:**	
A.11	**Email Address:**	
A.12	**Website address:**	
A.13	**Industry Type / Nature of Trade:**	
B. Nature of Process		
Item ID.	**Aspect**	**Information Required**
B.1	**Brief description of entire production process including current and approved processes that would be implemented in 2007:**	
B.2	**List of Scheduled Processes conducted at the premises by the industry:**	

	Scheduled process number	*Schedule process description*

C. Raw Material				
Raw Material type	**Maximum permitted Consumption Rate (Volume)**	**Design Consumption Rate**	**Actual Consumption Rate**	**Units (quantity/ period)**

D. Production Rates				
Product Name	**Maximum Production Capacity Permitted (Volume)**	**Design Production Rate (Volume)**	**Actual Consumption Rate (Volume)**	**Units (quantity/ period)**

E. Energy Sources Used						
Energy Source	Sulphur Content of Fuel (%) (if applicable)	Ash Content of Fuel (%) (if applicable)	Maximum Permitted Consumption Rate (Volume)	Design Consumption Rate (Volume)	Actual Consumption Rate (Volume)	Units (quantity/ period)

F. Sources of Atmospheric Emissions PLEASE PROVIDE SOURCE EMISSIONS REPRESENTATIVE OF 2007 OPERATIONS A MAP DEPICTING THE LOCATION OF THE POINT SOURCES IS TO BE PROVIDED								
F.1 POINT source parameters								
Source name	Height of release above ground (m)	Height above nearby building (m)	Nature of pollutants	Concentration of pollutants (mg/Nm^3 (for all listed pollutants	Emission velocity (Nm^3/s)	% Routine[1] or upset[2] emissions	Emission Temperature (K)	Control equipment % efficiency

NOTES: 1. Routine emissions- emissions to atmosphere with control equipment in place 2. Upset emissions- venting directly to atmosphere either during maintenance of equipment or incidental releases.								

F. Sources of Atmospheric Emissions PLEASE PROVIDE SOURCE EMISSIONS REPRESENTATIVE OF 2007 OPERATIONS A MAP DEPICTING THE LOCATION OF THE AREA SOURCES IS TO BE PROVIDED								
F.2 Area[1] source parameters								
Area Source	Pollutant name	Maximum Daily Release Rate (tons/ annum)	Average Annual Release Rate (tons/annum)	Type of emission (Continuous/ intermittent)	Wind dependent (yes/no)	Dimensions (where applicable)		
						Length	Width	Height

NOTES:
1. Area sources include roads and stockpiles

G. Meteorological Monitoring (Please tick where appropriate)					
G.1	Meteorological station:		Yes		No
G.2	Sampling Date Initiation (D/M/Y):				
G.3	Sampling Date Closure (if Applicable):				
G.4	Station Location (provide coordinates and a map)				
G.5	Instrumentation Type:				
G.6	Frequency of full calibration:				
G.7	Parameters measured:				
	Humidity		Yes		No
	Pressure		Yes		No
	Rainfall / Precipitation		Yes		No
	Sigma Theta		Yes		No
	Temperature		Yes		No
	Wind direction		Yes		No
	Wind speed		Yes		No
	Wind velocity		Yes		No
	OTHER - Please Specify				
G.8	In which format is the data available:				
G.9	Consent to use data		Yes		No

H. Monitoring		
H.1	Type of monitoring undertaken: (continuous, passive, dust fallout monitoring)	
H.2	Name of contact person for monitoring activities:	
	Telephone number:	
	Email address:	
H.3 *Ambient continuous monitoring*		
i	Parameter measured:	
ii	Sampling date initiation (D/M/Y):	
iii	Sampling date closure (if applicable):	
iv	Station type:	
v	Station location (please provide coordinates and map):	
vi	Frequency of full calibration:	
vii	Frequency of measurement:	
viii	Format of data:	
i	Parameter measured:	
ii	Sampling date initiation (D/M/Y):	
iii	Sampling date closure (if applicable):	
iv	Station type:	
v	Station location (please provide coordinates and map):	
vi	Frequency of full calibration:	
vii	Frequency of measurement:	
viii	Format of data:	
i	Parameter measured:	
ii	Sampling date initiation (D/M/Y):	

iii	Sampling date closure (if applicable):	
iv	Station type:	
v	Station location (please provide coordinates and map):	
vi	Frequency of full calibration:	
vii	Frequency of measurement:	
viii	Format of data:	
I	Parameter measured:	
ii	Sampling date initiation (D/M/Y):	
iii	Sampling date closure (if applicable):	
iv	Station type:	
v	Station location (please provide coordinates and map):	
vi	Frequency of full calibration:	
vii	Frequency of measurement:	
viii	Format of data:	
	H.4 *Passive Monitoring*	
i	Parameter measured:	
ii	Sampling date initiation (D/M/Y):	
iii	Sampling date closure (if applicable):	
iv	Sampling location (please provide coordinates and map):	
v	Sampling averaging period in which data is presented:	
	H.5 *Dust fallout monitoring*	
i	Methodology utilised:	
ii	Number of sampling points:	
iii	Location of sampling points: (please provide coordinates and map)	
	H.6 Emissions monitoring/ continuous *monitoring*	
i	Methodology utilised:	
ii	Number of sampling points:	
iii	Location of sampling points: (please provide coordinates and map)	

Thank you for your invaluable contribution to this study.

Airshed Planning Professionals

GONDWANA ENVIRONMENTAL SOLUTIONS

ZITHOLELE CONSULTING

Follow up letter:

environment & tourism

Department:
Environmental Affairs and Tourism
REPUBLIC OF SOUTH AFRICA

26 April 2007

Dear Sir / Madam
Of: **INDUSTRY NAME**

Re: Request for Information for the Development of the Vaal Triangle Air Shed Priority Area Air Quality Management Plan (AQMP)

The Department of Environmental Affairs and Tourism (DEAT) has appointed Gondwana Environmental Solutions in association with Airshed Planning Professionals and Zitholele Consulting to assist government to develop an air quality management plan for the area known as the Vaal Triangle Priority Area.

A letter was sent to you by the consultants in December 2006 requesting your participation in this process by providing information pertaining to the specific processes including a process description, type and amount of raw material used, and emission rates for the associated pollutants. The scope of work to be undertaken by the consultants for the Department does not include the source quantification of all emissions and therefore great reliance is placed on industry for data. To date no response has been received from your company and this letter serves as a final request to provide the requested information. In the event where no emissions data is available, you are still requested to provide a short process description and amount of raw materials used.

All data is to be forwarded to Airshed Planning Professionals by the **14th of May 2007.** The Department will take further steps in this regard should no response be received by the due date.

Your assistance ire is highly appreciated. Should you have any further queries pertaining to this project; please do not hesitate to contact us.

Best regards

Mr Peter Lukey
Chief Directorate: Air Quality Management & Climate Change
Department of Environmental Affairs and Tourism

Information to be sent to: Lerato Mudeme or Patricia Mashilo

Airshed Planning Professionals (Pty) Ltd, Tel: 011 805 1950, Fax: 011 805 7010

E-mail: lerato@airshed.co.za or patricia@airshed.co.za

Airshed Planning Professionals

APPENDIX B

INDUSTRIAL EMISSIONS FOR THE VAAL AIRSHED[4]

[4] The industrial emissions inventory includes the local municipality areas of Emfuleni, Midvaal and Metsimaholo, but excludes the Ekurhuleni Local Municipality.

Process	Company	Emissions (tons/annum)				Source Type	Release Height
		SO_2	NO	NO_2	PM10		
Ferroalloys	Metalloys	0.00	0.00	0.00	772.08	Stacks and Fugitive	From ground level to stack heights of 30m
Ferroalloys Total		**0.00**	**0.00**	**0.00**	**772.08**		
Petrochemical	Sasol	18520.70	13305.71	4968.03	1972.43	Stacks	Release height from 12m to 145m
	SMX Sasolburg	0.00	0.00	0.00	675.32	Stacks	Release height from 40m to 75m
	Natref	11605.25	0.00	870.39	1058.98	Stacks	145 m
Petrochemical Total		**30125.94**	**13305.71**	**5838.42**	**3706.73**		
Phosphate Fertilizer Process	Omnia Fertilizer	0.00	84.01	9.33	394.78	Stacks and Fugitive	Ground level to 60m
Phosphate Fertilizer Process Total		**0.00**	**84.01**	**9.33**	**394.78**		
Boilers	Aero Dry Cleaners	0.00	0.01	0.00	0.00	Stacks	Range from approximately 2 m to 30 m
	African Detinning	2.80	1.02	0.11	3.36		
	Air Products	0.02	0.05	0.01	0.00		
	Cargo Carriers	0.05	0.12	0.01	0.05		
	Central Hotel	0.00	0.00	0.00	0.00		
	Clover	3.06	1.12	0.12	3.69		
	DF Malherbe	0.04	0.00	0.00	0.00		
	Die Anker Skool	0.04	0.00	0.00	0.00		
	Drie Riviere Primary	0.00	0.00	0.00	0.00		
	Driehoek	0.04	0.00	0.00	0.00		
	Drive-In cleaners	2.62	0.94	0.10	3.18		
	Frikkie Meyer	0.04	0.00	0.00	0.00		
	General Smuts High	0.00	0.00	0.00	0.00		
	Handhawer Primary	0.00	0.00	0.00	0.00		
	Hendrik van Derbijl Primary	0.04	0.00	0.00	0.00		
	Historia Primary	0.04	0.00	0.00	0.00		
	Hoer Tegnies	0.00	0.00	0.00	0.00		
	Johan Heyns	12.10	4.41	0.49	14.55		
	Kaponong Hospital	0.51	0.13	0.01	0.18		
	Killarney Hotel	0.06	0.02	0.00	0.07		
	Kollegepark	0.04	0.00	0.00	0.00		
	KrugerIn School	0.00	0.00	0.00	0.00		
	Magistrate's Court	0.01	0.02	0.00	0.00		

Process	Company	Emissions (tons/annum)				Source Type	Release Height
		SO_2	NO	NO_2	PM10		
	Multispray	0.02	0.05	0.01	0.00		
	Noordhoek	0.04	0.00	0.00	0.00		
	Oliver Lodge	0.04	0.00	0.00	0.00		
	Oospark	0.04	0.00	0.00	0.00		
	Overvaal High	0.00	0.00	0.00	0.00		
	Park Panel Beaters	0.02	0.05	0.01	0.00		
	Park Ridge Primary	0.04	0.00	0.00	0.00		
	Pinedene	0.04	0.00	0.00	0.00		
	Riverside High	0.00	0.00	0.00	0.00		
	SAP	0.02	0.01	0.00	0.02		
	Sasolburg Hospital	0.00	0.00	0.00	0.00		
	Slagment	11.97	4.36	0.48	14.39		
	Sun Crest High	0.04	0.00	0.00	0.00		
	Suncrush	6.15	2.24	0.25	7.40		
	Superp Dry Cleaners	0.11	0.03	0.00	0.04		
	Supreme	0.00	0.03	0.00	0.01		
	Tanker Services	0.02	0.05	0.01	0.00		
	TNT Panel Beaters	0.02	0.05	0.01	0.00		
	Totius Primary	0.04	0.00	0.00	0.00		
	Transvalia	0.04	0.00	0.00	0.00		
	Unitaspark Primary School	0.00	0.00	0.00	0.00		
	Vaal High	0.04	0.00	0.00	0.00		
	Vaal Portugese Bakery	0.03	0.08	0.01	0.01		
	Vaal Technikon	0.00	0.00	0.00	0.00		
	Vaalmed	0.00	0.01	0.00	0.00		
	Van Zyl Panelbeaters	0.02	0.05	0.01	0.00		
	Vanderbijlpark High	0.04	0.00	0.00	0.00		
	Vereeniging High School	0.00	0.00	0.00	0.00		
	Voorslag	0.04	0.00	0.00	0.00		
	Willies Confectionary	0.05	0.12	0.01	0.01		
Boilers Total		**40.33**	**15.01**	**1.67**	**46.98**		
Brickworks	Ocon Bricks	0.00	0.00	0.00	430.22	Stacks and Fugitive	From ground level to 4 m
	Brickveld Stene	0.00	0.00	0.00	0.19		
	African Brick Lenasia	2.02	0.53	0.06	0.70		
Brickworks Total		**2.02**	**0.53**	**0.06**	**431.11**		

Process	Company	Emissions (tons/annum)				Source Type	Release Height
		SO_2	NO	NO_2	PM10		
Iron and Steel Processes	ArcelorMittal Vaal Works	11.24	142.29	22.25	81.82	Stacks and Fugitive	From ground level to stack heights of 145m
	ArcelorMittal Klip Works	0.00	25.28	2.81	0.00		
	ArcelorMittal Steel Vanderbijlpark Steel	13648.62	14740.85	125.99	5559.98		
	Davesteel (Cape Gate)	0.00	0.00	0.00	1022.98		
Iron and Steel Processes Total		**13659.86**	**14740.85**	**151.06**	**6582.97**		
Power Generation	Lethabo	171929.00	76374.00	2390.00	5776.00	Stacks	275m
Power Generation Total		**171929.00**	**76374.00**	**2390.00**	**5776.00**		
Mines	New Vaal Colliery	0.00	0.00	0.00	3467.00	Fugitive	Ground level
	Sigma Colliery	0.00	0.00	0.00	1087.23		
Mines Total		**0.00**	**0.00**	**0.00**	**4554.23**		
Smaller Industries	African Cables	0.00	0.00	0.00	65.83	Stacks	From 2 m to 100 m
	African Catalysts	0.00	0.00	0.00	0.00		
	African Pegmatite	0.00	0.00	0.00	0.02		
	Ambijo Lounges	0.00	0.01	0.00	0.01		
	Blitz Concrete Works (Westongoud)	0.00	0.00	0.00	5.68		
	Blue Armor	0.00	0.00	0.00	0.00		
	Brickveld Stene	0.00	0.00	0.00	42.60		
	Claasens Tegniek	0.00	0.00	0.00	0.00		
	Concorde Foundry	0.00	0.00	0.00	50.44		
	Consolidated Wire Industries	0.00	0.00	0.00	0.41		
	Coverland Roof Tiles	0.00	0.00	0.00	4.67		
	Dixon Batteries	0.59	0.00	0.00	0.23		
	Dorbyl Heavy Engineering	0.00	0.00	0.00	41.01		
	EMSA	0.00	0.00	0.00	95.32		
	Everite Building Products	1.97	0.51	0.06	44.17		
	Flexilube	0.00	0.00	0.00	0.34		
	Lime Distributors	0.00	0.00	0.00	99.06		
	Much Asphalt	1.95	0.19	0.02	0.11		
	Nampak	30.67	7.99	0.89	10.65		
	Non-Ferrous Cast Products	0.00	0.00	0.00	0.42		
	Polifin (AECI Midlands)	6.85	1.78	0.20	445.65		
	Rand Water Board	20.49	5.34	0.59	7.11		
	Safripol	0.00	0.00	0.00	219.71		
	Slagment	0.00	0.00	0.00	0.97		
	Superior Casting Supplies/Pattern Makers	0.00	0.00	0.00	5.81		

Process	Company	Emissions (tons/annum)				Source Type	Release Height
		SO_2	NO	NO_2	PM10		
	Suprachem	0.00	0.00	0.00	0.74		
	TOSA (Tubemakers of SA)	0.00	0.00	0.00	1.45		
	Vaal Potteries	1.10	0.29	0.03	166.02		
	Van Leer SA	0.00	0.00	0.00	0.10		
	Vereeniging Abbatoir	1.55	0.40	0.04	0.54		
	Vereeniging Crushers	0.00	0.00	0.00	0.02		
	Vitro Building Products	0.00	0.00	0.00	1658.65		
	Vryheidsmon	0.00	0.00	0.00	0.00		
	Zimmerman and Jansen SA	0.00	0.00	0.00	0.24		
	Zwartkoppies Pumping Station	93.99	24.49	2.72	32.65		
Smaller Industries Total		**159.16**	**41.01**	**4.56**	**3000.62**		