forestry, fisheries & the environment

Department:
Forestry, Fisheries and the Environment
REPUBLIC OF SOUTH AFRICA

DEVELOPMENT OF THE SECOND-GENERATION AIR QUALITY MANAGEMENT PLAN FOR THE HIGHVELD PRIORITY AREA

BASELINE ASSESSMENT REPORT

FINAL REPORT
02 JUNE 2023

EXECUTIVE SUMMARY

Background to Highveld Air Quality Priority Area

On 23 November 2007, the Highveld Priority Area was declared in terms of section 18.1. (a) and (b) of the National Environmental Management Air Quality Act, 2004 (Act No. 39 of 2004) (Republic of South Africa, 2004). The declaration was triggered by air quality in the area that has consistently exceeded National Ambient Air Quality Standards.

Following the declaration of the Highveld Priority Area, an Air Quality Management Plan was developed and completed in 2012 in terms of section 19 (1) (a) and (b) of the National Environmental Management Air Quality Act, 2004 (Act No. 39 of 2004). A Priority Area Air Quality Management Plan describes the current state of air quality in a priority area, sources of air pollution in the priority area, how air quality has been changing over the years, and what could be done to ensure clean air quality in a priority area. It provides the goals and objectives for a priority area and prescribes short- to long-term policies and controls to improve air quality in a priority area.

During the 2015 and 2016 financial year, the department conducted a mid-term review of the Highveld Priority Area Air Quality Management Plan through collaborative engagements with stakeholders within the priority area (Department of Environmental Affairs, 2017). The findings of the mid-term review showed that, although several 2012 Air Quality Management Plan interventions had been implemented, air quality in the area did not improve significantly to a level where the Minister is satisfied to undeclare the priority area as per section 18(5) of the National Environmental Management Air Quality Act. The mid-term review also recommended the development of the second-generation Highveld Priority Area Air Quality Management Plan.

Background Assessment

The objective of this Highveld Priority Area Baseline Assessment Report is to determine the current state of air quality in the area and to assess whether the interventions set by the 2012 Highveld Priority Area Air Quality Management Plan resulted in ambient air quality improvements. The main findings set out in this report are primarily based on the background assessment, the evaluation of ambient air quality in the priority area, the emission inventory associated with the area and the associated dispersion modelling. These provided a good understanding of the current state of air quality within the Highveld Priority Area and to some extent, the source contributions to the ambient pollution levels.

The background assessment used existing information to assess the current state of air in the Highveld Priority Area, as well as understanding the geographical context of the priority area, the drivers of air quality, and how the air quality has changed since the 2012 Air Quality Management Plan and the 2015/2016 mid-term term review.

This baseline assessment report will also inform the development of the second-generation Highveld Priority Area Air Quality Management Plan with relevant additional interventions to be undertaken and resources to be put in place to ensure that the plan is implemented effectively and efficiently to ensure that air quality in the priority area meets the National Ambient Air Quality Standards (NAAQS).

Ambient Air Quality

Since the declaration of the Highveld Priority Area and subsequent development of the Air Quality Management Plan, there has been to a certain extent, some improvements in ambient air quality monitoring. The number of monitoring stations have increased from 23 to 49 since the gazetting of the 2012 Air Quality Management Plan, and most of these stations are reporting ambient information in real-time to the South African Air Quality Information

System https://saaqis.environment.gov.za/. An assessment of historical ambient air quality data from 2007 to 2020, for Gert Sibande District Municipality, Nkangala District Municipality, as well as the City of Ekurhuleni was undertaken to assess ambient air quality trends in the region.

The main findings from critical pollutants are as follows:

Surface Wind Field:

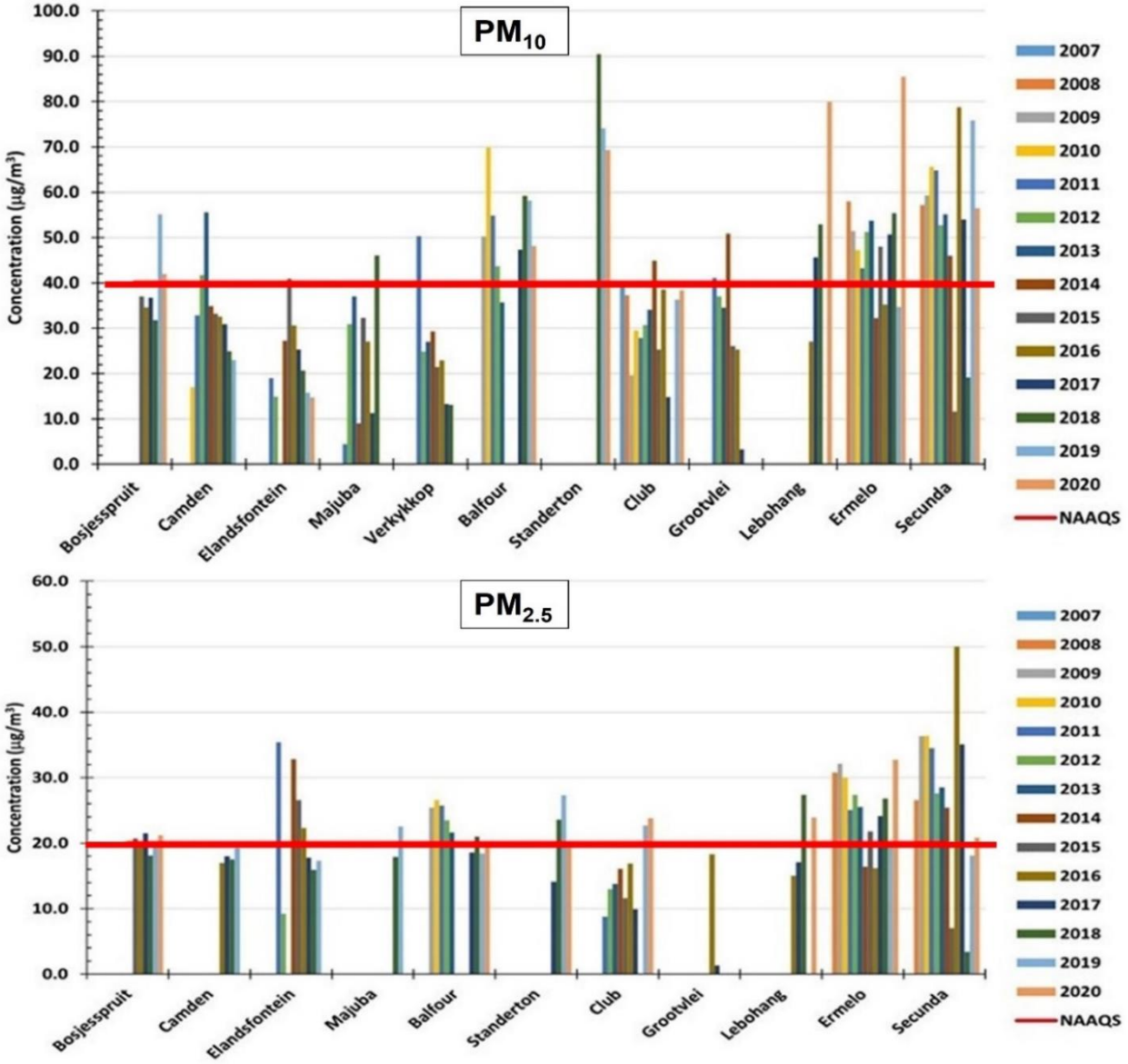
Wind rose analyses based on hourly data obtained from 6 air quality monitoring stations in the Highveld Priority Area indicate that there is a predominance of northerly and north-easterly winds at these stations, with average speeds varying between 2 m/s and 7 m/s.

Particulate Matter:

- **Daily averages**: While there has been a clear improvement in ambient air quality monitoring in some areas, ambient (PM_{10}) concentrations are still elevated over many areas in the Highveld Priority Area with daily exceedances of PM_{10} NAAQS (75 µg/m³). These elevated concentrations typically coincide with periods of low temperatures and stable atmospheric conditions associated with the winter months.
- **Annual trends:** As shown below for PM_{10} and $PM_{2.5}$, some areas have experienced significant improvements, namely Club, Camden and Elandsfontein from 2013 to 2020. However, very little-to-no improvement and even further deterioration has taken place at some sites, namely Komati, Bosjesspruit and Majuba. It is, therefore, recommended that more focused and strategic attention and intervention is paid in these areas.

Sulphur Dioxide (SO_2)

- Annual average SO_2 concentrations have been relatively higher than the other declared priority areas. The highest concentrations occurred in areas such as eMalahleni and Komati.
- Since 2007, annual SO_2 levels have decreased significantly in Ermelo, Hendrina, Secunda, eMalahleni, eMbalenhle and Phola.
- However, areas including Middelburg, Elandsfontein, Grootvlei, Komati and Leandra have seen significant increases in SO_2 levels during the same period.
- The rest of the stations showed that, even though there have been inter-annual variations, the levels of SO_2 have remained relatively unchanged over the entire period.
- Monthly average trends show typical annual cycles with the highest SO_2 level peaking in the winter and the lowest levels in summer.
- Winter peaks at eMalahleni have consistently been the highest in the area, and nearly double the regional average.
- The priority area monthly average shows a noticeable and gradual decrease across the region, especially in the winter peaks. On average, these winter peaks have decreased from around 25 ppb in 2009 to around 13 ppb in 2019.



Nitrogen Dioxide (NO_2)

- **Hourly averages:** The hourly NO_2 NAAQS of 106 ppb was seldom exceeded after 2012 with these exceedances taking place at the Elandsfontein and Club ambient monitoring stations. It is also important to note that consistent exceedances of the NAAQS were noted at Club prior to 2012 with a clear improvement thereafter, again speaking to the development of the priority area Air Quality Management Plan and the subsequent implementation from 2012 having an important bearing on the observed improvements.
- **Annual trends**: Annual average ambient NO_2 concentrations recorded at the Air Quality Monitoring Station of concern were well within the annual average NAAQS of 21 ppb with the exception of a single exceedance taking place at the Elandsfontein Air Quality Monitoring Station in 2014, which was most likely an extreme event. A slight increase in annual average ambient NO_2 concentrations has also been noted in 2017. However, the average concentrations are still well below the annual NAAQS.

Ozone (O_3)

- **Eight-hour running averages:** There has been a clear improvement in ambient monitoring from 2012 onwards. While this clear improvement is evident, exceedances of the eight-hour O_3 running average NAAQS of 61 ppb was evident prior to 2012, with exceedances occurring at the Club and Bosjesspruit Air Quality Monitoring Stations. Improved measurements were noted from 2016 to 2019. However, these measurements are still above the eight-hour running average O_3 NAAQS.

Highveld Priority Area Emission Inventory

Emissions were quantified for all main sources within the Highveld Priority Area for 2019, as well as sources from the surrounding areas to form input into air quality modelling. A comparison was made between the initial 2012 Air Quality Management Plan emission inventory and the 2019 emission inventory, which is the foundational input for the development of the Second Generation Highveld Priority Area Air Quality Management Plan.
Based on this comparison the main findings are:

- There are significant changes in emissions volumes between the initial 2012 Air Quality Management Plan emission inventory and the 2019 emission inventory, resulting in significantly less total emission quantified for SO_2 and NO_x in 2019.
- For PM_{10}, changes in emissions volumes between the initial 2012 Air Quality Management Plan emission inventory and the 2019 emission inventory are minimal, with only a 6% reduction being experienced. This is due to increased emissions from industries, residential fuel burning; and biomass burning, with industries noted to have the most pronounced increase (14% increase or 15 388 tpa). At the same time, significant reductions in estimated PM_{10} emissions are also noted for on-road vehicle emissions and windblown particulates with 85% and 23% reductions respectively.
- It is also important to note that the 2019 emission inventory incorporates both emission sources and pollutants previously not quantified in the 2012 Air Quality Management Plan emission inventory, yet clear emission reductions were still noted across all three pollutants.

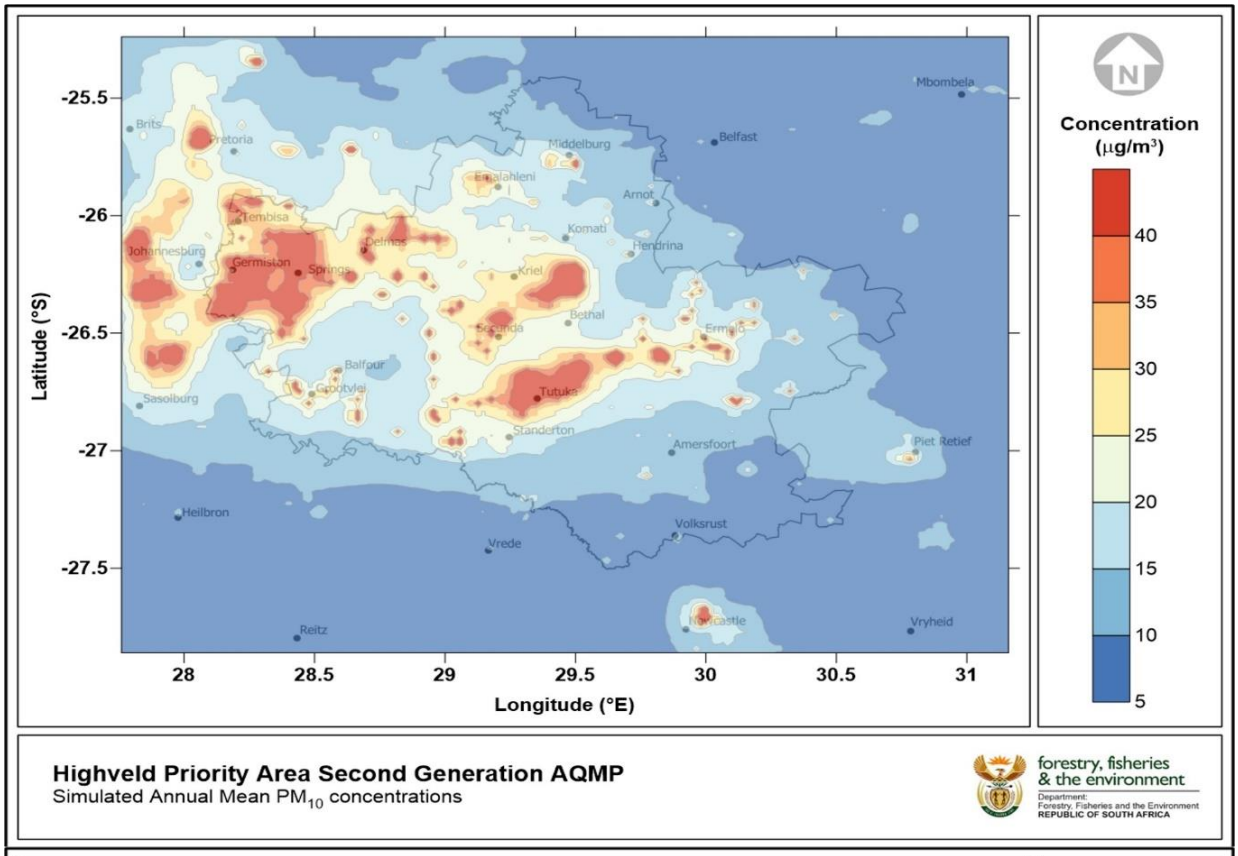
Photochemical Modelling

The CAMx chemical air quality model was used to simulate current ambient concentrations of pollutants within the Highveld Priority Area to assess ambient air quality on a more comprehensive spatial scale than what can be provided with monitoring stations. Areas of elevated concentrations can be identified for expanded monitoring and when viewed within the context of the emission inventory, likely contributing sources are targeted for intervention strategies.

A summary of the main finding for each pollutant is detailed below:

Particulate matter (PM_{10} and $PM_{2.5}$):

- As shown below, both the simulated PM_{10} and $PM_{2.5}$ concentrations tend to have similar characters in the spatial distribution of exceedances.
- For annual NAAQS, the same areas are also predicted to be impacted though the spatial extent is reduced for $PM_{10,}$ while it has become even more extended for $PM_{2.5}$ exceedances.
- In terms of 24-hour exceedances, the central part of the Highveld Priority Area, in areas such as Secunda and west of Ermelo, as well as the north (Emalahleni) to north-west regions, the concentrations for PM_{10} and $PM_{2.5}$ are exceeding the permissible number of exceedances, with a large portion of Gauteng (including the Vaal Triangle Priority Area) predicted to be impacted by both pollutants.



Highveld Priority Area Second Generation AQMP
Simulated Annual Mean PM_{10} concentrations

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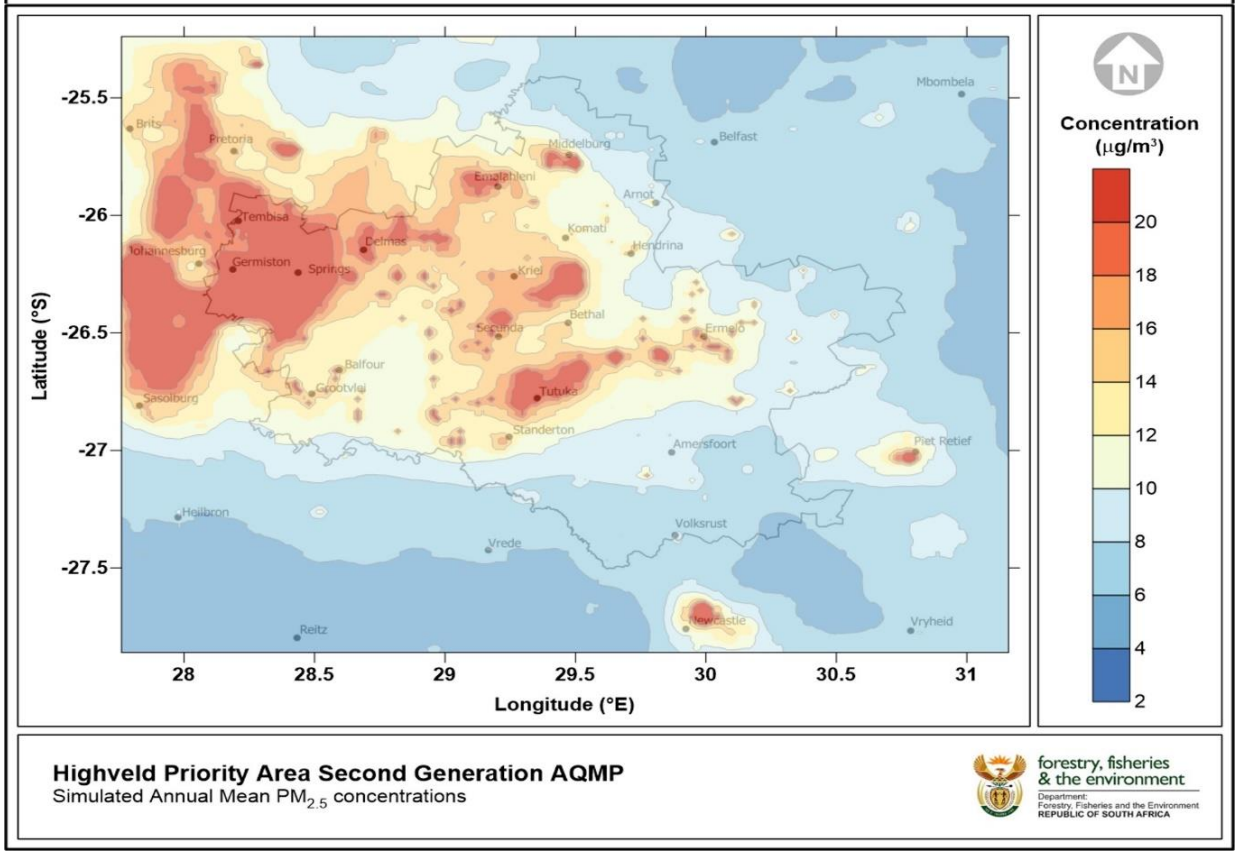

Highveld Priority Area Second Generation AQMP
Simulated Annual Mean $PM_{2.5}$ concentrations

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Sulphur Dioxide (SO_2):

- It is noted that annual SO_2 NAAQS (19 ppb) is exceeded primarily over the west (Sasolburg area, part of the Vaal Triangle Priority Area) with Secunda, eMalahleni, Witbank and the City of Ekurhuleni also illustrating pronounced areas of exceedance.
- A hotspot to the north of Secunda seems to stand out from the other spots within the Highveld Priority Area and occurs for all average periods, with daily impact having the largest spatial extent bulging northward towards the boundaries of the Highveld Priority Area.
- Other Highveld Priority Area bounded hotspots, such as areas around Amersfoort, eMalahleni and the City of Ekurhuleni, become more significant with regard to the 24-hour Frequency of Exceedance as they become more spatially extended.
- Various other hotspots are also predicted at the edges of the modelling domain over the west (Sasolburg area, part of the Vaal Triangle Priority Area) and the north-western region, which are outside the Highveld Priority Area.

Nitrogen Dioxide (NO_2):

- For annual NAAQS of NO_2 (21 ppb), limited number of areas were simulated to be impacted by the exceedances of the annual standard, including Secunda and in the north-western part of the Highveld Priority Area where a few numbers of hotspots were predicted in areas around Gauteng.

Ozone (O_3)

The simulated annual O_3 concentrations over the modelling domain indicate a generally lower O_3 concentration towards the centre of the Highveld Priority Area, with distinct elevated concentrations towards the outer border of the modelling domain.

Summary of the Highveld Priority Area Health study

A health study was conducted to determine the potential for health effects from ambient air pollution in communities in the Highveld Priority Area. The study was commissioned by the Department of Forestry, Fisheries and the Environment with the purpose of assisting the department in making informed decisions on air quality management in the area. The study comprised local and regional assessments in order to have a better understanding of the risk and impacts of air pollution on human health in the Highveld Priority Area. For this purpose, the report investigated the exposure of communities living in close proximity to Air Quality Monitoring Stations and to sources of SO_2, NO_2, particulate matter PM_{10} and $PM_{2.5}$ were considered. The study had three main assessments undertaken which include:

- Human Health Risk Assessment;
- Vulnerability Assessment, including a focus on children; and
- Impact Assessment.

As part of the Vulnerability Assessment, the regional study involved the assessment of human health risks resulting from exposure to air pollution. Local studies comprised a community survey in seven communities, namely eMalahleni, Ermelo, Etwatwa, Grootvlei, Middelburg, Tembisa and Tsakane, in the priority area and a child health study.

Mortality attributed to air pollution was determined for two scenarios, which include the baseline scenario for PM_{10} and $PM_{2.5}$ and the NAAQS threshold (in other words, calculating the mortality rate if the local municipality met the current NAAQS scenario for PM_{10} and $PM_{2.5}$. StatsSA population, mortality data, and the modelled ambient concentrations were used as input in the baseline scenario. The PM_{10} and $PM_{2.5}$ attributable mortality decrease in meeting the annual NAAQS were then estimated and provided the following results:

- Based on simulated Hazard Quotients, the central and towards the eastern parts of the Highveld Priority Area are at risk to the negative health impacts of exposure to SO_2. Within these areas, the communities most at risk are primarily located near intense industrial SO_2 emitters.
- Based on simulated Hazard Quotients, a large portion of the western part of the Highveld Priority Area is at risk to the negative health impacts of exposure to PM_{10}. Within this western region, the communities most at risk are primarily located in the City of Ekurhuleni, the Govan Mbeki Local Municipality, and the Msukaligwa Local Municipality.
- The City of Ekurhuleni and the Govan Mbeki Local Municipality are the main vulnerable areas in the Highveld Priority Area. The main conditions affecting vulnerability to the effects of air pollution in these areas are population characteristics and socio-economic conditions.
- The estimated attributable mortality decrease in meeting the annual NAAQS for PM_{10} is 5 125 people and 4 881 people for $PM_{2.5}$.
- The largest percentage attributable deaths from not meeting PM_{10} annual NAAQS occur in the City of Ekurhuleni and the Govan Mbeki Local Municipality. If the annual NAAQS for PM_{10} is met, all-cause mortality in the City of Ekurhuleni is expected to decrease by 18,75%
- For $PM_{2.5}$, the largest percentage attributable deaths from not meeting $PM_{2.5}$ annual NAAQS occur in the City of Ekurhuleni. If the annual NAAQS for $PM_{2.5}$ are met, all-cause mortality in the City of Ekurhuleni is expected to decrease by 16,62%

The abovementioned results are consistent with the health impacts detailed in the initial 2012 Highveld Priority Area Air Quality Management Plan, which found that the City of Ekurhuleni, Emalahleni, Steve Tshwete, and Secunda are areas with large populations possibly at risk from the ambient concentrations of SO_2 and PM_{10}. Hospital admissions with respiratory conditions were estimated to be significantly higher in the Johannesburg and City of Ekurhuleni conurbation (more than 34 000 cases) when compared to admissions in the Mpumalanga Highveld as a whole (more than 8 600 cases).

Way Forward

The baseline assessment assessed compliance with ambient air quality standards within the Highveld Priority Area while exploring the potential risk to human health and the degradation of the environmental medium air. Additionally, this baseline assessment is the basis for the development of the Second Generation Highveld Priority Area Air Quality Management Plan, whereby the information contained in this document is intended to lay the foundation for comprehensive strategies' assessment and focus on specific interventions informed by cost-effective pollution control measures (in other words, the Pollution Preventative Programme) for targeted emission reductions in line with the NAAQS objectives within a set timeframe. The next step in the Second-Generation Highveld Priority Area Air Quality Management Plan development process is the formulation of targeted emission reductions that are aligned to a set of intervention scenarios based on the same emission inventory used in this baseline assessment, which is expected to bring ambient air quality into compliance with the NAAQS.

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ABBREVIATIONS, SYMBOLS AND UNITS

°C	Degree Celsius
AAQ	Ambient Air Quality
AEL	Atmospheric Emissions Licence
AIR	Atmospheric Impact Report
APPA	Atmospheric Pollution Prevention Act, 1965 (Act No. 45 of 1965)
AQMP	Air Quality Management Plan
AQMS	Air Quality Monitoring Station
CoE	City of Ekurhuleni
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DEA	Department of Environmental Affairs, South Africa
DFFE	Department of Forestry, Fisheries and the Environment
EIA	Environmental Impact Assessment
EMP	Environmental Management Programme
g/kg	Gram per kilogram
GHGs	Greenhouse gases
GLCs	Ground Level Concentrations
GN	General Notice
HPA	Highveld Priority Area
I&AP	Interested and affected parties
ISO	International Organisation for Standardisation
$kg.yr^{-1}$	Kilograms per year
$\mu g/m^3$	Micro grams per cubic meter (concentration)
MES (S21)	Minimum Emission Standards (S21 MES): List of Activities which Result in Atmospheric Emissions from the National Environmental Management: Air Quality Act, 2004 (Act No. 39 of 2004)
MSW	Municipal Solid Waste
N/A	Not applicable
n/av	Not available
NAAQS	National Ambient Air Quality Standards (South Africa)
NAQO	National Air Quality Officer
NCAR	National Centre for Atmospheric Research
NEM: AQA	National Environmental Management: Air Quality Act, 2004 (Act No. 39 of 2004)
NO	Nitrogen Oxide
NO_2	Nitrogen dioxide
NO_x	Oxides of Nitrogen (expressed as NO_2)
PM	Particulate Matter
PM_{10}	Particulate Matter with an aerodynamic diameter of ≤ 10 micrometers
$PM_{2.5}$	Particulate Matter with an aerodynamic diameter of ≤ 2.5 micrometers
PMT	Project Management Team
ppm	Parts per million (g/Mg)
PSD	Particle Size Distribution
PSC	Project Steering Committee
SA/RSA	South Africa
SANRAL	South African National Roads Agency SOC Ltd

SANS	South African National Standard
SO_2	Sulphur dioxide
SO_x	Oxides of sulphur
$Tg.yr^{-1}$	Terra Grams per Year
TOC	Total Organic Compounds
TSP	Total Suspended Particulates (also refers to Particulate Matter with reference to this report)
US/USA	United States of America
US-EPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
WHO	World Health Organisation

1. INTRODUCTION

The highly industrialised South African Highveld is one of the most polluted regions in South Africa, which has one of the largest industrialised economies in the Southern Hemisphere (Freiman & Piketh, 2003; DEA, 2010a). There are exceedances of the National Ambient Air Quality Standards (NAAQS) recorded in the Highveld Priority Area (HPA), hence, the requirement for a specific air quality management action to rectify the situation. The HPA is also considered one of the major NO_2 hotspots in the world (Wenig, 2003; Lourens, 2012) and it was previously estimated that over 80% of SO_2 and NOx emissions in South Africa are from the Mpumalanga Province (Wells, 1996; NAEIS).

1.1 Background

On 23 November 2007, the HPA was declared in terms of section 18 (1) (a) and (b) of the National Environmental Management: Air Quality Act, 2004 (Act No. 39 of 2004) (NEM: AQA) (DEA, 2004). The declaration was based on the fact that ambient air quality in the area was consistently exceeding NAAQS.

The HPA falls within the boundaries of the following municipalities (see Figure 1-1):

- City of Ekurhuleni (CoE), Gauteng province;
- The Lesedi Local Municipality (LM) in the Sedibeng District Municipality (DM), Gauteng province;
- The Victor Khanye, Steve Tshwete, and eMalahleni LMs in the Nkangala DM, Mpumalanga province;
- The Govan Mbeki, Dipalaseng, Msukaligwa, Lekwa and Pixley ka Seme LMs in the Gert Sibande DM, Mpumalanga province.

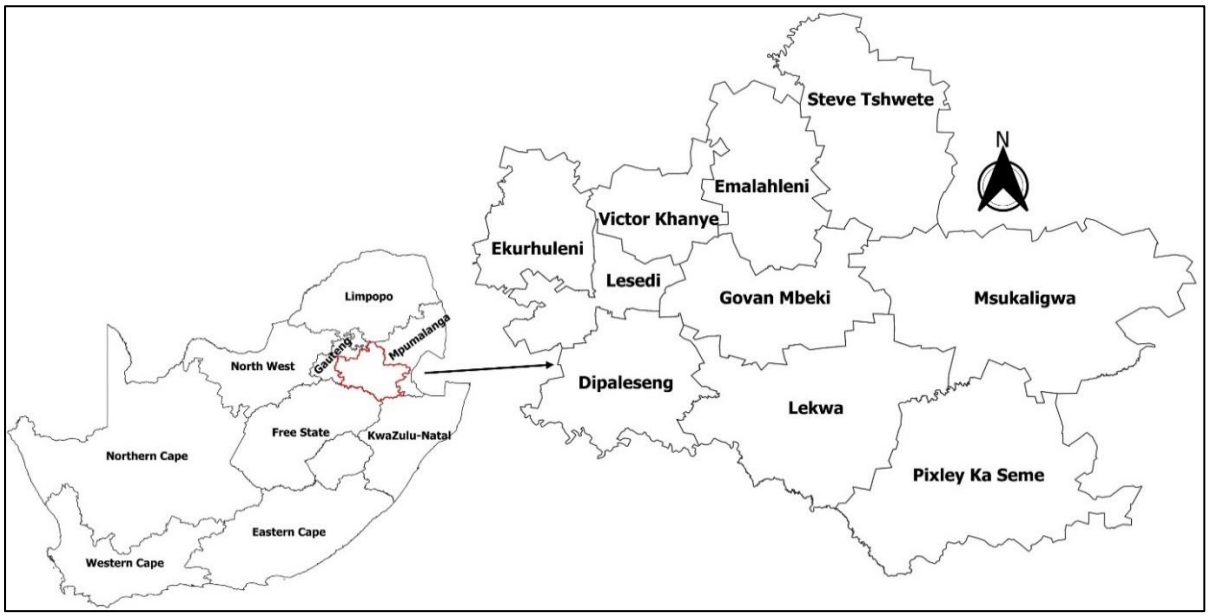


Figure 1-1: Map depicting the geographical extent of the Highveld Priority Area

The declaration of a priority area is a legislative mandate in the NEM: AQA aimed at providing key strategic elements for air quality management, such as prioritising limited resources, focusing on the problems within recognised hotspot areas, as well as building the necessary capacity to deal with air quality problems in the areas. The priority area approach focuses on intergovernmental cooperation, which allows for the management of air quality in problem areas that cross municipal boundaries to be coordinated by provinces and for problem areas that cross provincial boundaries to be coordinated by the national department. This approach also takes into consideration the issue of "air-shed management", which considers air pollutants emitted from certain areas that may contribute to air pollution.

Following the declaration of the HPA, an Air Quality Management Plan (AQMP) was developed. A priority area AQMP describes the current state of air quality in a priority area, sources of air pollution in the priority area, how air quality has been changing over the years, and what could be done to ensure clean air quality in a priority area. It provides the goals and objectives for a priority area and prescribes short- to long-term policies, and controls to improve air quality in a priority area.

The plan provided strategic direction for the implementation of air quality interventions in this priority area, as well as an essential blueprint for action to reduce emissions in the area. The First Generation HPA AQMP is currently under implementation through continuous involvement by different stakeholders, including government authorities, industries, non-governmental organisations [NGOs] and citizens in the priority area). The actions of stakeholders are directed by a coordinator (in other words, the developed AQMP) to achieve a common goal set out in the HPA AQMP. The department also initiated a number of projects with the aim of informing the development of the Second Generation HPA AQMP e.g., the HPA health study.

In the 2015/2016 financial year, the department conducted the HPA AQMP mid-term review through an interactive approach with stakeholders within the HPA (DEA, 2017a). The findings of the mid-term review showed that although most of the AQMP interventions were implemented, air quality in the area did not improve significantly to a level where the Minister is satisfied to undeclare the priority area, as per section 18(5) of NEM: AQA.

In the review report, several challenges experienced with the actual 2012 HPA AQMP, the implementation plan, and the monitoring and evaluation process were identified. Since the first AQMP was developed, there has been improvement in the methodology and data required for the baseline assessment. The department established the National Atmospheric Emission Inventory System (NAEIS) for the reporting of industrial emissions, and it is in the process of initiating a project to estimate non-industrial emissions. The objective of this centralised emission inventory reporting platform is to ensure that there is a complete and comprehensive emission inventory informed by international best practices guidance and principles of Transparency, Comparability, Completeness, Consistency and Accuracy (TCCCA) in emission inventory estimations.

The mid-term review of the 2012 HPA AQMP also recommended the development of the Second Generation HPA AQMP, which will provide a comprehensive assessment of the status of the plan in terms of its effectiveness in producing results that are of a sufficient type and known quality needed for its intended use. The Second Generation HPA AQMP will also take into consideration the recommendations of the 2015/2016 mid-term review report.

The results will then inform the relevant action to be taken and resources to be put in place to ensure that the Second Generation AQMP is implemented effectively and efficiently to ensure that air quality in the HPA meets the NAAQS (DEA, 2009).

The Minister must also develop regulations to implement and enforce priority area AQMPs. The regulations provide for the mandatory implementation of interventions, provide mechanisms for government to monitor and evaluate the effectiveness of the plans, as well as activating enforcement measures where non-compliance is identified. They apply to all key stakeholders identified to be significant contributors to poor air quality in the respective AQMPs, including listed activities (DEA, 2010b), controlled emitters, mining operations and government stakeholders.

1.2 Objective of the Highveld Priority Area Air Quality Baseline Assessment Report

The baseline assessment forms the basis for the development of the AQMP. The report advises and provides the basis for comprehensive strategies' assessment and focuses on specific interventions informed by cost-effective pollution control measures (in other words, Pollution Preventative Programme) for targeted emission reductions in line with the NAAQS objectives within a set timeframe. This baseline report also enables assessment of the current air quality in the HPA and will also inform the drafting of regulations that will enforce the HPA AQMP.

2. GENERAL DESCRIPTION OF THE HIGHVELD PRIORITY AREA

2.1 Geography and Demographics

The HPA exists entirely in the Grassland Biome ecosystem (DEAT, 2005), but as with virtually all ecosystems globally, it has been modified or transformed by human activities. These include cultivation for commercial crops or subsistence agriculture, livestock, forestation for commercial timber production, the invasive spread of alien plants, urbanisation and settlements, the impoundment of rivers, mining, transportation, and industrialisation (Macdonald, 1989).

2.1.1 Topography

The topography of an area plays a role in the dispersion of air pollutants. On hilltops and exposed areas, moderate winds will typically cause pollutants to be dispersed, however, in low-lying areas such as valleys, it is difficult for air flow to penetrate, resulting in pollutants being trapped and thereby increasing levels of pollution. Pollutant dispersion processes over complex terrain are more complicated than in areas with flat landscapes as they are affected by atmospheric interactions with the orography at different spatial scales. The HPA forms part of South Africa's elevated inland plateau. The topography of the HPA is relatively flat or gently undulating (Figure 2-1). It slopes gently from elevations of approximately 1 400 m in the northwest in the Delmas, Emalahleni and Steve Tshwete LMs, to 1 500 m in the central parts and to a little more than 1 600 m in the east in the Msukaligwa LM, reaching 1 800 m in the southeast in the Pixley Ka Seme LM. The southern part of the HPA slopes to 1 400 m into the Vaal River basin. The generally flat terrain is interspersed with relatively low koppies and rocky outcrops.

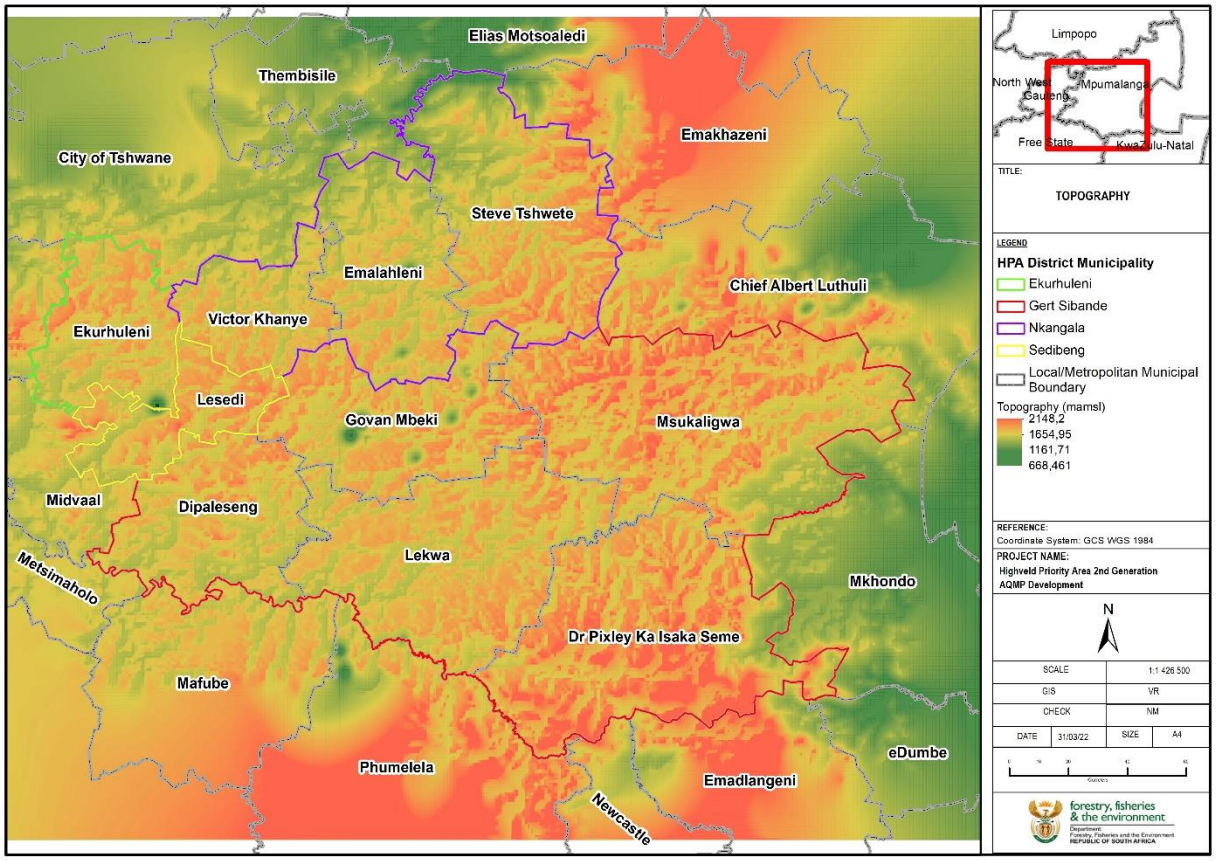


Figure 2-1: Topography of the Highveld Priority Area

2.1.2 Land Use

Land use changes through industrial, mining, and urban expansion can have an impact on air quality in the HPA. These expansions can lead to increased emissions from industries, mines and residential fuel burning in the HPA. The land cover of the HPA is predominantly grassland and irrigated agricultural lands (Figure 2-2) comprising 60% and 27% of the total land cover, respectively. Urban and build-up areas occur throughout the HPA and constitute 4% of the total land cover. However, this is dominated by the City of Ekurhuleni, which is mostly urbanised. Industrial areas and mining constitute 1% and 2% of the total land cover in the HPA.

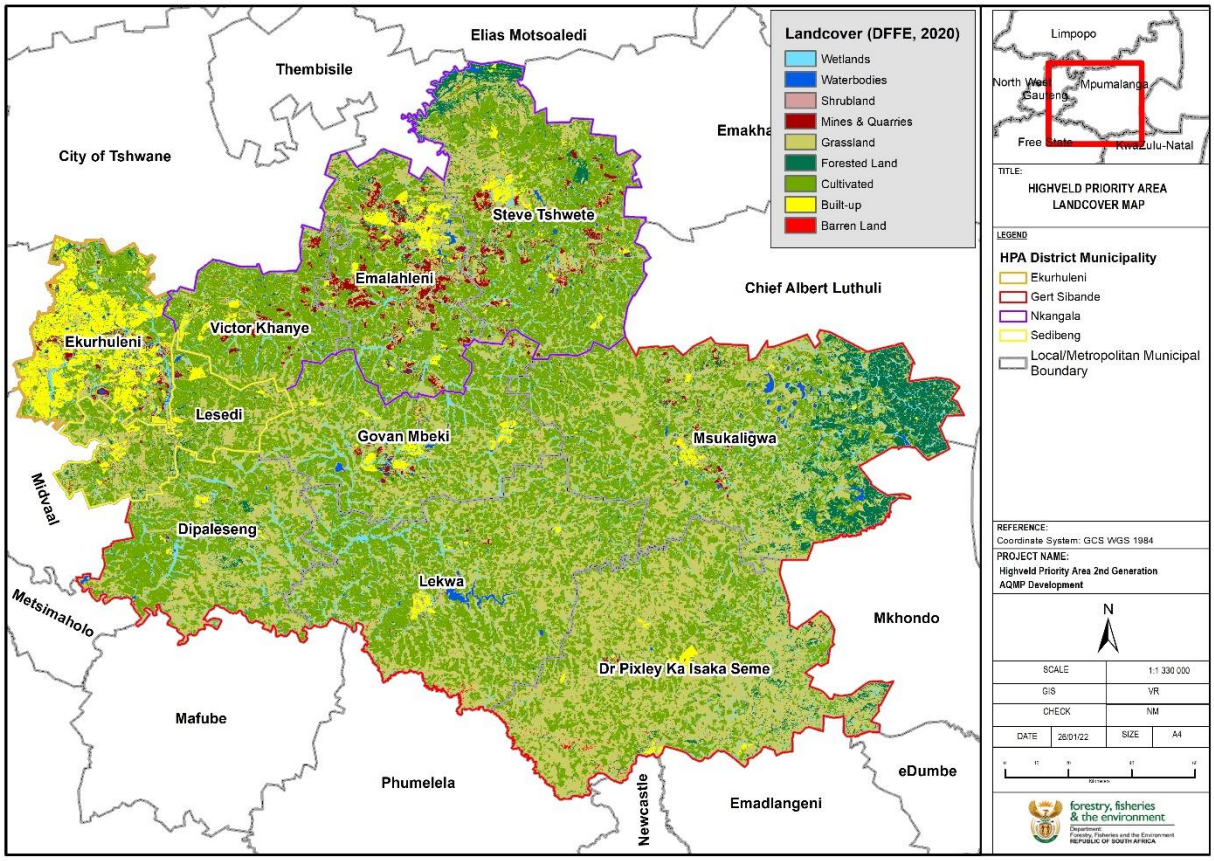


Figure 2-2: 2020 Land use distribution of the Highveld Priority Area

2.1.3 Population Distribution

As a more recent assessment, the Statistics South Africa (StatsSA) community surveys are deemed to be the most recent official population estimates for all provinces in South Africa and provide annual intercensal growth rates, which can be used to estimate future population increase at this rate (StatsSA, 2016). The population of the HPA was estimated to be 6 039 308 in 2020, as informed by the intercensal growth rates for the district and local municipalities provided in the StatsSA 2016 Community Survey (StatsSA, 2016). These population numbers are detailed in Table 2-1 along with each local/metropolitan municipalities' contribution to the overall population figure (Figure 2-3).

Table 2-1: Highveld Priority Area district municipalities and the respective populations in each local municipality

Region	Local Municipality	2011	% of Total 2011	2020	% of Total 2020
Gert Sibande	Msukaligwa	149 377	3%	167 206	3%
	Dr Pixley Ka Isaka Seme	83 235	2%	85 391	1%
	Lekwa	115 662	2%	118 874	2%
	Dipalaseng	42 390	1%	47 369	1%
	Govan Mbeki	294 538	6%	371 886	6%
Nkangala	Victor Khanye	75 452	2%	80 368	1%
	Emalahleni	395 466	8%	511 853	8%
	Steve Tshwete	229 831	5%	309 034	5%
Gauteng	City of Ekurhuleni	3 178 470	68%	4 219 829	70%
	Lesedi	99 520	2%	127 498	2%
TOTAL		**4 663 941**	**100%**	**6 039 308**	**100%**

From Table 2-1 above, it is evident that although the Gauteng province forms the smallest portion of the HPA, it hosts most of the population in the HPA. The majority of the population in HPA is concentrated in the Gauteng province within the City of Ekurhuleni, in other words, (70%) while the Lesedi LM is estimated to have 2% of the overall HPA population.

The Emalahleni LM is the second most densely populated LM housing 8% of the HPA population. These overall population contribution percentages are more or less consistent with the overall population contribution percentages noted during the development of the 2012 HPA AQMP. With respect to population change, comparing data from the Census 1996, 2001, and 2011 (StatsSA, 2011), it is noted that population growth was limited to the major urban municipalities in the HPA. This highlights the increasing rural-to-urban migration experienced in the Mpumalanga province as job seekers move to urban centres such as Witbank, Middelburg and Secunda to secure employment. This further highlights the migration to urban centres for improved education, employment, and service delivery prospects, albeit a pronounced migration from the City of Ekurhuleni, has been noted. The population increase taking place in the major urban municipalities in the HPA, however, can lead to an increase in energy demand as well as an upsurge in waste generation which in turn can lead to a rise in waste burning activities if waste is not frequently collected.

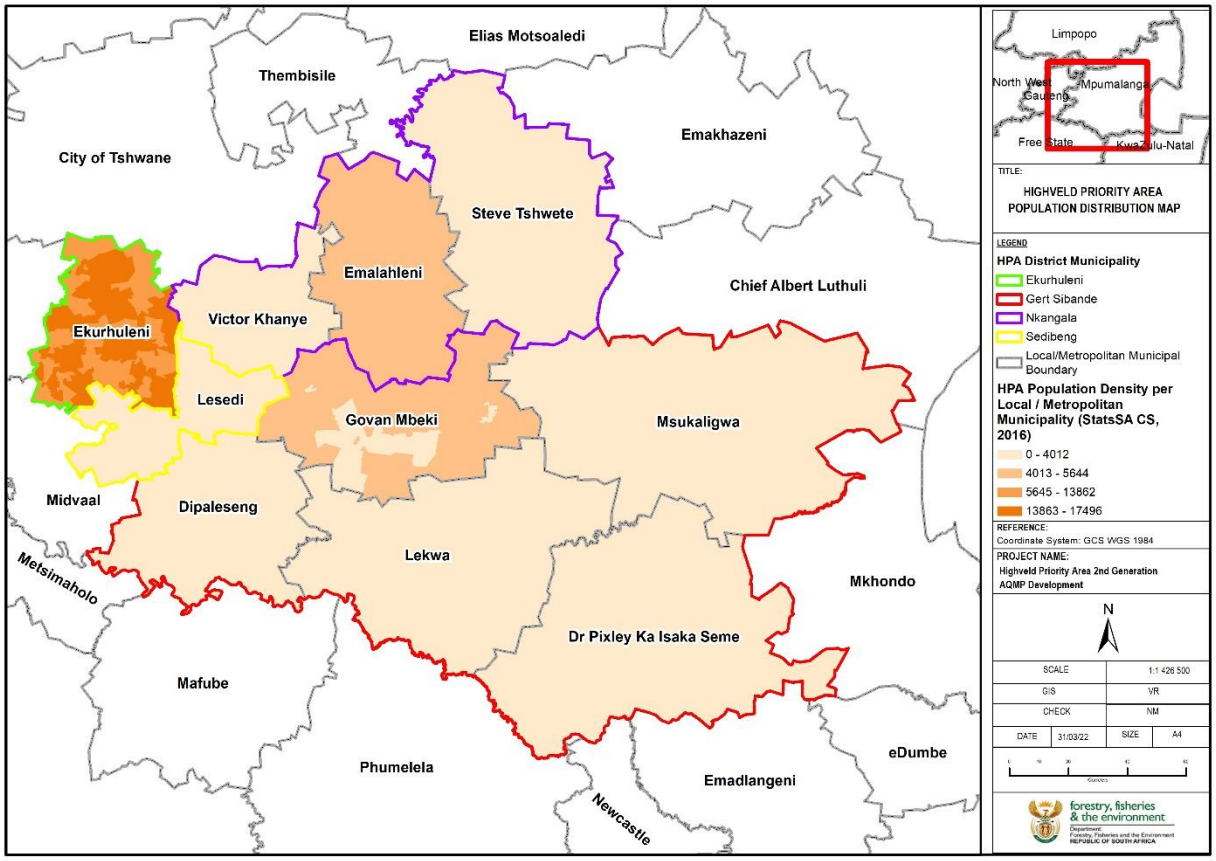


Figure 2-3: Population distribution in the Highveld Priority Area

2.1.4 Electricity access in the Highveld Priority Area

Access to electricity is thought to be a key indicator and contributor to the health impacts associated with air pollution exposure. While there is growing evidence of a decreased reliance on fuel combustion for energy use in the residential environment in South Africa primarily due to increased access to electricity, there is still a need to understand the overall state of electrification in the HPA. Table 2-2 summarises the access to electricity numbers in the Gert Sibande DM, Nkangala DM and the City of Ekurhuleni, respectively, as sourced from the StatsSA 2016 Community Survey (StatsSA, 2016). Additionally, the StatsSA 2016 Community Survey defines "None" as households that have no access to electricity and based on this description are more likely to rely on fuel combustion for energy. Additionally, "Other sources" relates to generators, solar systems, batteries, etc., as alternative sources of energy generation.

Table 2-2 indicates that 89% of residents in the Gert Sibande DM have access to electricity, while 9% of households have no access to electricity. In the Nkangala DM, 86% of households have access to electricity, while 13% of households have no access to electricity. The CoE has a similar electrification profile to that of the Nkangala DM, albeit with more households. In the City of Ekurhuleni, 86% of households are estimated to have access to electricity, while 13% of households have no access to electricity. The high accessibility to electricity in the HPA, however, does not necessarily translate to the total disuse of fossil fuel combustion in those homes (particularly for heating). Rising electricity tariffs coupled with population growth could discourage the complete switch from fossil fuels to electricity, specifically in low-income settlements in the HPA.

Table 2-2: Summary of electricity access per district municipality

Assessment Level	Connected to Electricity		Other Sources		None		Total Households
	Number	%	Number	%	Number	%	
Gert Sibande DM	298 461	89%	4 127	1%	31 227	9%	333 815
Nkangala DM	361 266	86%	5 492	1%	54 386	13%	421 144
City of Ekurhuleni (including Lesedi)	1 147 224	86%	18 239	1%	173 322	13%	1 338 785

2.2 Regional Climate and Atmospheric Dispersion Conditions

Meteorological data from Air Quality Monitoring Stations (AQMSs) in the HPA were accessed from the South African Air Quality Information System (SAAQIS) as an indication of climate and dispersion conditions. Owing to the large number of AQMSs in the HPA, it was necessary to balance the selection of these stations to best spatially represent the HPA, as well as include stations with adequate data availability. Consequently, the AQMSs detailed below are deemed to best represent the climate and atmospheric conditions in the HPA.

2.2.1 Surface Wind Field

The vertical and horizontal dispersion of pollution is strongly influenced by the wind field. Wind speed determines the distance of downwind transport and the dilution rates of pollutants. The generation of mechanical turbulence is similarly a function of wind speed, in combination with surface roughness. Figure 2-4 represents the wind roses for six monitoring stations in the HPA, each with surface wind field data analysed for various periods. There is a predominance of northerly and north-easterly winds at these stations, with average speeds varying between 2 m/s and 7 m/s.

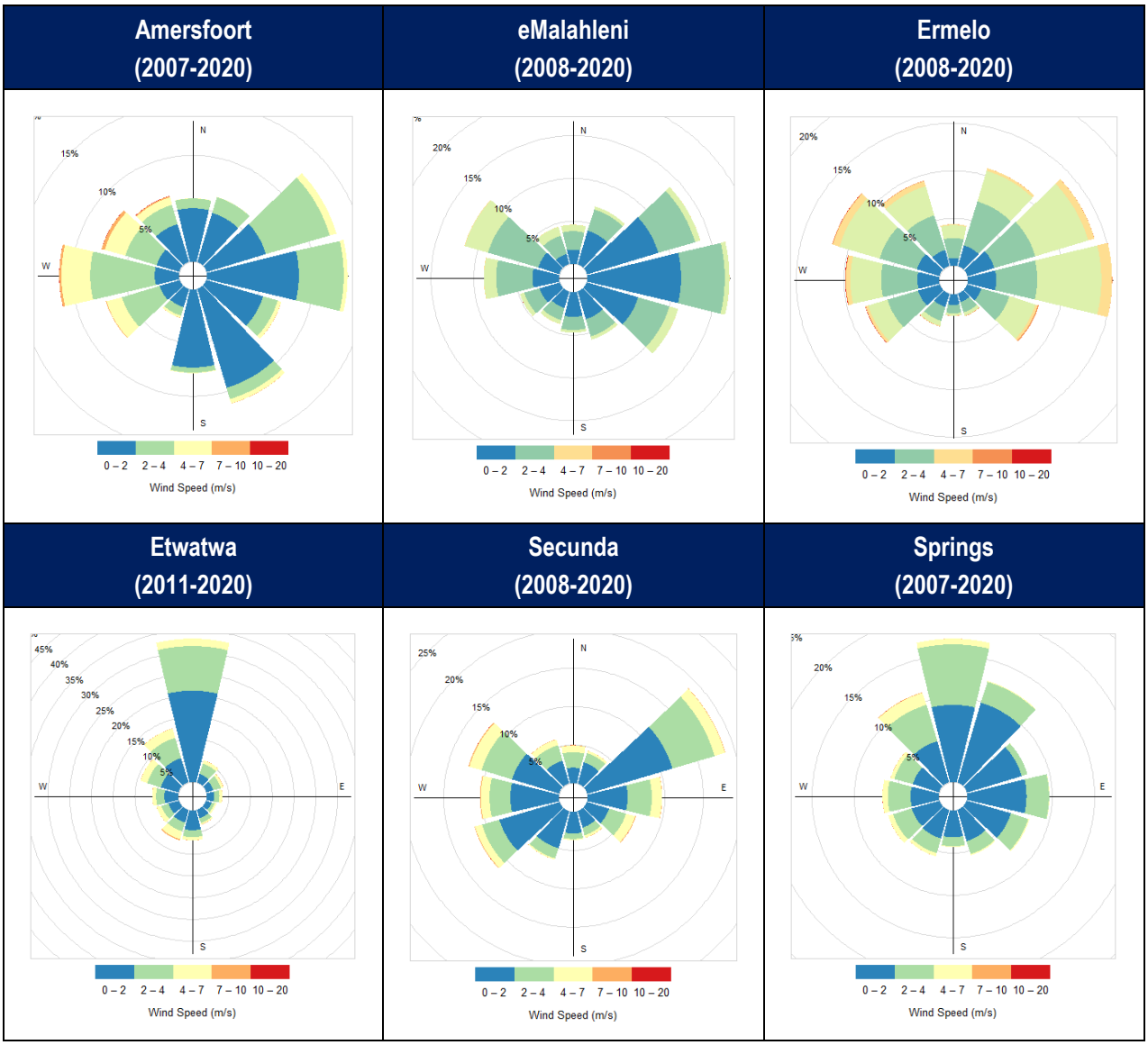


Figure 2-4: Wind roses for selected monitoring stations in the Highveld Priority Area

2.2.2 Temperature

Figure 2-5 summarises the maximum, average and minimum monthly temperatures recorded at selected stations for the data availability period. Average temperatures across the selected stations show that the warmest temperatures are observed between December and February, while the lowest temperatures are observed in June or July.

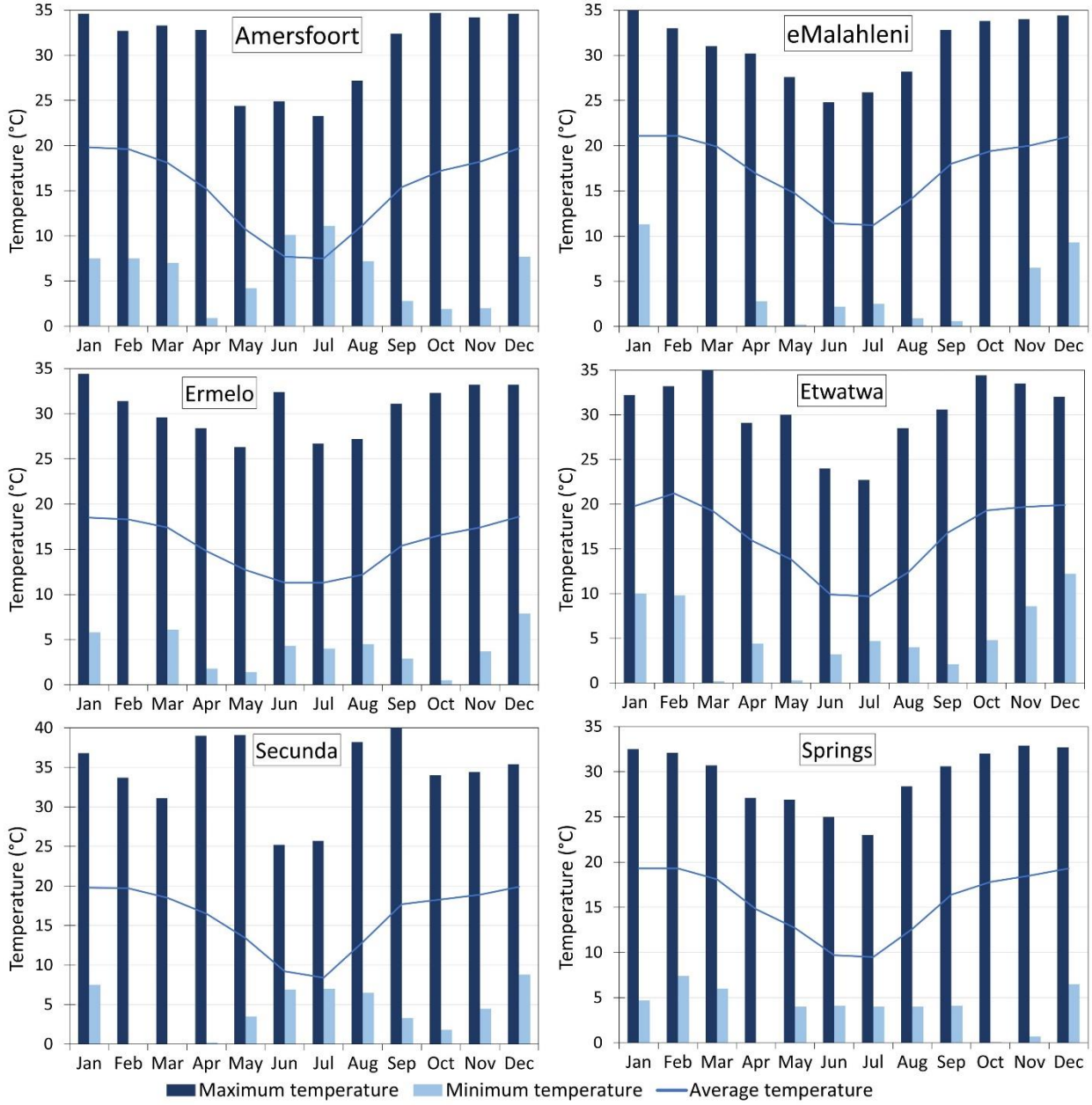


Figure 2-5: Monthly average, maximum and minimum temperatures at selected monitoring stations in the Highveld Priority Area (2007-2020)

2.2.3 Rainfall

As previously discussed above, the large number of AQMSs in the HPA necessitates balancing the selection of these stations to best spatially represent the HPA, including stations with adequate data availability. Consequently, the stations and rainfall detailed in Table 2-3 below are deemed to best represent the rainfall in the HPA, while being cognisant of adequate data availability.

The average rainfall varies across the HPA with higher lying areas in the east averaging approximately 900 mm and approximately 650 mm in the west. Rainfall is almost entirely in the form of showers and thundershowers and occurs mainly in the summer from October to March, with the maximum occurring in January. Winters are typically dry, but some rain occurs (see Table 2-3 below). The total annual rainfall (mm) recorded at selected monitoring stations in the HPA is summarised below.

Table 2-3: Total annual precipitation (mm/annum) at selected monitoring stations in the Highveld Priority Area (2011-2020)

Station	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Camden	589,7	529,7	774,9	374,9	335,3	125,7	67,8	494,9	338,1	-
Elandsfontein	513,7	530,8	-	286,3	167,6	84,0	49,9	495,5	249,1	354,7
Ermelo	1 323,7	1 644,8	303,5	204,0	44,3	47,2	658,8	528,6	599,1	358,1

3. BACKGROUND ASSESSMENT

3.1 Review of the 2012 Highveld Priority Area Air Quality Management Plan

The First Generation HPA AQMP (DEA, 2012) is currently under implementation through continuous support and guidance from the Implementation Task Team (ITT), as well as the Multi-Stakeholder Reference Group (MSRG), which operates as part of the broader governance structure and is a vehicle for facilitating public participation to ensure adequate oversight throughout the initial HPA AQMP implementation journey. A review of the initial 2012 HPA AQMP was necessary to identify the challenges encountered during the development and implementation of the initial AQMP, and to propose suitable alternatives. This is intended to ensure the implementation of lessons learnt and ultimately safeguard improvements in the development and implementation of the Second Generation HPA AQMP.

3.1.1 Emission Sources

The initial 2012 HPA AQMP Emission Inventory quantified emissions from seven emission sources, of which, at the time, mine haul roads were determined to contribute half of all PM emissions. The seven emission sources comprised the following:

- Industry;
- Residential fuel burning;
- Mines and quarries;
- Transport (motor vehicle emissions);
- Biomass burning; and
- Burning and smouldering coal dumps (spontaneous combustion).

Sources, where emissions could not be determined, were landfills, incinerators, wastewater treatment works, tyre burning, biogenic sources, and agricultural dust. While emissions from these sources were not quantified at the time, it was envisaged that the emissions related to these sources would be addressed through the implementation of the 2012 AQMP. The source contribution profile has remained the same between the two inventories (the 2012 and the current inventory) with industrial sources still being the main contributor to SO_2 and NO_X emissions in the HPA.

3.1.2 Ambient Air Quality (AAQ) Monitoring

At the time of the development of the 2012 HPA AQMP, a number of AAQ stations were considered. The baseline characterisation for the AQMP (DEA, 2010a) considered data for the period 2008-2009, as provided by stakeholders who were conducting monitoring in the HPA at that time, namely Eskom and Sasol. Data from the monitoring stations owned by the DFFE and the Mpumalanga Agriculture, Rural Development, Land and Environmental Affairs Department (DARDLEA) at the time were used until a certain period.

The 2012 HPA AQMP considered 23 Air Quality Monitoring Stations (AQMSs) each with different monitoring periods, as well as varying levels of data completion. Of these 23 AQMSs, only data from 10 stations were directly used as input into the dispersion modelling exercise for the three-year period of 2004 to 2006. These ambient AQMSs include the following:

- Kendal;
- Komati;
- Club;
- Langverwacht;
- Bosjesspruit;
- Elandsfontein;
- Leandra;
- Camden;
- Verkykkop; and
- Majuba 1.

3.1.3 Pollution and Health

The 2012 HPA AQMP presented health risk estimates derived from work undertaken by Scorgie, Annegarn and Burger (2004) that were directly relevant to the HPA based on 2002 data for two major areas, namely the Mpumalanga Highveld, and Johannesburg and the City of Ekurhuleni (Scorgie et al., 2004). While rather dated, at the time, the City of Ekurhuleni extended to a far greater population than considered in the extent of the HPA, which is still the case today. The following subsections highlight key findings from the initial 2012 health risk assessments.

3.1.3.1 Health Impact Source Contributions

Source sector contributions to the health risk estimates were estimated for Johannesburg, the City of Ekurhuleni and the Mpumalanga Highveld as conurbations (Scorgie et al., 2004). Respiratory hospital admissions were estimated to result primarily from residential coal, followed by wood burning (56% and 21%, respectively) in Johannesburg and the CoE. Similarly, regarding mortality outcomes, residential coal and wood burning were identified to be significant contributors. Petrol and diesel vehicles were identified to be the overwhelming contributors to leukaemia cases. Power generation activities were estimated to be the primary driver for hospital admissions in the Mpumalanga province, with a 51% contribution, followed by the Sasol Secunda complex at 17% and residential coal burning also made a significant contribution (12%). Similarly, contributions were recorded for mortality outcomes as well. Residential wood burning was the overwhelming contribution to leukaemia cases in the Mpumalanga Highveld, with vehicle emissions contributing very marginally. Point sources within the HPA with significant individual contributions are Highveld Steel and Vanadium and Sasol Secunda.

3.1.3.2 Pollution Exposure Estimates

According to the 2012 AQMP, some inferences can be made on health risk and exposure of populations in the HPA based on the location of hotspots relative to human populations. The City of Ekurhuleni, Emalahleni, Steve

Tshwete, and Secunda are the areas with large populations possibly at risk from the ambient concentrations of SO_2 and PM_{10}. Hospital admissions with respiratory conditions were estimated to be significantly higher in the Johannesburg and CoE conurbation (more than 34 000 cases) when compared to admissions in the Mpumalanga Highveld as a whole (more than 8 600 cases). Similarly, regarding all other health outcomes, with the exception of minor restricted activity days resulting from SO_2 exposure, impacts were approximately three times greater in the Mpumalanga province. Mortality was estimated at 71 deaths in Johannesburg and the City of Ekurhuleni, and 16 deaths in the Mpumalanga province, with unaccounted-for impacts of NO_2 exposure.

The significance of vehicle emissions was also seen in Johannesburg and the City of Ekurhuleni in the high number of cases of leukaemia and lead exposure, which were primarily from vehicle exhausts. Comparatively, in the Mpumalanga province, no excessive lead exposure in children was recorded, although the estimates did not consider proposed lower lead standards in South Africa.

3.1.3.3 Indoor Air Pollution and Health

According to the 2012 AQMP, indoor air quality is affected by outdoor ambient air quality issues through outside ventilation, such as windows and doors, as well as specific indoor sources, particularly residential fuel burning. Exposure to indoor air pollution was associated with several health outcomes, including chronic obstructive pulmonary disease (COPD), lung cancer, nasopharyngeal cancer, tuberculosis, cataracts, asthma, birth defects, and acute lower respiratory infections (ALRI) among children younger than five years (Norman et al., 2007). ALRIs were the leading cause of death of children under five years worldwide, and similarly, fourth highest in South African children.

As indicated in the 2012 AQMP, Norman et al. (2007) found that the total ALRI burden on children under five years was 24% in 2000, attributable to indoor air pollution from household fuel use (Norman et al., 2007). Similarly, for COPD, the female population experienced more than double the male-attributable burden. The lung cancer burden was relatively minor from indoor air pollution as a result of household fuel use. Indoor air pollution from household fuel use was responsible for 2 489 deaths or 0,5% of the total health burden on the individual, which resulted in the loss of 60 934 disability-adjusted life years or 0,4% of the total burden (Norman et al., 2007).

3.1.4 Air Quality Management Capacity

Adequate and sufficient capacity is an important element of implementing Air Quality Management initiatives regardless of the region concerned. To this end, authorities are the main actors with regard to regulation and enforcement, as well as the planning of Air Quality Management actions. It is important to note that while capacity is an overarching principle, capacity needs themselves are differentiated into a number of individual areas, such as skills, human and financial resources, equipment, and working relationships which determine a particular institution's overall level of capacity. In the context of HPA, the two provincial authorities, four districts or metropolitan municipalities, and nine local municipalities had initially completed capacity-related questionnaires as part of the development of the First Generation HPA AQMP. Additionally, the results of the questionnaires were analysed and presented as part of the First Generation AQMP to aid in defining the baseline capacity condition of HPA authorities with the intention of informing the implementation of the First Generation AQMP.

Clear designation of responsibilities is also key for efficient Air Quality Management. Consequently, roles and responsibilities for the different spheres of government, as well as other stakeholders for Air Quality Management are outlined in the NEM: AQA and are described in detail in the “logical implementation plan” developed to support the NEM: AQA, the National Framework for Air Quality Management in South Africa (DEAT, 2007). The National Framework further outlines principal, input, and oversight responsibilities for the three spheres of government, which promotes cooperative governance. The primary roles and responsibilities for the respective spheres of

government and the intergovernmental relationships for AQM are summarised in Table 3-1 for the seven areas of air quality governance. This is particularly relevant to consider in the assessment of capacity, as the development of capacity resources must be appropriate for the expected level of functioning.

Table 3-1: Primary roles and responsibilities for spheres of government in the seven areas of governance (adapted from the 2012 HPA AQMP)

NEM: AQA Governance Function	DFFE	Provincial	Municipalities		
			Metro	District	Local
Functions relating to information management	PR, O	PR, I, O	PR, I	PR, I	PR, I
Functions relating to problem identification and prioritisation	PR	PR	I	I	I
Functions relating to strategy development	PR, O	PR, I, O	PR, I	PR, I	PR, I
Functions relating to standard setting	PR, O	PR, O, I	PR, I	PR, I	PR, I
Functions relating to policy and regulation development	PR	PR, I	I	I	I
Functions relating to authorisations	O	PR	PR	PR	I
Functions relating to compliance monitoring	PR, O	PR, I, O	PR, I	PR, I	PR, I
Key: PR: Principle responsibility in the relevant jurisdiction		I: Input		O: Oversight	

3.1.4.1 Provincial Air Quality Management Perception

An initial capacity assessment undertaken as part of the 2012 HPA AQMP development process found that the Mpumalanga Department of Economic Development and Tourism (MDEDET) and Gauteng Department of Agriculture and Rural Development (GDARD) are both confident to implement the AQA, however, require extensive capacity building. Needs were expressed by MDEDET for capacity building in the areas of monitoring, modelling, emission inventory development and the assessment of emission impacts. GDARD only expressed needs in the development and application of the Atmospheric Emission Licence (AEL) function. Similarly, in 2014, DEA undertook a Status Quo Report for Assessment of the Requirements for Municipalities and Provinces to Fully Undertake Air Quality Functions. The status quo report concludes that it is evident that there are prevailing challenges across the municipal and provincial spheres of government with respect to the full implementation of the NEM: AQA. The report demonstrated that the effectiveness of Air Quality functions is significantly impacted by three factors i.e., human resource constraints: insufficient or no budget allocation and inadequate technical resources. Equally, these three factors are crucial to the effective execution of primary air quality management functions of municipalities taking into account both specific requirements under NEM: AQA and the governance cycle which are essentially linked to the functions detailed in Table 3-1 above.

3.1.4.1 Gauteng Province

The Gauteng Province is comprised of three (3) Metropolitan Municipalities i.e., City of Tshwane, City of Johannesburg, and Ekurhuleni Metro and two (2) District Municipalities i.e., Sedibeng DM and West Rand DM with

the City of Ekurhuleni and the Sedibeng DM falling within the HPA. The Gauteng province is currently in the process of developing the Second Generation AQMP for the province.

City of Ekurhuleni

According to the questionnaire responses, industries are a high priority air quality issue due to the hosting of 210 Scheduled Process industries as per the DEA database, with 5000 – 6000 these industries located in the City including non-regulated industries which is a symptom of a significant permit backlog. Motor vehicles are also high priority air quality issue, particularly diesel vehicles, with roadside testing being conducted two or three times a week with petrol vehicles remaining a challenge to address in the municipality. Residential fuel burning is also a high priority air quality issue with demonstration projects for BnM being conducted in informal settlements for over six years.

Key Air Quality Management Capacity and Practices are summarised from the First Generation HPA AQMP as follows:

- An Air Quality Officer, responsible for coordinating AQM activities, has been appointed in the City.
- Air Quality Management function is placed within the Environmental Health department of the municipal structure, where it is a full-time function.
- The metro is confident about the implementation of the AQA, however, requires capacity building in some areas. These include monitoring, enforcement, licensing, dispersion modelling and process design.

Sedibeng District Municipality

According to questionnaire responses, industries are an air quality issue in the Lesedi municipality of Sedibeng district. However, the district accorded it a medium priority, while officials from Lesedi rated it a high priority, particularly due to smoke and odours. Lesedi experiences air quality issues due to heavy vehicles travelling from Durban, with smoke and non-specified gas emissions. Residential fuel burning is a high priority in the local municipality, and in the surrounding townships, with the burning of coal, tyres and waste experienced. Mining and quarries are a low priority for Lesedi with problematic dust emissions identified. Agricultural burning is also a medium priority, with planned and spontaneous veld fires experienced. Tyre burning is a medium air quality priority, with smoke emissions listed. Farming activities are a high priority, particularly livestock such as cattle, chickens, and pigs, and it can be inferred that it is largely an odour issue.

Key Air Quality Management Capacity and Practices are summarised from the First Generation HPA AQMP as follows:

- Sedibeng has an appointed AQO; however, Lesedi has had an individual nominated by the district municipality though not officially designated in terms of the NEM: AQA.
- Sedibeng handles AQM through the Environmental Management department. Lesedi has various functions related to AQM spread across 3 departments. Environmental Health is responsible for assessing building plans, handling complaints and routine inspections In Lesedi.
- Both Sedibeng and Lesedi have indicated that they are confident to implement the NEM: AQA, however, require extensive capacity building. Sedibeng has expressed needs in monitoring, enforcement, and licensing, whereas Lesedi requires broader initiatives in all areas of AQM.

3.1.4.2 Mpumalanga Province

The Mpumalanga Province is comprised of three District Municipalities i.e., Ehlanzeni DM; Nkangala DM and Gert Sibande DM with certain Local Municipalities in both the Nkangala DM and Gert Sibande DM falling within the

HPA. While the provincial AQMP is still under development, an AQMP is currently being developed for the Nkangala DM whereas an AQMP has been finalised for the Ehlanzeni DM.

Nkangala District Municipality

Questionnaire responses show that major industries in the Nkangala area are the major source of emissions; these include Eskom, Columbus, Highveld Steel, Samancor, Rand Carbide, Vanchem, and Sasol. Industries were highly prioritised in all areas, with the exception of Delmas, since the region is more associated with chicken rearing at broiler houses. Motor vehicles are a medium priority in the district, with the major issues being coal and freight haulage. Coal trucks are associated with dust and emissions, with freight vehicles using Emalahleni town to bypass the tolling point. Vehicles with poor emission controls such as trucks and bakkies were also identified. Residential fuel burning varied between high and low priority across the municipalities in the district. It is particularly problematic in the winter, with smoke emissions from the primary fuel type, coal. The district municipality identified 5 settlements that are problematic in the winter and a single settlement in the summer. Mining and quarries are an air quality issue in all municipalities, particularly as the result of opencast coal mining, with dust fallouts experienced. The district municipality raised mining as a high priority, with varying degrees of emphasis by the local municipalities. Tyre burning is also a medium to low priority across the district, with burning carried out informally, as part of illegal dumping practices of recyclers and tyre companies. Emalahleni and Steve Tshwete experience tyre burning mostly in winter and at night.

Key Air Quality Management Capacity and Practices are summarised from the First Generation HPA AQMP as follows:

- Both the Nkangala DM, as well as the Delmas LM, have not appointed an AQO, which was underway at the time. Emalahleni and Steve Tshwete have appointed an AQO.
- All municipalities within the district are confident about the implementation of the NEM: AQA provisions provided some capacity building is undertaken, with Emalahleni indicating that comprehensive capacity building is needed. On the other hand, Nkangala would like to clarify their organisational structure before further efforts in AQM can be undertaken. Emalahleni highlighted a large number of needs, including in monitoring, legal, AQM, enforcement, licensing, emission inventories, and Environmental Management Inspector (EMI) training. Steve Tshwete expressed capacity building needs in the areas of monitoring, licensing, emission inventory development, and general areas of AQ

Gert Sibande District Municipality

Within the district, industries are ranked as a high priority, with Dipalaseng and Lekwa confirming the ranking. The district municipality lists petrochemical industries specifically as significant sources. Govan Mbeki did not provide a ranking but listed the Sasol plant, mines, and small industries as sources. Lekwa identified a power station in the municipality. Msukaligwa and Pixley ka Seme municipalities ranked industries as a low priority, with small industries and dry-cleaning operations being respective local sources. The district municipality also ranked motor vehicles as a high priority, particularly coal trucks, which was reiterated by Govan Mbeki, Lekwa and Msukaligwa. Govan Mbeki also listed daily spray activity as a related source. Pixley ka Seme experienced air quality issues related to CO emissions from heavy vehicles. Residential fuel burning is also a high priority for the district, with coal burning and stoves listed as a source in Govan Mbeki, Lekwa, Msukaligwa and Pixley ka Seme. Wood is an additional fuel used in Lekwa, and general fossil fuels are used in Pixley ka Seme. Wesselton is mentioned specifically as a problem area in Msukaligwa.

Mining and quarries are regarded as a medium priority source across the district and are associated with dust emissions. Gold and coal mining are significant activities in Govan Mbeki. Dipaleseng listed the power station as

a source in this category, possibly alluding to the coal mining operations that support power generation activities. Lekwa also experienced deep mining. Agricultural burning is a medium priority for the district, related to grazing fields, fire breaks and forestry. Dipaleseng and Pixley ka Seme experienced agricultural burning, with spontaneous veld fires being problematic in Pixley ka Seme. Tyre burning is regarded as a low priority in the district, with Govan Mbeki experiencing incidents with burning at dumpsites, and Pixley ka Seme recording incidents with small quantities of tyres burnt at landfill sites. Odour is problematic at Govan Mbeki due to H_2S and Sasol Secunda Synfuels tar products, and at Lekwa from poultry abattoir and wastewater treatment works. The only additional issue raised was noise in Govan Mbeki.

Key Air Quality Management Capacity and Practices are summarised from the First Generation HPA AQMP as follows:

- An AQO has been appointed at the district level, and in Govan Mbeki, Lekwa and Msukaligwa Local Municipalities. Dipaleseng has no dedicated air quality personnel, and the municipality is in the process of filling staff vacancies.
- Only the district municipality indicated they were fully confident about NEM: AQA implementation, with Govan Mbeki, Msukaligwa, and Pixley ka Seme requesting some capacity building in preparation for implementation. The district municipality expressed capacity-building needs for dispersion modelling and data analysis skills, Govan Mbeki with chemical and monitoring skills, Lekwa with monitoring and legal skills, including data analysis and operation, Msukaligwa for general Air Quality Management skills, and Pixley ka Seme with monitoring skill.

3.2 Highveld Priority Area Health study

A human health risk assessment (HHRA) was conducted to determine the potential for health effects from ambient air pollution on communities in the HPA. The study was commissioned by the DFFE with the purpose of assisting the department in making informed decisions on air quality management in the area. The study comprised both local and regional assessments to have a better understanding of the risk and impacts of air pollution on human health in the HPA.

For this purpose, the report investigated the exposure of communities living in close proximity to AQMSs and sources of SO_2, NO_2, particulate matter PM_{10} and $PM_{2.5}$. The study had three main assessments undertaken which include:

- Human Health Risk Assessment;
- Vulnerability Assessment (including a focus on children); and
- Impact Assessment.

As part of the HHRA, the project identified the potential for human health risks for the population in the entire HPA, related to the physical and/or chemical properties of air pollutant concentrations. The exposure of communities to ambient air pollution is estimated using air quality modelling output.

As part of the Vulnerability Assessment, the regional study involved the assessment of human health risks resulting from exposure to air pollution. Local studies comprised a community survey in seven communities (eMalahleni, Ermelo, Etwatwa, Grootvlei, Middelburg, Tembisa and Tsakane) within the priority area and a child health study.

Finally, the study details the results of the Impact Assessment to determine the potential health impacts associated with pollution levels, using appropriate exposure-response functions. Each of the main assessments is summarised below.

3.2.1 Human Health Risk Assessment

Gridded AAQ concentrations (for SO_2, NO_2, PM_{10} and $PM_{2.5}$) were simulated for 2016 using the Chemical Transport Model CAMx. These simulations were conducted over a region larger than only the HPA to account for the influence of transboundary transport of pollutants into and out of the HPA. The values of the gridded ambient air pollutant concentrations were then spatially aggregated to the small area level (SAL) as Census data is provided only in SAL units. In this spatial aggregation process, the maximum value within a SAL unit was used.

The HHRA was then done by relating the simulated ambient concentrations of pollutants to their respective NAAQS. This involved quantifying risk in terms of a Hazard Quotient (HQ). HQ describes the potential risk to human health for non-cancer health effects from exposure to air pollution. The HQ is calculated by dividing the ambient concentration (in other words, exposure) by the relevant benchmark (in other words, NAAQS). An HQ less than or equal to one indicates a negligible risk to human health. An HQ above one indicates that there is a potential risk to human health, as the simulated ambient concentrations exceed the benchmark. The HQ was calculated per SAL.

Simulated HQs for SO_2 reveal that values above one are located in the central and towards the eastern parts of the HPA. Based on the simulated HQs, the communities most at risk are primarily located near intense industrial SO_2 emitters. HQs determined for SO_2 based on the 99th percentile of hourly concentrations indicate a maximum value of 3 and those determined from the 24-hr average concentrations of SO_2 show a maximum value of 4.5. Simulated HQs for PM_{10} based on the 99th percentile daily averages show that a large portion of the western part of the HPA is at potential risk for negative impacts on health from exposure to PM_{10}. The small regions with larger HQs (greater than 5) fall within the City of Ekurhuleni Metro and the Govan Mbeki LM boundaries. Similarly, simulated HQs for PM_{10} based on annual averages indicate that the areas at risk include the City of Ekurhuleni Metropolitan Municipality, the Govan Mbeki LM, and the Msukaligwa LM.

3.2.2 Vulnerability Assessment

The vulnerability of communities to air pollution was assessed by deriving scores that measure the relative pollution burdens and vulnerabilities in one Census tract at Small Area Level (SAL), compared to other SALs. This involved the use of proxy indicators for population characteristics derived from Census 2011 data. The CalEnviroScreen 3.0 (California Office of Environmental Health Hazard Assessment, 2017) was used as a guide to select relevant and readily available indicators of population characteristics and pollution burden. The resultant output from the vulnerability assessment were three score measures, which included the aggregated population characteristics, pollution burden population-unadjusted vulnerability score, and population-adjusted vulnerability score. Based on the population characteristic score, the people who were found to be relatively more vulnerable to air pollution and the ability to cope with the effects of air pollution due to their population characteristics, are located largely in the Msukaligwa and Pixley Ka Seme LMs, followed by the Lekwa LM, with smaller pockets in most other LMs. The population-unadjusted vulnerability score reveals that the City of Ekurhuleni and the Govan Mbeki LM are vulnerable areas of concern. This score is derived by adding the pollution burden (represented by PM_{10} HQ) to the population characteristics score. The population adjusted vulnerability score puts the situation into perspective in terms of where most people reside. Based on this score, the main vulnerable area of concern is the City of Ekurhuleni. This is due to the contribution of the pollution burden and the area having a relatively high density of vulnerable population groups. These include the following:

- The proportion of children (those below 15 years of age) and the elderly (those above 65 years of age) as their physiological systems are respectively underdeveloped and declining.

- The proportion of the population in an area on chronic medication was used as an indication of people with existing diseases that may make them more vulnerable to air pollution, as asthma data per SAL were not readily available.
- Overcrowding was determined by household density, where the proportion of the population who live in a house where there are more than three people per room, because overcrowding may lead to transmission of diseases, including respiratory diseases such as tuberculosis, which render them sensitive to air pollution. The proportion of people who live in houses where no electricity is used for cooking or heating, in other words, people who will use residential fuel for cooking and/or heating and, therefore, be exposed to indoor pollution, was used.

3.2.3 Impact Assessment

A health impact assessment was performed to determine the impact of air pollution on mortality rates at the LM level in the HPA. This involved aggregating simulated 95th percentile ambient air pollution concentrations from SAL units to LM levels. The 95th percentile value is considered a conservative estimate of the concentration values in the LMs. Mortality attributed to air pollution was determined for two scenarios, which include the baseline scenario for PM_{10} and $PM_{2.5}$, and the NAAQS threshold scenario for PM_{10} and $PM_{2.5}$. StatsSA population, mortality data, and the modelled ambient concentrations were used as input in the baseline scenario. The NAAQS threshold scenario involved calculating the mortality rate if the LM met the current PM NAAQS. The PM_{10} and $PM_{2.5}$ attributable mortality decrease in meeting the annual NAAQS were then estimated by multiplying the calculated change in mortality rate between the baseline and the NAAQS threshold scenario by the population per LM. This can be interpreted as how many fewer people would have died if the annual NAAQS for PM_{10} and $PM_{2.5}$ had been met in the LM. The estimated attributable mortality decrease in meeting the annual NAAQS for PM_{10} is 5 125 people and 4 881 people for $PM_{2.5}$.

The largest percentage attributable deaths from not meeting PM_{10} annual NAAQS occur in the CoE and the Govan Mbeki LM. If the annual NAAQS for PM_{10} is met, all-cause mortality in the CoE is expected to decrease by 18,75% For $PM_{2.5}$, the largest percentage attributable deaths from not meeting $PM_{2.5}$ annual NAAQS occur in the CoE. If the annual NAAQS for $PM_{2.5}$ are met, all-cause mortality in the CoE is expected to decrease by 16,62%

3.3 Legislative Updates and Development

There have been substantial legislative changes since the initial HPA AQMP was developed, which are intended to further strengthen the usability of the NEM: AQA in terms of managing and reducing air pollution in South Africa. Naturally, the interventions developed at the time, in other words, 2012, were not cognisant of these additions and must, therefore, be considered during the development of the Second Generation HPA AQMP. Each of the revised or newly developed portions of legislation are chronologically detailed below.

3.3.1 Legislative Amendments

3.3.1.1 National Environmental Management: Air Quality Amendment Act, 2014 (Act No. 20 of 2014)

An amendment of the NEM: AQA (Republic of South Africa, 2014) was undertaken so as to substitute certain sections; to provide for the establishment of the National Air Quality Advisory Committee; to provide for the consequences of the unlawful commencement of a listed activity; to provide for monitoring, evaluation and reporting on the implementation of an approved pollution prevention plan; to empower the MEC or Minister to take a decision on behalf of the licensing authority under certain circumstances; to provide for the Minister as licensing authorities in situations where the province, as a delegated licensing authority by the municipality, is the applicant for an atmospheric emission licence, where the applications are transboundary, where the air activity forms part of a national priority project, where the activity is also related to the environmental impact and waste management activities authorised by the Minister, where the air activity relates to a prospecting, mining, exploration or production

activity; to delete cross-references to the Environmental Conservation Act, 1989; to clarify that applications must be brought to the attention of I&APs soon after the submission to the licensing authority; to provide for a validity period of a provisional atmospheric emission licence; to create an offence for non-compliance with controlled fuels standards; to provide for the development of regulations on climate change matters and the procedure and criteria for administrative fines; to delete certain obsolete provisions; and to provide for matters connected therewith.

3.3.1.2 National Environmental Management Laws Amendment Act, 2022 (Act No. 2 of 2022) Amendment of section 47A of NEM: AQA

In the overall context of environmental protection as part of NEMA (Republic of South Africa , 2022), various legislations were amended to provide the Minister with the discretion to establish the National Air Quality Advisory Committee; to provide clarity on the consequences of the unlawful commencement of a listed activity; to provide clarity that a provincial department responsible for environmental affairs is the licensing authority where a listed activity falls within the boundaries of more than one metropolitan municipality or more than one DM; to provide for textual amendment to section 36(5)(d); and to provide for revocation or suspension of atmospheric emission licence.

3.3.2 Declarations

3.3.2.1 Declaration of Small Boiler as a Controlled Emitter and Establishment of Emission Standards

The Declaration of a Small Boiler as a Controlled Emitter and Establishment of Emission Standards was promulgated, on 1 November 2013 (DEA, 2013b) under NEM: AQA. This notice declared that boilers with design capacities equal to or greater than 10 MW thermal input, but less than 50 MW thermal input per unit be classified as "small boilers". Emission limits were specified for these "small boilers" depending on the fuels that they were burning. The notice required that these "small boilers" undergo annual stack emission measurements and that annual emission results be submitted by the operators of "small boilers" to the Air Quality Officer (AQO).

3.3.2.2 Declaration of Greenhouse Gases as Priority Air Pollutants

In the overall context of air quality management as part of NEM: AQA (DEA, 2017d), it was necessary for certain GHGs to be regarded as priority pollutants. The following GHGs are declared priority air pollutants in terms of section 29(1)(a) of NEM: AQA: (a) Carbon dioxide ($C0_2$); (b) Methane (CH_4); (c) Nitrous oxide (N_20); (d) Hydrofluorocarbons (HFCs); (e) Perfluorocarbons (PFCs); and (f) Sulphur hexafluoride (SFG).

3.3.3 Regulations

3.3.3.1 National Dust Control Regulations

The National Dust Control Regulations, 2013, (DEA, 2013a) were established to give effect to section 32 of the NEM: AQA, which provides for "the Minister or MEC to prescribe: measures for the control of dust, in specified places or areas, either in general or by specified machinery or in specified instances; steps that must be taken to prevent nuisance by dust; or other measures aimed at the control of dust".

These Regulations were put in place to control all significant dust that, after initial dust-fall monitoring, were found to have exceeded the two-bands dust fall rates set. The National Environmental Management Act, 1998 (NEMA) prescribes the principle of the best practicable environmental option which formed the basis of the National Dust Control Regulations to ensure that each dust generator chooses mitigation measures that are best suited for their dust source. The implementation of the dust management plan and monitoring programme was prescribed as measures for the prevention, mitigation, and compliance assessment.

3.3.3.2 National Atmospheric Emission Reporting Regulations

The National Atmospheric Emission Reporting Regulations, (DEA, 2015) were established for reporting data and information from identified point, non-point and mobile sources of atmospheric emissions to an Internet-based National Atmospheric Emissions Inventory System towards the compilation of atmospheric emission inventories.

3.3.3.3 National Greenhouse Gas Emission Reporting Regulations

The National Greenhouse Gas Emission Reporting Regulations, (DEA, 2017b) were established to introduce a single national reporting system for the transparent reporting of greenhouse gas (GHG) emissions, which will be used (a) to update and maintain a National Greenhouse Gas Inventory; (b) for the Republic of South Africa to meet its reporting obligations under the United Framework Convention on Climate Change (UNFCCC) and instrument treaties to which it is bound; and (c) to inform the formulation and implementation of legislation and policy.

3.3.3.4 National Pollution Prevention Plans Regulations

Under the Pollution Prevention Plans Regulations (DEA, 2017c), the first Pollution Prevention Plan prepared specifically for the mitigation of GHGs emitted from the listed production processes (for example, coal mining, production and/or processing of natural gas, iron and steel production) was to cover the period from the date of promulgation of these Regulations until 31 December 2020. As this date is approaching, affected companies conducting the listed production processes are required to reconcile their pollution prevention plans, and to develop and finalise new plans for the subsequent phase covering the period 1 January 2021 to 31 December 2025.

3.3.3.5 Proposed Regulations for Implementing and Enforcing Priority Area Air Quality Management Plans

In the overall context of air quality management as part of NEM: AQA (DFFE, 2021), it was necessary for Regulations to prescribe requirements for implementing and enforcing priority area AQMPs. The Regulations detail the requirements necessary for implementing and enforcing approved priority area AQMPs, including funding arrangements, measures to facilitate compliance with such plans, penalties for any contravention of or any failure to comply with such plans and the regular review of such plans.

4. AIR QUALITY MONITORING

Ambient monitoring provides a measure of the efficacy of interventions implemented towards compliance with NAAQS. To assess whether the area is in compliance with the NAAQS, there are several AAQ monitoring stations that monitor criteria pollutants. The NAAQS indicate safe exposure levels for the population, including vulnerable groups, such as children and the elderly. Figure 4-1 illustrates all the ambient AQMS located within the HPA. Details of these stations are provided in Annexure A.

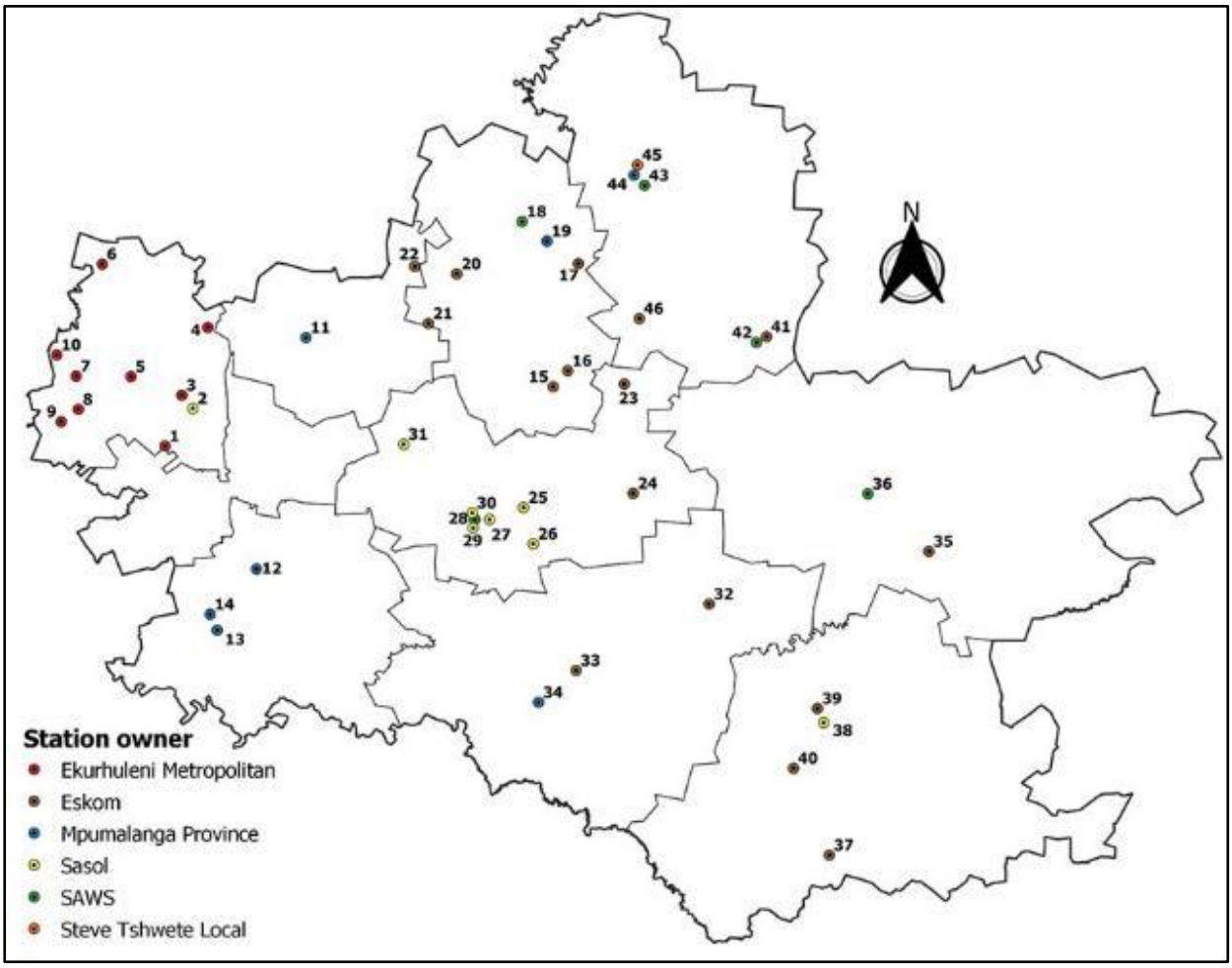


Figure 4-1: Location of ambient air quality monitoring stations in the Highveld Priority Area

Since the declaration of the HPA and subsequent development of the AQMP, there has been an improvement in AAQ monitoring. The number of monitoring stations have increased from 23 to 49 (reporting on SAAQIS).

An assessment of historical AAQ data (2007-2020) for the Gert Sibande DM, Nkangala DM, as well as the CoE, is provided below.

4.1 Long-term Air Quality Data Trend Snapshots

Sections 4.1.1 to 4.1.8 detail the annual air quality concentration trends for the Gert Sibande and Nkangala DMs and the CoE Metropolitan Municipality, respectively. However, long-term trends were generated to understand the variability of monthly averages (using the OpenAir "smooth trend" function with the option to de-seasonalise the data and bootstrap simulations to estimate a 95% confidence interval) (Carslaw, 2015). One advantage of using monthly average concentrations is that the smoothness in the trend is optimised such that it is neither too smooth (therefore missing important features), nor too variable (perhaps fitting "noise", rather than real effects).

4.1.1 Sulphur Dioxide (SO_2)

Regarding sulphur dioxide (SO_2), Figures 4.2 to 4.4 exhibit that there have been continuous and consecutive periods of compliance at most of the monitoring sites, with 2014 showing SO_2 exceedances occurring in at least one monitoring site of the monitoring networks presented here. It is evident from the figures that incidences of SO_2 exceedances were more apparent in the Nkangala DM monitoring network and even more so prior to 2014. Though there is a recognisable inter-annual fluctuation in the SO_2 concentrations, most stations have generally demonstrated a decreasing trend in SO_2 concentrations since 2014, more importantly for monitoring stations in the Nkangala and Gert Sibande DMs. There is no clear long-term trend in the City of Ekurhuleni monitoring network as the stations are mostly characterised by a strong inter-annual fluctuation, with one monitoring station in Tsakane revealing an increasing trend of SO_2 over time.

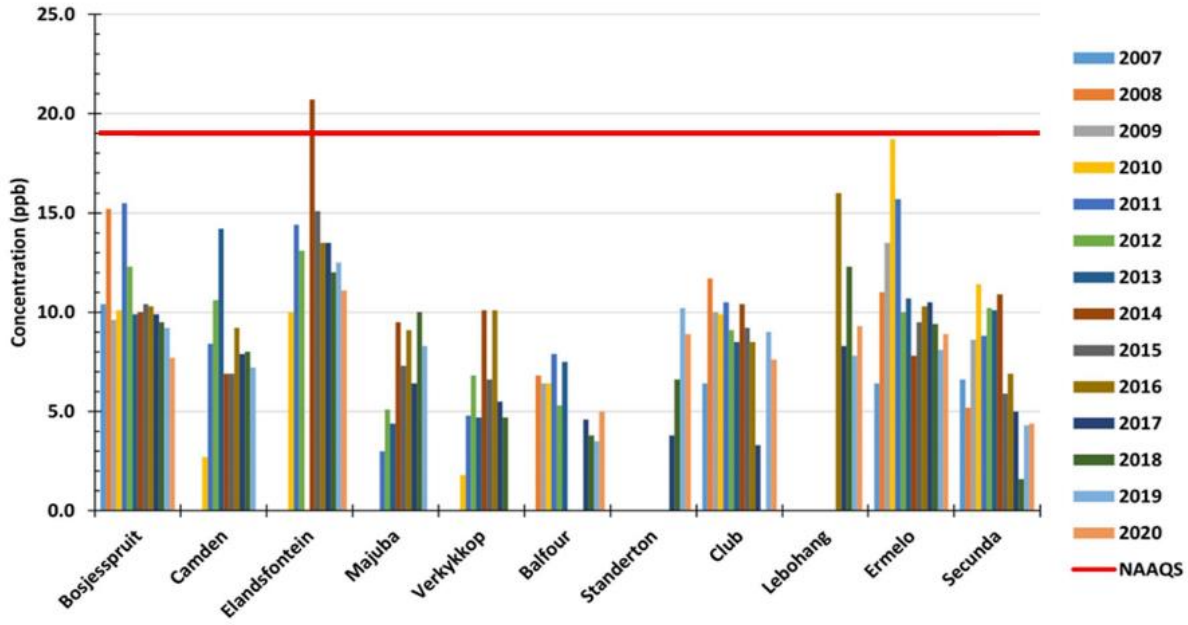


Figure 4-2: Annual average SO_2 concentrations at the Gert Sibande District Municipality air quality monitoring station between 2007 and 2020 (NAAQS:19 ppb)

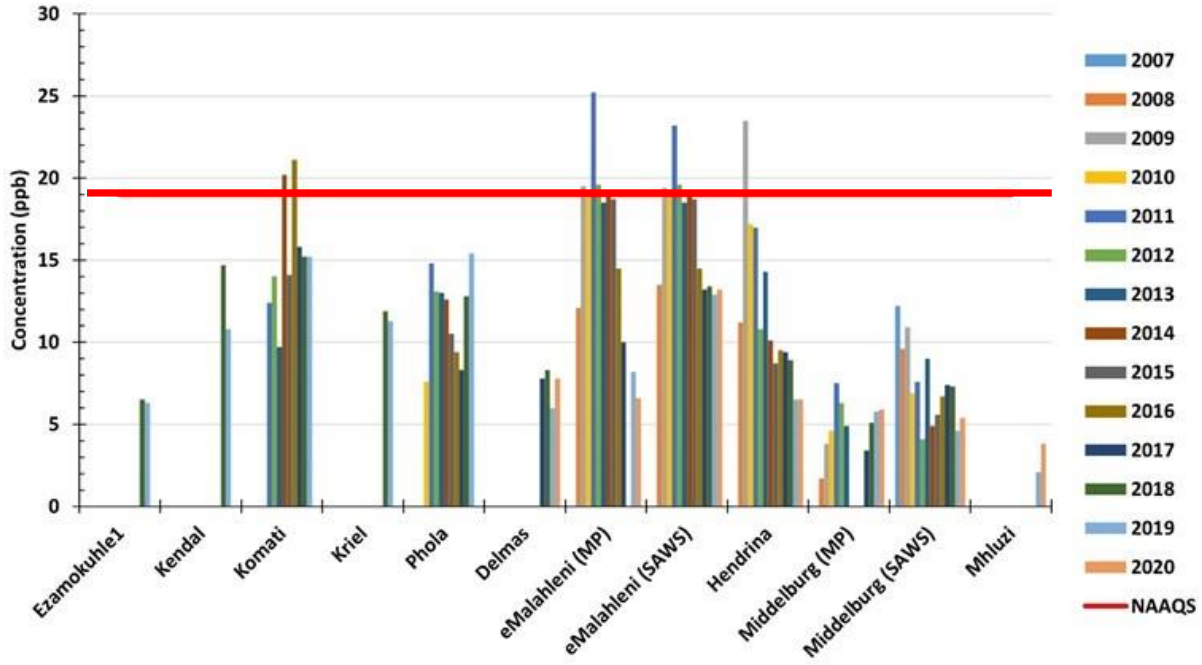


Figure 4-3: Annual average SO_2 concentrations at the Nkangala District Municipality air quality monitoring station between 2007 and 2020 (NAAQS:19 ppb)

Figure 4-3 indicates that a majority of AQMSs in the Nkangala DM were determined to illustrate continuous and consecutive periods of compliance with an instance of non-compliance noted at both the eMalahleni and Komati stations with a single non-compliance noted at Hendrina in 2009.

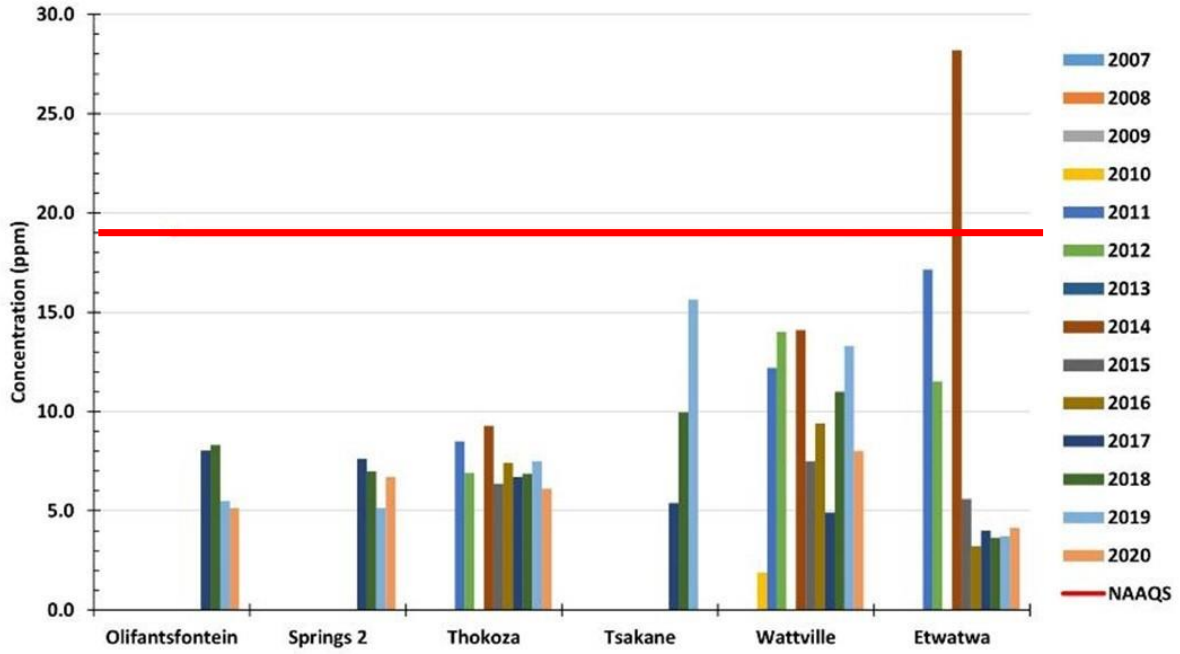


Figure 4-4: Annual average SO_2 concentrations at the City of Ekurhuleni air quality monitoring station between 2007 and 2020 (NAAQS:19 ppb)

4.1.2 Particulate Matter (PM_{10})

Regarding PM_{10}, as presented in Figures 4-5 to 4-7, PM_{10} concentrations were in exceedance of the NAAQS at all the stations at least once over the period of analysis, with a significant number of stations continually exceeding the limit value for almost all the years. A decreasing trend of PM_{10} concentrations is observed for stations in Camden, Verkykkop and Grootvlei (since 2014), as well as in Elandsfontein (since 2015), while the rest of the stations have been characterised merely by interannual variability. The plots also reveal that there was a distinct increase in PM_{10} concentrations during 2018 and 2019 at most of the stations. Generally, lower PM_{10} concentrations were observed across the monitoring stations in 2017; however, five of the six stations in the City of Ekurhuleni still experienced exceedances during this period.

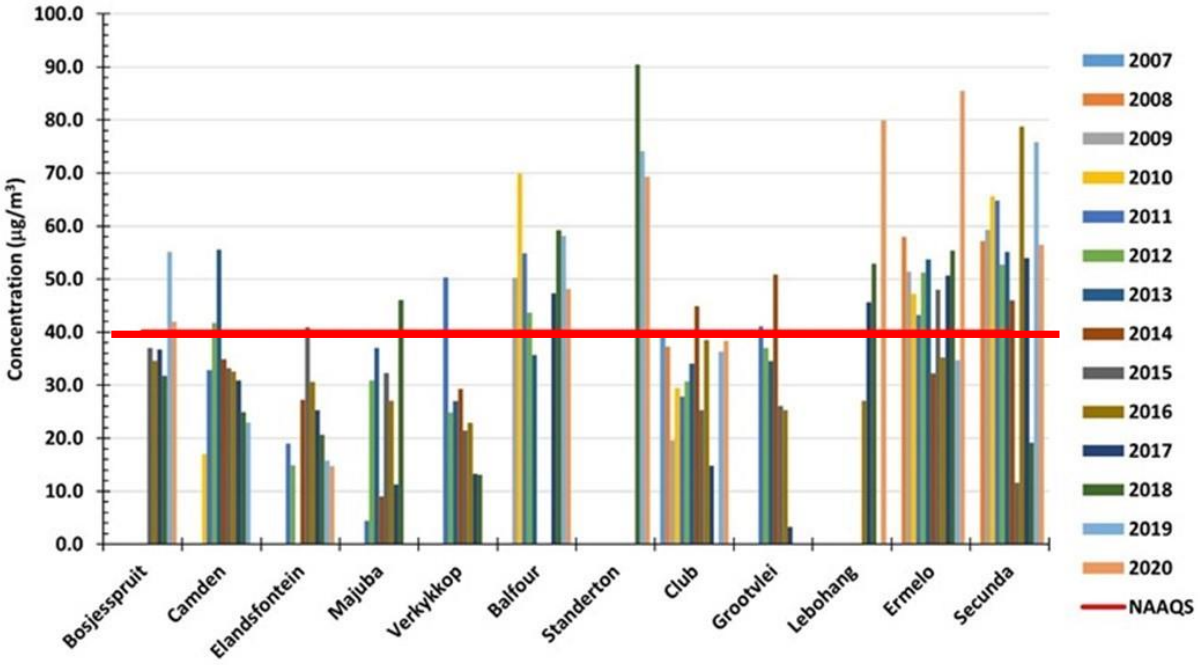


Figure 4-5: Annual average PM_{10} concentrations at the Gert Sibande District Municipality air quality monitoring station between 2007 and 2020 (NAAQS:40 µg.m^{-3})

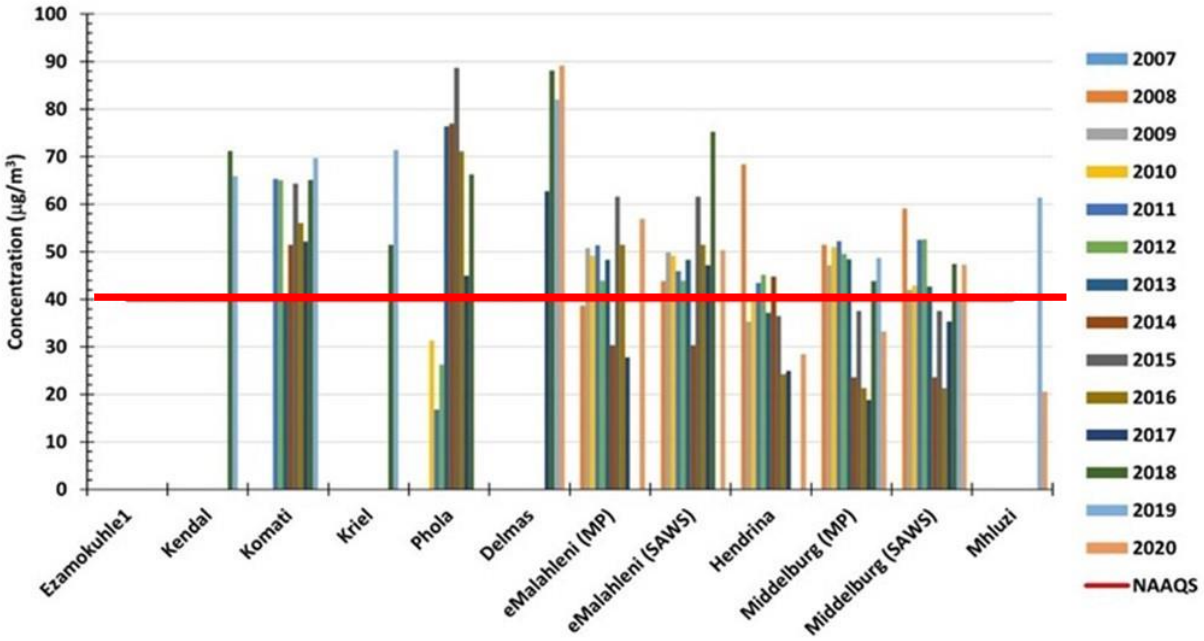


Figure 4-6: Annual average PM_{10} concentrations at the Nkangala District Municipality air quality monitoring stations between 2007 and 2020 (NAAQS:40 µg.m^{-3})

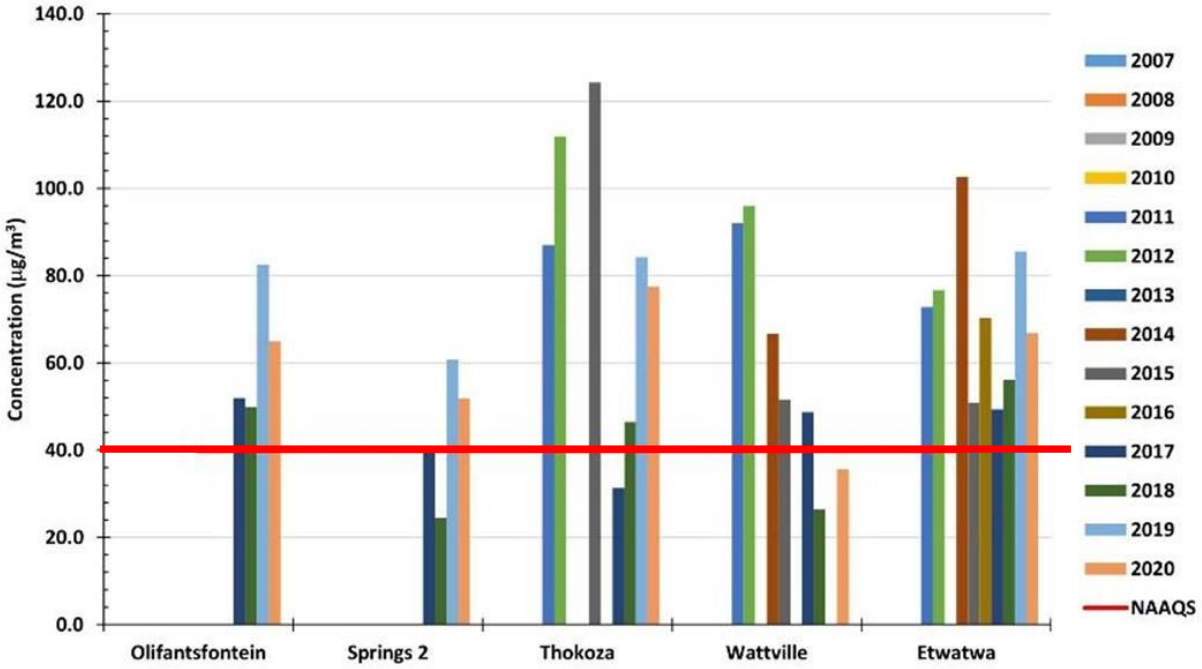


Figure 4-7: Annual average PM_{10} concentrations at the City of Ekurhuleni air quality monitoring station between 2007 and 2020 (NAAQS:40 µg.m^{-3})

4.1.3 Particulate Matter ($PM_{2.5}$)

The $PM_{2.5}$ ambient concentrations show a similar character to that of the PM_{10} concentrations. From Figures 4-8 to 4-10, it is revealed that $PM_{2.5}$ exceedances are frequent at most of the stations during the period under review. Significant $PM_{2.5}$ annual average concentrations are also noted during 2018 and 2019. Again, relatively lower concentration values of $PM_{2.5}$ were measured at the Gert Sibande and Nkangala DMs during 2017, while there were no $PM_{2.5}$ observations at the City of Ekurhuleni during the same year.

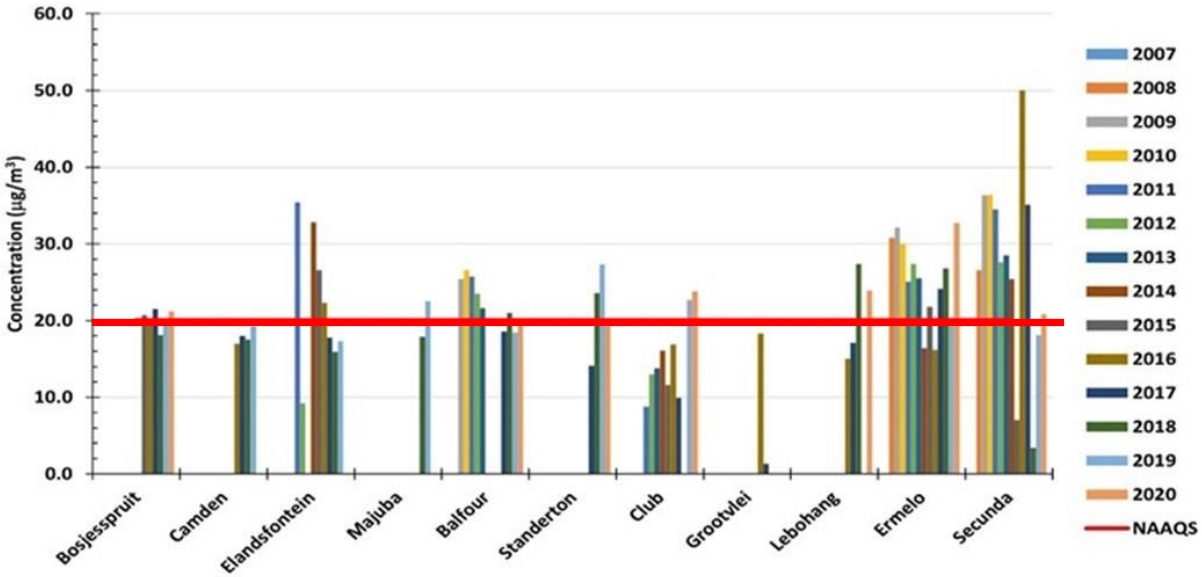


Figure 4-8: Annual average $PM_{2.5}$ concentrations at the Gert Sibande District Municipality air quality monitoring station between 2007 and 2020 (NAAQS:20 µg.m^{-3})

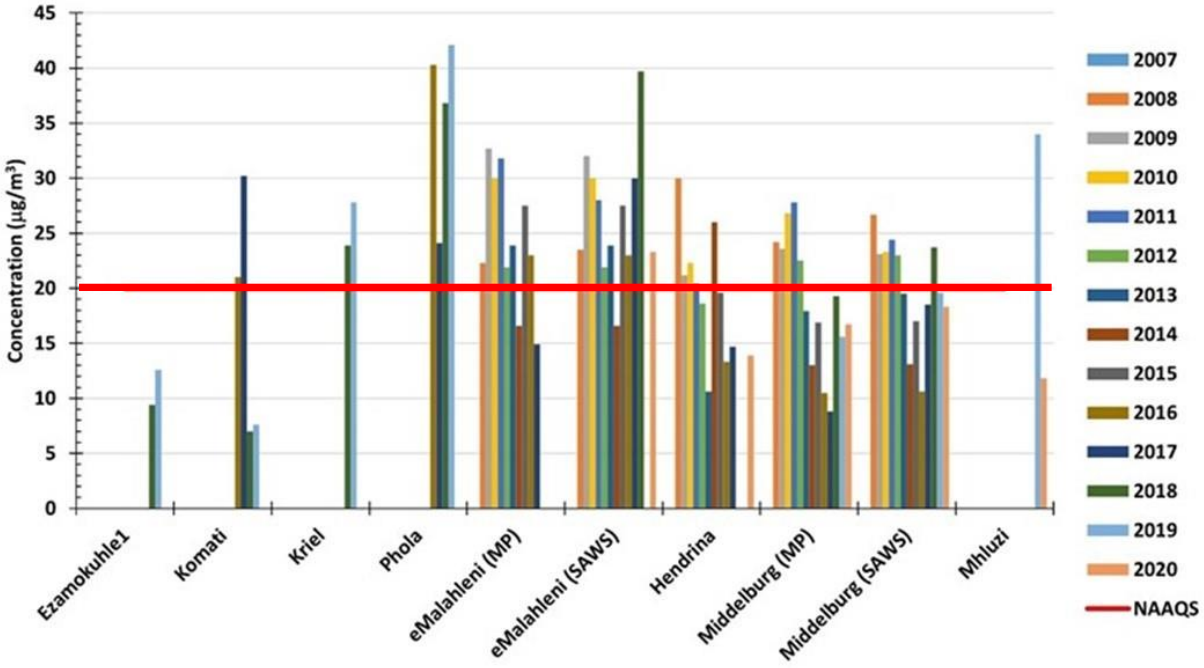


Figure 4-9: Annual average $PM_{2.5}$ concentrations at the Nkangala District Municipality air quality monitoring station between 2007 and 2020 (NAAQS:20 µg.m^{-3})

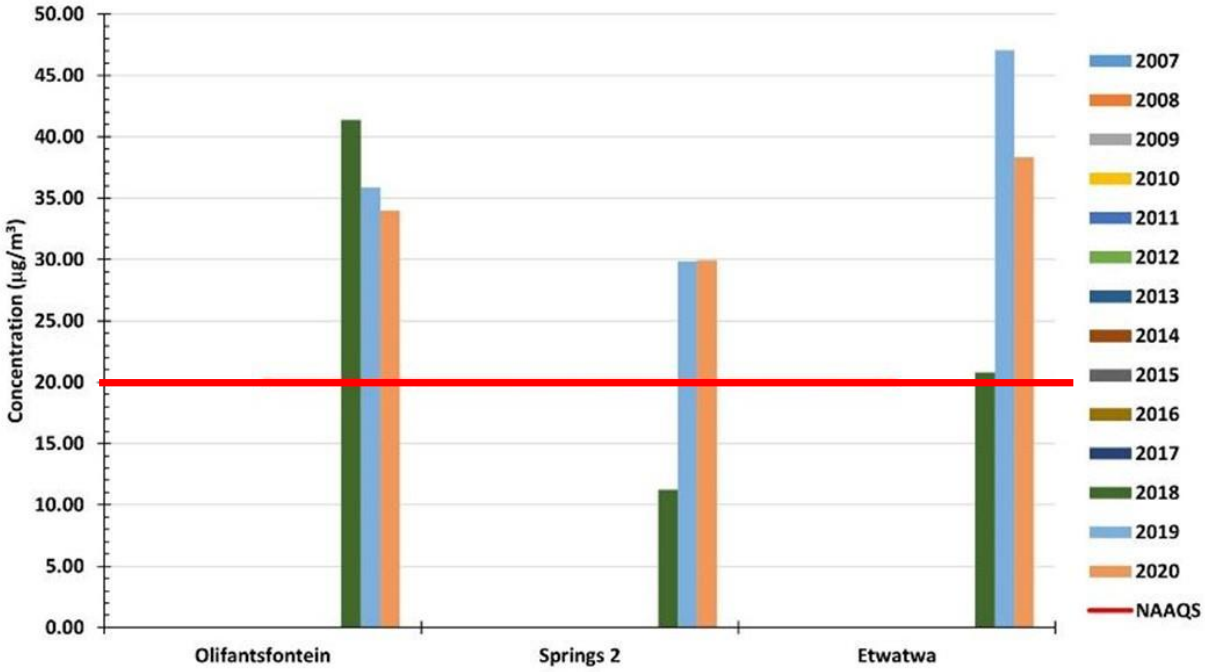


Figure 4-10: Annual average $PM_{2.5}$ concentrations at the City of Ekurhuleni air quality monitoring station between 2007 and 2020 (NAAQS:20 µg.m^{-3})

4.1.4 Nitrogen Dioxide (NO_2)

Figures 4-11 to 4-13 present NO_2 concentrations at three monitoring networks within the HPA. Poor data recovery was noted for a number of stations of the Nkangala DM monitoring network during an earlier period of assessment from 2007 to 2014 with improved data recovery from 2008. Data recovery of NO_2 concentrations was generally better for most of the stations, including Ermelo, Hendrina, Middelburg and Secunda. With regard to NO_2 compliance, a large number of stations indicated that they were compliant with the NO_2 NAAQS. In the Nkangala DM, 45% of the stations showed to have experienced at least one exceedance over the period of assessment. For both the Gert Sibande DM and the City of Ekurhuleni, three stations are noted to have been non-compliant with the NAAQS at each network (in other words, Verkykop, Ermelo, as well as Secunda, for the Gert Sibande DM and Olifantsfontein, Thokoza and Etwatwa for the City of Ekurhuleni monitoring network). The station in Secunda indicated to have the greatest number of incidences of annual exceedance over the assessment period, with approximately 32 annual exceedances occurring in 2017 alone. It was also noted that there is no clear trend in NO_2 concentration at all the stations.

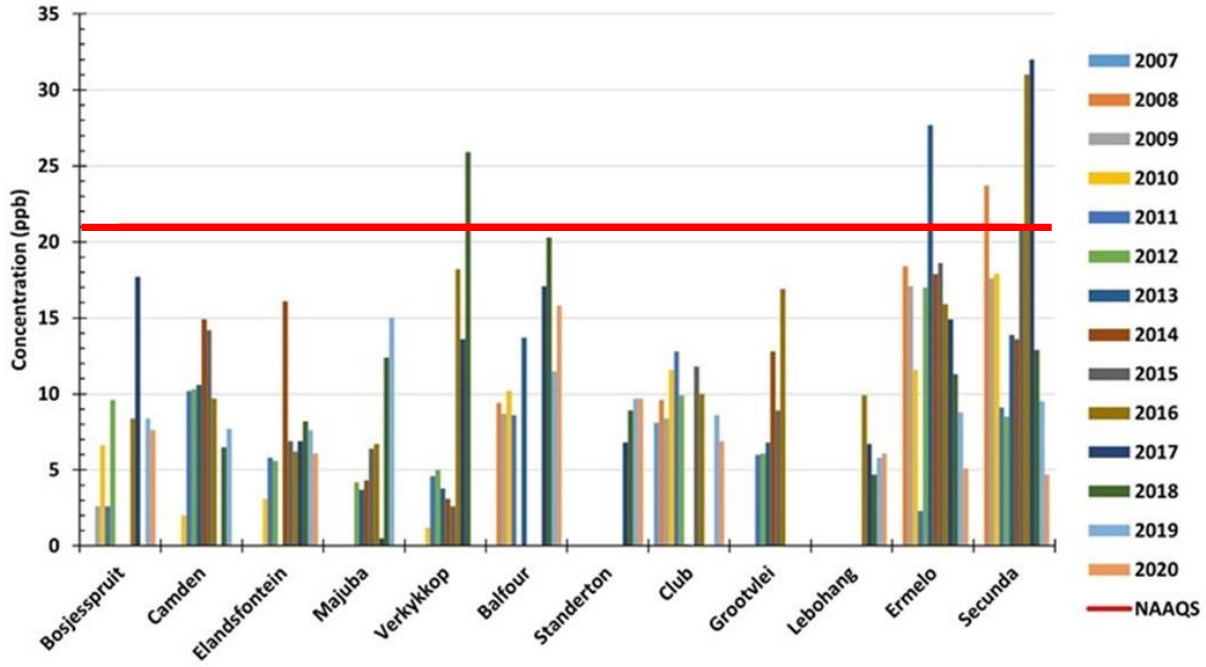


Figure 4-11: Annual average NO_2 concentrations at the Gert Sibande District Municipality air quality monitoring station between 2007 and 2020 (NAAQS:21 ppb)

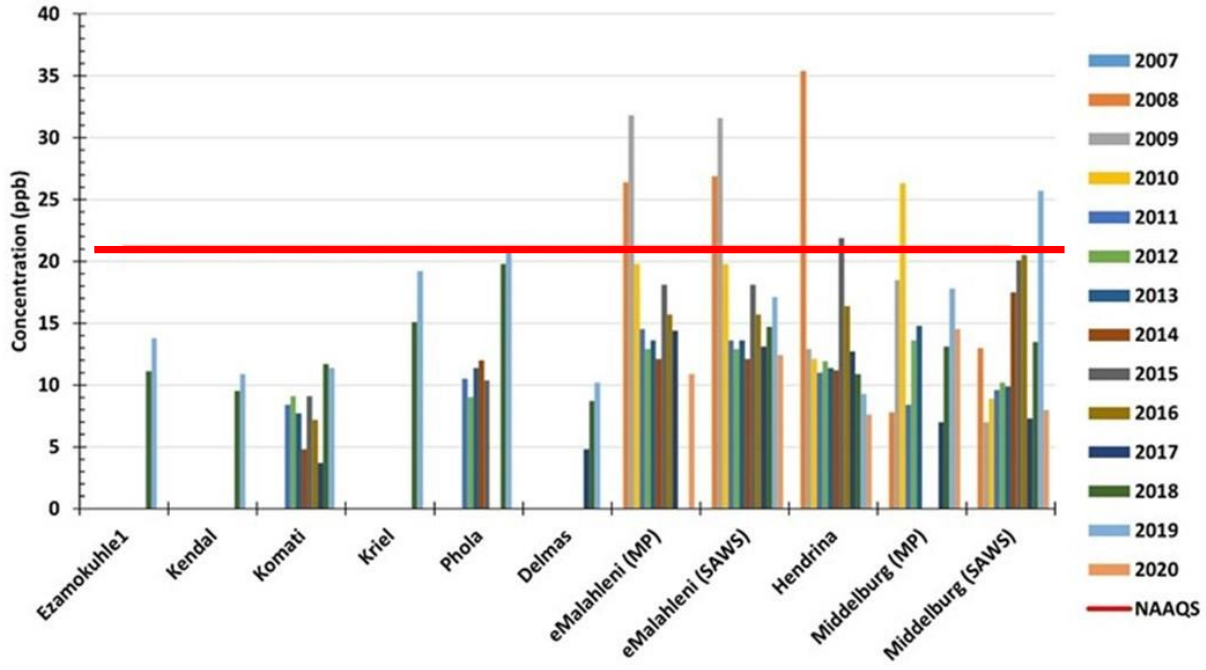


Figure 4-12: Annual average NO_2 concentrations at the Nkangala District Municipality air quality monitoring station between 2007 and 2020 (NAAQS:21 ppb)

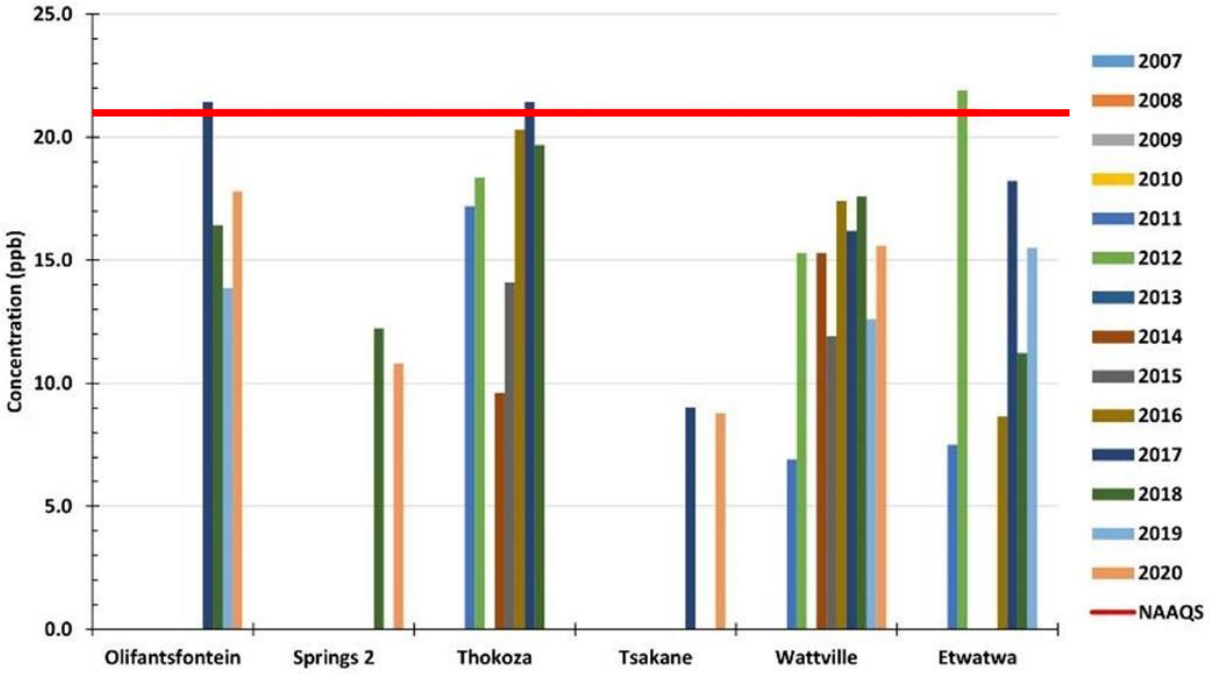


Figure 4-13: Annual average NO_2 concentrations at the City of Ekurhuleni air quality monitoring station between 2007 and 2020 (NAAQS:21 ppb)

4.1.5 Ozone (O_3)

Similarly, for O_3, poor data recovery was noted at a number of monitoring stations, with better data availability at Ermelo, Secunda, Hendrina, Middelburg and Emalahleni. Figures 4-14 to 4-16 present O_3 concentrations measured at various monitoring sites within the HPA against the annual NAAQS of O_3. The plots suggest that there has been a slight decrease in O_3 concentrations over the years since 2011, which is more pronounced for monitoring sites at the Gert Sibande and Nkangala districts. Though this is not the case for the CoE monitoring network, which exhibits a strong variability. Relatively lower O_3 concentrations were reported at most of the stations. Though there is some overlapping among the annual average concentrations over the years, 2019 seems to stand out with higher annual concentration values, resulting in NAAQS exceedances for most of the monitoring stations.

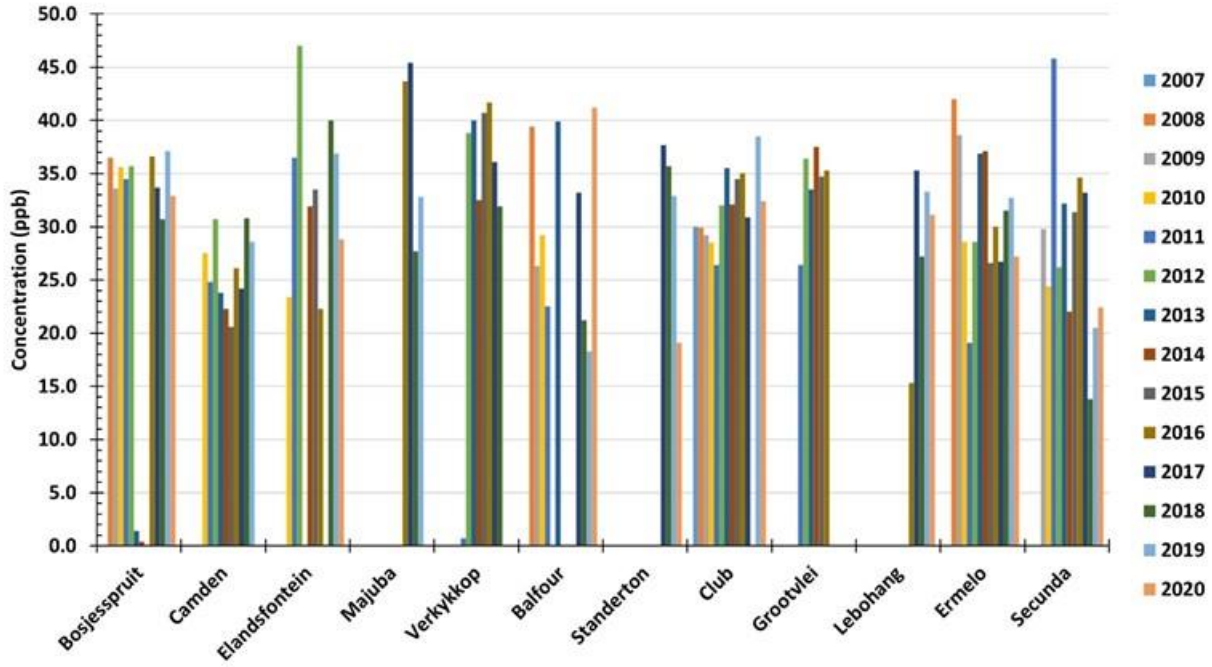


Figure 4-14: Annual average O_3 concentrations at the Gert Sibande District Municipality air quality monitoring station between 2007 and 2020

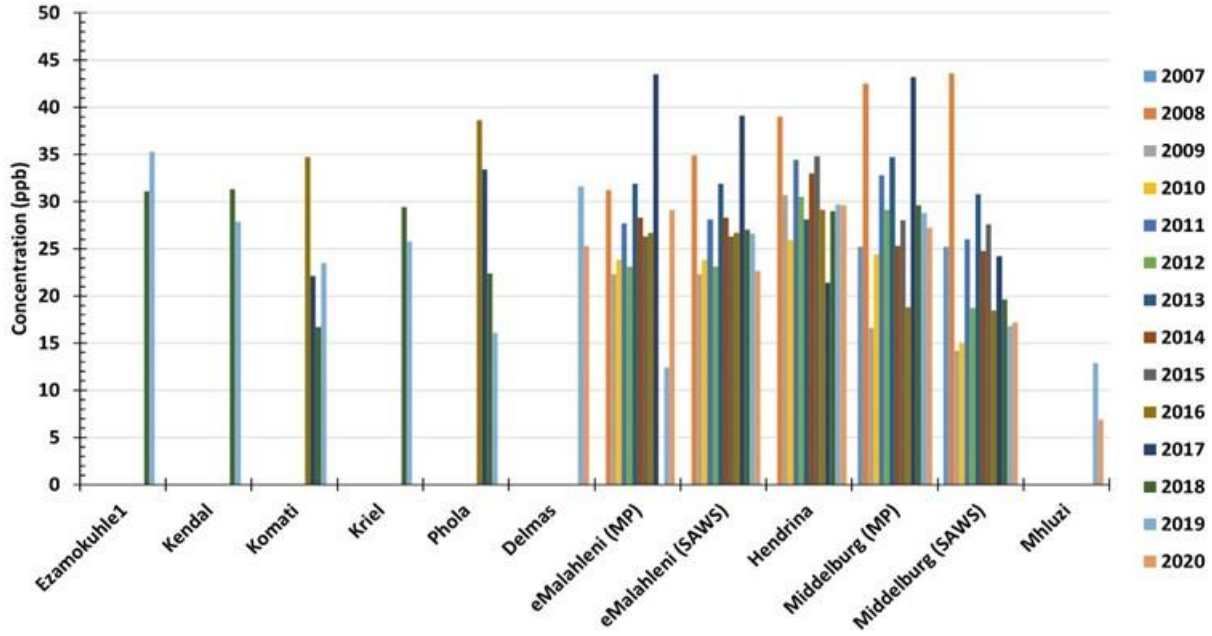


Figure 4-15: Annual average O_3 concentrations at the Nkangala District Municipality air quality monitoring station between 2007 and 2020

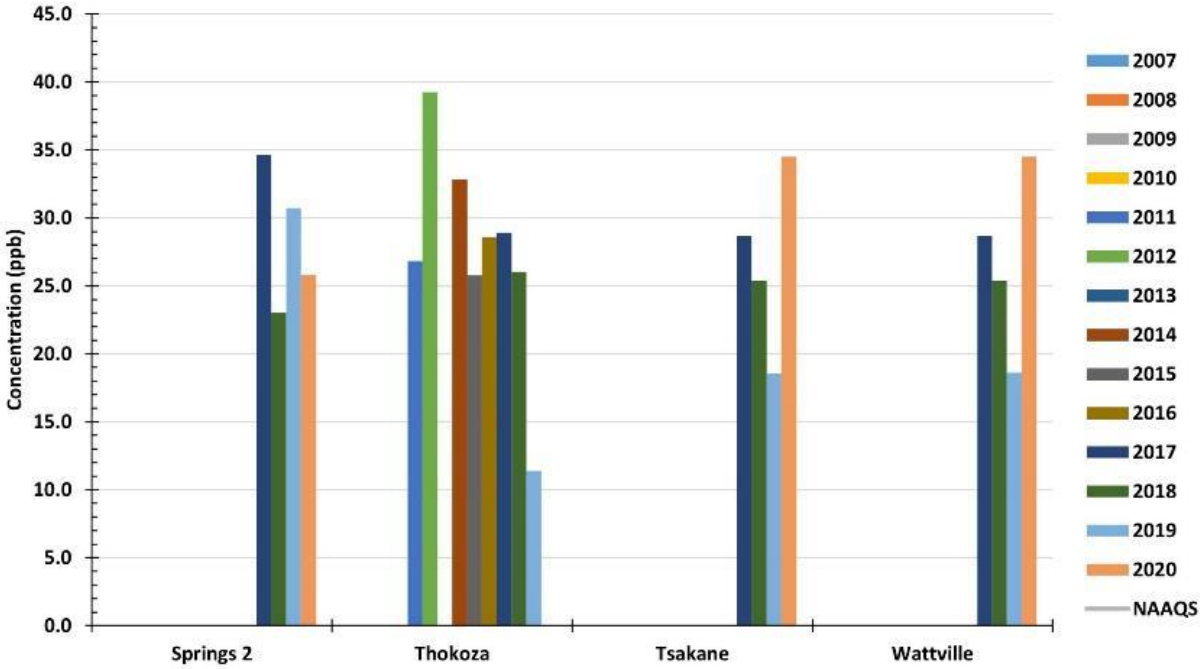


Figure 4-16: Annual average O_3 concentrations at the City of Ekurhuleni air quality monitoring station between 2007 and 2020

4.1.6 Carbon Monoxide (CO)

Figures 4-17 to 4-19 present the annual average concentrations of CO at various monitoring sites. No annual NAAQS is stipulated for CO ambient concertation. Poor data recovery was noted for the City of Ekurhuleni monitoring network in earlier years of the analysis period with improvement only observed from 2017 onwards. As shown from the plots, events of pronounced annual average CO concentrations were apparent during 2014, which is clearly demonstrated in the Ermelo and Secunda monitoring sites. Consistently higher concentration values of CO are recorded at the Emalahleni stations, with generally lower (< 0.3 ppb) concentrations observed in Hendrina prior to 2019. The trend in CO concentrations over time has been fairly static but mostly overlaid by inter-annual fluctuation.

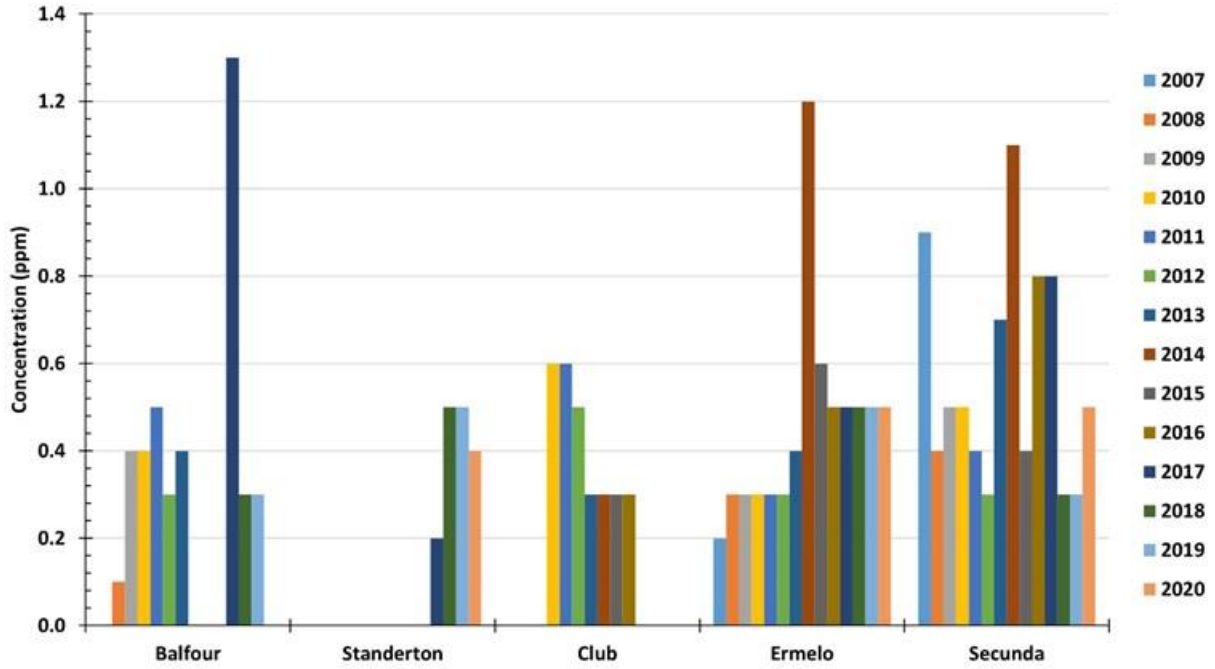


Figure 4-17: Annual average CO concentrations at the Gert Sibande District Municipality air quality monitoring station between 2007 and 2020

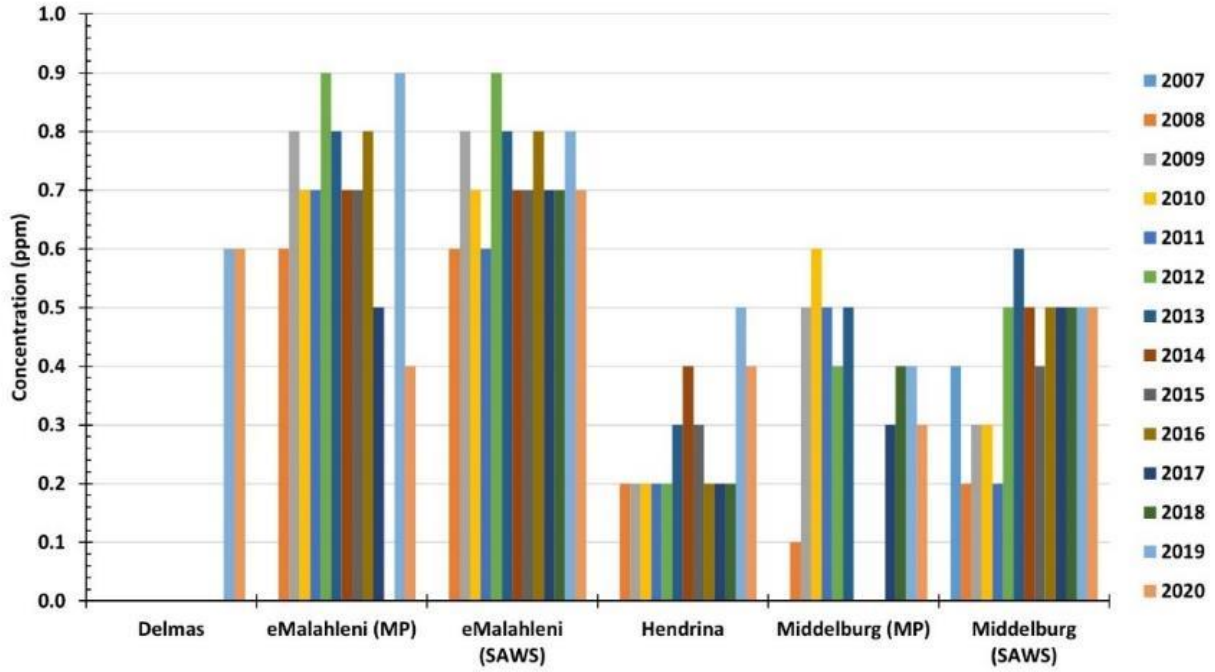


Figure 4-18: Annual average CO concentrations at the Nkangala District Municipality air quality monitoring station between 2007 and 2020

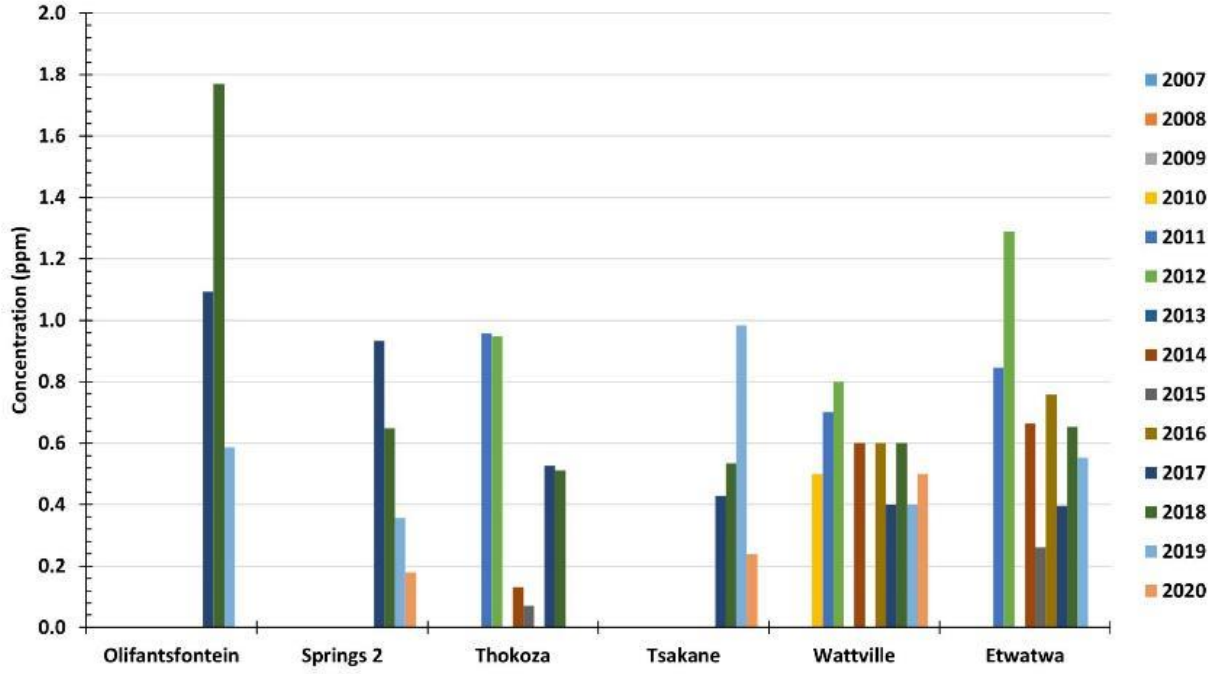


Figure 4-19: Annual average CO concentrations at the City of Ekurhuleni air quality monitoring station between 2007 and 2020

4.1.7 Benzene (C_6H_6)

For Benzene (Figures 4-20 to 4-22), data completeness was poor with no data available for most of the stations. Only in Middleburg, the concentrations of benzene were continuously recorded; however, it never reached above 57% in each year of the assessment period. Exceedance of the benzene annual NAAQS were observed over the period at various monitoring stations, including two incidences at both eMalahleni stations (2008 and 2011), Hendrina (2008 and 2010), the entire CoE network during 2018, as well as one incidence at Secunda during 2013. Regarding long-term trend variability, the results are not conclusive as data recovery was very poor.

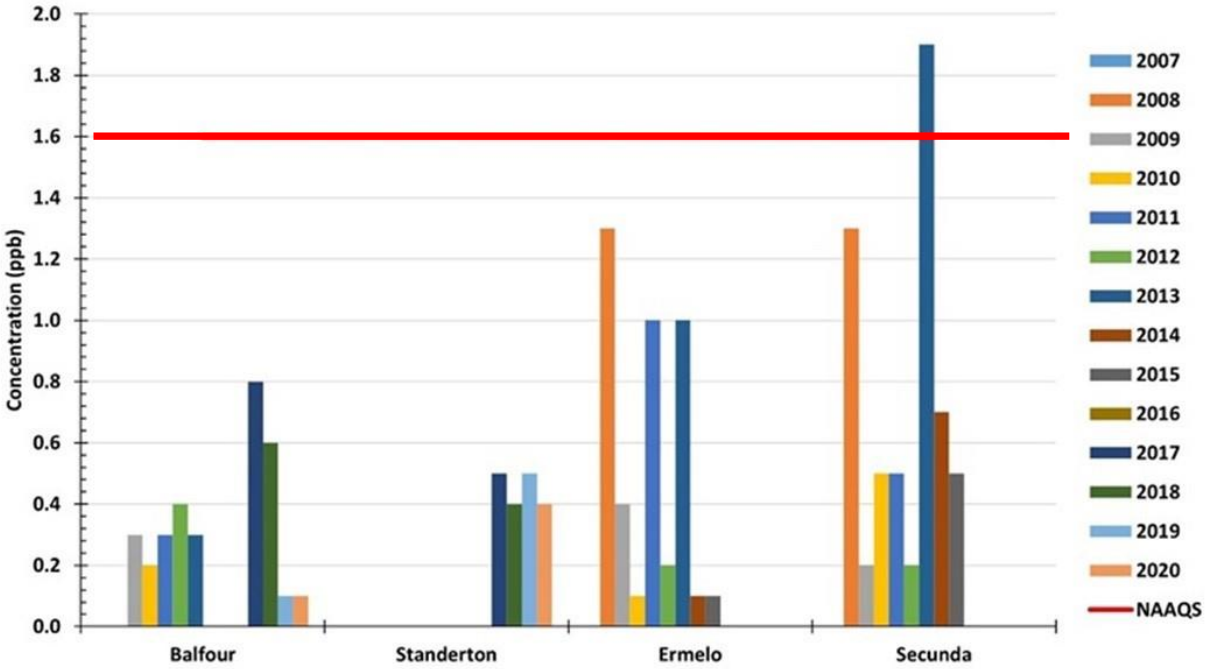


Figure 4-20: Annual average benzene concentrations at the Gert Sibande District Municipality air quality monitoring station between 2007 and 2020 (NAAQS:1.6 ppb)

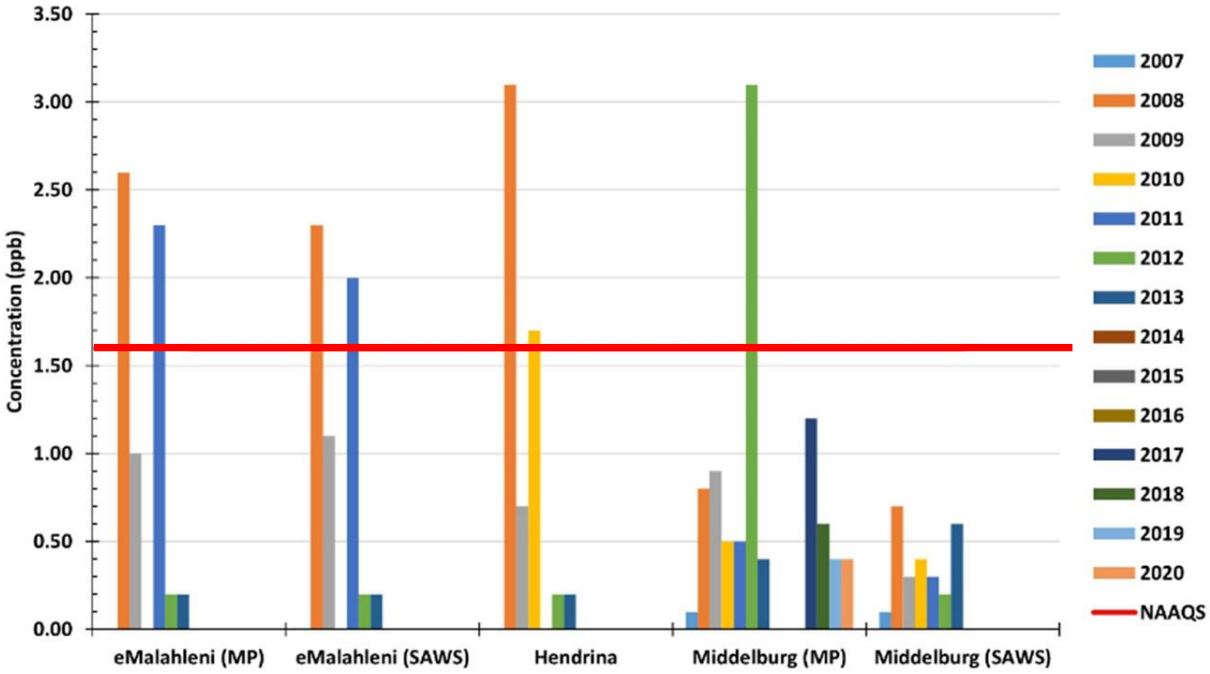


Figure 4-21: Annual average benzene concentrations at the Nkangala District Municipality air quality monitoring station between 2007 and 2020 (NAAQS:1.6 ppb)

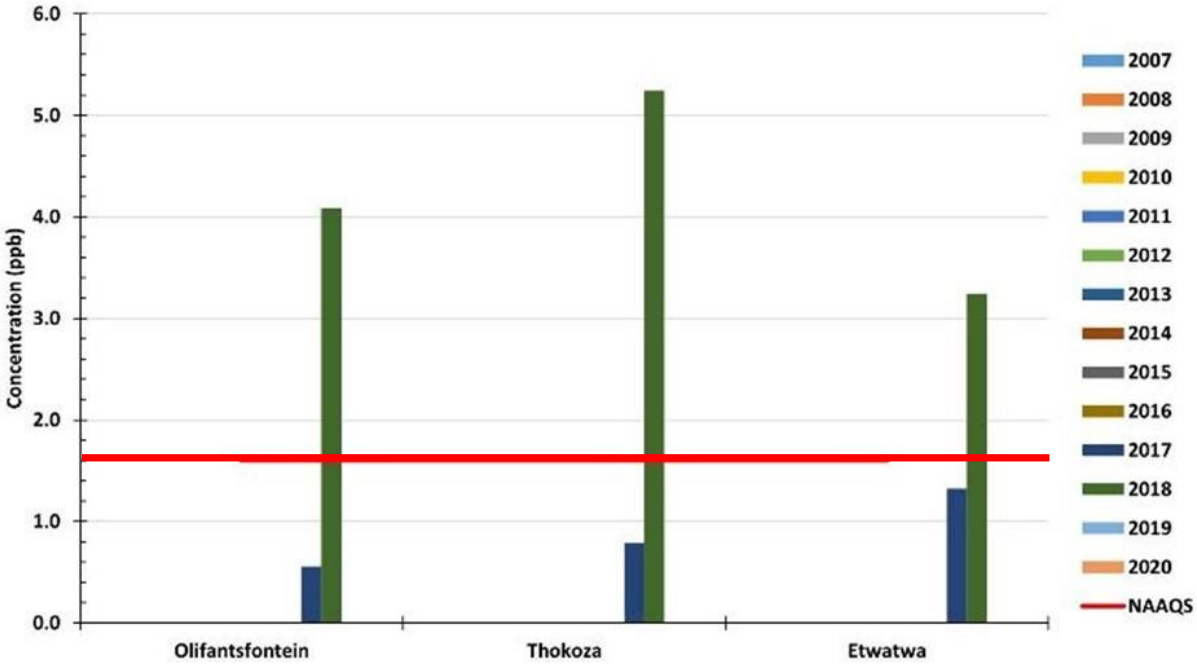


Figure 4-22: Annual average benzene concentrations at the City of Ekurhuleni District Municipality air quality monitoring station between 2007 and 2020 (NAAQS:1.6 ppb)

4.1.8 Hydrogen Sulphide (H_2S)

Figure 4-23 indicates H_2S monitoring at various ambient AQMSs for both the Gert Sibande and Nkangala DMs, with the WHO threshold nuisance value of 5 ppb used instead. Most stations indicate reasonable monitoring levels throughout the monitoring period with the exclusion of the eMalahleni and Elandsfontein stations. Only the Grootvlei station is noted to have H_2S measurements well below the WHO guideline.

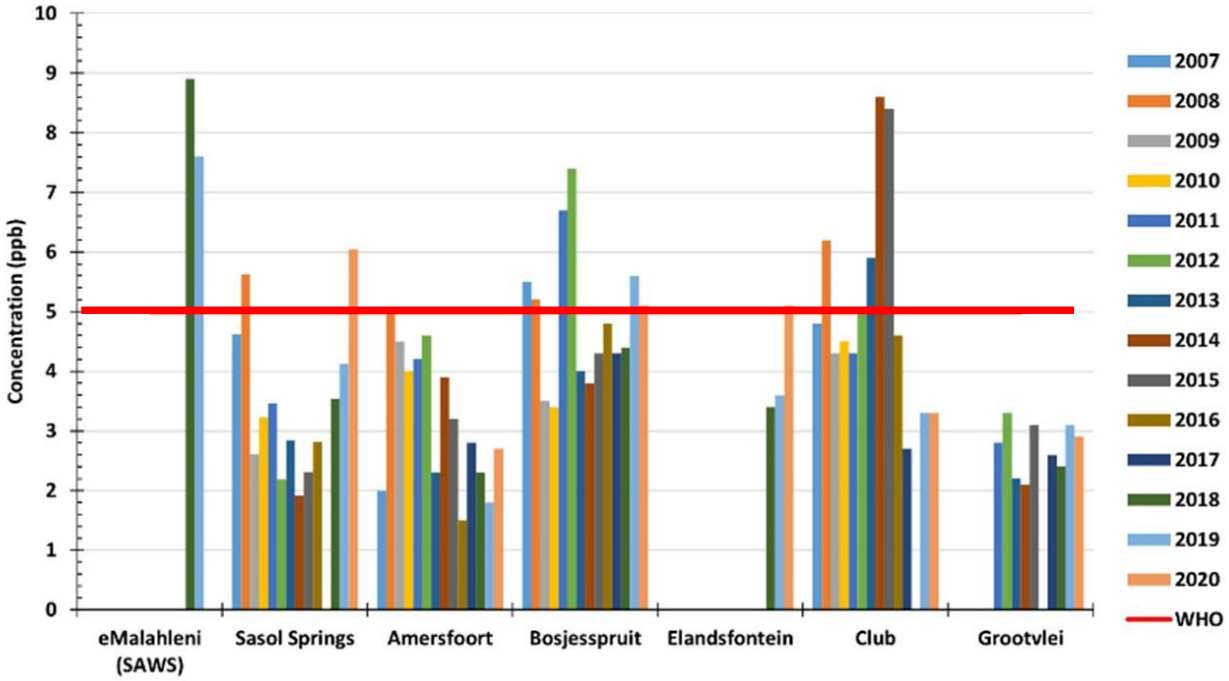


Figure 4-23: Annual average H_2S concentrations for all district municipalities in the Highveld Priority Area between 2007 and 2020 (WHO threshold nuisance value: 5 ppb)

5. CHARACTERISATION OF AIR POLLUTION SOURCES

An emission inventory has been developed for two purposes, namely, to show emissions emanating within the HPA, thereby being geared for air quality management within the priority area and secondly, from the surrounding areas to form input into the atmospheric modelling. The management-geared inventory includes emissions only from within the HPA boundaries, while the nested domain (modelling) inventory considers all sources within the model nested domains (see Section 6). This section details the various emission sources found in the HPA, the methodology used to quantify each pollutant emission, and the results thereof. Since this is the Second Generation HPA AQMP, it is important to note that an emission inventory was also developed for the initial First Generation HPA AQMP, whereby different emission quantification methodologies were initially used. The various emission sources detailed below indicate the key differences in emission quantification methodologies between the two inventories (2012 and 2020) where applicable.

5.1 Industrial Sources

Industrial sources of air pollutants represent mostly stationary facilities operating under Atmospheric Emission Licences (AELs), Section 23 facilities where emissions are reported to the NAEIS annually. Emissions from these sources are, therefore, available, or easily calculated from available activity data. In practice, gaps in industrial emission inventories are usually associated with smaller industries where detailed activity information may not be tracked or is not reportable. The verification and quantification processes have been initiated by identifying gaps in the industrial emission inventory. These gaps can be addressed as part of the capacity-building process to run in parallel with the Second Generation AQMP implementation.

5.1.1 Methodology

Both the First Generation and Second Generation HPA AQMPs quantified industrial emissions in the HPA. However, for the Second Generation, the quantification of air pollutant emissions from industrial activities relied on reported data through the NAEIS for the 2019 calendar year. There is a substantial change in the number of industries across the entire HPA when compared to those industries that were documented in the 2010 baseline assessment report. As an example, in the CoE, only 172 facilities (Section 21 and Section 23 facilities) were confirmed to be currently operational in the 2019 emission compared to 244 facilities which were considered in the 2010 baseline emission inventory. It is assumed that the decrease in the number of industrial facilities could be attributed to the following:

- Some of the facilities are no longer operational;
- Some facilities are no longer listed in terms of section 21. The amendment of the NEM: AQA Section 21 listed activities led to some of the Atmospheric Pollution Prevention Act, 1965 (Act No. 45 of 1965) (APPA) scheduled activities being delisted.
- Some facilities have their AELs merged, especially when they are in one vicinity.

5.1.2 Results

The available information recognised 842 emission sources in the HPA (Table 5-1). The locations of these sources are shown in Figure 5-1, while the total estimated from these sources is presented in Table 5-1 below.

Table 5-1: Total industrial emissions from sources in Highveld Priority Area per source category

Priority Area and Classification	Number of Individual Sources	Reported Emissions in 2019 (Kilo-Tonne/Annum)							
		PM_{10}	$PM_{2.5}$	SO_2	NO_X	CO	VOC	NH_3	H_2S
HPA	**842**	**127.17**	**64.73**	**1277.29**	**790.62**	**107.36**	**226.02**	**0.54**	**81.44**
Section 21 Category 1	90	110.25	56.13	1073.22	651.67	19.70	183.58	0.02	0.00
Section 21 Category 2	101	7.95	4.58	184.82	128.67	78.12	40.80	0.00	80.42
Section 21 Category 3	19	0.18	0.03	0.01	0.00	0.02	0.00	0.00	0.00
Section 21 Category 4	448	3.91	1.43	12.12	1.36	0.25	1.03	0.45	0.24
Section 21 Category 5	66	3.48	1.32	2.56	6.50	0.74	0.12	0.00	0.00
Section 21 Category 6	14	0.03	0.00	0.09	0.12	0.16	0.33	0.00	0.00
Section 21 Category 7	38	0.00	0.00	0.13	0.37	0.74	0.00	0.07	0.00
Section 21 Category 8	15	0.09	0.08	0.01	0.21	0.02	0.14	0.01	0.00
Section 21 Category 9	6	0.24	0.23	0.02	0.22	2.40	0.01	0.00	0.00
Section 21 Category 10	3	0.01	0.01	0.13	0.00	0.00	0.01	0.00	0.78
Section 23 Controlled Emitter	42	1.03	0.91	4.18	1.49	5.22	0.01	0.00	0.00

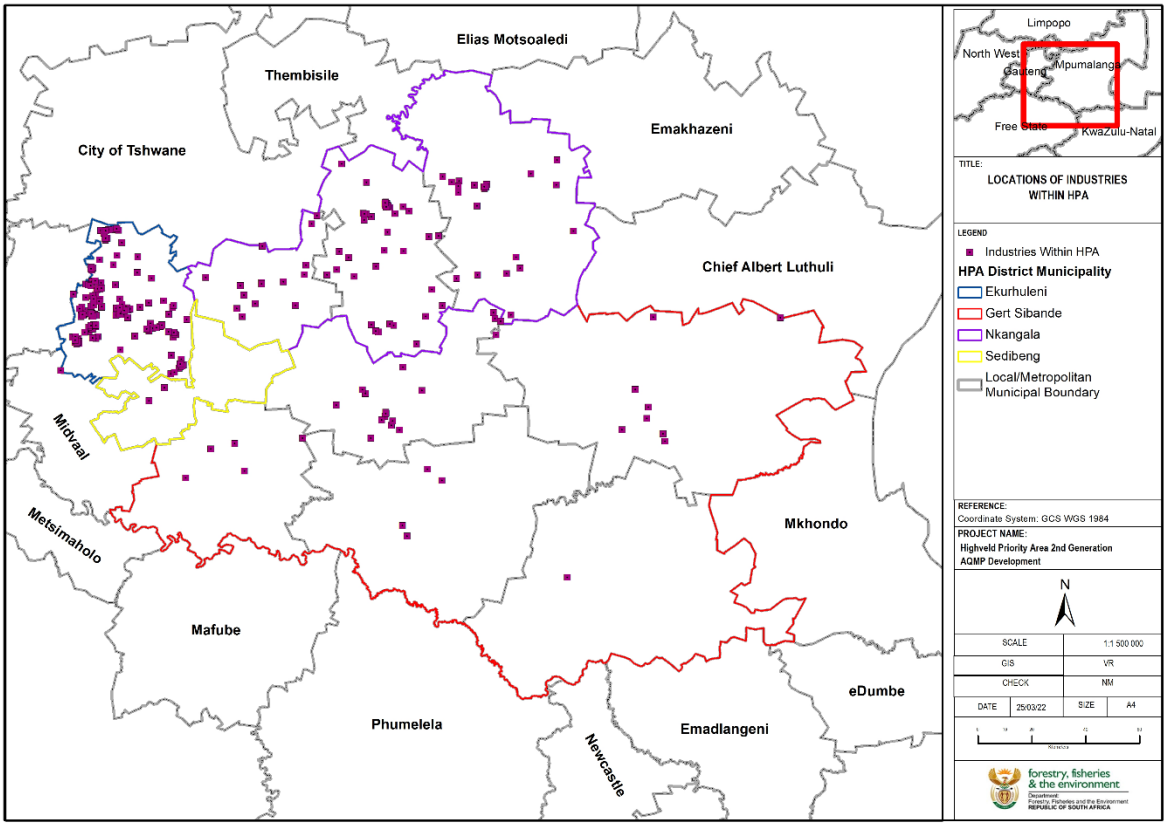


Figure 5-1: Industrial sources identified in the Highveld Priority Area

5.2 Mobile Sources

The modern internal combustion engine can emit various pollutants into the atmosphere, including NO_x, SO_2, carbon monoxide (CO), PM, and volatile organic compounds (VOC). Air pollution from traffic is known to have negative health impacts due to factors such as its emission at ground level (for example, levels where people can be directly exposed) and its composition. Diesel exhaust was classified as a confirmed human carcinogen in June 2012 (Silverman et al., 2012; WHO, 2012). In terms of the HPA modelling domain, vehicle emissions are not only important because of the inclusion of the Gauteng province, but also due to the widespread use of vehicles for personal transport and commercial purposes in much of the Mpumalanga province, resulting in a regional pollution source of both NO_x and VOC. This has an impact on ozone formation and, in general, the oxidative nature of regional atmospheric chemistry (in conjunction with other emission sources such as biogenic and biomass burning). Figure 5-2 shows the road network within the HPA.

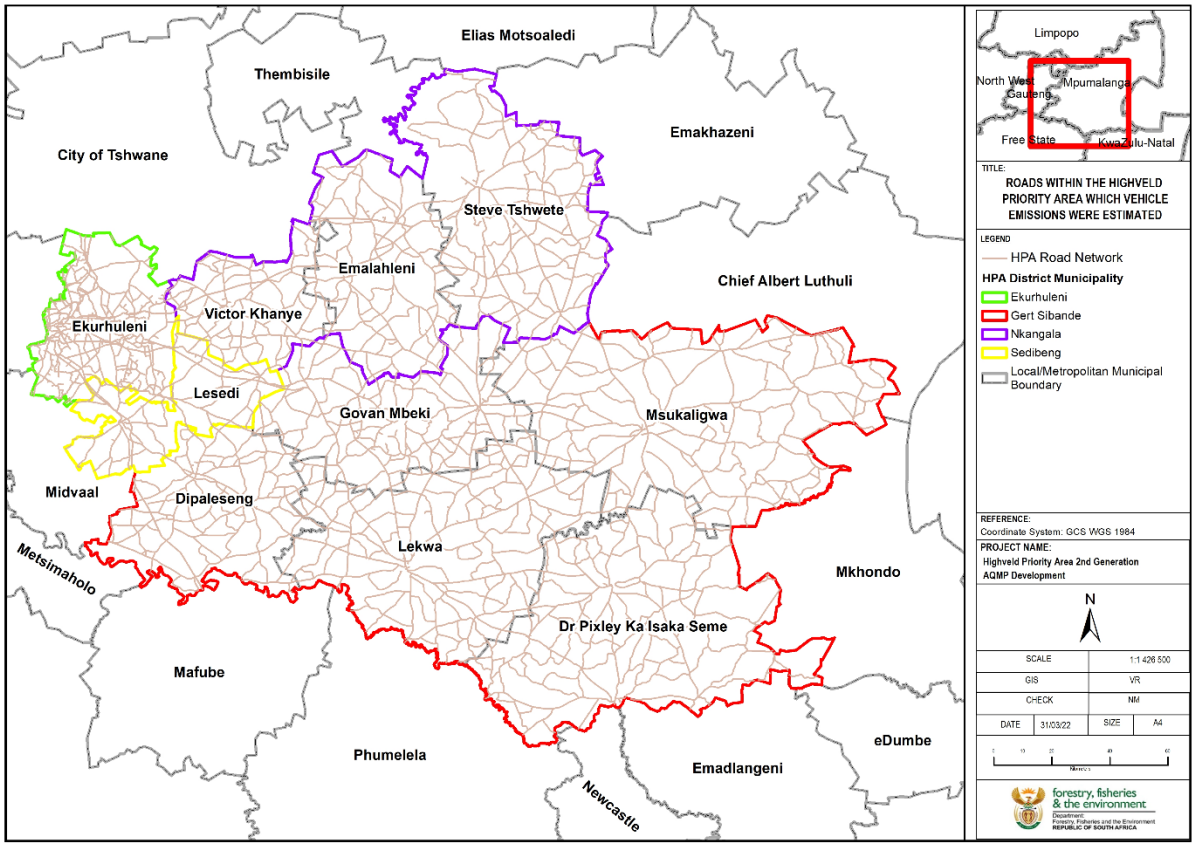


Figure 5-2: Road network within the Highveld Priority Area

The network shown in Figure 5-2 is sourced from the World Bank data CatLog for South African roads delineated by the Word Bank (https://datacatalog.worldbank.org/dataset/south-africa-roads) and based on the South African national roads network. The World Bank data CatLog indicator will be used in this section to refer to the official road's dataset.

The dataset classifies roads into three basic classes, namely primary, secondary, and tertiary, with road traffic apportioned according to these classifications, and primary carrying high volumes of traffic and tertiary carrying less traffic. Therefore, two factors play a role in emission intensity when considering these three types of roads. Primary roads may carry more volume and lead to higher emissions, congestion (therefore lowering speed and travel time) can also increase emissions. In general, the factors that impact vehicle emission estimates are as follows:

- Fuel type;
- Fuel specifications;
- Engine technology;
- Engine capacity;
- Vehicle speed;
- Vehicle age;
- Engine/Exhaust temperature; and
- Number of kilometres travelled.

Other, more detailed factors requiring information that is generally not available (particularly on such a large scale) are gearing, driving style, tyre friction and road grading. The basis of deriving vehicle emissions is an estimate of Vehicle Kilometres Travelled (VKT). This data represents an activity to which emission factors are applied. The emission factors are dependent on all other factors noted above. Therefore, any approach to generate a vehicle emission inventory includes an estimation of VKT and the use of appropriate emission factors. The level of detail included in each factor varies depending on the available information. One of the largest obstacles in vehicle emission estimation for air quality modelling lies in the requirement that a realistic emission inventory will also need to be spatially representative at each grid cell, in other words, the goal is to achieve the best information at every grid cell. This is not necessarily possible for all the above-listed factors as many (for example, fuel type) are not tracked at a fine scale.

Therefore, assumptions are made using spatial surrogates to generate a grid-based emission inventory that is spatially representative. There are instances when very detailed information is available (such as traffic count data); however, these are then often spatially limited. Assumptions are then used to extrapolate this data to the larger spatial scale, which is termed a bottom-up approach. When larger scale, but more generalised data exist, assumptions are made to create a finer scale variation based on surrogates, which is termed a top-down approach. Both these approaches are viable when estimating vehicle emissions, but largely depend on the available data.

5.2.1 Methodology

The previous 2012 emission inventory quantified emissions from motor vehicles using the emission factors from Wong (1999) and Stone (2000), and VKT in km x 1 km grid blocks in the HPA. The VKT data were obtained from the CSIR's Sasol–Eskom-funded project to determine the ozone-forming potential of the Highveld. It is assumed that the decrease in motor vehicles emission could be attributed to the difference in the underlying methodologies and databases, in other words, different emissions factors, VKT, different fuel sale data, etc.

On the other hand, the 2019 on-road vehicle emission inventory employs both a top-down and bottom-up approach. This is possible due to road count data being available from various sources. For both the top-down and bottom-up methodologies, the common underlying spatial units are the World Bank data CatLog for South African road links (see Figure 5-2). The road link spatial data are for 2017. Emissions are estimated for the classes listed in Table 5-2. These follow the eNATIS broad classifications, as reported in the provincial statistics.

Table 5-2: Vehicle classes for which emissions are estimated

eNATIS Class	ADDT Light
Motor cars and station wagons	Car Diesel
	Car Petrol
	SUV Diesel
	SUV Petrol
Motorcycles, quads and tricycles	MotoBike Petrol
LDVs, panel vans, etc.	LCV Diesel
	LCV Petrol
eNATIS Class.	**ADDT Heavy**
Trucks	HCV1 Petrol
	HCV1 Diesel
	HCV2 Diesel
	HCV3 Diesel
	AADT Very Heavy
Trucks	HCV4 Diesel
	HCV5 Diesel
	HCV6 Diesel
	HCV7 Diesel
	HCV8 Diesel
	HCV9 Diesel
eNATIS Class	**ADDT Bus**
Buses, bus trains, minibuses	Bus
Taxi	**Minibus Taxis**

A top-down approach uses fuel sales to estimate VKT and allocates this to roads by their type; however, the bottom-up approach serves as a starting point for the emission inventory.

Road count data are used to estimate VKT for each station by applying the count to the immediate road link. The extents are limited in this way as there is no other methodology to describe traffic flow in other links around the station, except using a full-scale network flow model. These links are then removed from the full road network, together with estimated fuel consumption for that link by converting VKT to fuel-use using fuel efficiency data. This ensures that there is no double counting of both VKT and spatial features. After all bottom-up estimations are done, the remaining road network is used for the top-down approach.

i. Bottom-up

For this approach, two sources of road counts data were used, namely Figure 5-3:

- Mpumalanga Road Assets Management System (MP RAMS) traffic count data (2019 update).
- SANRAL national counts for 2016 (through the SANRAL Yearbook Traffic Summaries).

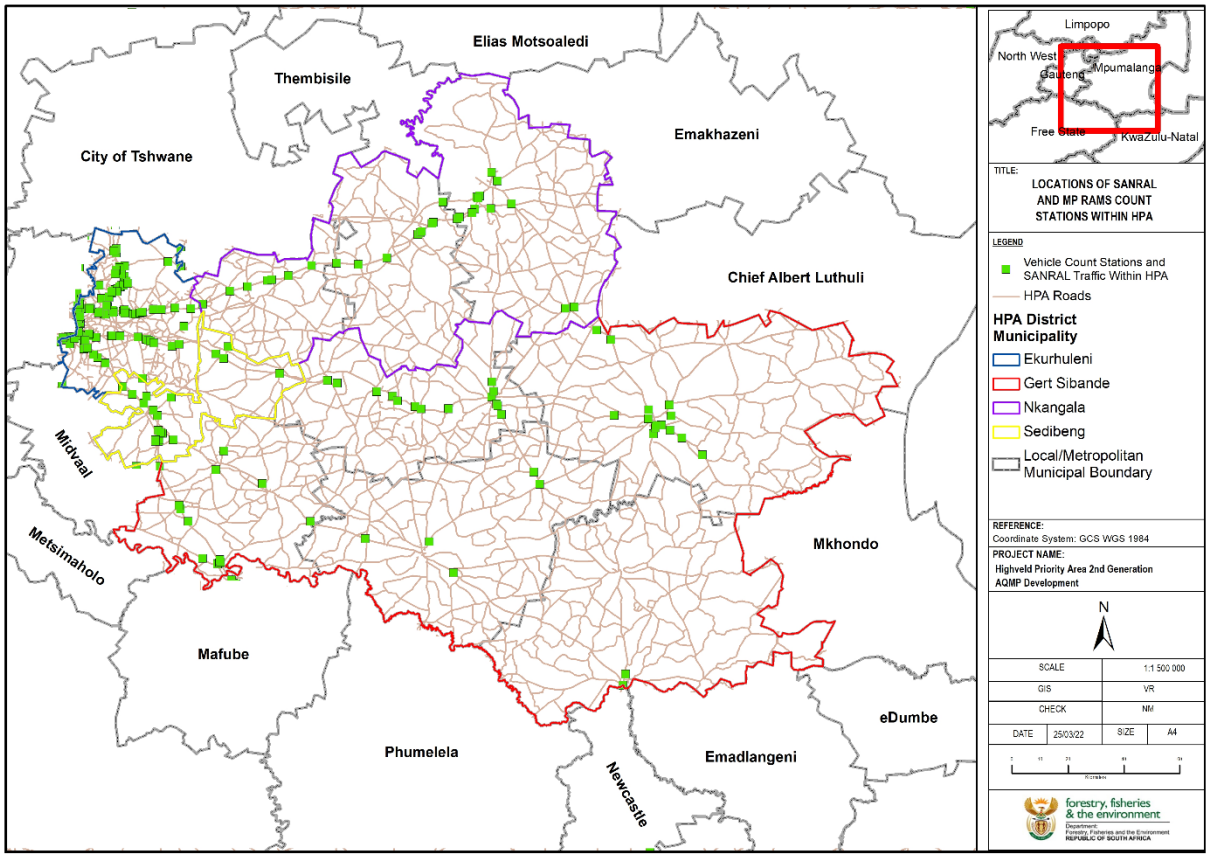


Figure 5-3: Locations of the South African National Roads Agency SOC Ltd and MP RAMS count stations used for the bottom-up approach

The MP RAMS counts cover only roads maintained in the Mpumalanga province, which primarily include the national routes and is the most recent dataset in terms of vehicle count, with the data representing 2019 traffic count data. The SANRAL counts cover only SANRAL-maintained roads, which primarily include the national routes. These traffic counts are slightly outdated with a traffic count having taken place in 2016 with no split of annual traffic count by vehicle class.

As such, the only useful traffic count data set is the MP RAMS where the annual traffic totals are split by class, thereby allowing an annual VKT to be derived by assigning the MP RAMS (and, therefore, length) to each count station. All VKT are converted into fuel consumption using the efficiency data extracted from the COPERT Model (see the "Emission factors" section below). This fuel consumption is subtracted from the provincial fuel sales, together with the road links associated with counts, going into the top-down methodology. The SANRAL count data are also useful in that average vehicle speeds are given. Using this information, it was possible to assign typical speeds for different World Bank data CatLog Road types. These speeds are necessary for selecting appropriate emission factors further in the process. Figure 5-4 shows the average speeds for light, heavy and overall classes for each World Bank data CatLog Road class.

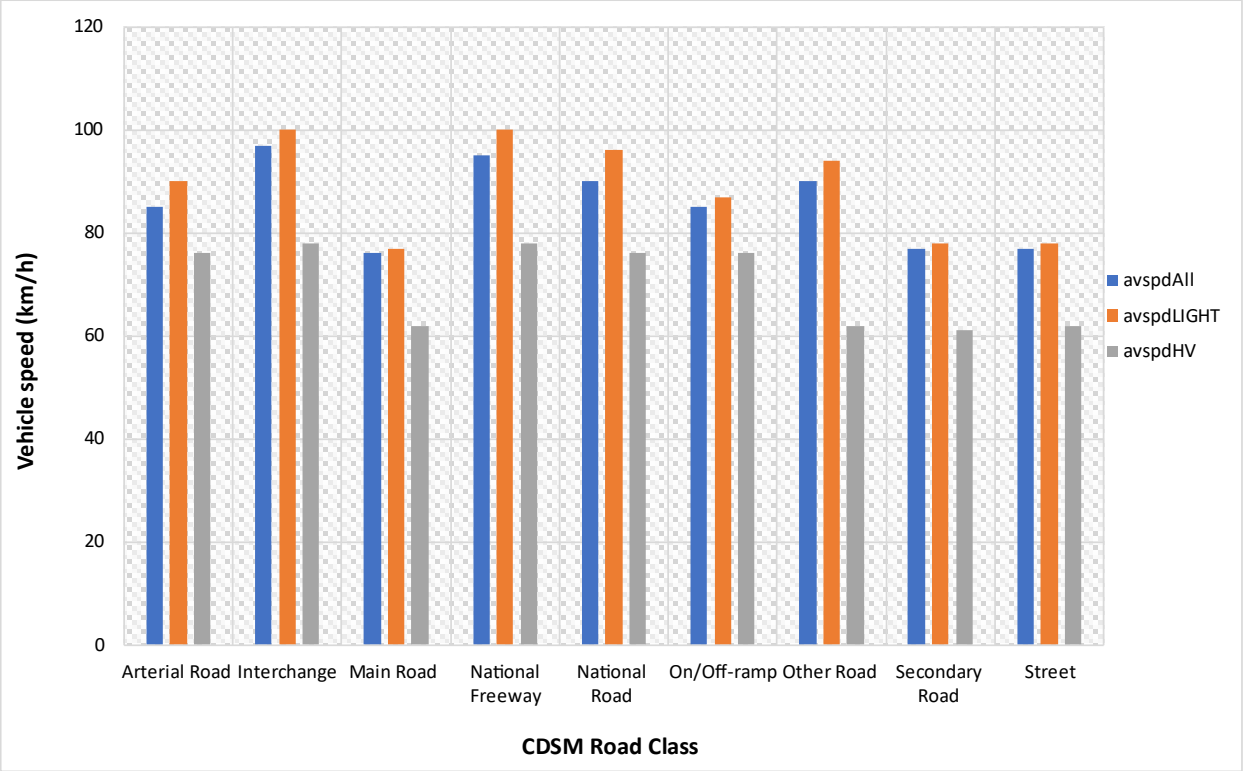


Figure 5-4: Average vehicle (all light and heavy [speeds for each CDSM road class] (derived from South African National Roads Agency Limited count data)

ii. Top-down

The top-down approach uses provincial fuel sales and fuel efficiency data (from COPERT; see "Emission factors" section) to estimate VKT. A key assumption is that fuel sales equate to fuel consumption. This is true for total national volume; however, if one tries to look at sales spatially, the possibility of fuel sales being consumed elsewhere is likely. Therefore, magisterial district sales are used, rather than provincial sales (also available from DoE) to minimise this effect.

There is an inherent difficulty in assigning the fuel/VKT to specific road links. Similar to the residential fuel use emissions methodology, national household survey data are used to further disaggregate provincial fuel sales based on travel activity. The National Household Travel Survey 2013 (Stats SA, 2013) trip information per mode of transport was used to this end. Survey data are collected at the Travel Analysis Zone (TAZ) level, and is a unique demarcation compared to Census spatial units. A provincial proportion of trip activity was derived, and fuel sales were disaggregated accordingly. Since the HPA effectively encompasses two provinces in other words, Mpumalanga and Gauteng, fuel sales data from two larger magisterial districts are required, in other words, Mpumalanga and Gauteng, which is based on 2019 fuel sales. Figures 5-5 and 5-6 illustrate the total petrol and diesel fuel sales, in other words, million litres (Mℓ) in the Mpumalanga province and the CoE.

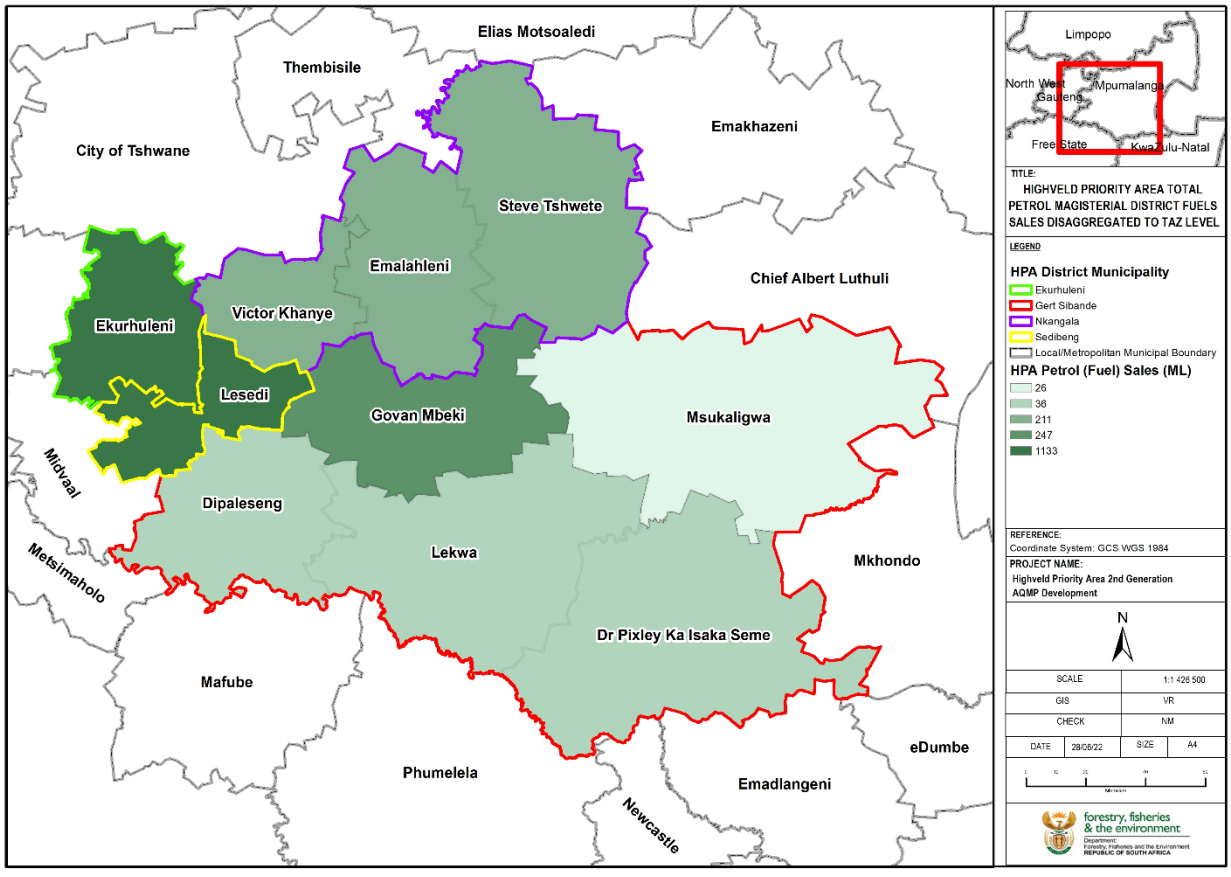


Figure 5-5: Mpumalanga Total Petrol Magisterial District fuel sales disaggregated to the Travel Analysis Zone level

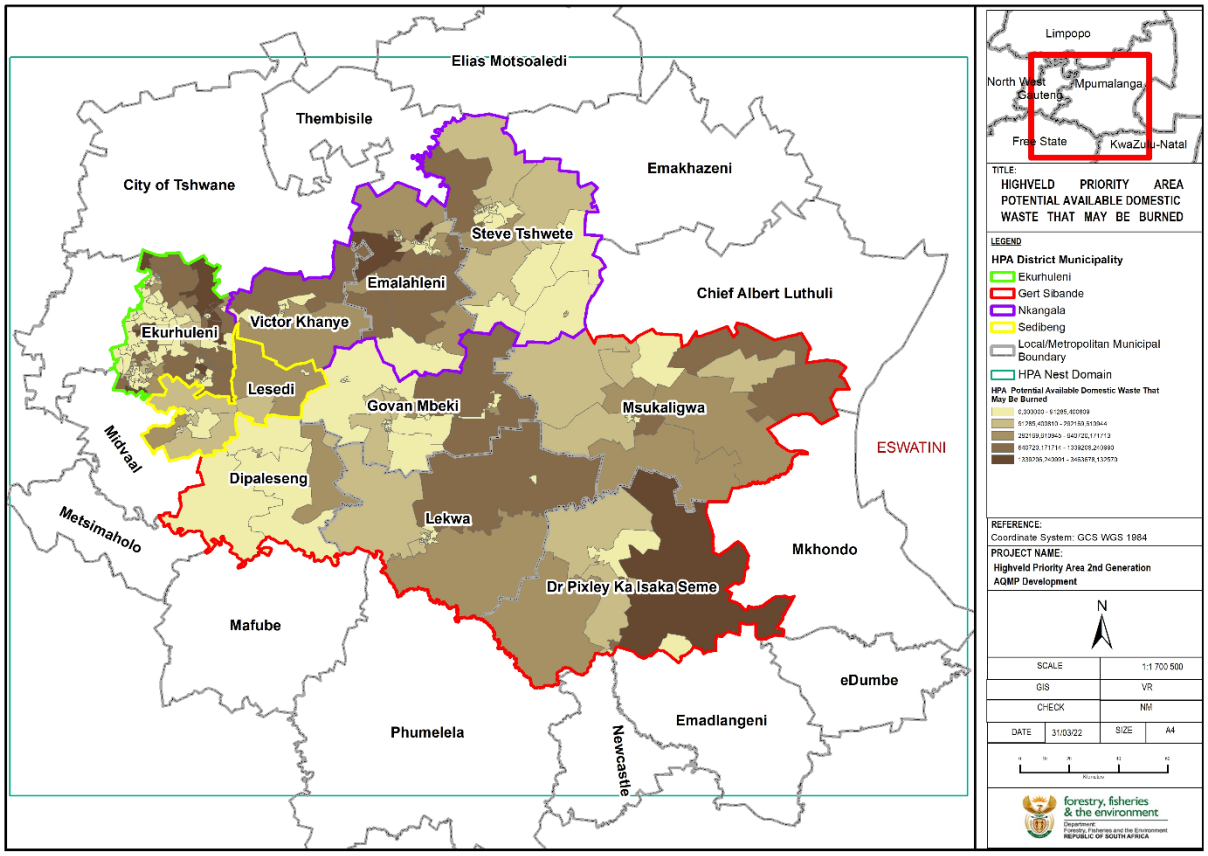


Figure 5-6: Mpumalanga Total Diesel Magisterial District fuels sales disaggregated to the Travel Analysis Zone level

Once fuel sales have been allocated to the TAZ, it is necessary to disaggregate further down to road level. This is accomplished by using data from the South African Road Classification and Access Manual (SARCAM) (SANRAL, 2012). Tables B and C of the manual provide the typical average annual daily traffic (AADT) for different road classes. These typical road AADTs were used to proportionally distribute fuel to different World Bank data CatLog for South African road classes. However, further refinement to the World Bank data CatLog for South African road classes was necessary to assign both a commercial and urban/rural status. This was achieved using Census 2011 household weighted Enumerator Type and Geotype data at the subplace level. This effectively means assigning a commercial/non-commercial and urban/rural status to the World Bank data CatLog Road types seen in Figure 5-3.

The result is unique road classes, to which typical AADT from the SARCAM can be assigned. Fuel within each TAZ is then distributed by the typical AADT proportion among classes. The final level of disaggregation is achieved by then allocating fuel proportionally within classes based on link length. The result is a fuel consumption estimate on each of the remaining (after removals from the bottom-up processing) CDSM roads. This fuel consumption is converted to VKT using the COPERT-derived fuel efficiency data.

iii. Emission Factors

For this study, "hot running" (thermally stabilised engine and exhaust treatment) emission factors were derived from the COPERT 5 (Version 5.0.1145) Model. The model is developed by EMISIA SA and supported by the European Environment Agency (EEA). The methodological approach (and, therefore, formulae) for COPERT 5 is identical to the Tier 3 methodology laid out in the EMEP/EEA Air Pollutant Emission Inventory Guidebook 2013 (European Environment Agency, 2013) for "Exhaust emissions from road transport" (Part B, Section 1.A.3.b.i-iv).

The COPERT approach was chosen as all other locally derived emission factors (for example, Stone, 2000; Wong, 1999; Wong & Dutkiewicz, 1998) provided an emission factor at a generalised single speed, while what is required for this emission inventory is a speed-based estimate as emission factors are sensitive to vehicle speed that are effectively linked to the CDSM roads and vehicle speeds. Additionally, locally derived emission factors represent a much older vehicle fleet; typically, pre-EURO2. Emission factors were modelled for EURO 1-6 stage vehicles from the classes specified in Table 5-3. Table 5-3 lists the approximate manufacture years for each EURO stage.

Table 5-3: Vehicle EURO stage and corresponding manufacture years

EURO Stage	Vehicle Model Year
EURO 1	1992-1995
EURO 2	1996-1999
EURO 3	2000-2004
EURO 4	2005-2009
EURO 5	2010-2014
EURO 6	2015 to date

Emission factors for CO, NOx, non-methane VOC (NMVOC), $PM_{2.5}$, methane (CH_4), ammonia (NH_3) and SO_2 were estimated in COPERT for speeds from 20 km/hr to 120 km/hr (in 20 km/hr increments). COPERT also estimated fuel consumption (in other words, efficiency in ℓ/km) for each speed.

Note that in practice, the closest emission factor speed is matched to the specific speeds in Figure 5-4 for vehicles travelling on that road. The full emission factor/fuel consumption dataset, therefore, comprised 4 536 factors (6 EURO classes by 6 speeds by 18 vehicle classes by 7 pollutants).

As there is no indication of vehicle age or technology within the activity data used (both counts for the bottom-up and fuel sales for the top-down), it is necessary to aggregate the emission factors by the EURO stage. To simply take an average would not be accurate as that would assume that all vehicle ages exist at an equal proportion in the vehicle parc. This is not true as newer vehicles enter the parc and older ones leave, resulting in a shift towards newer vehicles.

The spread of vehicle age in a parc can be determined through scrapping curves. A weighted average of emission factors between EURO stages can then be obtained to derive a single emission factor per vehicle class and pollutant (still at different speeds). The scrapping curve used in this study is based on Merven et al. (2012) eNATIS calibrated (2010). Weibull cumulative distribution functions show the probability of vehicle survival as a function of age. These functions are then applied to the time periods relevant to this study (Table 5-3). Figure 5-7 shows the scrapping curves used for each class (after Merven et al., 2012).

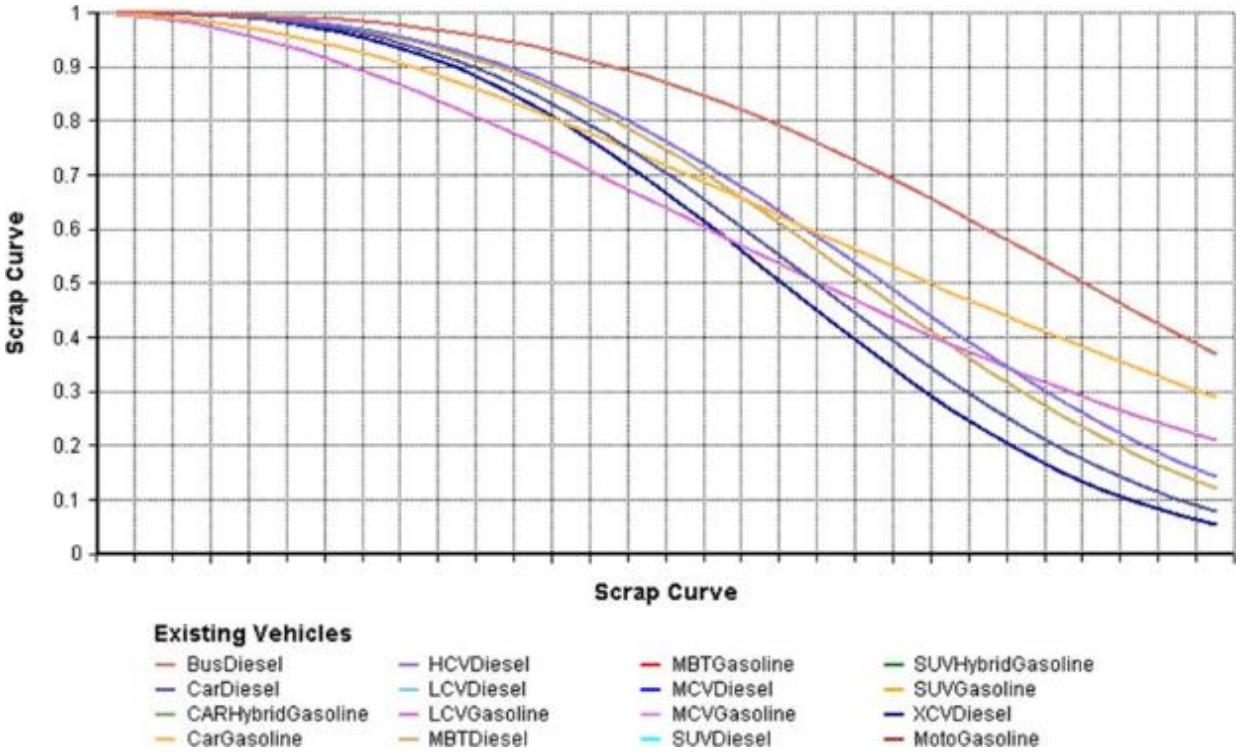


Figure 5-7: Base year scrapping curves for the vehicle technology types in the Vehicle Parc Model (after Merven et al., 2012)

These curves were used for deriving an age proportion weighted average emission factor for each speed (now synonymous with road type) and pollutant per vehicle class. Figure 5-8 shows diesel NOx emission factors derived from COPERT and illustrate the importance of vehicle speed. Figure 5-9 shows emissions for petrol classes.

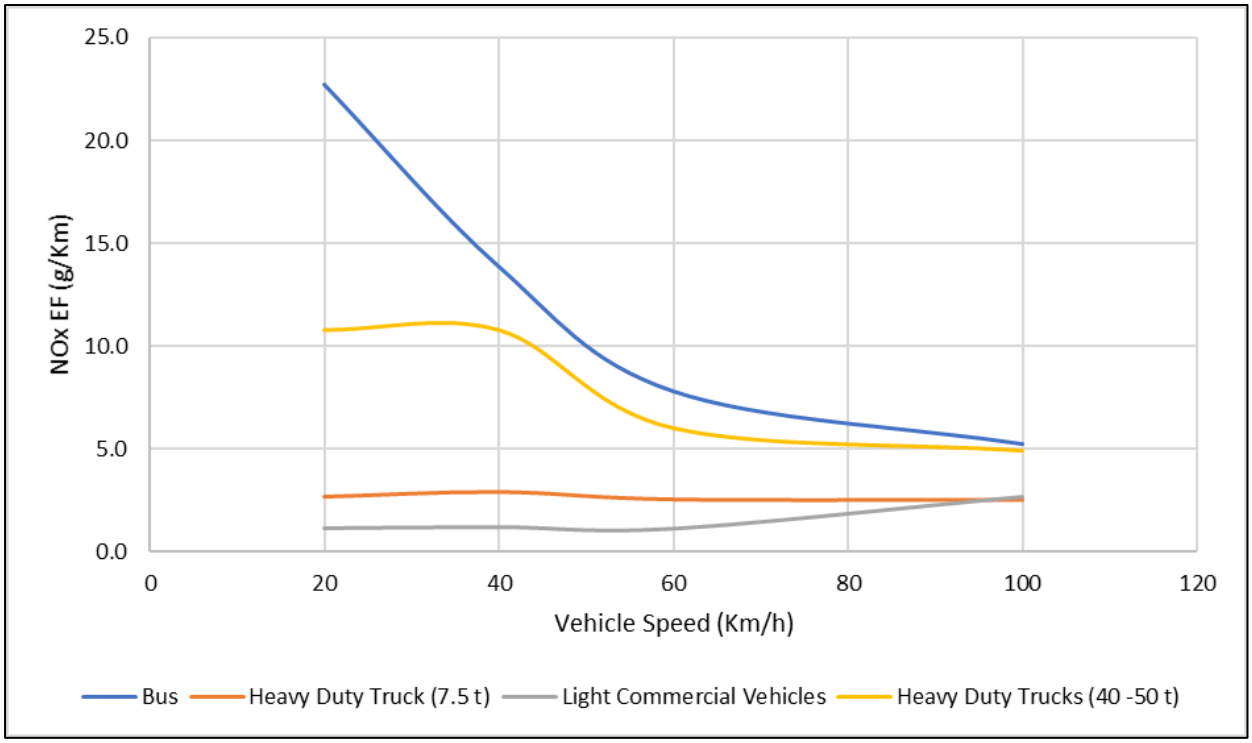


Figure 5-8: NOx emission factors for diesel classes

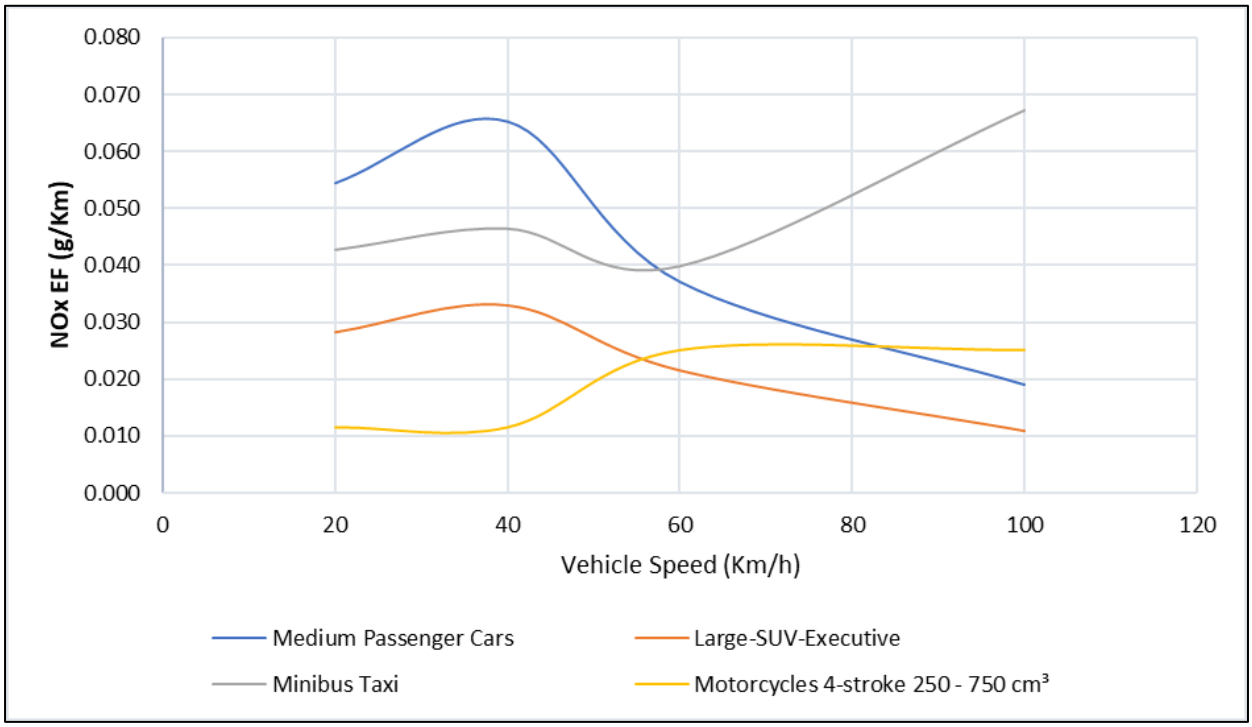


Figure 5-9: NOx emission factors for petrol classes

The emission factors were then applied to the VKT per vehicle class and road type to derive an annual emission estimate per road link for all pollutants of concern. For verification, the VKT and fuel consumption estimates derived from the COPERT Model are adjusted to ensure a ±10% agreement with petrol and diesel fuel sales determined for each TAZ, ensuring accurate estimation of emissions in each area.

As indicated earlier, the management-geared inventory includes emissions only from within HPA boundaries, while the modelling inventory considers all sources within the model domains, in other words, nested and parent domains. As such, A TAZ level emission quantification was required for the nested domain, which comprised vehicle emissions from both within and beyond the HPA. The HPA TAZ areas and their corresponding fuel sales are detailed in Table 5-4, while the TAZ areas outside of the HPA are detailed in Table 5-5.

Table 5-4: Within Highveld Priority Area Travel Analysis Zone total fuel sales

TAZ	Diesel (Million Litres)	Petrol (Million Litres)	Total Fuel Sales (Million Litres)
Albert Luthuli LM and Msukaligwa LM (Alb_Msu) *	20	26	45
Mkhondo (Mkho)	35	18	53
Pixley Ka Seme LM, Lekwa LM and Dipalaseng LM (Pix_Lek_Dip)	181	36	217
Govan Mbeki	268	247	515
Victor Khanye; Steve Tshwete Emalahleni LM and Emakhazeni LM (Vic_Ste_Emal_Ema)	618	211	829
Thembisile Hani LM and Dr JS Moroka LM (Them_JS Moroka)	6	20	25
CoE (Eku)	912	1133	2 045
TOTAL	**2 039**	**1 690**	**3 729**

Note: * Indicates the abbreviated name for the Local Municipalities (LMs) that have been combined to form a TAZ

Table 5-5: Outside Highveld Priority Area Travel Analysis Zone total fuel sales

TAZ	Diesel (Million Litres)	Petrol (Million Litres)	Total Fuel Sales (Million Litres)
City of Johannesburg (CoJ)	1 506	1 698	3 204
City of Tshwane (CoT)	808	931	1 739
Nketoane LM & Phumelea LM in FS	59	136	196
Ngwathe & Metsimaholo LM in FS	164	119	283
eDumbe LM in KZN	167	102	270
Danhauser LM & Emadlangeni LM in KZN	0.5	0.6	1
Newcastle LM in KZN	10	15	25
TOTAL	**2 715**	**3 003**	**5 718**

5.2.2 Results

Expectedly, higher on-road vehicle emissions are observed in TAZ areas with greater fuel sales with the CoE having the greatest volume of daily traffic and fuel sales, subsequently resulting in the greatest emission from on-road vehicles in the HPA.

Figure 5-10 illustrates TAZ level roads that fall within the HPA for which vehicle emissions were estimated. The corresponding estimated total annual emissions from on-road vehicles within the HPA are detailed in Table 5-6, while Figure 5-11 provides a breakdown of estimated emissions per TAZ.

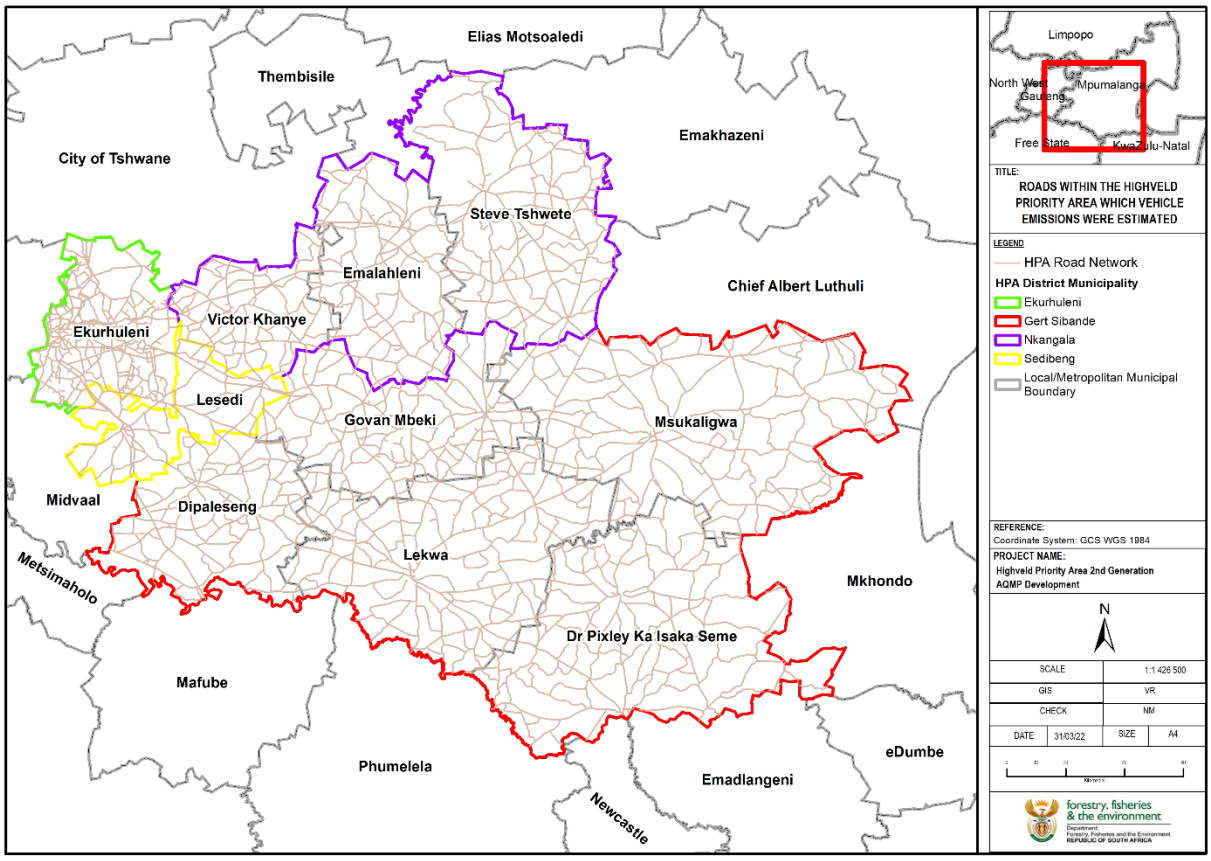
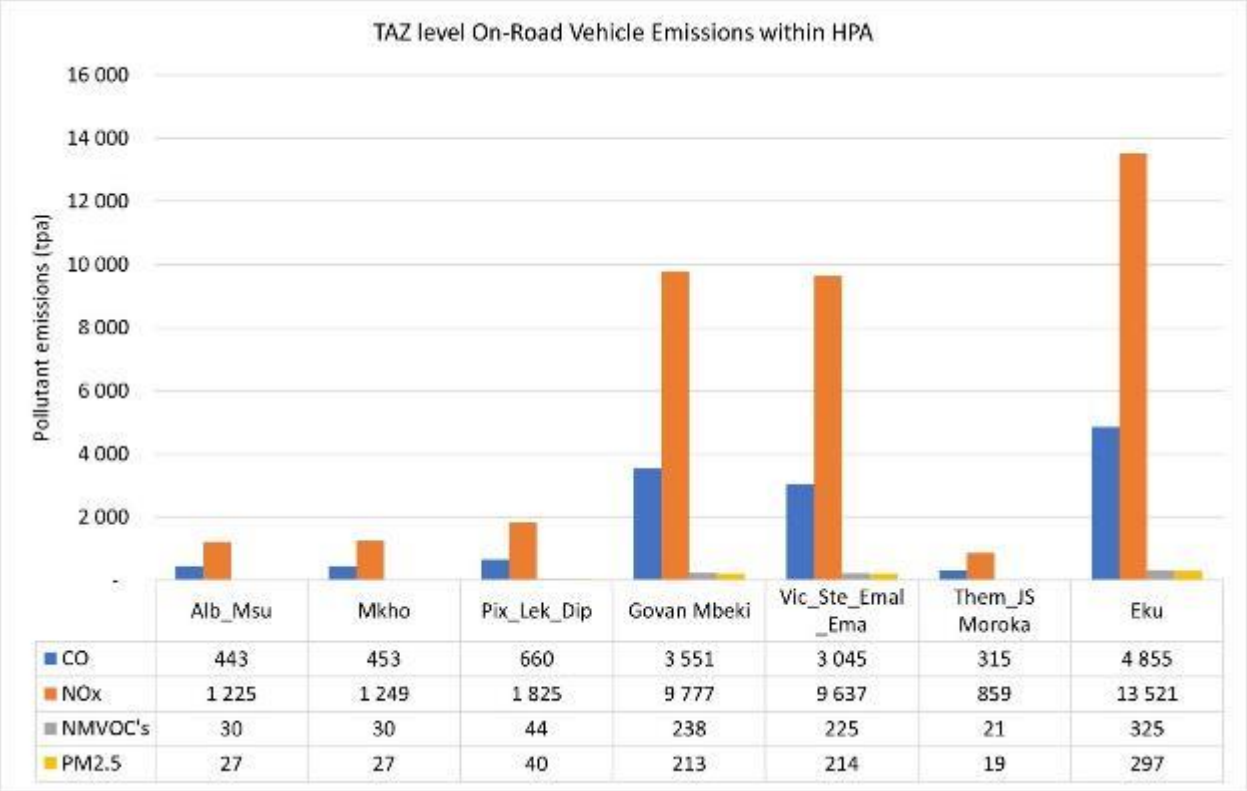


Figure 5-10: Roads within the Highveld Priority Area for which vehicle emissions were estimated



	Alb_Msu	Mkho	Pix_Lek_Dip	Govan Mbeki	Vic_Ste_Emal _Ema	Them_JS Moroka	Eku
CO	443	453	660	3 551	3 045	315	4 855
NOx	1 225	1 249	1 825	9 777	9 637	859	13 521
NMVOC's	30	30	44	238	225	21	325
PM2.5	27	27	40	213	214	19	297

Figure 5-11: Travel Analysis Zone level on-road vehicle emissions within Highveld Priority Area

Table 5-6 shows the total tonnage of estimated annual tonnage of estimated on-road vehicle emissions within the HPA.

Table 5-6: Estimated on-road vehicle emissions (tonne/annum) within the Highveld Priority Area

Inventory Development Area	CO	NOx	NMVOC's	$PM_{2.5}$	SO_2
On-road vehicle Emissions (HPA alone)	13 321	38 093	913	837	734

5.3 Residential Fuel Burning

There is growing evidence of a decreased reliance on fossil fuel combustion for energy use in the residential environment in South Africa. This is primarily due to increased access to electricity. According to Statistics South Africa (via the official Census and annual general household surveys), the percentage of households, as of 2019, with access to electricity is 85% While this does not necessarily mean the total disuse of fossil fuel combustion in those homes (particularly for heating), it does offer an indication of potentially decreased residential fuel combustion. This could potentially be offset by population growth, particularly in areas predominantly reliant on indoor fuel combustion. Figure 5-12 illustrates the population density in the HPA, which is based on the StatsSA 2016 Community Survey results. The most densely populated areas include the City of Ekurhuleni and the Emalahleni LM with more than 398 000 persons per km^2.

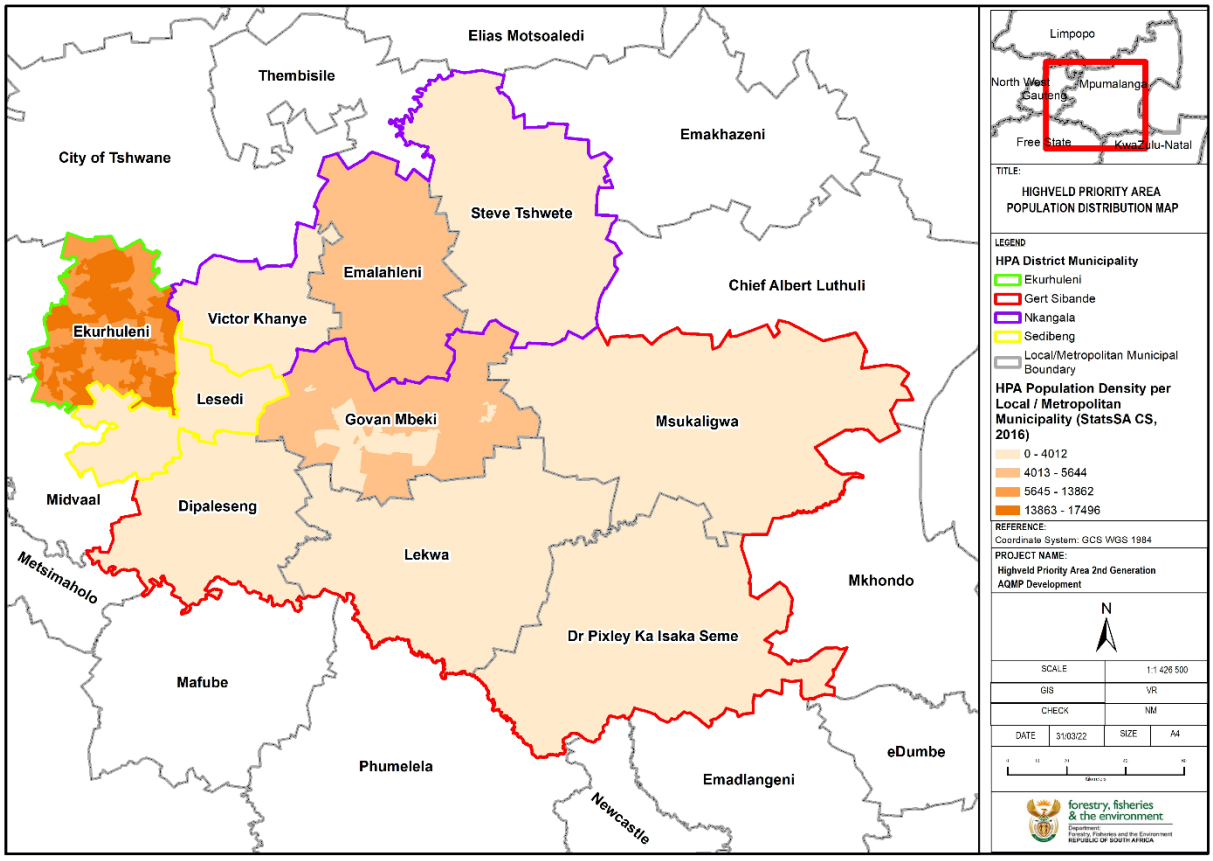


Figure 5-12: Population density within the Highveld Priority Area (derived from StatSA Community Survey, 2016)

The proximity of the emission source to people is one of the key issues concerning household fuel combustion. This issue is exacerbated by inadequate combustion devices and poor indoor ventilation. Important pollutants include PM, CO, SO_2, NO_X and various VOCs. Importantly, not all fuels emit equal quantities of certain pollutants, with the amount of each pollutant emitted depending on the type of fuel burnt. As an example, SO_2 is relevant for coal combustion, while PM is less of a concern for LPG. Considering these pollutant complexities, it is important to understand the type of fossil fuel being burned, for which purpose and in which area so as to ensure the development of appropriate air pollution interventions.

The spatial variability and different pollutant contributions (both primarily driven by variability in fuel use by type) need to be captured in detail to estimate a gridded representation of emissions from residential fuel burning. Approaches to derive an emission inventory for residential fuel use generally rely on activity data from a national census. The data from the South African Census, in other words, StatSA 2016 Community Survey is based on questions about the type of fuel used for cooking, heating, and lighting. This represents, at a spatial level of Census geographic units, the number of households using a specific type of fuel. Top-down approaches, that use a regional fuel consumption estimate, disaggregate the regional sum down to these geographic units. Bottom-up approaches, that use a fuel consumption estimate per household, scale up fuel use by the number of households within each geographic unit. Each approach has benefits and disadvantages and depends highly on available data and its uncertainty.

5.3.1 Methodology

The previous 2012 HPA Emission Inventory used the same methodology to quantify emissions of residential fuel burning. However, there is a material difference in the utilised databases whereby the previous 2012 emission inventory used 2001 Census data, which essentially details the total number of households using fossil fuels to undertake household activities, in other words, cooking, heating, and lighting. The 2019 inventory used both 2012 and 2016 StatsSA Census data, as well as the General Household Survey data (StatsSA, 2019), which also detailed the total number of households using solid fuels to undertake household activities. This presents a material difference in the underlying total household figures, which is exacerbated by inconsistencies in the information pertaining to fuel types combusted, applied emission factors (EFs), volumes of fuel used, diurnal and seasonal patterns of fuel usage, as well as the manner in which fuel is used. It is assumed that the differences in residential fuel burning-related emissions could be attributed to –

- the difference in the underlying databases, in other words, census data, fuel consumption volumes, fuel consumption patterns; and
- a change in the electrification figures for the number of households which received electricity and in living conditions in the HPA.

The 2019 Residential Fuel Burning Emission Inventory employs both a top-down and bottom-up approach. A top-down (for gas, paraffin, and coal) approach was used for the residential fuel use emissions in this study and the spatial aspect was refined using a dwelling inventory. Naturally, the top-down approaches have inherent uncertainties as it relies on a national fuel consumption estimate, which is subject to uncertainty in assumptions on the aggregated national level. On the other hand, while wood burning is a well-known fuel used for residential purposes, in other words, cooking, heating, and lighting, the data from the South African Census, in other words, StatSA 2016 Community Survey, does not have questions around wood as the type of fuel used residentially. As such, it is difficult to obtain the spatial variability for wood burning captured in detail to estimate a gridded representation of emissions from residential fuel burning.

i. Top-down

The national residential fuel consumption data (Table 5-7) was acquired from the annual published Department of Mineral Resource and Energy (DMRE) energy balance data (DMRE, 2018). The methodology used to derive energy balance statistics is based on International Energy Agency (IEA) best practices and is applied through the collaboration of the DMRE with Statistics South Africa. Commodity flow (defined as the movement of a commodity from its point of production to where it is transformed or finally consumed) consumption estimates for the residential sector where used. The data represented 2018, as statistics for 2019 have not yet been collated due to the Covid-19 global pandemic.

The DMRE energy balance data for the fuels of interest are selected based on national commodity flows because of commerce purchases and public services, ensuring that the industrial consumption of fuels is omitted from the assessment, while publicly used fuels are included in the assessment. This assessment also used the StatSA General Household Survey (2019), which detailed a percentage distribution of the main energy sources used for residential fuel burning at the provincial level, which allowed the allocation of national publicly consumed fossil fuels to a provincial level. The provincial proportion of fossil fuel consumption is then allocated into the various LMs according to the StatSA 2016 Community Survey. A useful feature of the StatSA 2016 Community Survey is information on the number of households in each LM using specific fossil fuel for residential fuel-burning activities and, as such, the provincial fossil fuel consumption is aggregated by the number of households using residential fuel burning to obtain a household fossil fuel consumption figure.

This figure is then used to estimate the fossil fuel consumption per household at the LM level. Table 5-7 provides the DOE reported consumption data, as well as the household fuel consumption per residential fuel burning fuel type.

Table 5-7: Top-down residential fuel consumption as estimated by the Department of Mineral Resources and Energy (2018)

Province	Fuel	National 2018 Consumption [a].	2019 % Distribution of Main Energy Sources Used for Residential Fuel Burning [b]	MP 2019 Energy Sources Consumption Used for Residential Fuel Burning	Household Fuel Consumption per Residential Fuel Burning Fuel Type [c]
Mpumalanga	Bituminous coal (t)	380 955	3%	11 428,65	46,44 (kg)
	LPG (kℓ)	364,53	2%	7,29	0,03 (ℓ)
	Paraffin (kℓ)	373 703,31	3%	12 332,21	50,11 (ℓ)
Gauteng	Bituminous coal (t)	380 955	0,1%	380,96	0,64 (kg)
	LPG (kℓ)	364,53	3,8%	13,85	0,02 (ℓ)
	Paraffin (kℓ)	373 703,31	7,3%	27 280,34	46,07 (ℓ)

Note:

a) Obtained from the Department of Energy (2018) National Commodity Flows Commerce and Public Services.
b) Obtained from StatsSA General Household Survey (2019).
c) Determined by dividing the total number of households using a specific residential fuel burning fuel for cooking as per StatsSA 2016 Community Survey by the provincial residential fuel burning consumption.

While residential wood combustion is a component of residential fuel burning, this data is not detailed in the DMRE National Commodity Flows Commerce and Public Services (2018). In order to overcome this, literature values are used as a substitute with the value of 3 tonnes of wood being assumed to be burned at the household (HH) level, as informed by the HPA health study (HPAHS) published by the CSIR & SAMRC (2019). Similarly, the national total of 380 955 (t) for residential bituminous coal combustion is noted to significantly underestimate residential coal combustion at the HH level, for example, 46,44 kg/HH in the Mpumalanga province. Once again, literature values are used as a substitute with the value of 2,4 tonnes of coal being assumed to be burned at the household (HH) level also informed by the HPAHS (CSIR, 2017).

ii. Emission Factors

A comparison of emission factors was done, considering those from the FRIDGE study (Scorgie et al., 2004), the USEPA AP-42 dataset, the GAINS United States and Australia Model (Ballard-Treemer, 1997; Britton 1998; Amann et al., 2011; Scorgie, 2012; Makonese, 2015). Many South African studies have focused on coal. A hybrid selection from the studies mentioned is considered in this household fuel combustion emissions methodology and is presented in Table 5-8.

Table 5-8: Emission factors used for residential fuel combustion

Pollutant	LPG		Paraffin		Coal		Wood	
	Factor (g/Kg)	Source	Factor (g/Kg)	Source	Factor (g/Kg)	Source	Factor (g/Kg)	Source
SO_2	0,0100	FRIDGE	0,8510	FRIDGE	11,6	Scorgie, 2012	0,123	Ballard-Tremeer, 1997
PM_{10} (a)	0	NA	0	NA	0	Makonese, 2015	1,035	AP-42
$PM_{2.5}$	0,068	AP-42	0,359	AP-42	16,146	Makonese, 2015	13,745	AP-42
NOx	1,4	FRIDGE	1,5	FRIDGE	3,95	Makonese, 2015	1,224	AP-42
VOC	0,018	AP-42	0,085	AP-42	5	FRIDGE	19,867	AP-42
NH_3	0	NA	0	NA	0,0003	AP-42	0	N/A
CO	13,6	FRIDGE	44,9	FRIDGE	94,38	Makonese, 2015	114,577	FRIDGE
CH_4	0,012	AP-42	0,213	AP-42	3,6	AP-42	2,177	AP-42

Note: (a) PM_{10} represents only the coarse fraction (in other words, PM with a diameter of 2.5 µm to 10 µm).

5.3.2 Results

As indicated earlier, it is important to understand the type of fossil fuel being burned, for which purpose and in which area to ensure the development of appropriate air pollution interventions. To this end, household fuel consumption estimates are presented per household to account for the fact that some areas will have higher consumption purely due to a higher number of households. In addition, fuel type and application are also presented per household to allow comparison against non-electrical cooking and space heating in the HPA. This is to gain insight into the relationship between electrification and residential fuel burning practices, as well as fossil fuel consumption at the LM level. Emission estimates were calculated by simply multiplying the gridded fuel use (obtained via top-down and bottom-up approaches) by emission factors in Table 5-8 above (see Figure 5-13 below).

The residential fuel burning emissions were estimated for areas within the HPA (see Figure 5-13) with the various associated emissions detailed in Table 5-9.

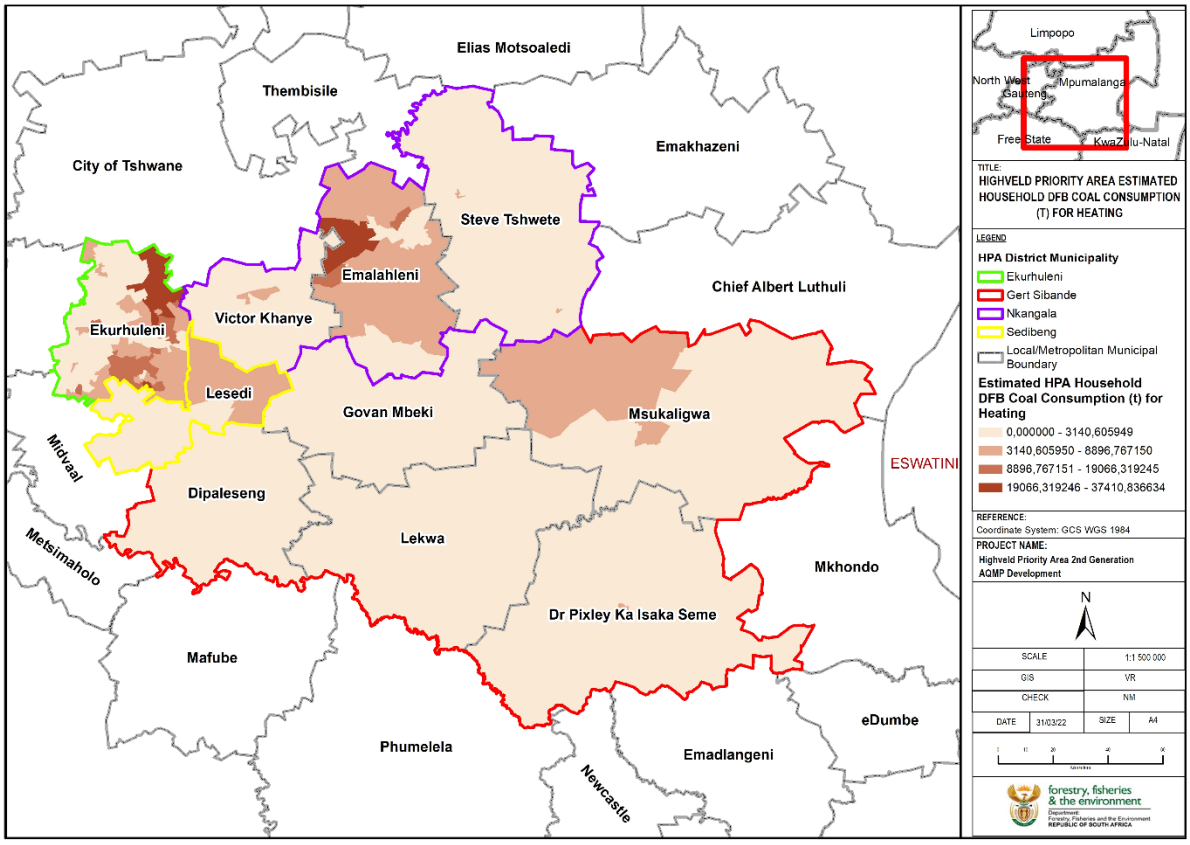


Figure 5-13: Annual estimated fuel consumption for different fuels used for residential combustion – coal

Figure 5-13 indicates that the areas with the highest ward level residential fuel burning-related coal consumption are found to the east of the CoE and north of Emalahleni with the Msukaligwa LM and Lesedi (incorporated into the CoE), as well as illustrating elevated coal consumption rates.

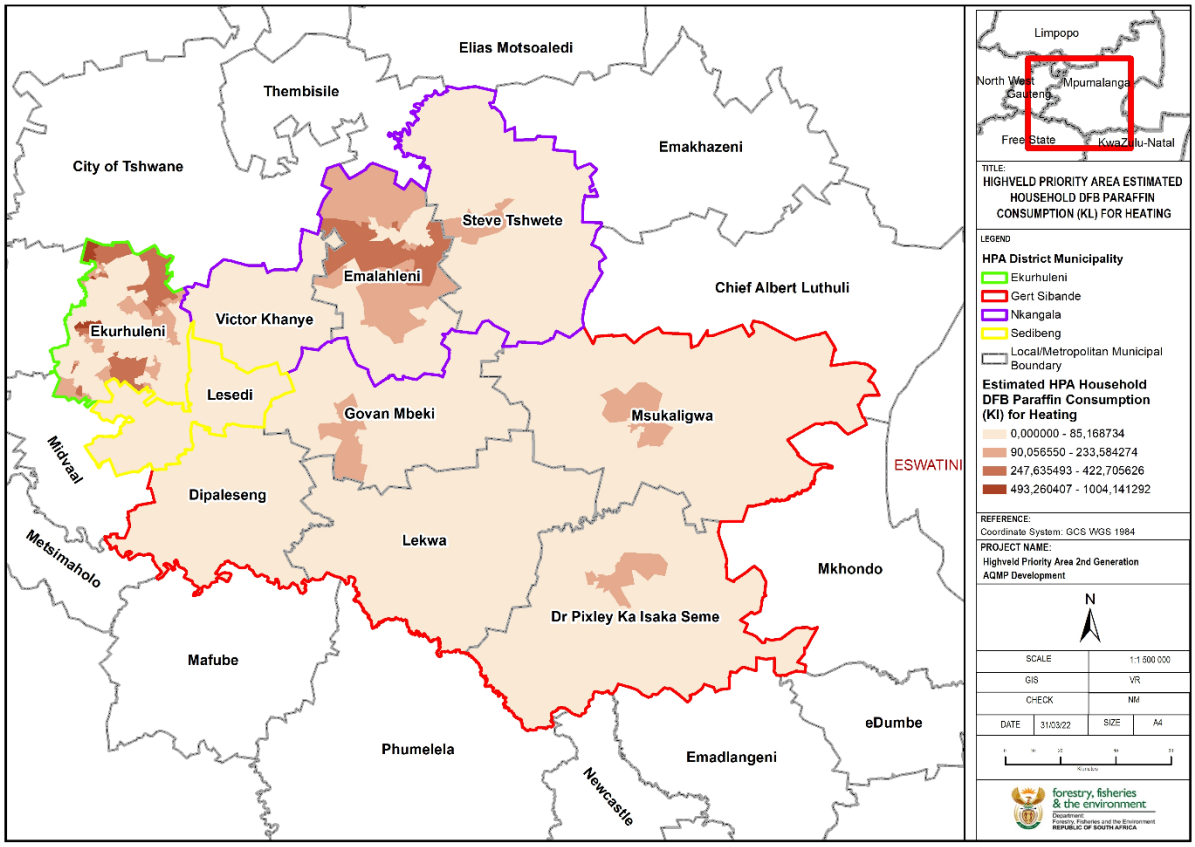


Figure 5-14: Annual estimated fuel consumption for different fuels used for residential combustion – paraffin

Figure 5-14 indicates that the areas with the highest ward level residential fuel burning-related paraffin consumption are found in the outskirts of the CoE. Similarly, central Emalahleni also indicates elevated paraffin consumption rates with the Steve Tshwete, Govan Mbeki, Msukaligwa, Dipalaseng and Dr Pixley LMs showing high consumption hotspots.

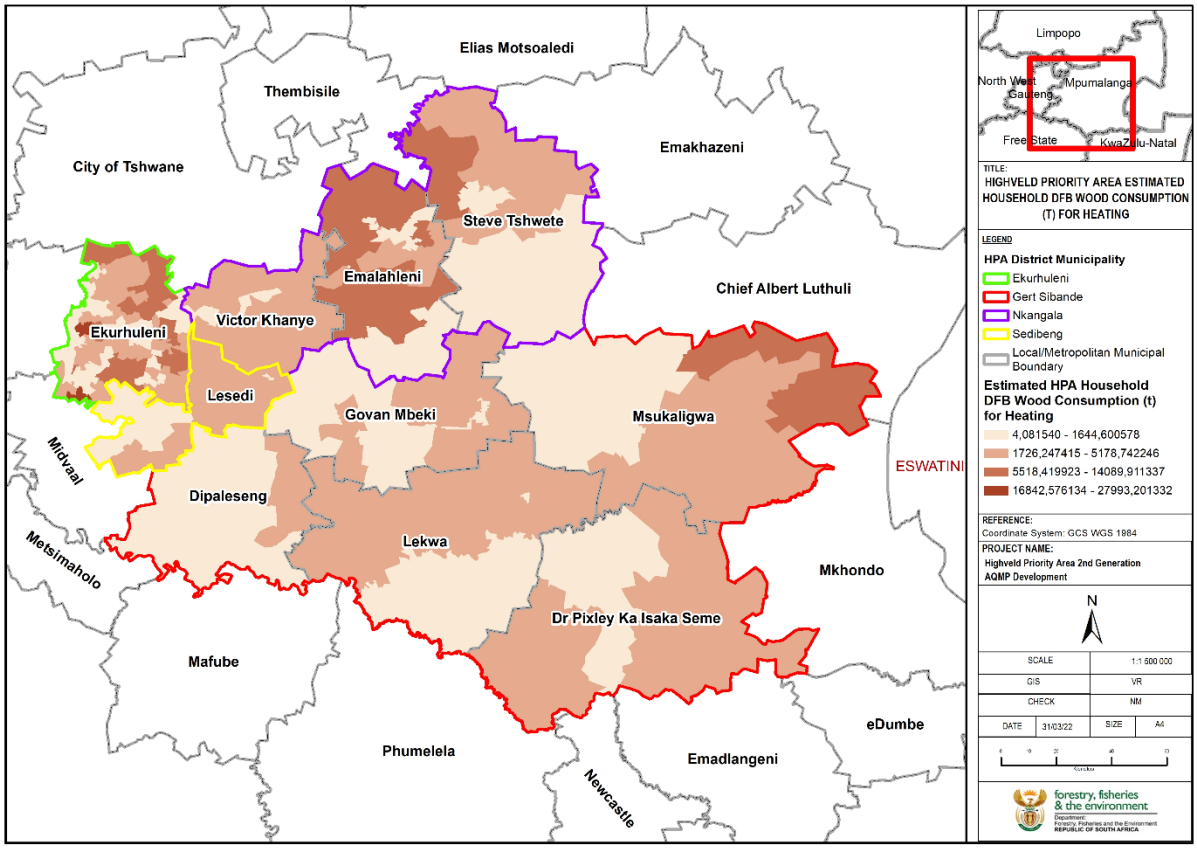


Figure 5-15: Annual estimated fuel consumption for different fuels used for residential combustion – wood

Figure 5-15 indicates that there are significantly more areas of residential fuel burning-related wood combustion in comparison to other residential fuel burning-related fuels with a part of the CoE, Emalahleni and Steve Tshwete showing elevated wood consumption rates.

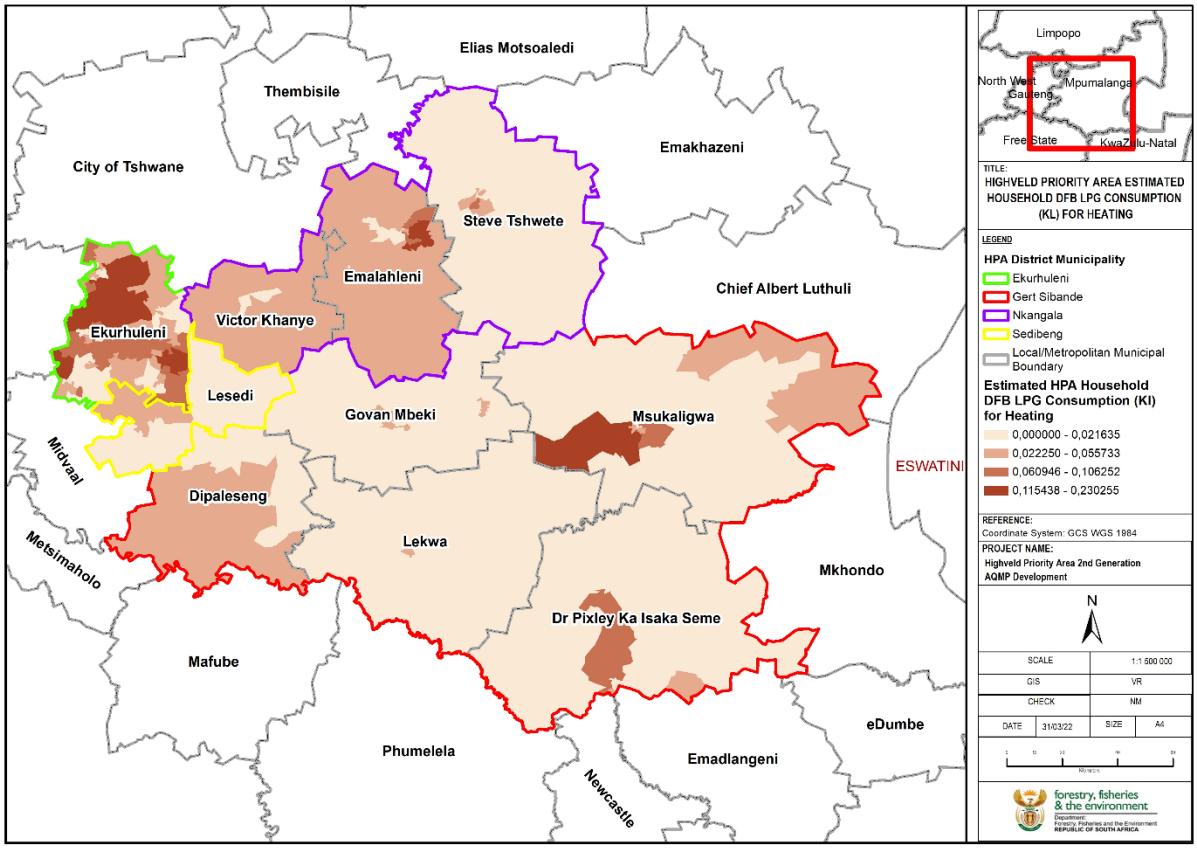


Figure 5-16: Annual estimated fuel consumption for different fuels used for residential combustion – LPG

Figure 5-16 indicates that the areas with the highest ward level residential fuel burning-related LPG consumption are found in central CoE, as well as a part of Emalahleni and Msukaligwa. In general, the central area of the HPA is noted to have low LPG consumption rates.

From an emission volume point of view, space heating is the largest residential fuel burning emission contributor accounting for more than double the cooking pollutant emissions. This observation is key for the determination of adequate air pollutant management interventions and strategies. Table 5-9 below provides a breakdown of residential fuel burning emissions for the HPA alone.

The residential fuel burning emission quantification from a variety of fuels inherently introduces significant variability, more so when undertaken over a study area as large as the nested model domain. To this end, understanding the total pollutant emission contribution from each fuel type is key to this type of assessment. Table 5-9 summarises the pollution contribution of each residential fuel burning fuel type to the total residential fuel burning emission estimated for the HPA.

Table 5-9: Pollution contribution summary for each residential fuel burning fuel type to the total residential fuel burning emission estimated for the Highveld Priority Area

Fuel Type	SO_2	PM*	NOx	VOC	NH_3	CO	CH_4
Coal	9 019	12 553	3 071	3 887	0	73 379	2 799
LPG	0	0	0	0	0	0	0
Paraffin	14	6	103	1	0	998	1
Wood	60	7 182	595	9 654	0	55 676	1 058
TOTAL	**9 092**	**19 741**	**3 769**	**13 543**	**0**	**130 054**	**3 858**

Note: * Emissions are estimated as the sum of PM_{10} and $PM_{2.5}$

Table-5-9 indicates that the majority of residential fuel burning-based emissions emanate from coal combustion, followed by wood combustion, with LPG and paraffin indicating significantly lower pollution contribution rations. This is of course expected as evidenced by the lower emission factors detailed for both LPF and paraffin (see Table 5-8). Figure 5-17 graphically summarises Table-5-9 in terms of pollution contribution.

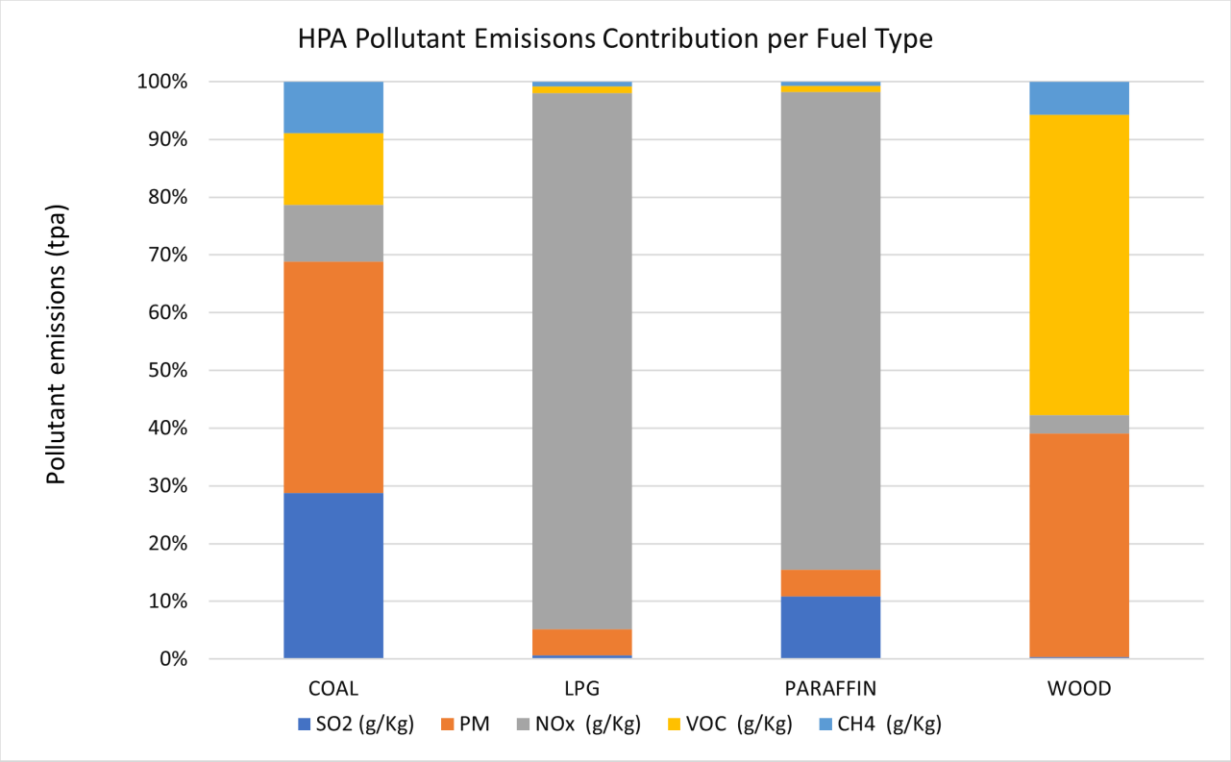


Figure 5-17: Highveld Priority Area pollutant emissions contribution per fuel type

5.4 Residential Waste Burning

Landfill emissions, due to decomposition, primarily comprise CO_2, methane (CH_4), and non-methane VOCs. Wastewater treatment facilities are likely to result in emissions of CO_2, methane (CH_4), non-methane VOCs, and potentially odorous compounds such as hydrogen sulphide (H_2S) and ammonia (NH_3). Emissions from treatment facilities are dependent on the type of treatment units, temperature of wastewater, liquid density, concentrations of the various compounds in the liquid waste, residence, and turnover of liquids in treatment units.

Open burning of waste can impact air quality through the emissions of a range of pollutants. In this emission inventory, an international database was used to estimate the emissions from waste burning in the HPA by following a top-down approach. The approach for the development of the inventory is briefly described below. The detailed methodology and data used are included in Wiedinmyer et al. (2014).

5.4.1 Methodology

The First Generation HPA AQMP baseline emission inventory only qualitatively quantified waste-related emissions, whereas the Second Generation HPA AQMP estimates and quantifies residential waste burning emissions. The method used is similar to that reported by Wiedinmyer et al. (2014), which follows the IPCC methods (IPCC, 2006). The emissions of pollutant i (Ei) are estimated as the product of the emission factor of the waste (EFi) and the amount of waste burned (WB), as shown in Equation 5-1.

$$E_i = W_B \text{ x } EF_i \qquad \textbf{Equation 5-1}$$

where:

Ei	The emissions of pollutant *i (Ei)*
W_B	The amount of waste burned
EF_i	The emission factor of the waste

The generalised equation to estimate waste burned is shown in Equation 5-2.

$$W_B = P \; x \; P_{frac} \; x \; MSW_P \; x \; B_{frac} \qquad \textbf{Equation 5-2}$$

where:

P	Population
P frac	The fraction of the population accounts whose waste is not collected, in other words, assumed to burn their waste
MSW P	The mass of annual per capita waste production
B frac	The fraction that is available to be burned that is actually burned

For this methodology, local data on waste per person and composition were used, in other words, waste generated per person per capita. Waste information was taken from Jeffares & Green (Pty) Ltd. (2016), in which waste composition and the amount for 2015 were calculated and assessed for six municipalities in South Africa. LM data are used to calculate a waste per person per year estimate. This was accomplished by using the StatsSA Community Survey 2016 data on the number of people who use landfills. Waste per capita is simply the tonnage of household waste reaching the landfills (provided by the Jeffares & Green [Pty] Ltd, 2016, study) divided by the number of people whose waste is sent to landfills (from the Community Survey 2016 data for the Emfuleni LM). The value estimate is 0,217 tonne/person/annum.

However, the more recent 2018 Sasol Waste Collection Interventions (WCI) study (Mamadi & Co., 2018) noted a waste generated per capita of 0,612 tonne/person/annum, which is then assumed to be representative of the entire HPA. According to Equation 5-2, not all waste is combustible. As an example, glass and metals will not readily burn, therefore, a burn fraction is required. The IPCC recommended fraction of 0,6 is used, in other words, 60% of the waste generated by people who do not receive removal services is burned.

Equation 5-1 also requires the use of emission factors. The most recent compilation of waste emission factors in a South African context is detailed in the Sasol South Africa Emission Factors for Criteria Pollutants from Solid Waste Material Combustion Report (Mamadi & Co., 2018). Several categories of materials that are common in waste burned in South Africa townships are identified in the report. Figure 5-18 below illustrates a weight distribution for the composition of waste materials collected by Sasol's WCI programme. The major waste components of the programme were paper, leather/rubber, textile, plastic bottles and bags, ceramic, metal, and glass.

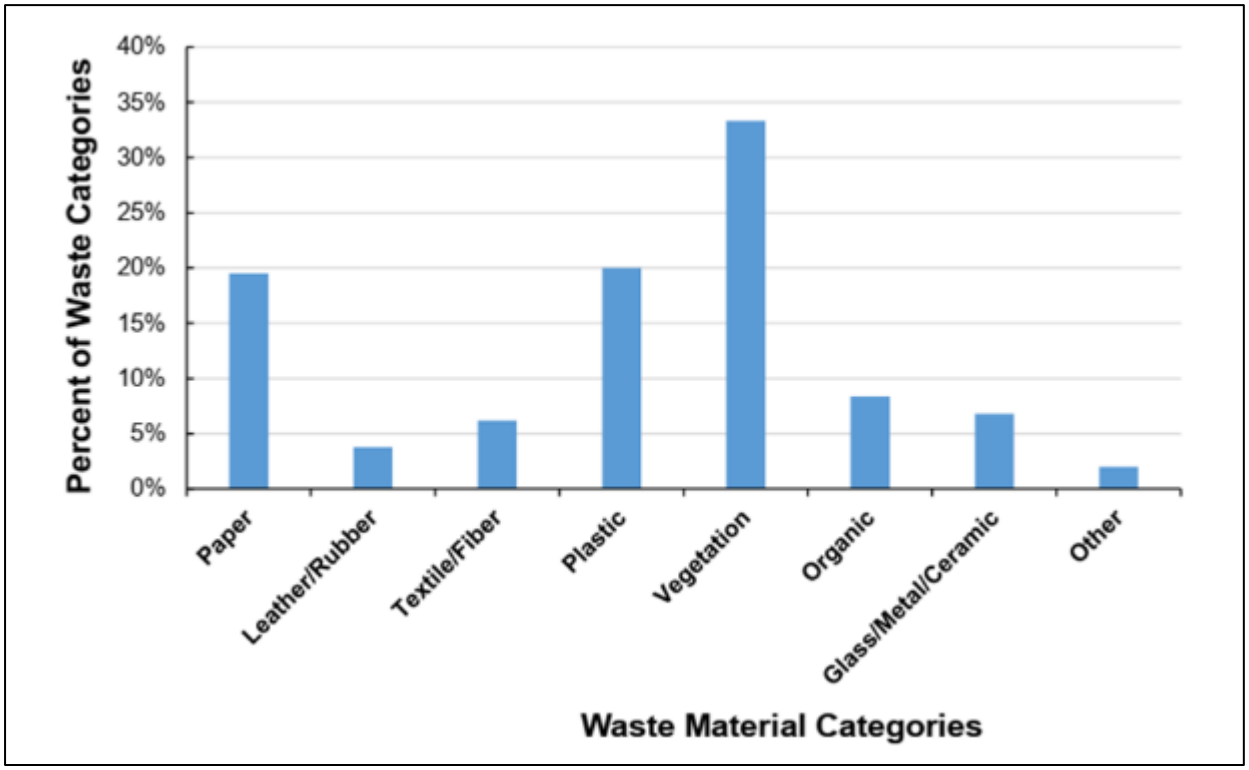


Figure 5-18: Weight fraction of municipal solid waste categories collected by Sasol (Data provided by Mr Warren Carter, Sasol Technology)

In Table 5-10, a summary is provided of the average emission factors reported separately for the flaming and smouldering phases, as well as for the entire combustion process. Among the eight material categories tested, leather/rubber, plastic bottles, and food discards did not flame. Therefore, the total emissions consist of the smouldering phase emissions.

Table 5-10: Measured emission factors (average ± standard deviation) for waste materials tested in South African townships.

Pollutant Emission Factor (g/kg Fuel)						
Burn Type	**CO_2**	**CO**	**NO_x (As NO_2)**	**SO_2**	**$PM_{2.5}$**	**PM_{10}**
Flaming	1 443 ± 8	14,9 ± 0,7	2,29 ± 0,16	1,13 ± 0,15	6,94 ± 2,32	7,34 ± 2,36
Smouldering	1 302 ± 28	105,1 ± 11,0	2,95 ± 0,26	0,17 ± 0,06	6,55 ± 3,01	6,95 ± 3,22
Combined	1 417 ± 8	31,6 ± 1,8	2,41 ± 0,11	0,95 ± 0,13	6,86 ± 2,08	7,26 ± 2,12

5.4.2 Results

By multiplying the waste generated per capita by the number of people not receiving waste services, as per StatsSA Community Survey 2016, an estimate of the amount of waste generated (that may likely be burned) is calculated. Figure 5-19 below spatially details the available residential waste that may be burned due to a lack of waste collection services, as per the StatsSA Community Survey 2016. Notably, while the CoE and Emalahleni have the highest available waste for combustion, the areas also have high rates of waste collection, thereby highlighting the influence of population density and waste per capita production.

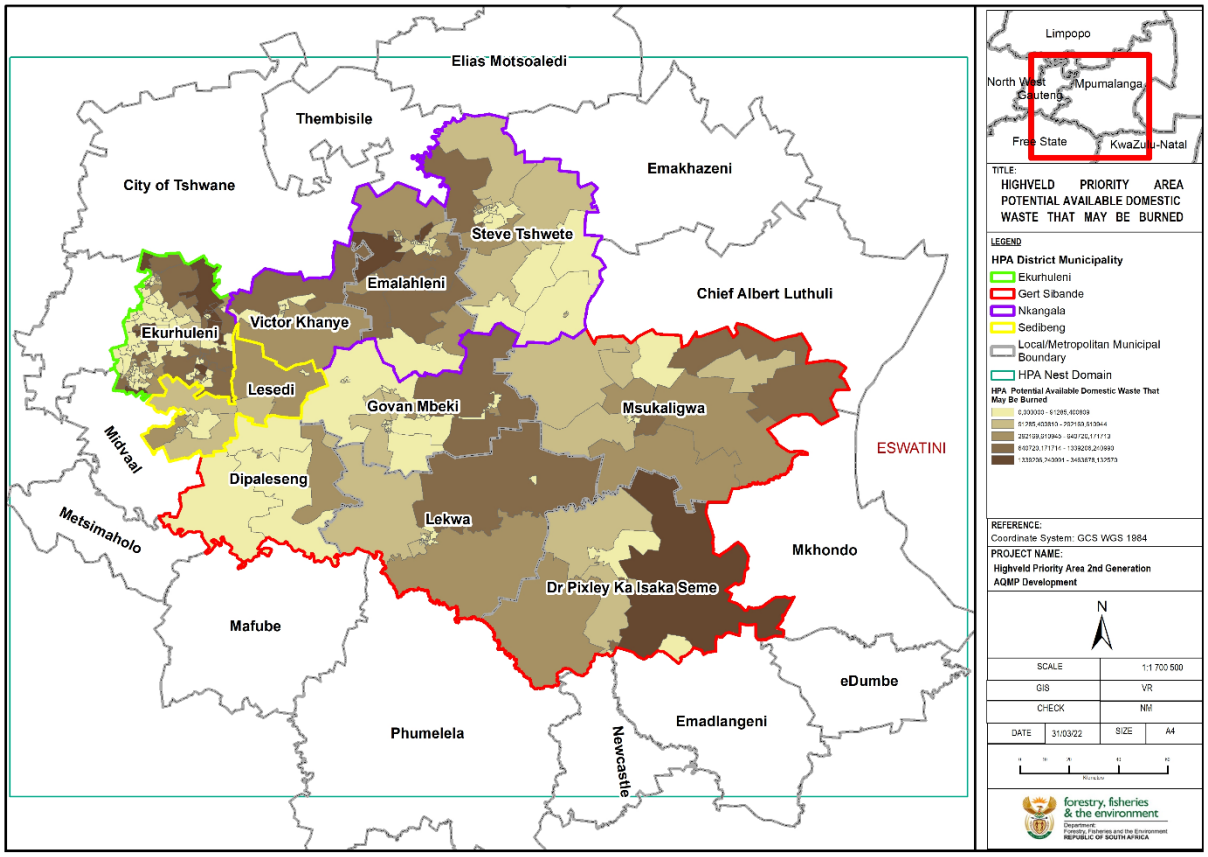


Figure 5-19: Potential available residential waste that may be burned due to a lack of waste collection services as per the StatsSA Community Survey 2016

Equation 5-2 is applied to the available waste in Figure 5-19 above and the emission factors detailed in Table 5-10 are applied thereafter, thereby determining grams per species emitted per kilogram of waste burned. The results of this determination are presented in Table 5-11 below.

From an air quality management point of view, the HPA-geared emission inventory is presented in Table 5-11 below, detailing the total tonnage of estimated annual pollutant emissions due to residential waste burning in the HPA. These emissions are estimated for the HPA alone, as illustrated in Figure 5-20, and do not include areas that fall outside of the HPA, in other words, white polygon.

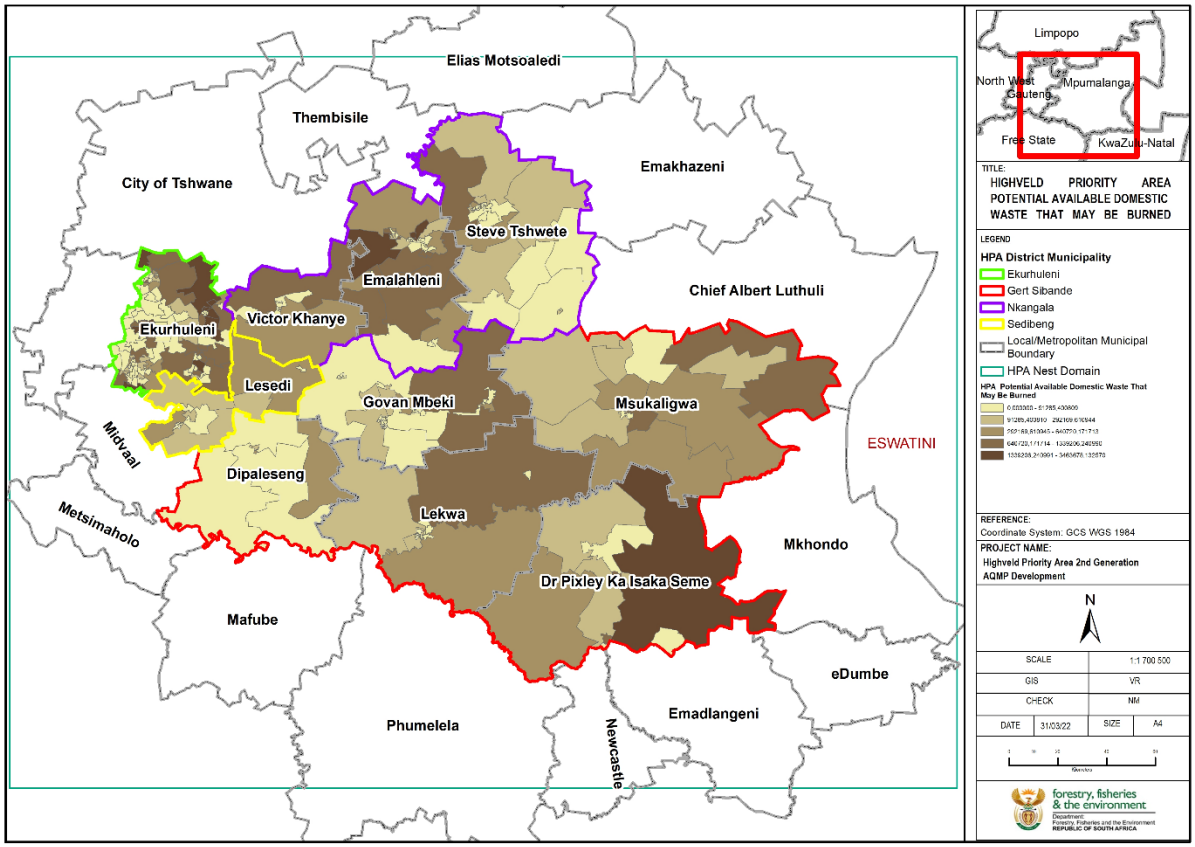


Figure 5-20: Potential available residential waste that may be burned due to a lack of waste collection services in the Highveld Priority Area as per the StatsSA Community Survey 2016

Once again, Equation 5-2 is applied to the available waste in Figure 5-20 above and the emission factors detailed in Table 5-10 are applied thereafter, thereby determining grams per species emitted per kilogram of waste burned. The results for the HPA-aligned waste burning emissions are detailed in Table 5-11 below.

Table 5-11: HPA residential waste burning emissions

Inventory Development Area	CO_2	CO	NO_x (as NO_2)	SO_2	$PM_{2.5}$	PM_{10}
HPA alone	129 701	2 892	221	87	628	665

5.5 Windblown Particulate Emissions

The prevailing dry climatic conditions in the urban and peri-urban areas of South Africa make windblown dust a potential nuisance. Windblown dust can be a road traffic safety concern as these particles obscure visibility for

vehicles. The high particulate concentrations emanating from dust emissions can have substantial effects on the quality of air breathed and in turn human health. The sources of windblown particulates include exposed topsoil areas. In HPA, windblown particulates from mine waste facilities, product stockpiles, as well as ash storage facilities for large combustion sources, can result in significant dust emissions with high concentrations near the source locations.

5.5.1 Methodology

Windblown particulate emission rates were quantified using the Airborne Dust Dispersion Model from Area Sources (ADDAS) developed by Airshed Planning Professionals (Burger, 2010). This is an in-house model that is based on the dust emission scheme by Marticorena and Bergametti (1995). This model accounts for the variance in source erodibility by parameterising the erosion threshold (based on particle size distribution of the source) and roughness length of the surface matter. Material particle density, moisture content, particle size distribution and site-specific surface characteristics were used as inputs into this model. The initial 2012 HPA AQMP emission inventory quantified particulate emissions from coal mining associated with major haul roads at open cast coal mining facilities. The estimations were undertaken using the US-EPA's AP42 emissions factors for the estimation of dust entrainment from vehicles on unpaved roads. Mines and major haul roads were identified through the combined use of Geographic Information System (GIS) data and satellite imagery for the HPA. The difference between the two inventories is attributed to the following:

- The difference in the underlying methodologies and databases i.e., different emissions factors; total number of identified mines; differences in PM_{10} generating physical parameters etc.

5.5.2 Results

A total of 225 sources of mine dust particulates were identified and assessed within the HPA study area. Of these, 186 were coal discard dumps, 20 were stockpiles and exposed surfaces, 15 were ash dumps and 4 were gold tailings. These windblown dust sources were identified using landcover data (https://egis.environment.gov.za/sa_national_land_cover_datasets) global mining areas data, operating mines data from the Department of Mineral Resources and Energy (https://www.dmr.gov.za/mineral-policy-promotion/operating-mines/mpumalanga) and google earth satellite imagery.

The total contribution from windblown dust to PM_{10} and $PM_{2.5}$ within the HPA is 100 622 tpa and 13 751 tpa, respectively (See Table 5-12). Most of these emissions within the HPA emanate from coal discard dumps.

Table 5-12 summarises the particulate matter associated with windblown dust sources in the HPA. Figure 5-21 is indicative of the windblown dust sources in the HPA.

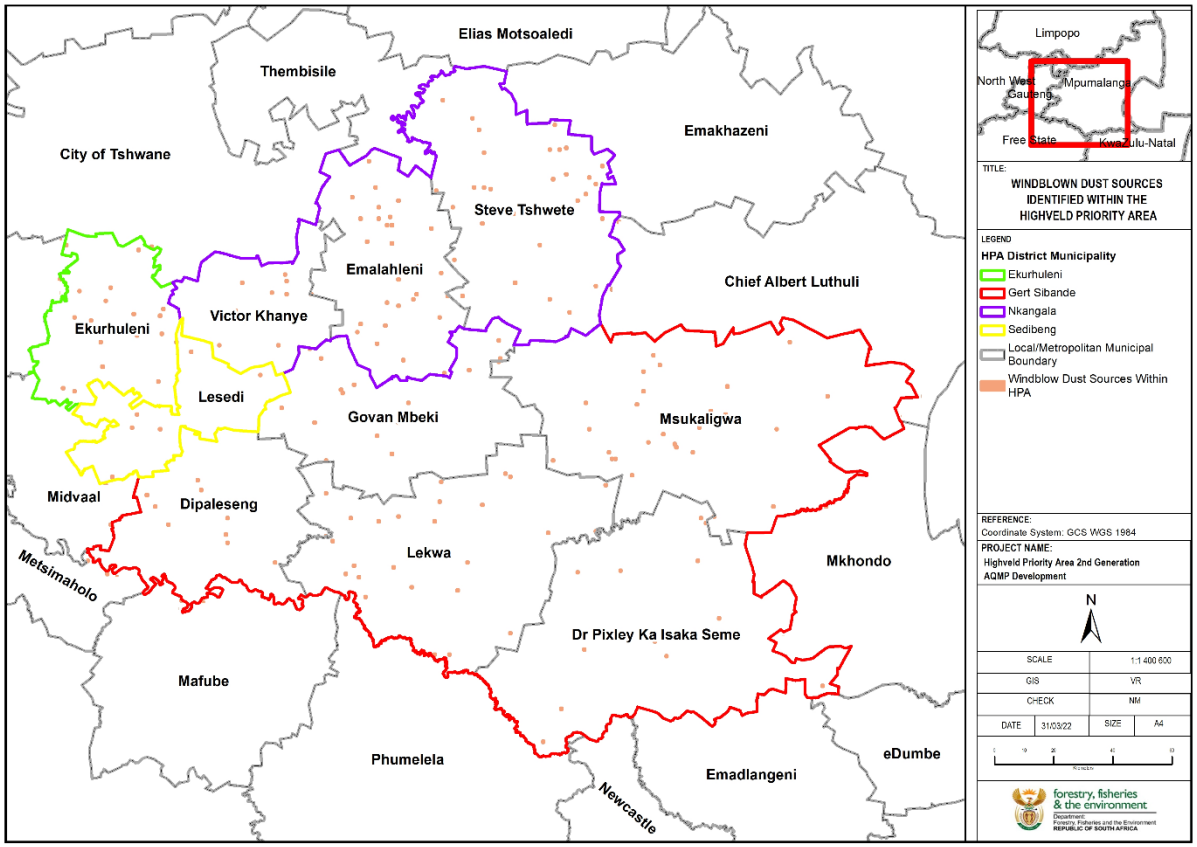


Figure 5-21: Illustration of the identified windblown dust sources identified within the Highveld Priority Area

Table 5-12 indicates that the total contribution of PM_{10} and $PM_{2.5}$ from windblown dust sources in the HPA estimated were 104 901 tpa and 30 465 tpa, respectively.

Table 5-12: Particulate emissions due to windblown dust sources within the Highveld Priority Area alone

Description	Area (m^2)	Emission Rates (Tonne/Annum)	
		PM_{10}	$PM_{2.5}$
Exposed topsoil	52 250 227	104 901	30 465

5.6 Biogenic Volatile Organic Compound Emissions

In response to stress, terrestrial vegetation can release non-methane VOCs mainly in the form of isoprene (Sindelarova et al., 2014). These biogenic VOC emissions can have a substantial effect on atmospheric chemistry by reacting with ozone, OH and NO_3 radicals (Sindelarova et al., 2014). Biogenic VOCs are also a major source of secondary organic aerosols.

5.6.1 Methodology

The First Generation HPA AQMP baseline emission inventory did not quantify biogenic VOC-related emissions, whereas the Second Generation HPA AQMP estimates and quantifies these emissions. The CAMS global emissions dataset (https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-global-emission-inventories?tab=form) was used to provide biogenic VOC emission estimates. These emissions were simulated using the Model of Emissions of Gases and Aerosols from Nature (MEGAN). The meteorological variables used in MEGAN were obtained from the ERA-Interim dataset. The spatial distribution of vegetation in the MEGAN Model was defined using plant functional types that were grouped according to similar leaf physiology.

The CAMS dataset (0.25° x 0.25° grid resolution) was downloaded for 2019. This dataset was then spatially disaggregated onto a 0.02° x 0.02° grid using a non-interpolating technique, which involves assigning a fractional value (based on the fraction of area) within each domain's grid cell.

5.6.2 Results

The results from the CAMS global emissions dataset for the HPA, as well as the nested domain, are provided below. From an air quality management point of view, the HPA-geared emission inventory is presented in Figure 5-22, which shows the CAMS estimated total annual biogenic VOC (isoprene) emissions for the HPA alone. Accordingly, Table 5-13 shows the total tonnage isoprene within the HPA alone.

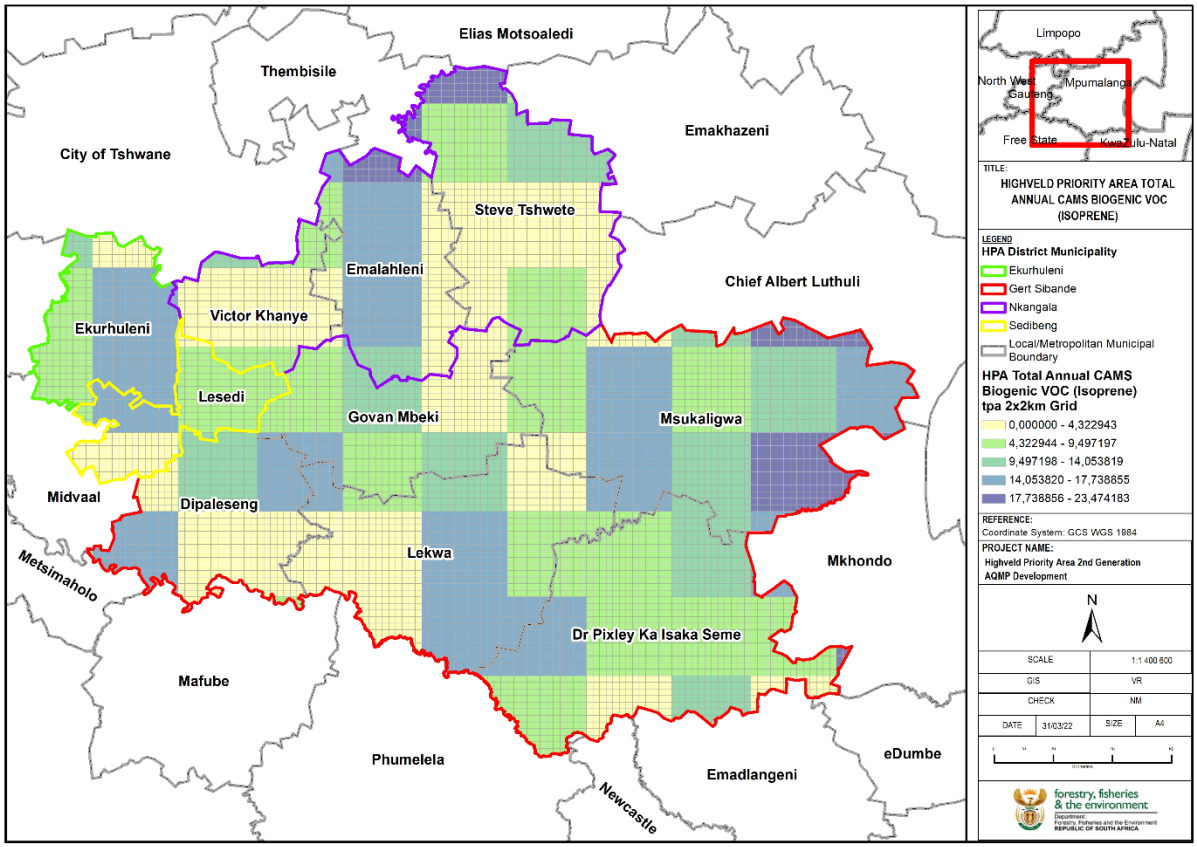


Figure 5-22: Total annual Copernicus Atmosphere Monitoring Service biogenic volatile organic compound (isoprene) emissions over the Highveld Priority Area domain

Table 5-13: Copernicus Atmosphere Monitoring Service estimated biogenic volatile organic compound annual tonnage in the Highveld Priority Area alone

Area	Isoprene
HPA	75 498

5.7 Biomass Burning

Biomass burning over southern Africa is a significant source of particulate emissions in the atmosphere. Biomass burning alters the quality of air and has an impact on the climate system by modifying solar radiation and cloud properties (Pan et al., 2020). Natural fires and large-scale burning in agricultural areas are major sources of biomass burning over southern Africa's landscape dynamic.

Owing to the spatiotemporal dynamics of landscape fires, remote sensing techniques are used to estimate biomass burning emissions over large spatial scales (Nguyen, 2020). Remotely observed active fire counts, fire radiative power and burned area are multiplied with landcover specific emissions to develop global biomass burning emissions datasets.

5.7.1 Methodology

Both the First Generation HPA AQMP baseline emission inventory, as well as the Second Generation HPA AQMP, estimated biomass burning-related emissions. The 2012 emission inventory utilised a general formula applied to landcover types in the HPA used to estimate emissions from burning episodes as a function of various generic factors (in other words, area burned, fuel load, vegetation type, combustion completion, and the relevant emission factor. Changes in total biomass burning-related emissions are also attributed to a difference in the underlying databases, quantification methodologies, and the spatial and temporal resolution of burning episodes.

Biomass burning emissions from large-scale agricultural burning and natural fires for 2019 were obtained from the University Corporation for Atmospheric Research (n.d.) dataset (https://www.acom.ucar.edu/Data/fire/). This dataset uses active fire count observations, landcover cover from MODIS sensors and estimated fuel consumption to quantify biomass burning emissions. It is assumed that the active fire pixel is 0,75 km^2 for grasslands and savannas and 1 km^2 for other landcover types. This spatial resolution is suitable for regional/urban scale air quality modelling. Emissions data are downloaded as daily totals for a specific year.

Corrections were made to the FINN data by first identifying fires that had been apportioned incorrectly to surface coal mines and large hot/reflective rooftops, and removing these fires through a masking procedure.

5.7.2 Results

FINN data were obtained for 2019 and processed following the described methodology. Table 5-14 depicts the annual tonnage emissions from biomass burning within the nested model domain and HPA. Figure 5-23 shows the annual FINN PM_{10} estimates gridded into the 1 km model grid (gridded for display purposes).

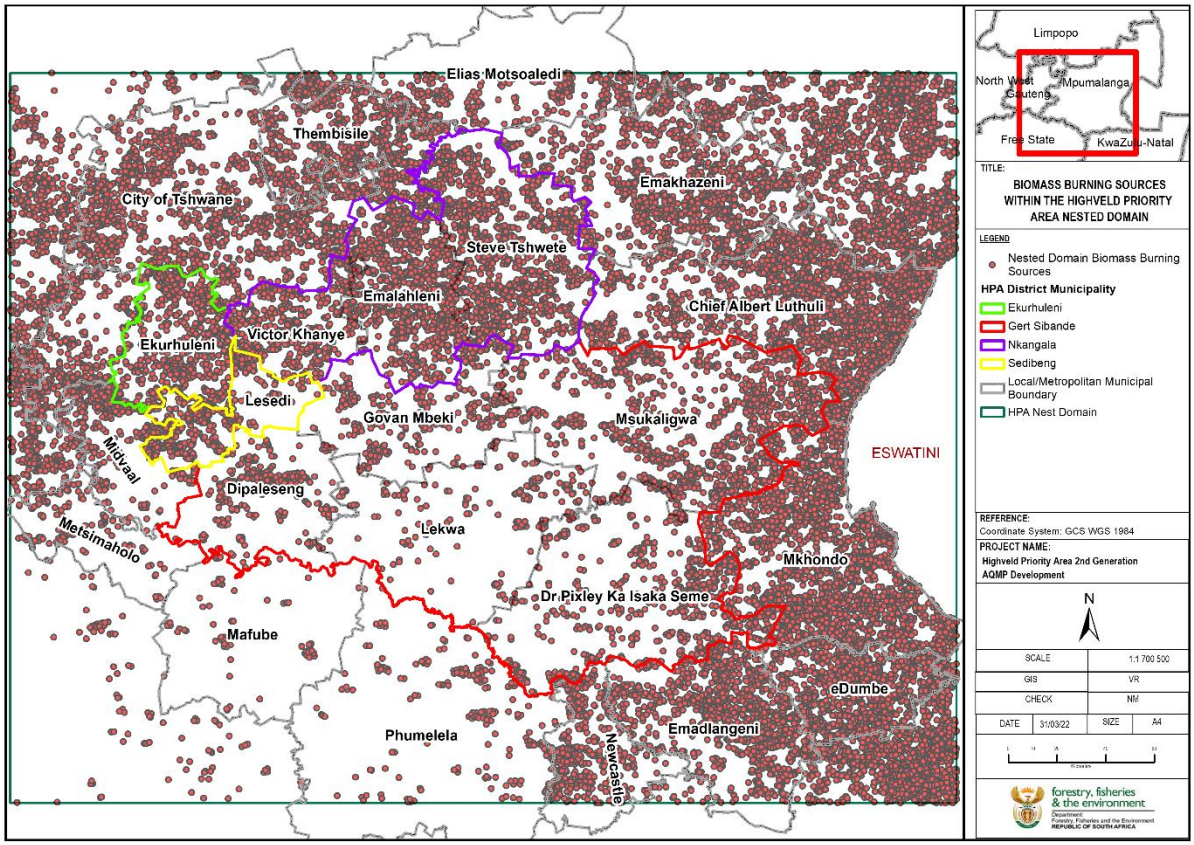


Figure 5-23: Map showing gridded (to 1 km resolution) FINN estimated PM_{10} emissions from biomass burning (total tonnes per annum per cell)

When considering Figure 5-23, it is evident that a large majority of the biomass burning events occur outside of the HPA with a significant number of burning events noted in the eastern region of Mpumalanga, parts of KwaZulu-Natal, Limpopo and the North-West. Taking the HPA into consideration, areas with significant biomass burning events include the CoE, Victor Khanye, Emalahleni and Steve Tshwete LMs with minimal burning events noted to have taken place in the Lekwa LM.

The HPA emission inventory is presented in Figure 5-24, which shows the gridded (to 1 km resolution) FINN estimated PM_{10} emissions from biomass burning (total tonnes per annum per cell) for the HPA alone. Accordingly, Table 5-14 details the FINN estimated annual emissions from biomass burning (units: tonnes per annum) in the HPA alone.

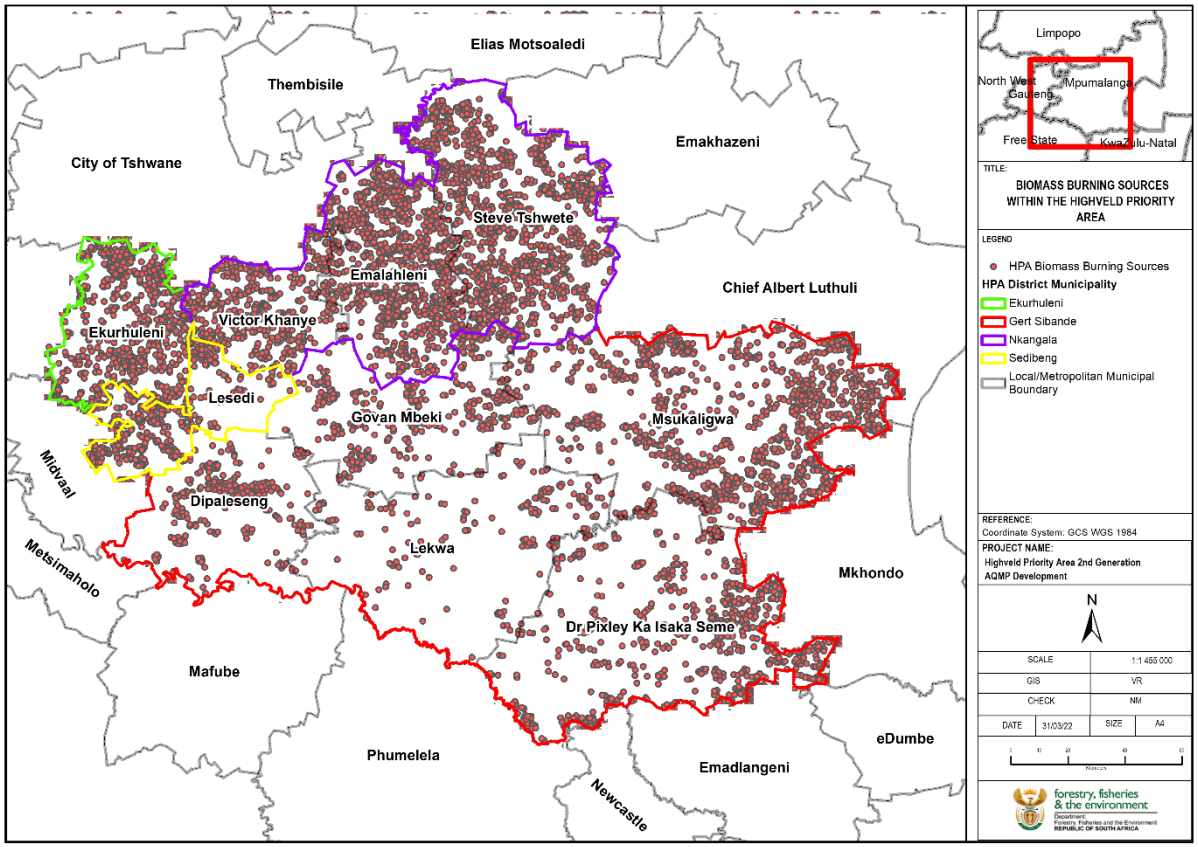


Figure 5-24: Map showing gridded (to 1 km resolution) FINN estimated PM_{10} emissions from biomass burning (total tonnes per annum per cell) in the Highveld Priority Area

Table 5-14: FINN estimated annual emissions from biomass burning (units: tonnes per annum) in the Highveld Priority Area alone

Area	PM_{10}	$PM_{2.5}$	SO_2	NO_x	CO	NH_3	CH_4
HPA	10 290	9 901	1 080	1438	98 018	1 360	4 152

5.8 Spontaneous Coal Combustion

Fires that occur in coal mines are largely a result of spontaneous combustion events. When coal is exposed to air and moisture, exothermic reactions can take place leading to self-heating. As the heat accumulates, temperatures will rise and accelerate the oxidation process, which in turn, can result in the ignition of coal. The burning of coal can result in the emission of pollutants harmful to humans.

5.8.1 Methodology

The First Generation HPA AQMP baseline emission inventory quantified spontaneous coal combustion-related emissions, albeit a qualitative assessment, whereas the Second Generation HPA AQMP estimates and quantifies these emissions and provides absolute estimates, in other words, actual numbers. However, currently, there is no acceptable standard method for estimating emissions from spontaneous combustion. This is due to the difficulty in obtaining reliable measurements in coal mining areas. For the HPA, emissions emanating from spontaneous combustion were estimated by multiplying the emission rates obtained from Cook and Lloyd (2012) with the area of each coal mine operating in the HPA. The location and shape of the coal mines were obtained using land cover data (https://egis.environment.gov.za/sa_national_land_cover_datasets), global mining areas data, operating mines data from the Department of Mineral Resources and Energy (https://www.dmr.gov.za/mineral-policy-promotion/operating-mines/mpumalanga) and Google Earth satellite imagery.

5.8.2 Results

Figure 5-25 shows the spatial distribution of coal mines in the HPA. A total of 186 coal mines were identified and assessed within the HPA study area.

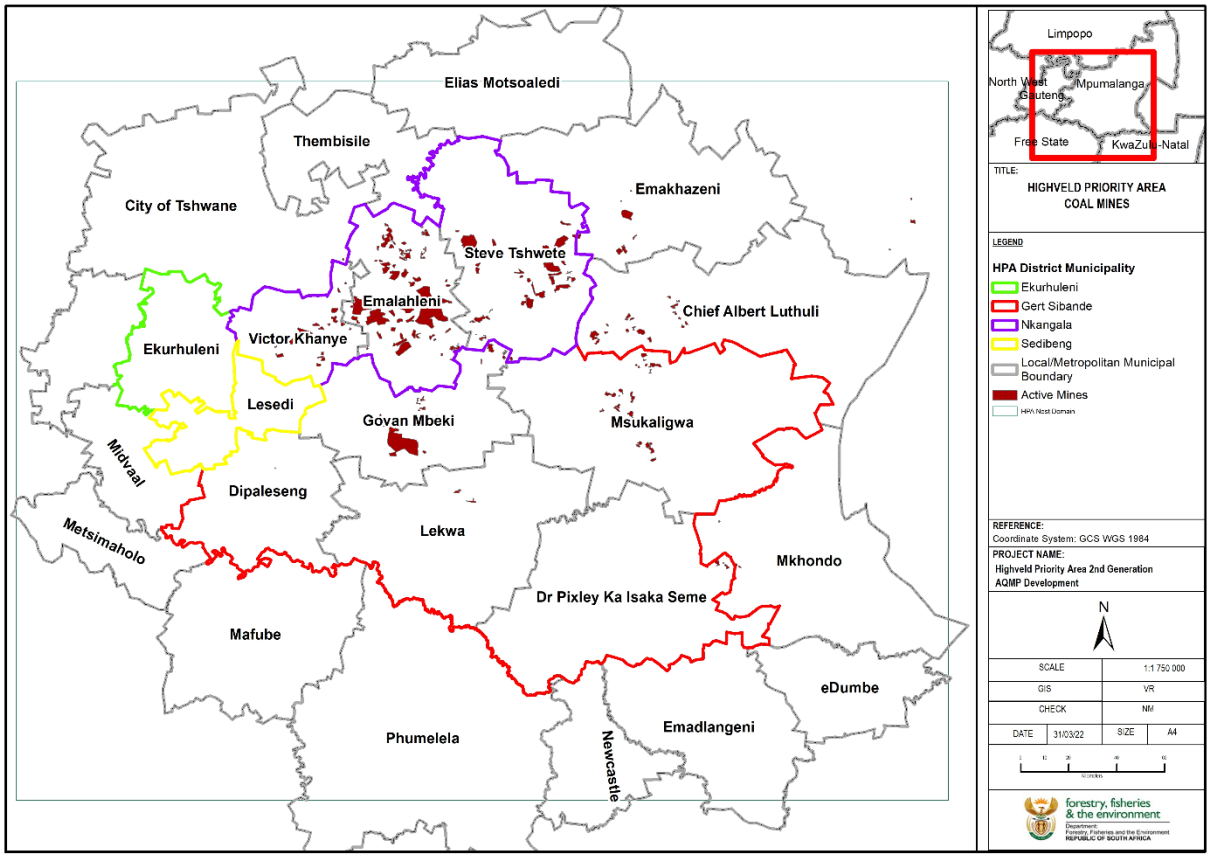


Figure 5-25: Coal mine sources in the Highveld Priority Area

Table 5-15 details various spontaneous combustion-related emissions from the HPA alone. A majority of South Africa's coal mines are concentrated within the HPA.

Table 5-15: Emissions from spontaneous combustion within the Highveld Priority Area (tonne/annum)

Area	CO_2	SO_x	NO_x	NH_3	CO	CH_4	H_2S
HPA alone	533 029	920	149	7.8	7 815	12 281	38

Note: [a] Emissions represent 53% of all surface coal mine activity in South Africa

5.9 Ammonia Emissions

Ammonia (NH_3) is a highly reactive gaseous substance that has significant impacts on air quality and sensitive terrestrial and aquatic ecosystems (Moran, 2016). Ammonia can act as a neutralising agent in the atmosphere by reacting with sulphur and nitrogen oxides to form ammonium salts (secondary aerosols), which can be transported over long distances before deposition (Hou & Yu, 2020). Agriculture is a major source of ammonia through the rapid hydrolysis of urea excreted from livestock and urea from fertilisers. Ammonia production industries and biogenic (soil) are also important sources. The relative contribution of each source will depend on the area of concern.

5.9.1 Methodology

The First Generation HPA AQMP baseline emission inventory did not quantify ammonia emissions, whereas the Second Generation HPA AQMP estimates and quantifies these emissions. The Copernicus Atmosphere Monitoring Service (CAMS) global emissions dataset (https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-global-emission-inventories?tab=form) was used to provide NH_3 emission estimates from agriculture (livestock [animal excreta], soils [fertiliser application] and agricultural waste burning). This dataset is based on different existing datasets, for example, nationally reported emissions from EDGAR (0.1° x 0.1°) and CEDS (0.5° x 0.5°). Trends for CEDS are disaggregated to the same grid resolution as EDGAR and the sectors for both datasets are then merged and aligned.

The CAMS dataset (0.1° x 0.1° grid resolution) for 2019 was downloaded, then spatially disaggregated onto a 0.02° x 0.02° grid using a non-interpolating technique which involves assigning a fractional value (based on the fraction of area) within each domain's grid cell. This form of spatial disaggregation does not use interpolation and is, therefore, mass consistent between the original CAMS dataset and the resulting domain emissions estimated here.

5.9.2 Results

The CAMS dataset (0.1° x 0.1° grid resolution) for 2019 is presented below. This form of spatial disaggregation does not use interpolation and is, therefore, mass consistent between the original CAMS dataset and the resulting domain emissions estimated here.

In line with the air quality management-geared emission inventory, Figure 5-26 below shows the CAMS estimated total annual NH_3 emissions from agriculture for the HPA alone, while Table 5-16 details the total tonnage in the HPA alone. More than one third of NH_3 emissions from agriculture occur in the HPA.

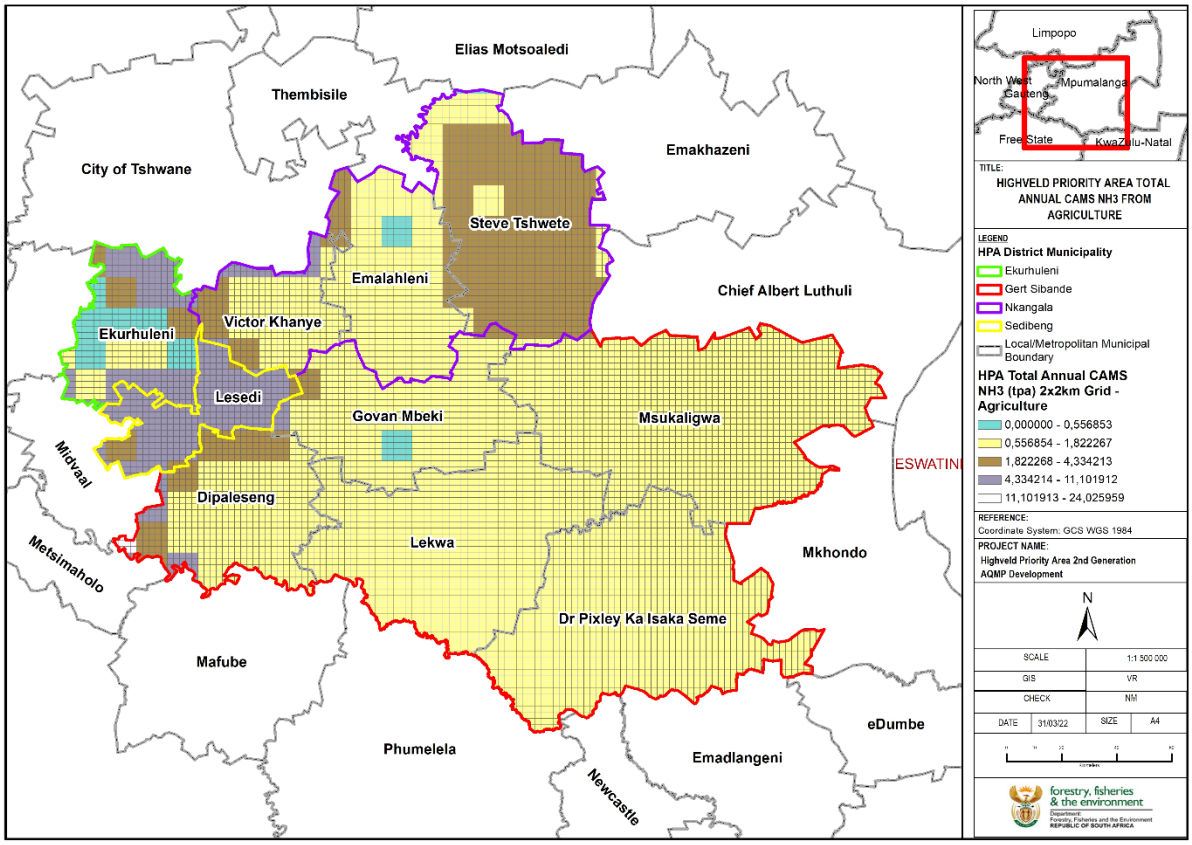


Figure 5-26: Total annual Copernicus Atmosphere Monitoring Service NH_3 from agriculture over the nested domain

Figure 5-26 above shows the CAMS estimated total annual NH_3 emissions from agriculture. The highest emissions occur along the western corner of the HPA stretching in a southwestern direction into the Free State province. This corresponds to the agricultural regions.

Table 5-16: Copernicus Atmosphere Monitoring Service estimated agricultural NH_3 annual tonnage in the HPA

Area	NH_3
HPA	14309

5.10 Synopsis of Emission Inventories

The initial 2012 HPA AQMP Emission Inventory quantified emissions from seven emission sources, of which at the time mine haul roads were determined to contribute to half of all PM emissions. The seven emission source categories comprised the following emission sources:

- Major industry;
- Residential fuel burning;
- Coal mining;
- Mobile sources;
- Biomass burning; and
- Burning and smouldering coal dumps (qualitative assessment of spontaneous combustion emissions).

Source categories where emissions could not determine were landfills, incinerators, wastewater treatment works, tyre burning, biogenic sources, odour, and agricultural dust. While emissions from these sources were not quantified, the aim was that emissions related to these sources would be addressed through the implementation of the 2012 AQMP. As part of the initial 2012 HPA AQMP review process, it is necessary to compare the initial 2012 AQMP Emission Inventory to the recently developed 2019 emission inventory, which is the foundational input for the development of the Second Generation HPA AQMP. It is important to note that there were methodological improvements to the initial 2012 HPA Emission Inventory brought about by the 2016 HPA AQMP mid-term review (DEA, 2017), which were focused on industrial sources (Section 21 Listed Activities), mobile sources, residential fuel burning, mining operations, as well as biomass burning. While these improvements were significant, it is necessary to review the initial 2012 AQMP Emission Inventory and the AQMP itself as the interventions and implementation plans were based on the initial inventory. Accordingly, Table 5-17 below details emission volumes from each source category and the percentage change in emissions between the two emission inventories.

Table -5-17: Comparison of the 2012 Highveld Priority Area Air Quality Management Plan Emission Inventory to the 2019 Highveld Priority Area Second Generation Air Quality Management Plan Emission Inventory

Emission Sources	PM_{10} (tpa)			SO_2 (tpa)			NOx (tpa)		
	2012	2019	% Change	2012	2019	% Change	2012	2019	% Change
Industrial sources	111 785	127 170	+14%	1 612 174	1 277 290	-21	885 990	790 620	-11%
On-road vehicle emissions	5 402	837	-85%	10 059	734	-93%	83 607	38 093	-54%
Residential fuel burning	17 239	19 741	+15%	Not Quantified	9 092	ND	5 600	3 769	-33%
Windblown Particulate	135 766	104 901	-23%	No Data	No Data	ND	No Data	No Data	ND
Biomass burning	9 438	10 290	+9%	Not Quantified	1 080	ND	3 550	1438	-59%
Total HPA	**279 627**	**262 939**	**-6%**	**1 622 233**	**1 288 196**	**-21 %**	**978 781**	**833 920**	**-15%**

An analysis of Table 5-17 above indicates significant changes in emissions levels between the two inventories with the 2019 emission inventory resulting in significantly less total emission quantified for SO_2 and NO_X in particular. In contrast, increased estimated PM_{10} emissions are noted for Industrial; Residential Fuel Burning; and Biomass Burning with Industrial emissions noted to have the most pronounced increase in estimated emissions i.e., 14% or 15 388 tpa. At the same time, significant reductions in estimated PM_{10} emissions are also noted for On Road Vehicle emissions and Windblown Particulate with 85% and 23 % reductions respectively. These changes resulted in an estimated 6% decrease in total PM_{10} emissions between the two inventories while reductions are also noted for SO_2 and NO_X. It is also important to note that the full 2019 emission inventory incorporates emission sources and pollutants previously not quantified in the 2012 emission inventory i.e., residential waste; spontaneous combustion; and agricultural ammonia. This means that the reductions noted for PM_{10}, SO_2, and NO_X are effectively offset by these newly quantified emission sources. Table 5-18 provides a summary of the total annual emissions from each emission source covered in the HPA emissions inventory that will inform the development of the Second Generation HPA AQMP.

Table 5-18: Emission inventory summary for all sources within the Highveld Priority Area (tpa)

Emission Source	CO	NOx	NMVOC's	SO_2	$PM_{2.5}$	PM_{10}
On Road Vehicles	13 321	38 093	913	734	837	-
Residential Waste Burning	2 892	221	-	87	628	665
Residential Fuel Burning	130 054	3 769	-	9 092	19 228	19 741[b]
Windblown Particulate	-				30 465	104 901
Biomass Burning	98 018	1 438		1 080	9 901	10 290
Industry	107 360	790 620	226 000	1 277 290	64 730	127 170
Spontaneous Combustion	7 815	149		924 [a]		
Total	**359 460**	**834 290**	**226 913**	**1 289 207**	**125 789**	**262 767**

Note: [(a)] Emissions are estimated as SO_X
[(b)] Emissions are estimated as the sum of PM_{10} and $PM_{2.5}$

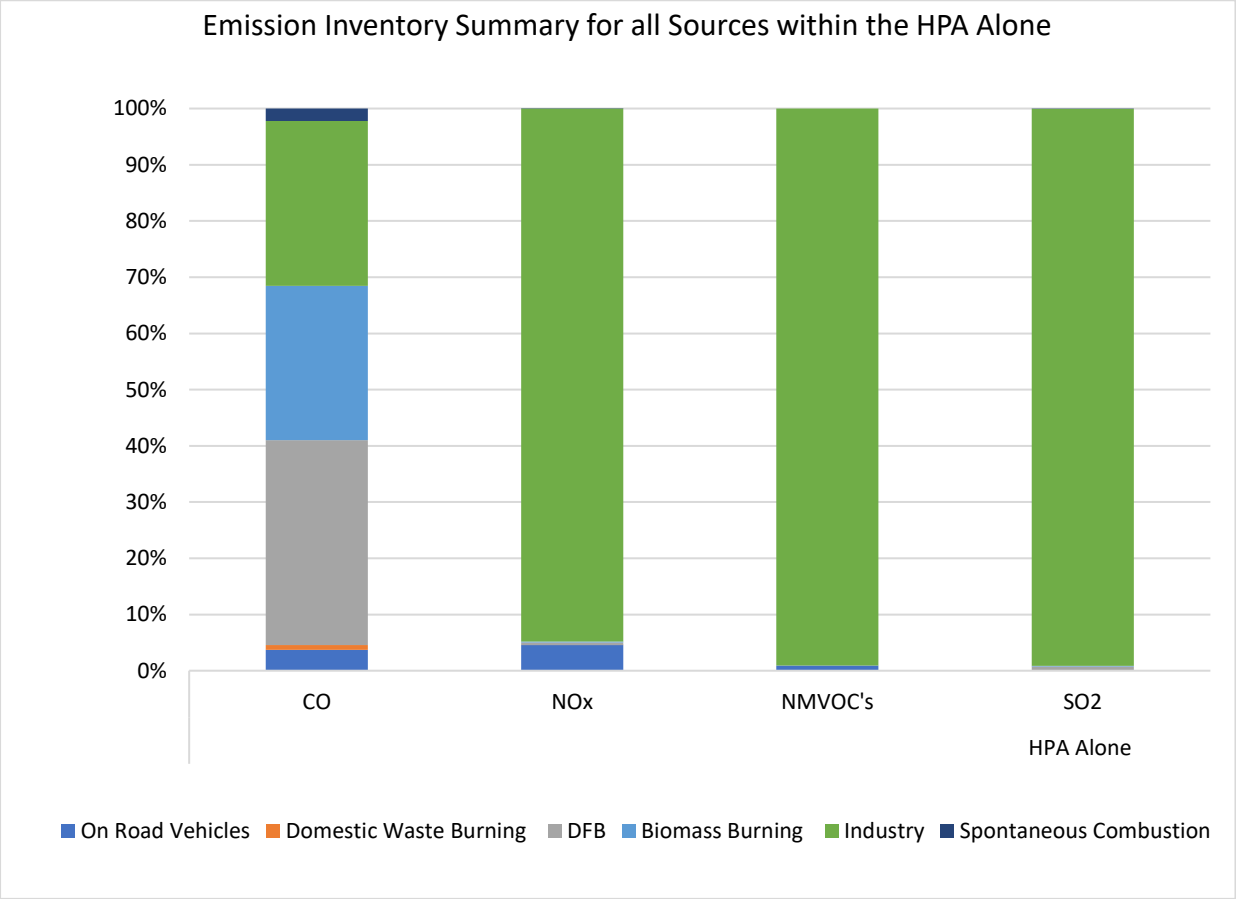


Figure 5-27: Emission inventory summary for all sources within the Highveld Priority Area (CO, NO_x, NMVOCs and SO_2)

Figure 5-27 graphically summarises Table 5-18 above and it is evident that industry is the largest contributor to NO_x; NMVOCs and SO_2 emissions, while residential fuel burning and biomass contributions are more pronounced for CO.

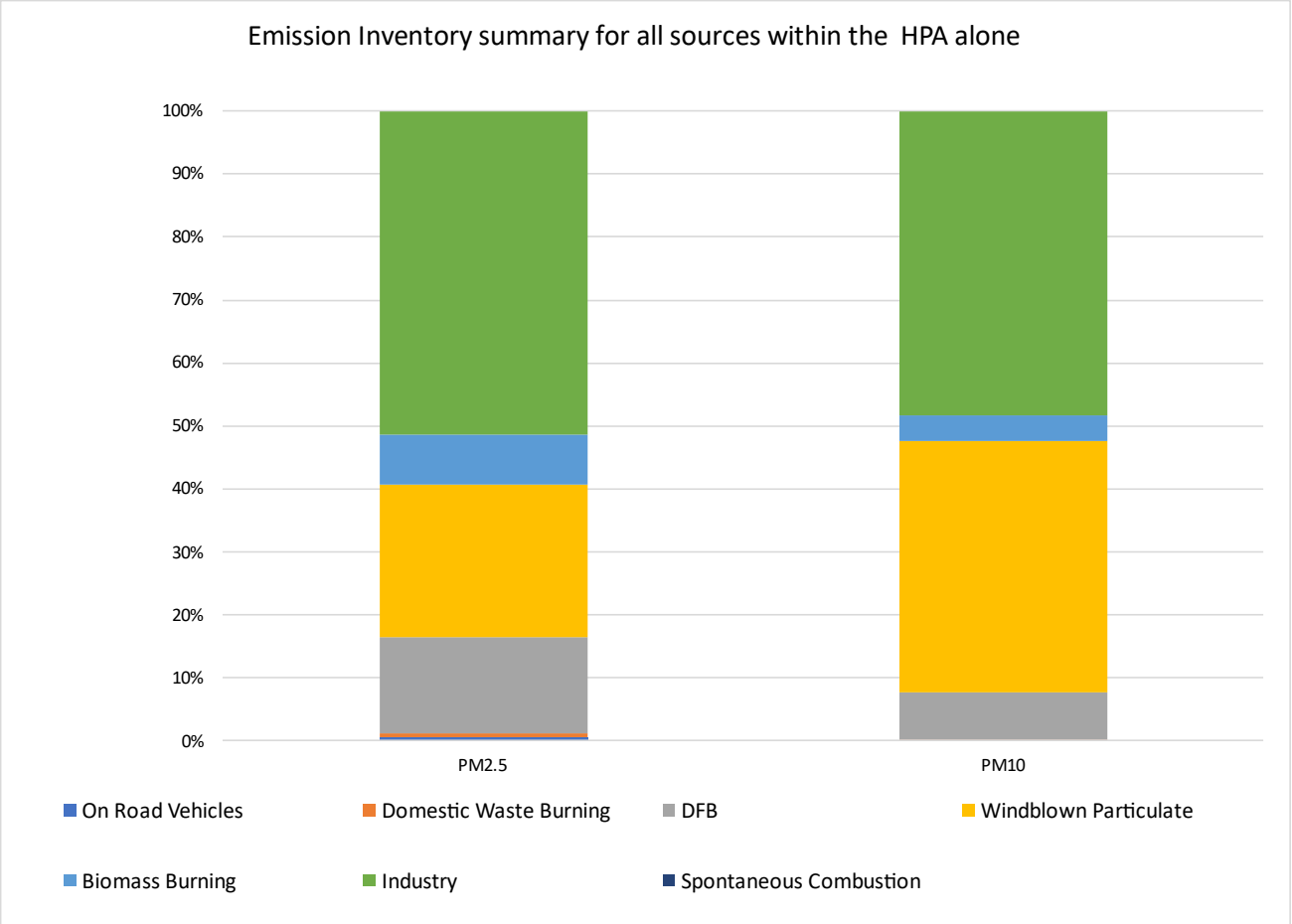


Figure 5-28: Emission inventory summary for all sources within the Highveld Priority Area ($PM_{2.5}$ and PM_{10})

Figure 5-28 graphically summarises Table 5-18 and it is evident that industry and windblown particulate emission sources are the largest contributors to PM_{10} and $PM_{2.5}$ emissions with mine dust particulates incorporated in the windblown particulate also contributing significantly to overall PM emissions.

6. ATMOSPHERIC MODELLING

6.1 Overview

The assessment of air quality by an ambient monitoring network is limited to the specific location. Air quality models are aimed at assessing the air quality for a specific region on a more comprehensive spatial scale than what can be provided with monitoring stations. These models can simulate the changes in pollutant concentrations in the atmosphere using a set of mathematical equations characterising the chemical and physical processes in the atmosphere. The models can be applied at multiple spatial scales from local, regional, and national to global.

The air quality model used to achieve these tasks is the Comprehensive Air Quality Model with extensions (CAMx; version 7.20) developed and maintained by Ramboll (Ramboll, 2022). Since 1996, CAMx has been employed extensively throughout the US by local, state, regional, and federal government agencies; academic and research institutions; as well as private consultants for regulatory assessments and general research internationally. It is one of only four chemical air quality models recommended by the US Environmental Protection Agency (US EPA). The US EPA has approved the use of CAMx for numerous ozone and PM assessments for State implementation plans throughout the US and has used this model to evaluate regional mitigation strategies.

In terms of the South African Code of Practice for Air Dispersion Modelling in Air Quality Management in South Africa (*Gazette* No. 37804, 11 July 2014) CAMx is able to provide a Level 3 assessment. The model has been applied previously in South Africa for numerous regional studies, such as the Sasol/Eskom Photochemical Ozone Study, the Western Cape Health Study, the City of Johannesburg AQMP, the Highveld Health Study, the Vaal Triangle Airshed Priority Area AQMP, and the Eskom Waterberg Study.

CAMx is an Eulerian chemical transport model that is suitable for the integrated assessment of gaseous and particulate air pollution. The model allows for integrated “one-atmosphere” (signifying that all sources and pollutants are to be modelled simultaneously) assessments of gaseous and particulate air pollution over many spatial scales, ranging from suburban to continental. This is achieved by solving Eulerian pollutant mass continuity equations forward in time on three-dimensional grids. It is designed to unify all the technical features required of “state-of-the-science” air quality models into a single system. CAMx is, therefore, able to simulate AAQ due to primary and secondary air pollutants at varying spatial and temporal scales.

CAMx comprises the core component of an air quality modelling system and requires emissions and meteorological data on a temporal and special scale as input into the model. Other inputs required by CAMx include photolysis rates and boundary conditions. Figure 6-1 shows a schematic diagram of the CAMx modelling system.

Figure 6-1 summarises the input data requirements of CAMx. Preparing this information requires several models and preprocessing steps to translate emissions, meteorological, air quality and other data into input file formats expected by CAMx. CAMx produces gridded time-averaged concentration (usually hourly) output files for two-dimensional surface layer fields or entire three-dimensional fields.

In order to account for the large-scale transport and recirculation of pollutants, necessary when considering atmospheric chemistry in the Highveld region, a model grid covering a domain much larger than the HPA boundaries is required. This is particularly relevant in the HPA as high intensity elevated stack sources are present, which may impact further afield. Another reason for a large enough model domain is to minimise impacts of the boundary conditions on the area of interest, in other words, the HPA, since CAMx is a limited area model (as opposed to a global model).

However, a drawback of using a large domain is the computational resources required to simulate chemistry and transport on many grid points (noting that the domain covers horizontal and vertical extents). A solution to this is using two (or more) nested grids, with the desired resolution covering the area of interest and a coarser resolution outer grid encompassing this. The coarser grid, often called the parent, is used to alleviate boundary effects and cater for recirculation; issues which do not require very high resolutions. Since CAMx and the majority of air quality models use multiple nested domains with feedback between grids, emission and pollutant mass are conserved.

Figure 6-2 illustrates the CAMx grid configuration used for simulations. A parent grid of ~6 km resolution extends over much of the eastern half of South Africa, while a nested grid of ~2 km resolution caters for simulation over the HPA. CAMx was run over the HPA from 2018 to 2020.

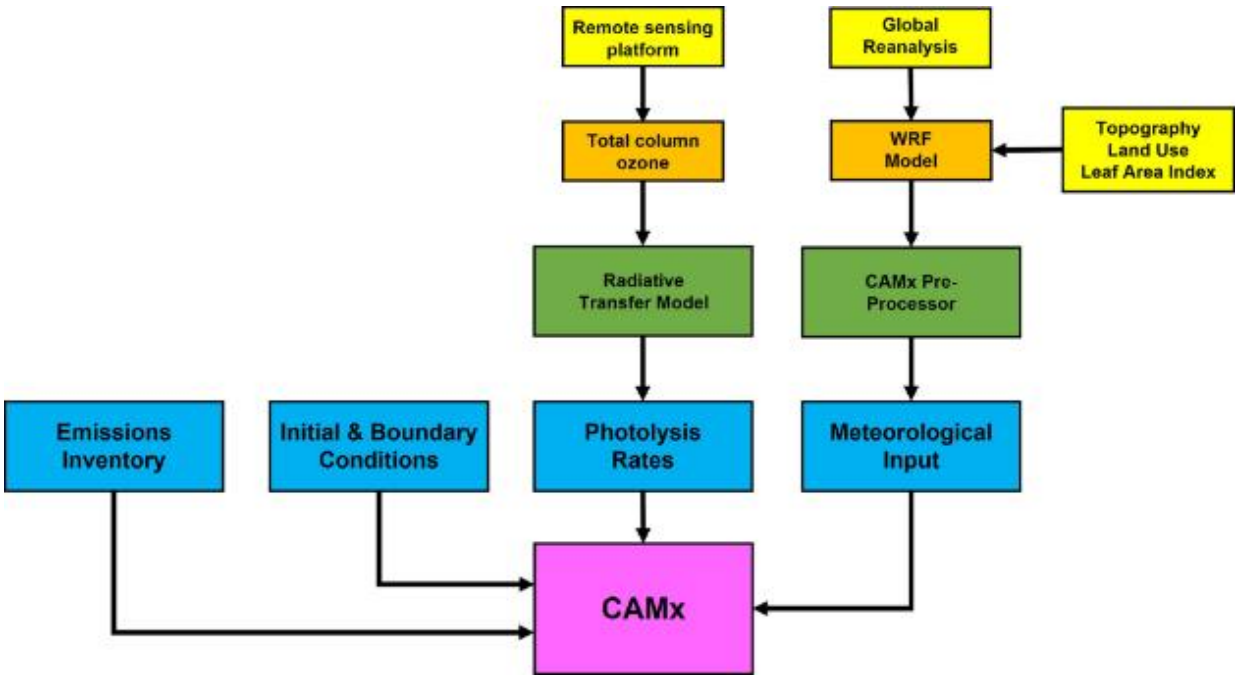


Figure 6-1: Schematic diagram of the CAMx modelling system

6.1 Meteorological Input

CAMx requires gridded meteorological data for the required meteorological parameters. The data are required on an hourly basis and, as such, the most preferred way to generate this information is via a meteorological model. The Weather Research and Forecasting Model (ARW core) was used to generate meteorological data for input into CAMx.

The Weather Research and Forecasting (WRF) Model (Advanced Research WRF (ARW), Version 4.1) was developed by the National Centre for Atmospheric Research (NCAR). The WRF model is a non-hydrostatic, fully compressible, and terrain-following sigma coordinate model. In this study, WRF simulations over South Africa are performed using a two-way nested domain with horizontal resolutions of 12km and 4km. The model domains extend vertically up to 50 hpa and are divided into 24 vertical layers. The WRF domain with 12km horizontal resolution covers southern Africa, as well as parts of the surrounding Indian Ocean. The nested inner domain with a 4 km horizontal resolution covers the HPA (Gauteng and Mpumalanga provinces), all centred over the HPA.

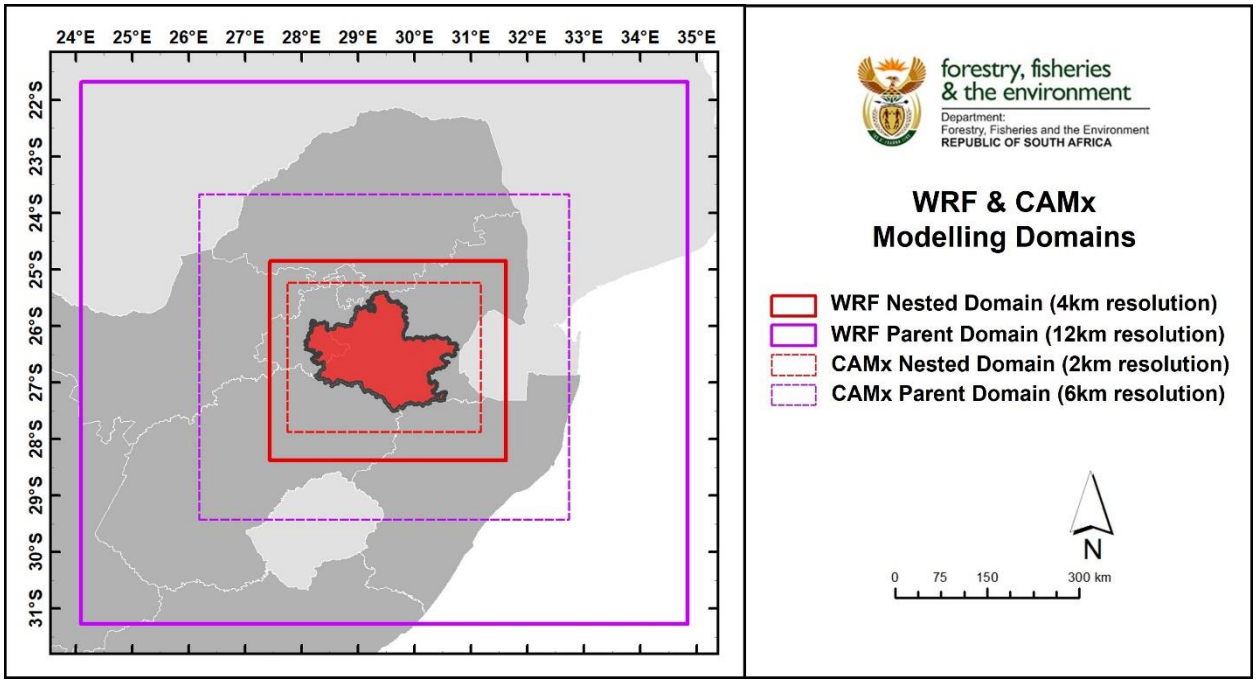


Figure 6-2: Weather Research and Forecasting Parent Domain (12km), Weather Research and Forecasting Nested Domain (4km), CAMx Parent Domain (6km), CAMx Nested Domain (2km)

The initial and boundary conditions for meteorological fields were from the Global Forecast System (GFS); a global numerical weather prediction system containing a global computer model and variational analysis run by the US National Weather Service (NWS). GFS data is publicly available and is located on the University Corporation for Atmospheric Research (UCAR) Research Data Archive (RDA) webpage (https://rda.ucar.edu/datasets/ds083.1/index.html#sfol-wl-/data/), and has a horizontal grid spacing of 0.25° and a temporal resolution of 6 h.

The model topography and boundary conditions were obtained from the US Geological Survey, with a resolution of at least 2 arc minutes. Figure 6-2 is a graphical illustration of the WRF modelling domains.

The 4km WRF domain was used as meteorological input for CAMx as it corresponds to the CAMx (1km x 1km) domain. Table 6-1 summarises the main physics options that are applied to represent the atmospheric process during simulations.

Data assimilation (nudging) was not used for this WRF run. WRF was run for three years (2018, 2019 and 2020) in line with the DEA Air Quality Modelling Guidelines (DEA, 2012).

In terms of vertical extents, the CAMx vertical grid structure is defined by the input WRF meteorological data. For these simulations, the first 25 of 32 WRF levels were selected for use in CAMx. These matched the WRF levels and, therefore, no interpolation for vertical data to CAMx was required.

6.2.1 Weather Research and Forecasting results compared to measured meteorological parameters

It is acknowledged that meteorological conditions constitute a strong influence on the model's ability to accurately reproduce observed chemical concentration values. Meteorology allows for the transport and transformation of chemical species in the atmosphere and errors in specification of the physical atmosphere, such as temperature, clouds and winds, can affect the air quality predictions. As such, an evaluation of the WRF Model predicted meteorological fields is necessary to ascertain model performance and the applicability of model results. For this work, model performance has been analysed by comparing the model results for the lowest model layer with surface observations at various locations in the model domain. The most relevant meteorological parameters for chemical transport models include 2 m temperature (T2), 10 m wind speed (WS) and direction (WD), and rainfall. For this, work parameters that were verified were temperature, wind direction and wind speed at 10 m, which were simulated on an hourly interval.

Rainfall data from the stations were insufficient for use in verification in that instead of representing hourly integrated rainfall, they erroneously provided an hourly average, in other words, for readings within an hour, rainfall is averaged instead of summed. Meteorological measurements originating from AQMSs in the HPA (SAAQIS) were used. The observation hourly data from the study area were collected and ranged over the period 1 January 2018 to 31 December 2020.

A wide variety of indexes can be found in the literature and are proposed for different fields of applications (meteorology, air quality, etc.), different scopes (for example, forecast, episode study) or different type of applications (for example, regulatory). Annexure C discusses in detail the statistical indexes that are commonly used in air quality studies. Besides the statistical measures, one other important aspect of model evaluation is the availability of appropriate data for comparison. The robustness of model evaluation is directly proportional to the amount and quality of the ambient data from the monitoring network. It envisaged that finer temporal resolution data can provide a better picture of the air quality model's overall performance. Generally, if the model performs better in a higher temporal resolution, one expects similar behaviour at a lower temporal resolution. It is suggested that the one hour averaging time be the basic element of meteorology and air quality model evaluation. For this study, hourly average observed and modelled meteorological and concentration values are used to calculate their comparison.

Figures 6-3 to 6-6 Illustrate time variation plots for the temperature data from the WRF Model compared to measure data from the Balfour, Middelburg, Secunda and Standerton AQMSs, respectively. The red line indicates the modelled WRF values compared to the blue line indicating the measured values. Temperature is underestimated in lower temperature conditions, as noted by the larger temperature differences in the early morning when temperatures are decreasing, as well as in the evening, predominantly in the winter periods.

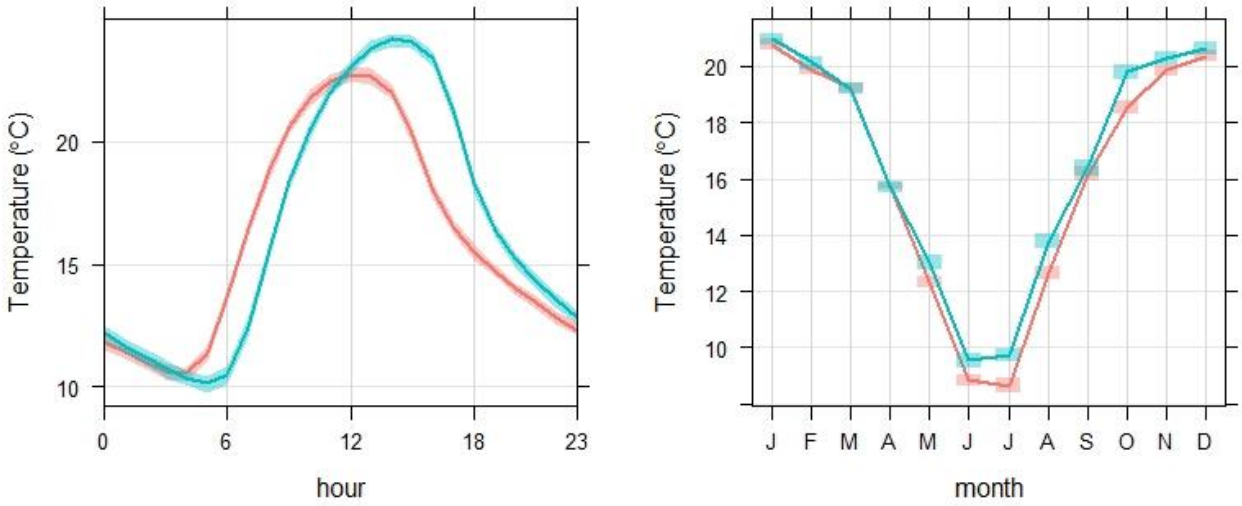


Figure 6-3: Time variation plot of modelled ambient temperature data from Weather Research and Forecasting and the Balfour Air Quality Monitoring Station

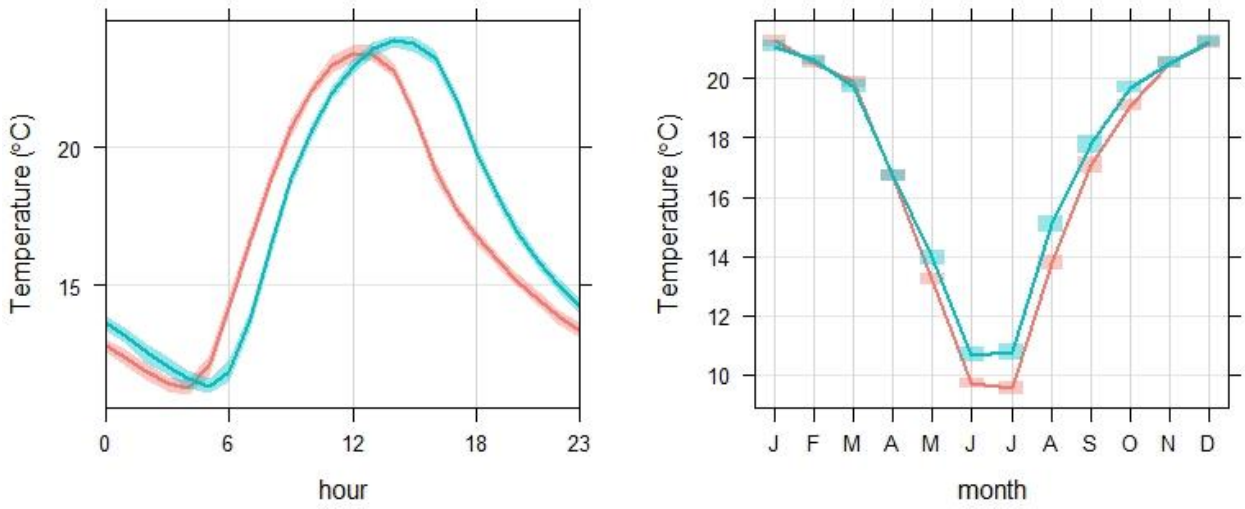


Figure 6-4: Time variation plot of modelled ambient temperature data from Weather Research and Forecasting and the Middelburg Air Quality Monitoring Station

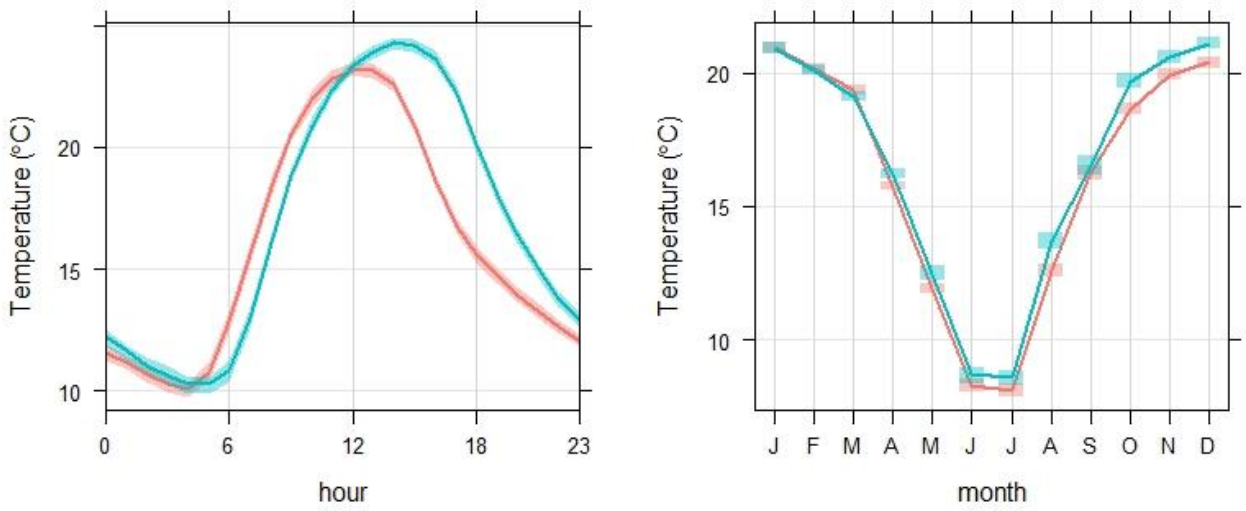


Figure 6-5: Time variation plot of modelled ambient temperature data from Weather Research and Forecasting and the Secunda Air Quality Monitoring Station

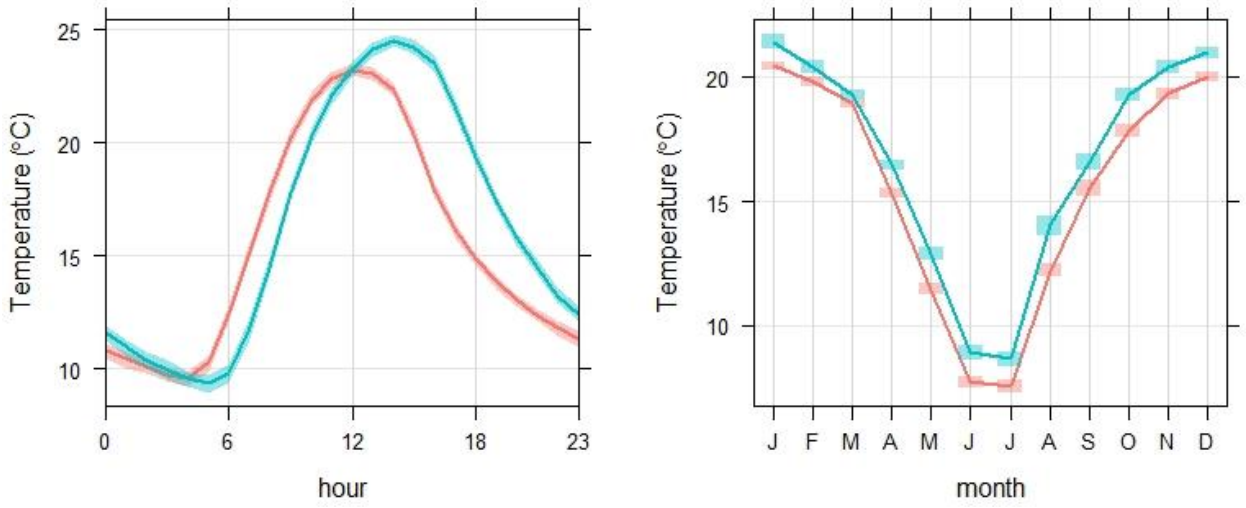


Figure 6-6: Time variation plot of modelled ambient temperature data from Weather Research and Forecasting and the Standerton Air Quality Monitoring Station

Figures 6-7 to 6-10 Illustrate time variation plots for the wind speed data from the WRF Model compared to measure data from the Balfour, Middelburg, Secunda and Standerton AQMSs respectively. The red line indicates the modelled WRF values compared to the blue line indicating the measured values. Wind speed is mostly overestimated by the WRF Model, but generally follows the same behaviour of the observed wind as it peaks and dips in the same time frame.

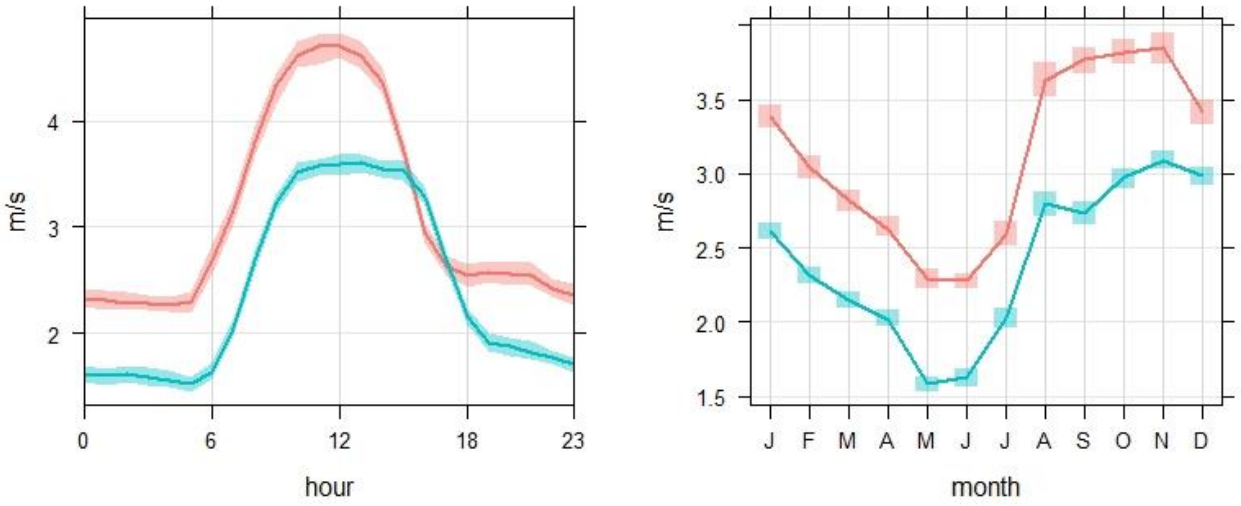


Figure 6-7: Time variation plot of modelled wind speed data from Weather Research and Forecasting and the Balfour Air Quality Monitoring Station

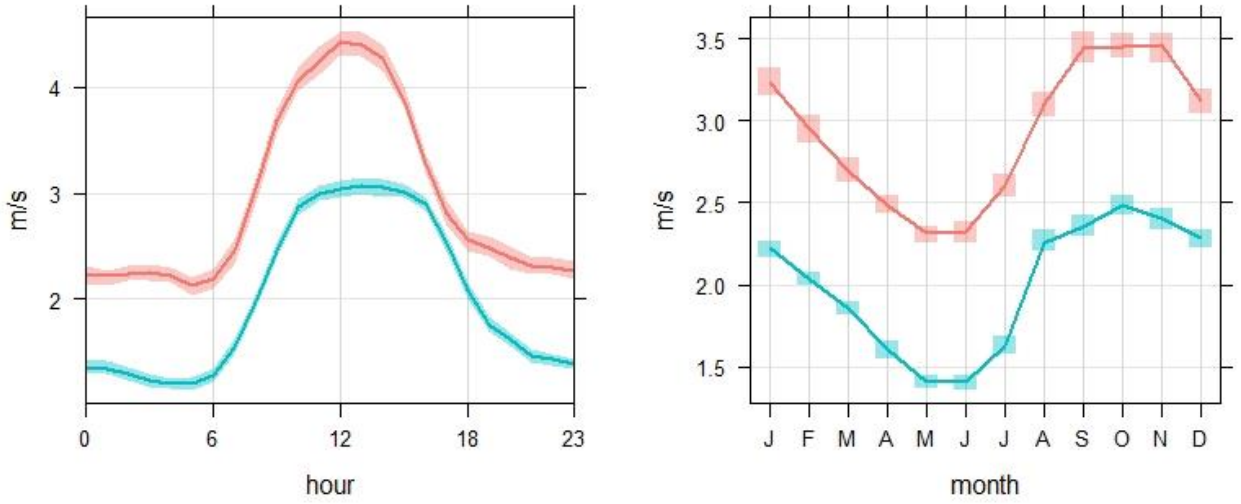


Figure 6-8: Time variation plot of modelled wind speed data from Weather Research and Forecasting and the Middelburg Air Quality Monitoring Station

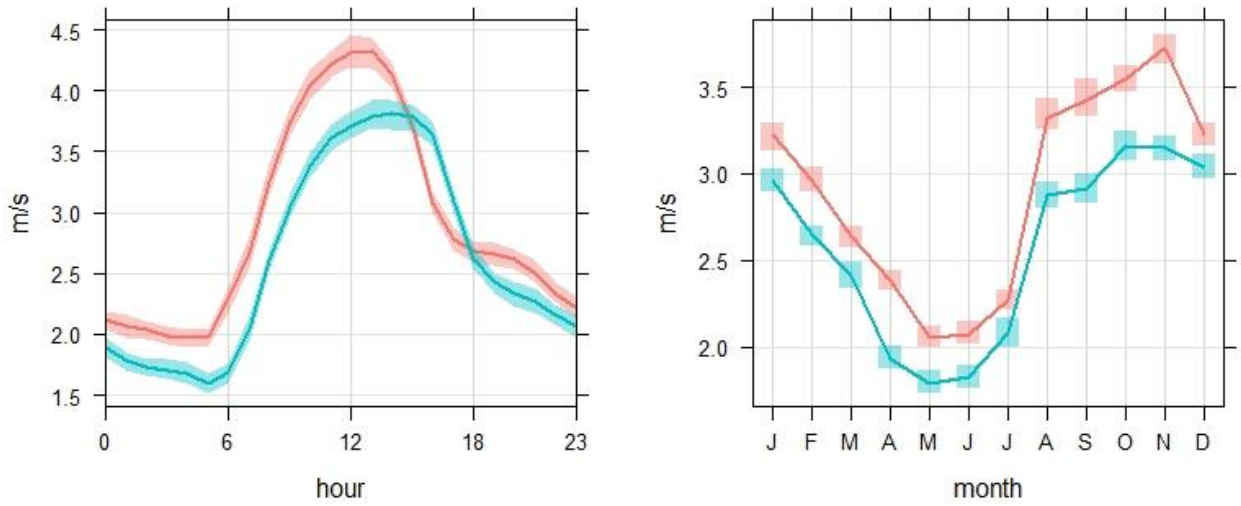


Figure 6-9: Time variation plot of modelled wind speed data from Weather Research and Forecasting and the Secunda Air Quality Monitoring Station

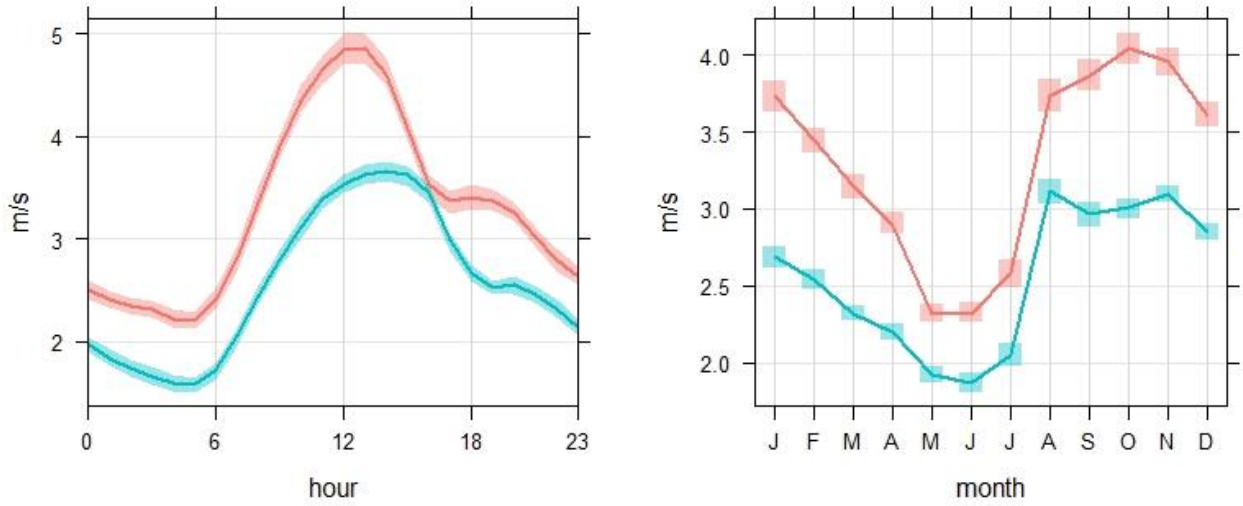


Figure 6-10: Time variation plot of modelled wind speed data from Weather Research and Forecasting and the Standerton Air Quality Monitoring Station

Figures 6-11 to 6-14 Illustrate time variation plots for the wind direction data from the WRF Model compared to measure data from the Balfour, Middelburg, Secunda and Standerton AQMSs, respectively. The red line indicates the modelled WRF values compared to the blue line indicating the measured values. Wind direction is overestimated as the day begins, but gradually becomes underestimated past noon to the evening, with this observation being at its greatest in the winter periods.

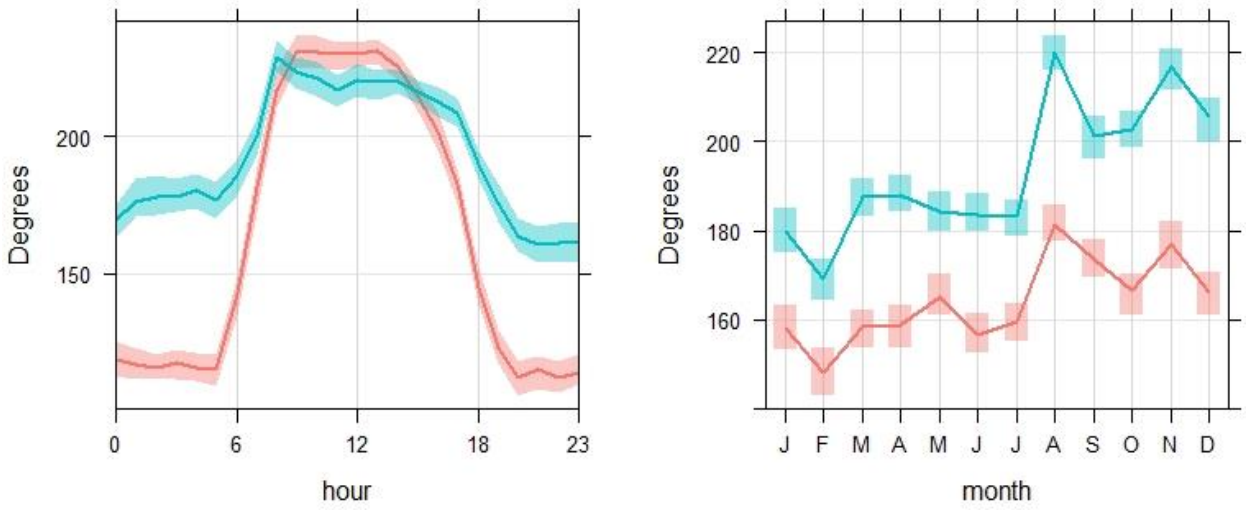


Figure 6-11: Time variation plot of modelled wind direction data from Weather Research and Forecasting and the Balfour Air Quality Monitoring Station

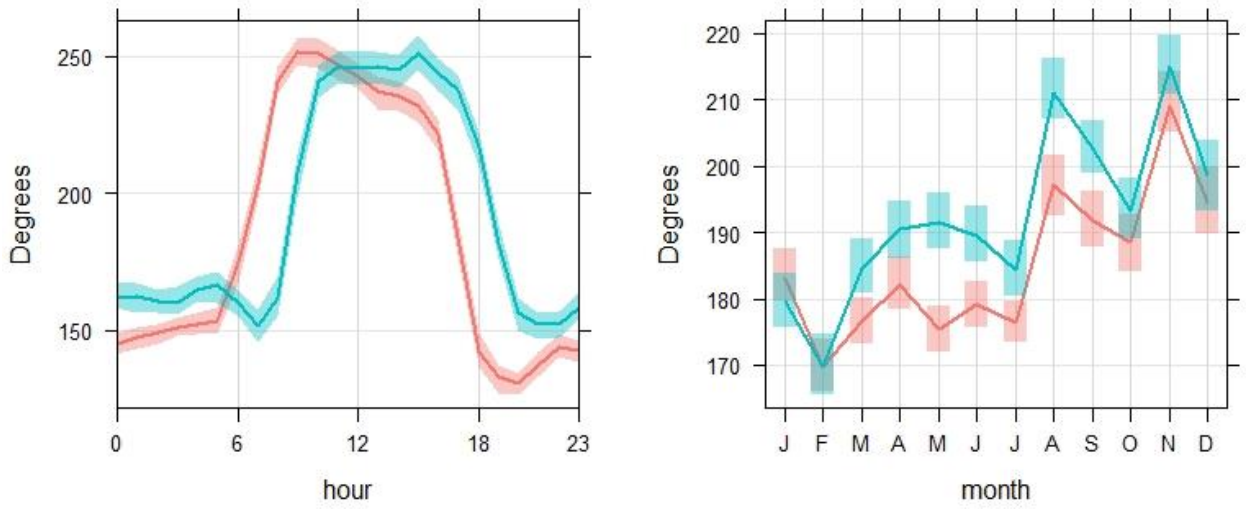


Figure 6-12: Time variation plot of modelled wind direction data from Weather Research and Forecasting and the Middelburg Air Quality Monitoring Station

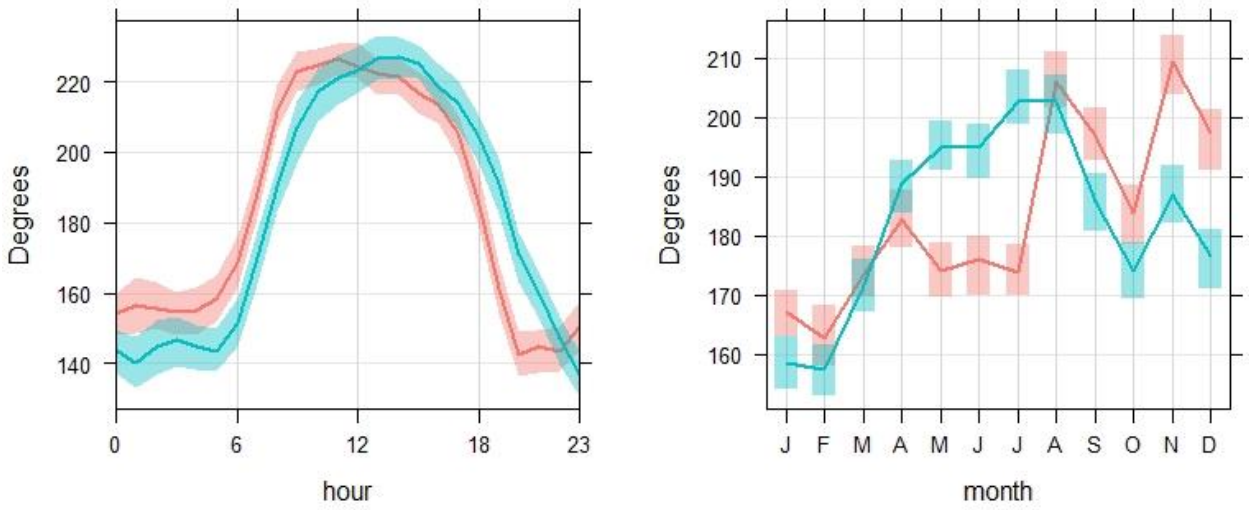


Figure 6-13: Time variation plot of modelled wind direction data from Weather Research and Forecasting and the Secunda Air Quality Monitoring Station

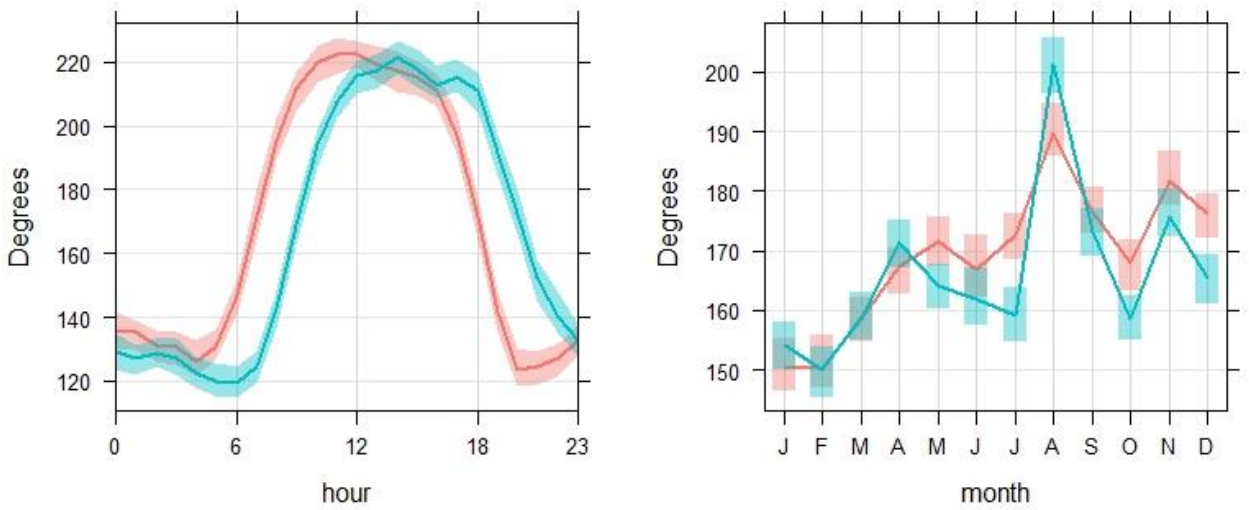


Figure 6-14: Time variation plot of modelled wind direction data from Weather Research and Forecasting and the Standerton Air Quality Monitoring Station

6.3 Initial and boundary conditions

Initial conditions input for the model set the ambient atmospheric state of chemical species (including intermediate) considered by the selected chemical mechanism (in this case Carbon Bond 6 Revision 5) at the beginning of a model run. Boundary conditions are an important consideration for any limited area model. Boundary conditions must represent the inflow of chemical species at regular intervals into the parent domain such that the model is contextualised spatially within the area of interest. Concentrations are, therefore, allocated to the edges of the parent domain (including at the model top). Both initial and boundary conditions were derived from the Whole Atmosphere Community Climate Model (WACCM) Gettleman et al., 2019) run by the US NCAR Atmospheric Chemistry, Observations and Modelling (ACOM) group. WACCM is a global Chemistry Transport Model and provided information about continental scale air quality concentrations in the CAMx model domain. This would include large sources such as biomass burning across sub-Saharan Africa. The WACCM is run at 0.9 x 1.25-degree horizontal resolution with 88 levels, with the output written every six hours. Model output is provided to the general public and is often used as boundary conditions for other models and studies.

Global models are generally run at coarse resolutions with emissions inventories relevant to the global context. As such, there may be uncertainty at the subregional scale as global inventories often do not contain locally derived information. This is particularly true for southern Africa (Garland et al., 2017). Therefore, these model outputs are not ideal for the detailed analysis required for the AQMP assessment; and indeed, the reason for the AQMP assessment including CAMx using locally derived and specific input. However, the global inventories characterise large-scale sources, such as biomass burning and very large industries making it into the global analysis. Therefore, it is appropriate for use as boundary conditions. Any impacts on the CAMx model simulation due to uncertainties in the global model are mitigated by using a spatial buffer for boundary condition input and a temporal buffer for initial conditions. Therefore, a very large CAMx domain is used, such that influence from boundaries does not significantly impact the area of concern. The effect of the boundary concentrations decreases as one moves further into the domain. To mitigate impacts due to initial conditions, a five-day model spin-up period is used. As the simulation progresses, the influence of initial conditions decreases, and the input emissions and model chemistry dominate.

A CAMx pre-processor is used to interpolate (horizontal and vertical) WACCM output to the CAMx parent domain, as well as map WACCM native species and units to what is required by CAMx. Boundary conditions are input into the CAMx parent domain at every hour. Initial conditions are input into CAMx only at the first model hour.

6.4 Photolysis rates

The development of photolysis rate inputs for CAMx is crucial for photochemical mechanisms, as tropospheric ultraviolet (UV) radiation is the driving force for all tropospheric photochemical processes. Photolysis rates are used by the CAMx chemical solvers for reactions that are heavily dependent on solar radiation. These are initially determined by modifying standard photochemical reaction rates according to how much solar radiation is available. These must be provided to the CAMx Model at each grid point and vertical level.

Photolysis rates are initially estimated by the NCAR TUV Radiative Transfer Model (see http://cprm.acd.ucar.edu/Models/TUV/ and http://www.camx.com/download/support-software.aspx) and various look-up tables developed by the CAMx model developer. TUV calculates clear sky photolysis rates for the most important photochemical reactions to be used during the CAMx model run. The TUV Model determines the state of the atmosphere by considering total column ozone, which in this study was based on NASA OMPS data (Jaross, 2017). These are provided to CAMx as an initial estimate. Further modifications are made to the photolysis rates

in line with a CAMx run by considering the simulated aerosol impact and cloud cover on atmospheric radiative transfer within the model column.

6.5 Emission inventory

A detailed emissions inventory was developed for the HPA, as discussed in Section 4, for both model domains at the appropriate resolution (see Figure 6-2). The inventory included the following sources:

- Biogenic VOC;
- Biomass burning;
- Ammonia from agriculture;
- Residential fuel combustion;
- Residential waste combustion;
- On-road vehicles;
- Industrial facilities; and
- Windblown particulates.

Table 6-1 is a summary of the nested modelling domain emissions utilised for the modelling. The developed inventory is for the 2019 calendar year. Refer to Section 5 of the report for the detailed methodologies applied in developing the emissions inventory.

Table 6-1: Summary of the nested modelling domain emissions (kilo-tonne/annum) inventory utilised for the baseline modelling.

	PM_{10}	$PM_{2.5}$	SO_2	NO_X	CO	VOC	NH_3
Industrial Sources	168.8	83.7	1541.2	929.5	912.8	281.6	1.0
Mining and Wind Blown Dust	118.9	32.7	-	-	-	-	-
Mobile Sources	-	1.7	1.6	79.2	28.1	1.9	-
Domestic Fuel Burning	54.7	53.3	25.0	10.2	360.1	37.9	-
Domestic Waste Burning	2.2	2.1	0.3	0.7	9.7	-	-
Biogenic Emissions						225.8	
Biomass Burning	48.8	44.7	4.8	5.7	402.3	-	5.4
Agricultural	-	-	-	-	-	-	39.6

6.5.1 Temporal variation of emissions

Annual emission totals were provided, which necessitated applying temporal disaggregation profiles, such that hourly rates were derived. For some sources, a linear disaggregation was applied, such that the source may be seen as emitting at a constant rate throughout the year. Information for temporal variation of such sources was not available. These sources include industry, informal waste burning and windblown dust. The only source that inherently included sub annual variation is biomass burning, as the global dataset used (Fire Inventory from NCAR – FINN) is provided as daily fires.

Temporal variation of biogenic VOC is vital as the source is highly dependent on sunlight and temperature. Downwelling shortwave radiation data from the WRF simulations (variable SWDOWN) were used to derive monthly and diurnal variation profiles for biogenic VOC emissions. SWDOWN is preferable as it will include impacts from all parameters contributing to sunlight attenuation (for example, clouds). It is acknowledged that SWDOWN will include a broader spectrum of wavelengths than those used by photosynthesis. However, it is the closest proxy

available in the WRF output for the given radiation scheme used. While not ideal (the WRF data used are not consistent with the global MEGAN Model input and using downwelling radiation as a proxy lacks further constraints to emissions from the Leaf Area Index), this approach provides the best estimate of variation, other than running an emissions model specifically for this application.

Seasonal, diurnal and even day-of-week variation of domestic fuel combustion is important to characterise as there are distinct patterns depending on when people tend to burn fuel for heating or cooking. For these simulations, this sector was disaggregated to hourly rates by using profiles developed during the most recent Vaal Triangle Priority Airshed AQMP study (VTAPA AQMP; DEA, 2019). These profiles are derived from black carbon measurements at Zamdela.

Similarly, variation of on-road vehicle emissions in time is vital to the proper characterisation of the source. Traffic generally displays a bimodal peak on weekdays, while weekends typically have a single peak during midday. Seasonal variation may be influenced by end-of-year or school holiday periods. The variation may differ between high-level vehicle classes, and indeed freight and passenger traffic exhibit distinctly different patterns. However, emissions are provided as a single all-class encompassing total and, therefore, one temporal profile is used for the entire sector. For this study, the on-road vehicle emissions temporal profiles developed for the VTAPA AQMP were used (DEA, 2019). These were derived from the analysis of 3569 SANRAL automated count station average diurnal data.

6.5.2 Chemical speciation

Gas-phase chemical reaction mechanisms (reaction schemes) are an essential part of CAMx. Emissions of NMVOC and $PM_{2.5}$ require speciation such that the necessary chemical species are input into the model as both NMVOC and $PM_{2.5}$ are a generalised grouping of important individual components that have different chemical characteristics with respect to atmospheric chemistry. Therefore, total NMVOC and $PM_{2.5}$ need to be split into these components, which may represent discrete chemical compounds or groups of compounds. Speciation should ideally be emission process specific.

For these simulations, Revision 5 of the Carbon Bond 06 CAMx chemistry scheme (Yarwood et al., 2010) was used for gaseous species with static coarse and fine modes (CF) aerosol chemistry. The CF scheme treats aerosols statically as either fine ($PM_{2.5}$) or coarse (PM_{10}), with $PM_{2.5}$ requiring further emissions speciation to sulphates, nitrates, primary organic aerosol, elemental carbon and other primary aerosols. The secondary aerosol produced in the model is only in the $PM_{2.5}$ fraction.

CB6 is a kind of condensed reaction mechanism, which lumps VOCs by chemical moiety (Gery et al., 1989; Stockwell et al., 2020). In Carbon Bond Mechanisms (CBMs), the carbon bond is treated as a reaction unit, and the carbon that bonds with the same bonding state are treated as a group, while the exact location of the carbon bonds in the molecule is neglected. CBMs are conveniently implemented in the ADMs because of their small size and high accuracy in predicting the concentration change in the pollutants. However, due to the lumping technique, biases are inevitably brought into computations.

The methodology for NMVOC and PM emission speciation was based on the US EPA SPECIATE database tool (Simon et al., 2010). The profile database contains approximately 2171 unique process profiles for VOC and 125 profiles for PM. It should be noted that this database is made up of speciation profiles derived from measurements

that may or may not be representative of local sources. This is particularly so if a local emission source is unique and a similar source has not been measured for the purpose of VOC speciation before.

6.6 Photochemical Modelling Results

Concentration maps of pollutants have been prepared using the time-averaging applicable to each pollutant according to the NAAQS. Verification of the modelled results with available measurements from monitoring stations in the HPA is contained in Annexure B of this report.

The frequency of exceedance means a frequency (number/time) related to a limit value representing the tolerated exceedance of that limit value at a specific location, in other words, if exceedances of a limit value are within the frequency, then there is still compliance with the NAAQS. The exceedance is applicable to a calendar year. The values summarised in Table 6-2 indicate a tolerable exceedance of 1% of values for each averaging period. As an example, for the 24-hour (daily) averaging period, 4 of 365 daily concentrations (1%) over a calendar year can exceed the NAAQS limit value and compliance with the standard can still be met. This implies that if the 99th percentile of measured/modelled data is below the ambient air limits for a relevant pollutant, there will be compliance with the standard.

Table 6-2: Tolerated frequency of exceedances for the NAAQS.

Tolerated Frequency of Exceedances for the NAAQS	
Averaging Period	**Tolerated Frequency of Exceedance of the Limit Value**
1 Hour	88 exceedances of the 1-hr NAAQS per year
8 Hour	11 exceedances of the 8-hr NAAQS per year
24 Hour	4 exceedances of the 24-hr NAAQS per year
1 Year (Annual)	0 exceedances of the yearly (annual) NAAQS

6.6.1 Nested Domain Model output as time averaged concentration maps

6.6.1.1 Particulate matter (PM_{10})

Figure 6-15 illustrates simulated annual mean PM_{10} concentrations over the HPA region, while Figure 6-16 is indicative of the simulated 24-Hr PM_{10} concentration exceedance counts.

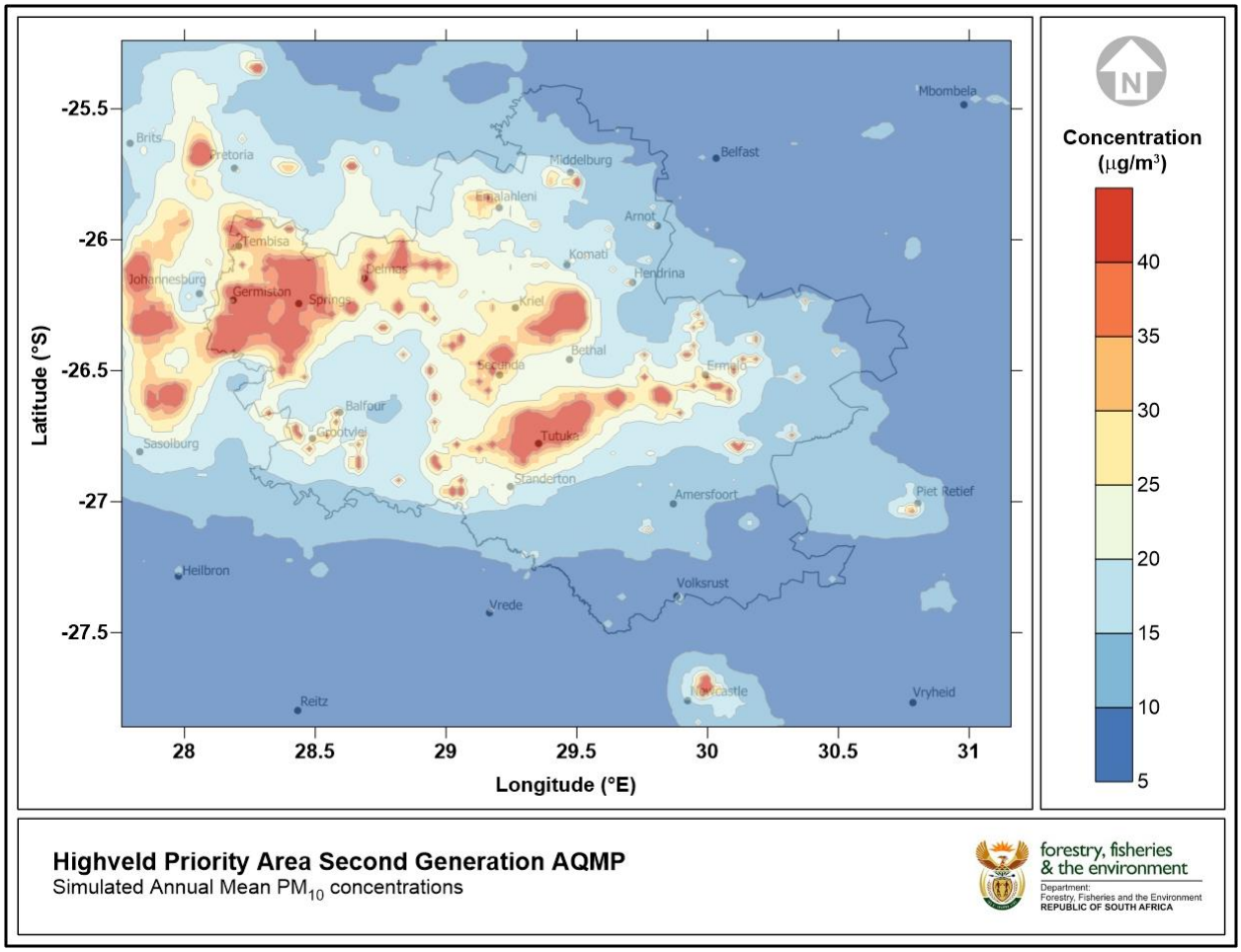


Figure 6-15: Map showing simulated annual mean PM_{10} concentrations.

High PM_{10} concentrations (NAAQS is 40µg/m³, indicated by the red isopleths) are simulated over the central and western region of the HPA (Secunda, Tutuka, Kriel and majority of the CoE, Johannesburg, Vereeniging, and Tshwane). There are also smaller regions around eMalahleni, Middelburg and Ermelo.

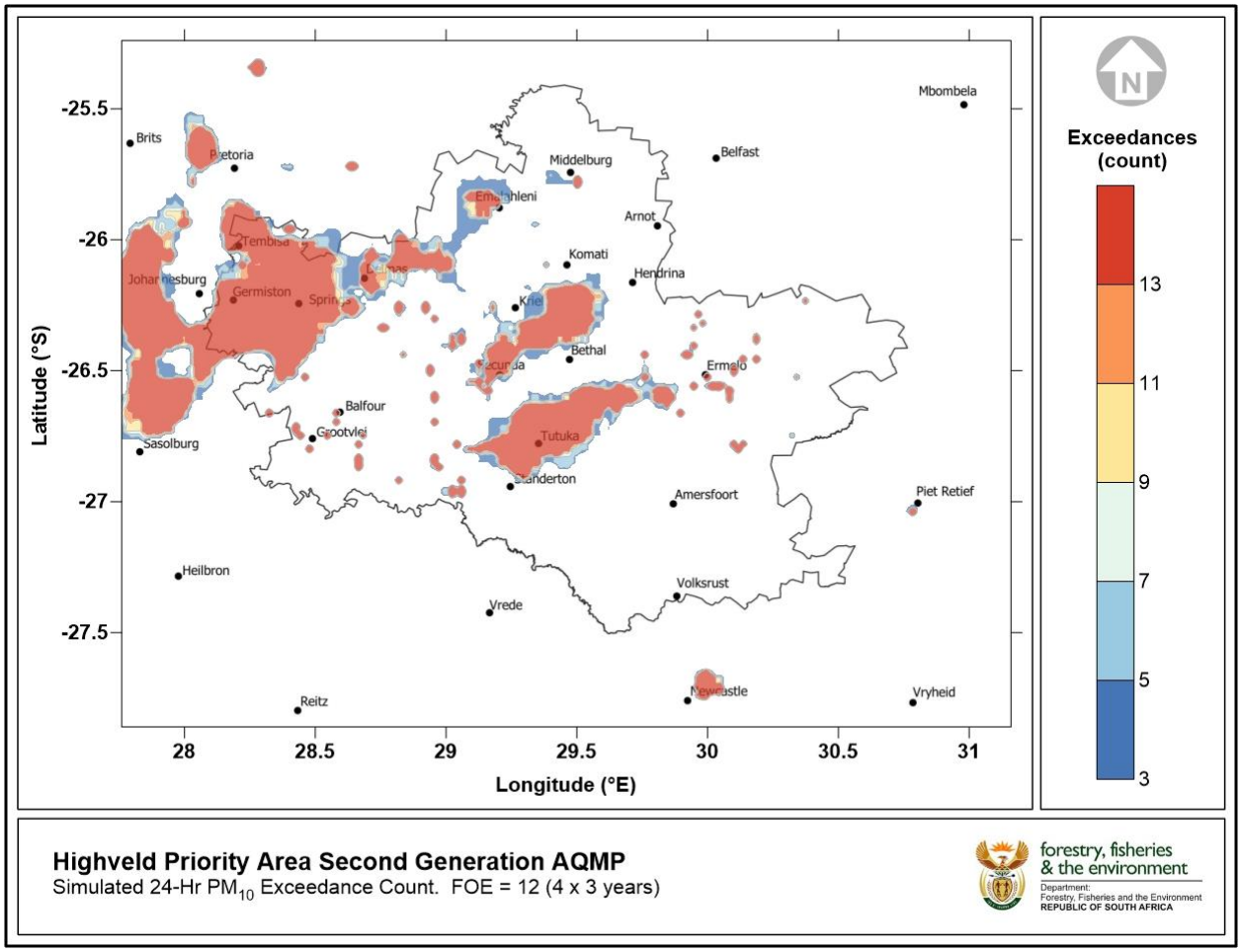


Figure 6-16: Map showing simulated 24-Hr PM_{10} concentration exceedance counts.

Figure 6-16 highlights the frequency of exceedances for the 24-Hr time averaging period for the three-year simulation period. The permissible number of exceedances is 12 and the red isopleth indicates regions exceeding this permissible number of exceedances. These regions include the central HPA region (Standerton towards Komati), as well as a region from Sasolburg towards Tshwane, encompassing the majority of the CoE. Isolated regions are reported for eMalahleni, Middelburg and Ermelo.

6.6.1.2 Particulate matter ($PM_{2.5}$)

Figure 6-17 illustrates simulated annual mean $PM_{2.5}$ concentrations over the HPA region, while Figure 6-18 is indicative of the simulated 24-Hr $PM_{2.5}$ concentration exceedance counts.

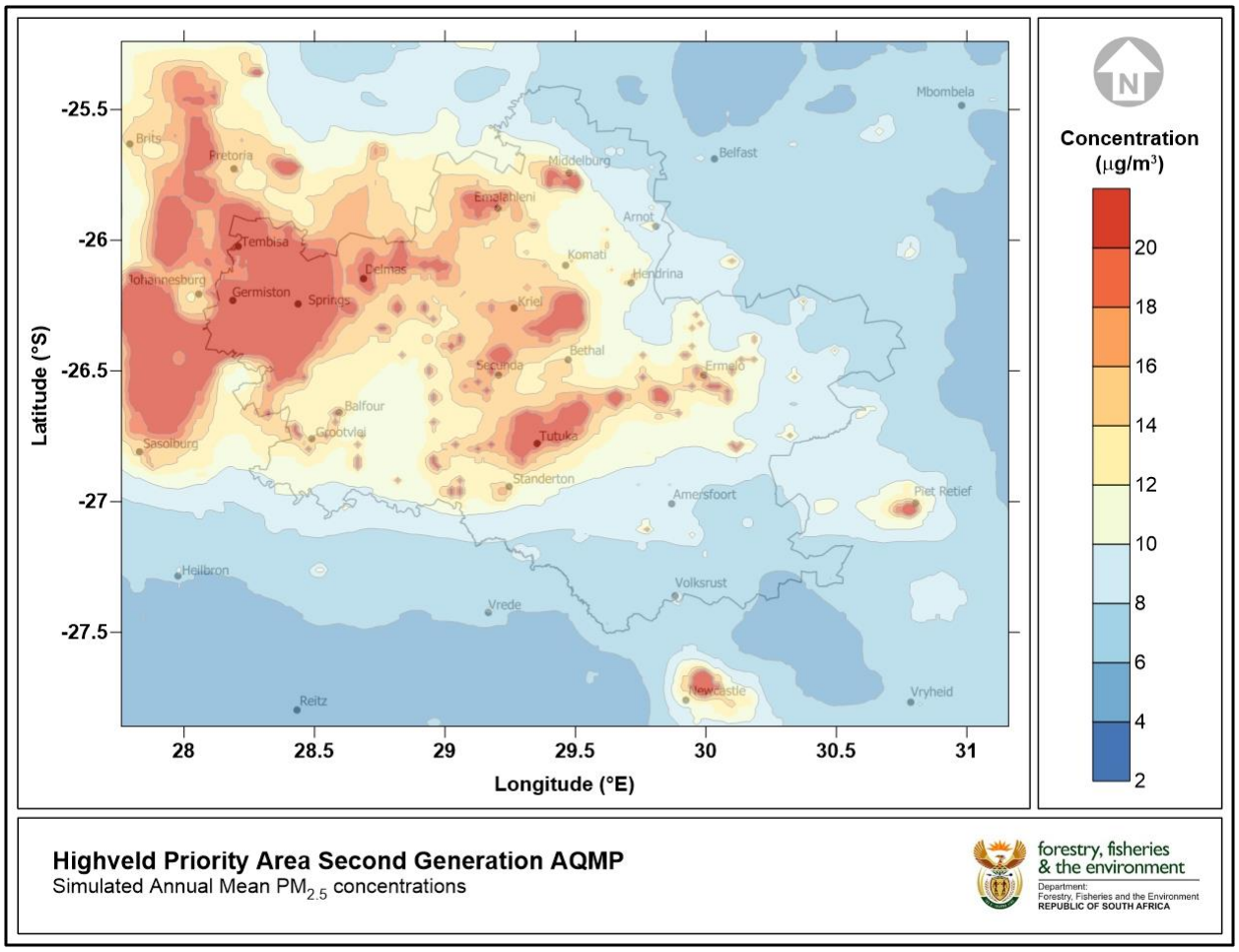


Figure 6-17: Map showing simulated annual $PM_{2.5}$ concentrations.

Both the simulated annual mean PM_{10} and $PM_{2.5}$ concentrations tend to have similar character in the spatial distribution. High $PM_{2.5}$ concentrations (NAAQS is 20µg/m³, indicated by the red isopleths) are simulated over the central and western region of the HPA (Secunda, Tutuka, Kriel and majority of CoE, Johannesburg, Vereeniging, and Tshwane). There are also smaller regions around eMalahleni, Middelburg and Ermelo.

Figure 6-18 highlights the frequency of exceedances for the 24-Hr time averaging period for the three-year simulation period. The permissible number of exceedances is 12 and the red isopleth indicates regions exceeding this permissible number of exceedances. These regions include the central HPA region (Standerton towards Komati), as well as a region from Sasolburg towards the north of Tshwane, encompassing the CoE toward eMalahleni. Isolated regions are reported for Middelburg and Ermelo.

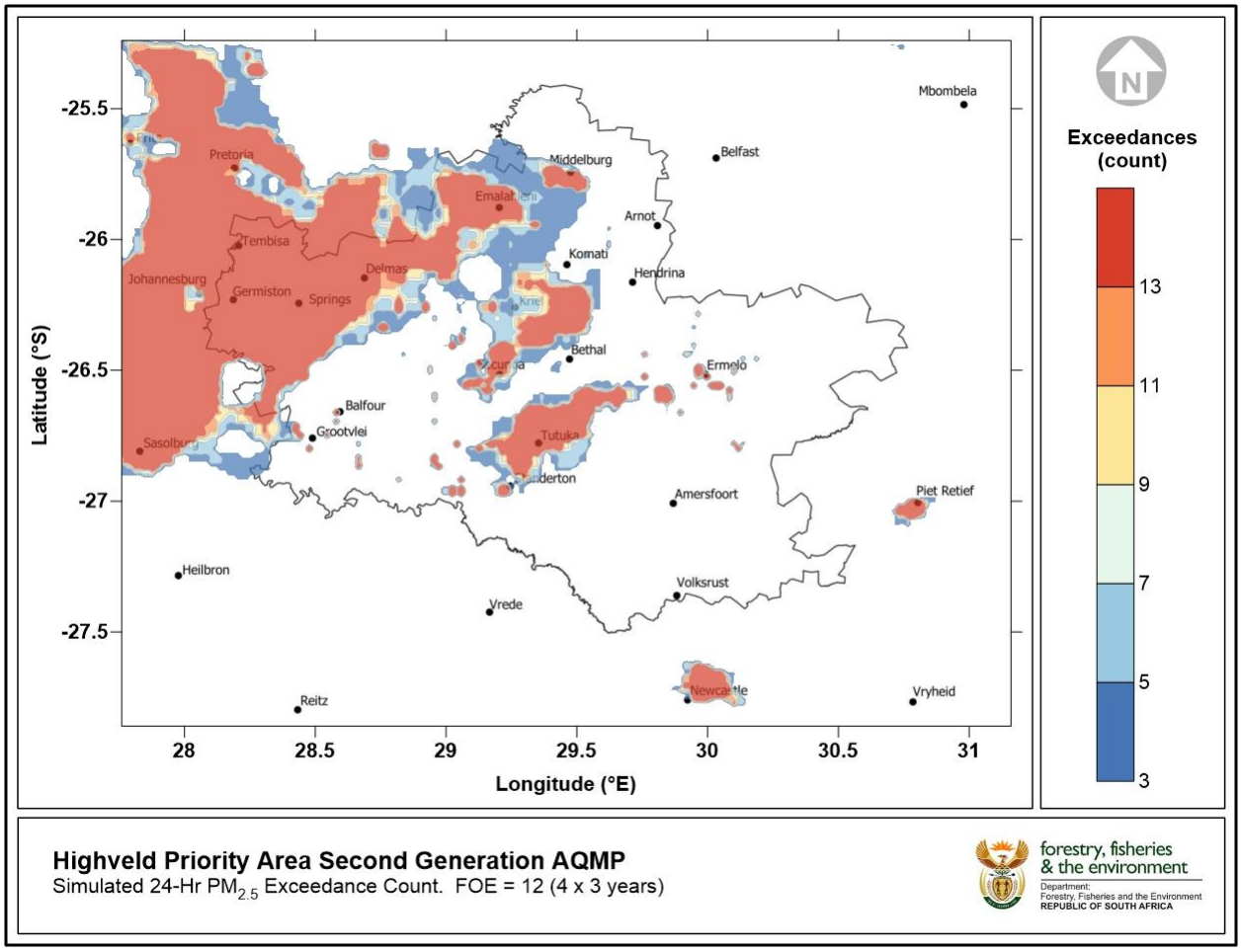


Figure 6-18: Map showing simulated 24-Hr $PM_{2.5}$ concentration exceedance counts.

6.6.1.3 SO_2

Figure 6-19 illustrates simulated annual mean SO_2 concentrations over the HPA region, while Figures 6-20 and 6-21 are indicative of the simulated 1-Hr and 24-Hr SO_2 concentration exceedance counts, respectively. From Figure 6-19, it is noted that the annual SO_2 NAAQS (19 ppb, indicated by the red isopleths) is exceeded primarily towards the west (Sasolburg area, part of the VTAPA) with Secunda, Kriel, eMalahleni, Middelburg and CoE, also illustrating areas of exceedances. Exceedances were also simulated around Tutuka and towards the south of Amersfoort.

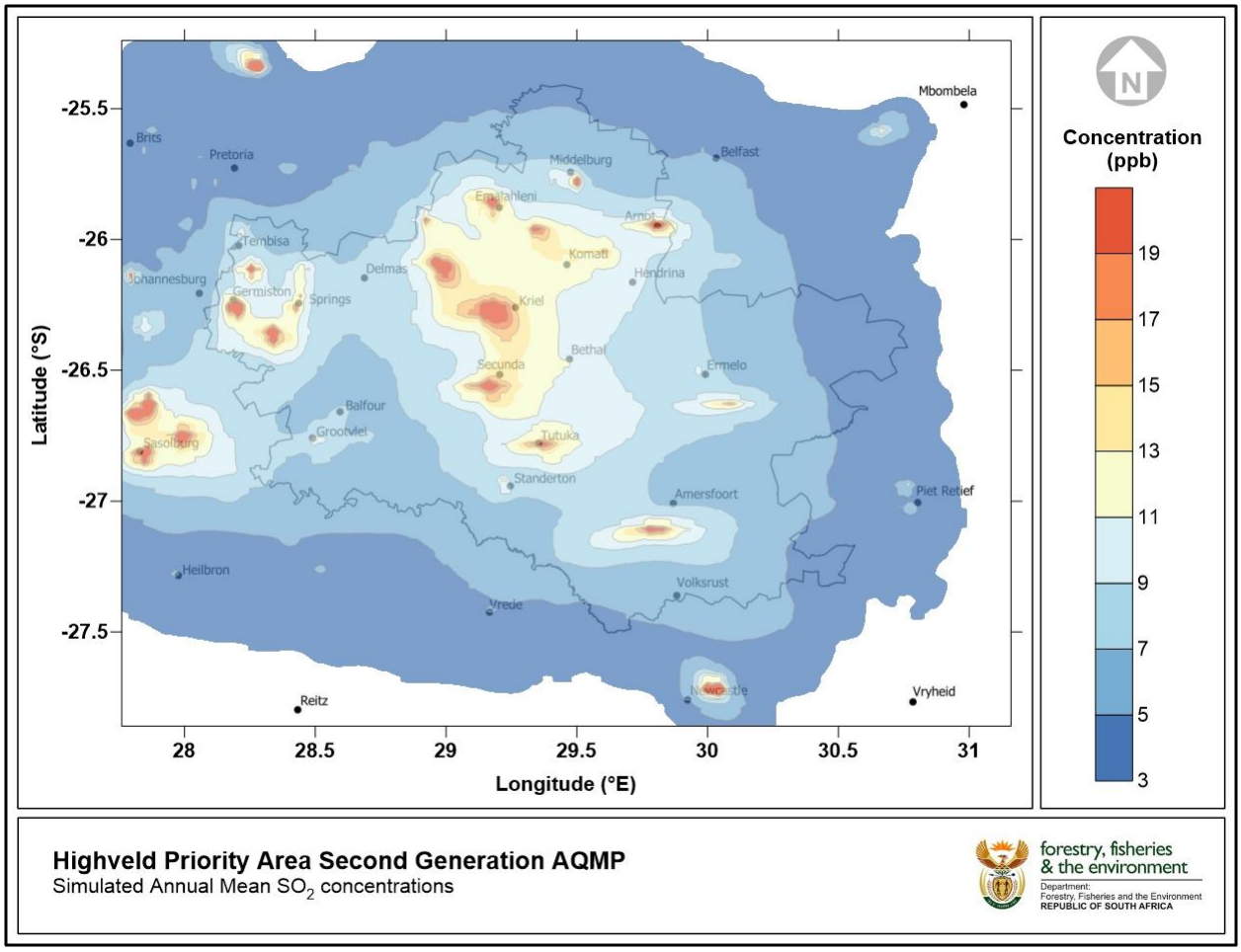


Figure 6-19: Map showing annual simulated SO_2 concentrations.

Figure 6-20 highlights the frequency of exceedances for the 1-Hr time averaging period for the three-year simulation period. The permissible number of exceedances is 264, and the red isopleth indicates regions exceeding this permissible number of exceedances. Figure 6-20 indicates several isolated areas where SO_2 concentrations are above the permissible Frequency of Exceedance and are clearly depicted in the concentration surface map (red isopleths). These regions include Sasolburg, Secunda, Kriel, Germiston, Springs, and Tutuka, as well as towards the south of eMalahleni, Ermelo and Amersfoort.

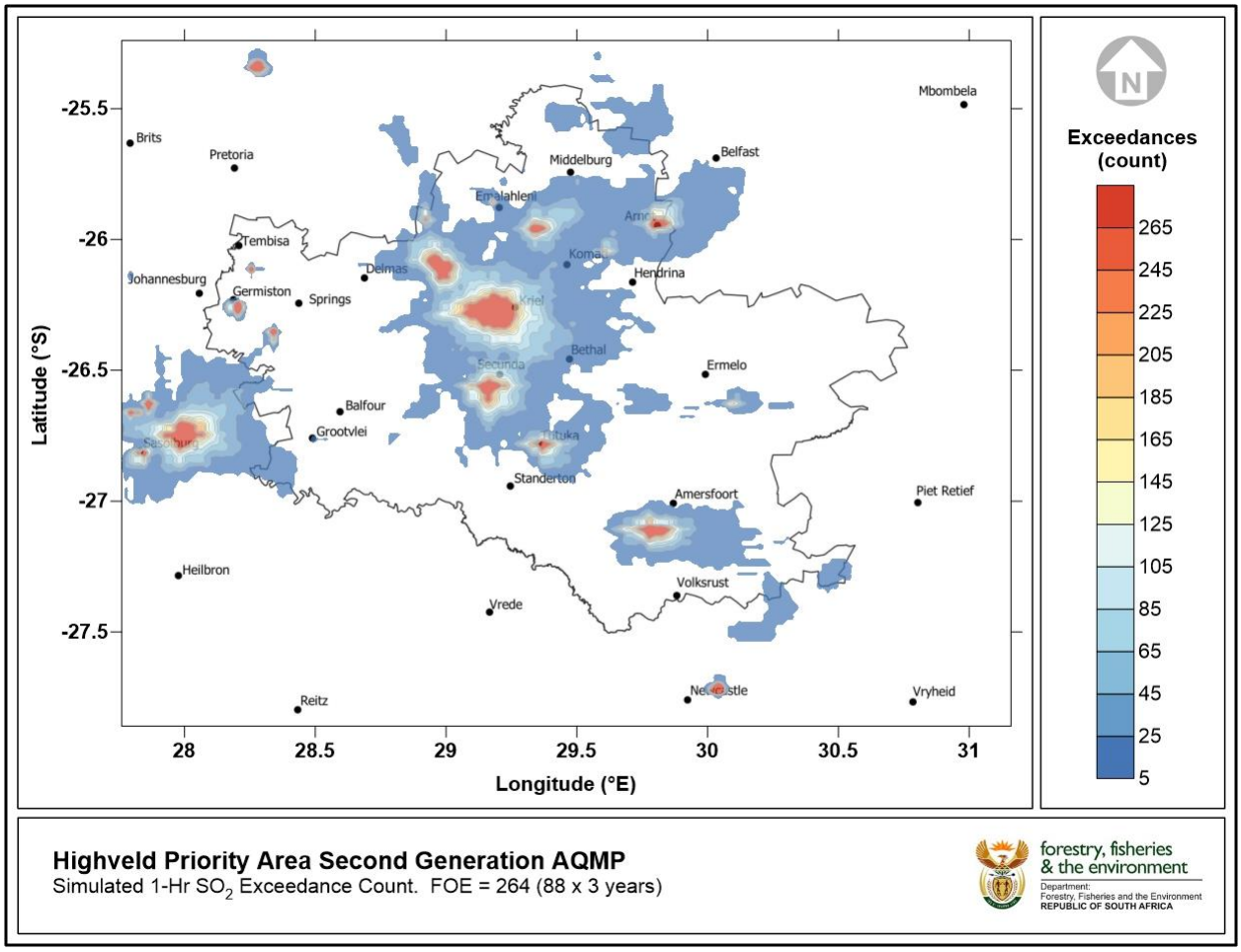


Figure 6-20: Map illustrating simulated 1-Hr SO_2 concentration exceedance counts.

Figure 6-21 highlights the frequency of exceedances for the 24-Hr time averaging period for the three-year simulation period. The permissible number of exceedances is 12, and the red isopleth indicates regions exceeding this permissible number of exceedances. These areas include an extended region around Sasolburg, with Germiston and Springs highlighted regions in the CoE, Secunda and a region from Kriel towards Delmas, eMalahleni, Middelburg, Komati, Kriel, as well as to the south of Amersfoort.

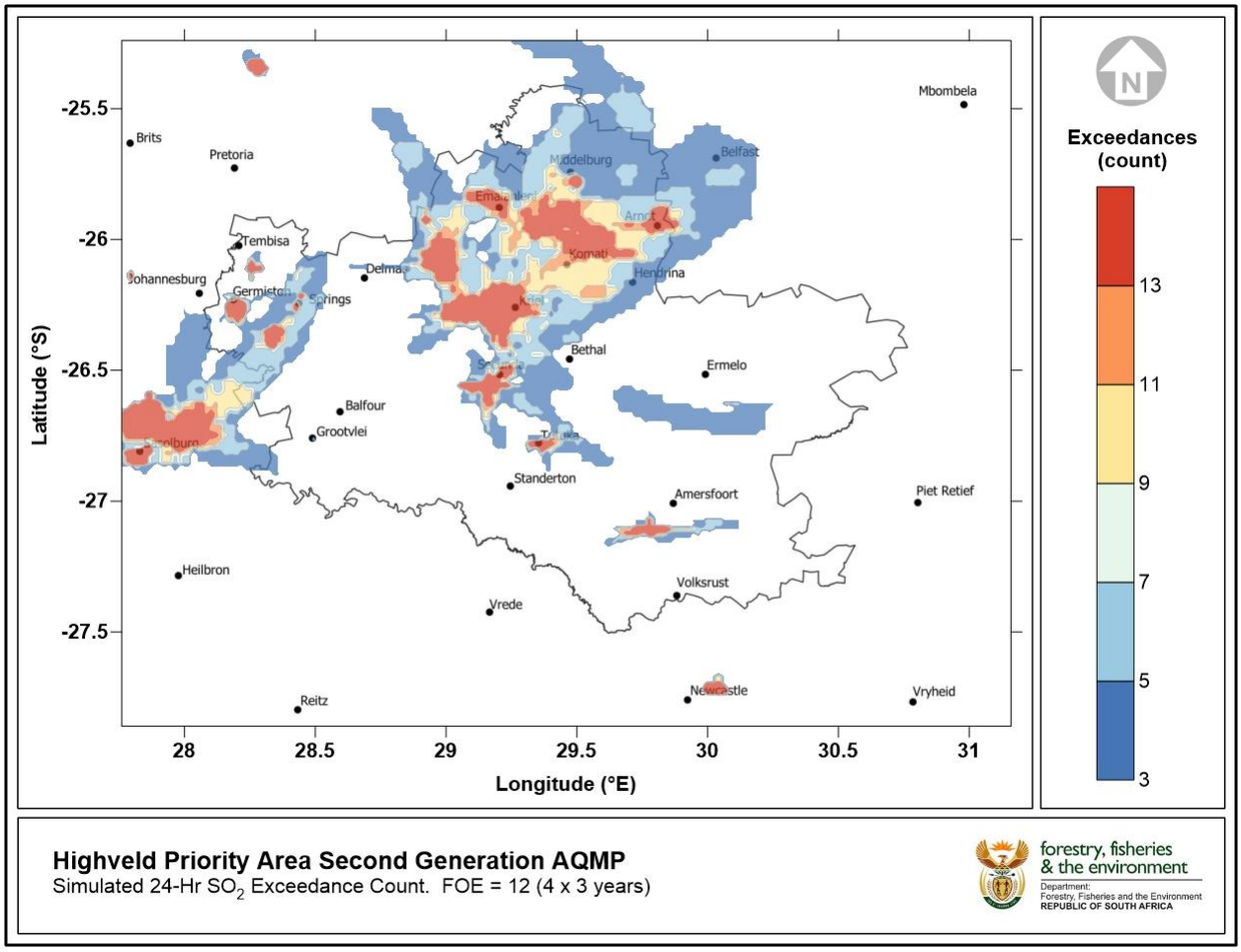


Figure 6-21: Map illustrating simulated 24-Hr SO_2 concentration exceedance counts.

6.6.1.4 NO_2

Figure 6-22 illustrates the simulated annual mean NO_2 concentrations. The NAAQS of NO_2 (21 ppb, indicated by the red isopleths) highlights the areas above the NAAQS. These regions include Secunda, and Sasolburg, as well as areas in the CoE. Figure 6-22 also highlights that most of the HPA are complying with the annual NO_2 NAAQS.

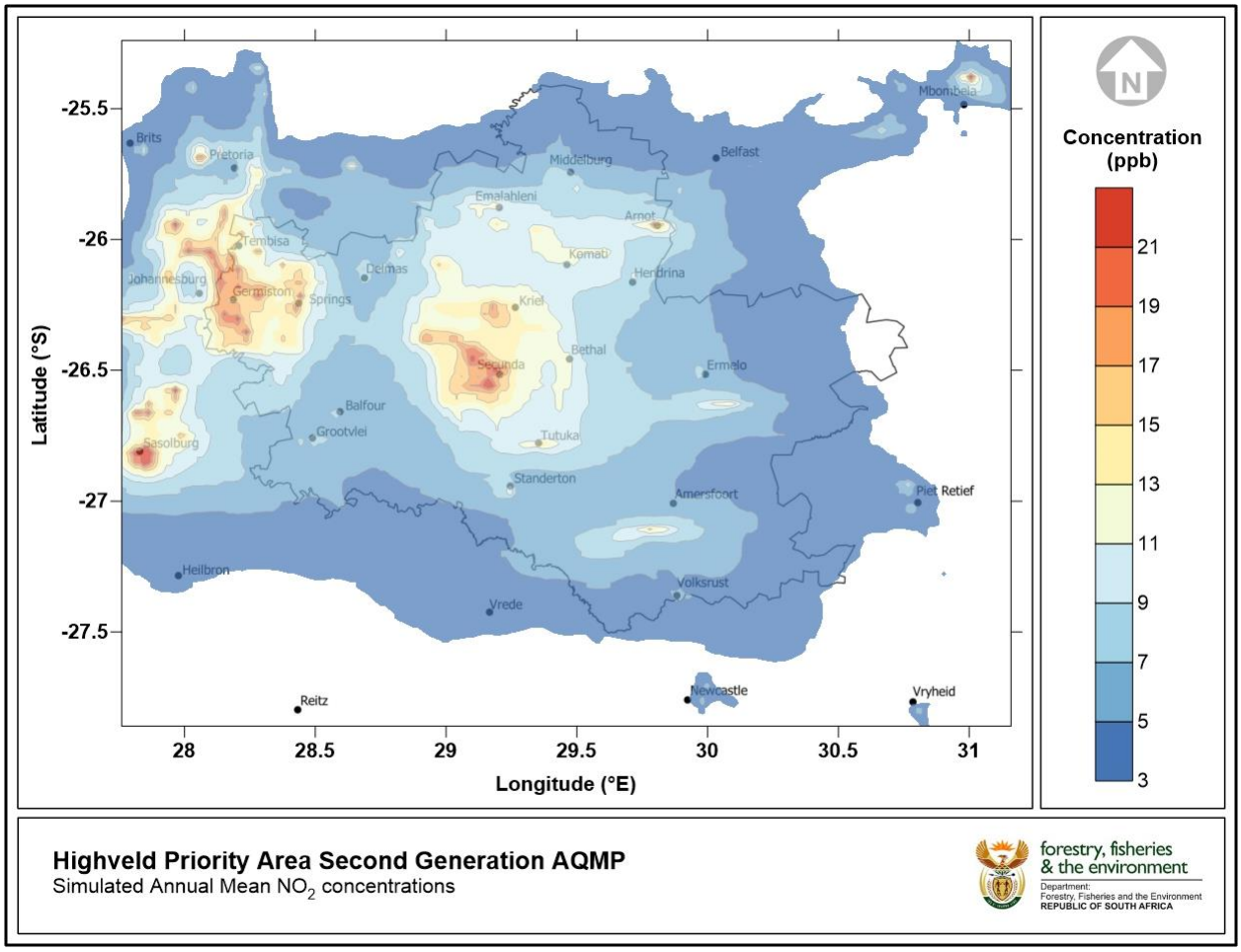


Figure 6-22: Map showing simulated annual NO_2 concentrations.

Figure 6-23 highlights the frequency of exceedances for the 1-Hr time averaging period for the three-year simulation period for NO_2. The permissible number of exceedances is 264, and the red isopleth indicates regions exceeding this permissible number of exceedances. Simulated results, as illustrated in Figure 6-23, indicate no regions in the HPA exceeding the permissible number of exceedances.

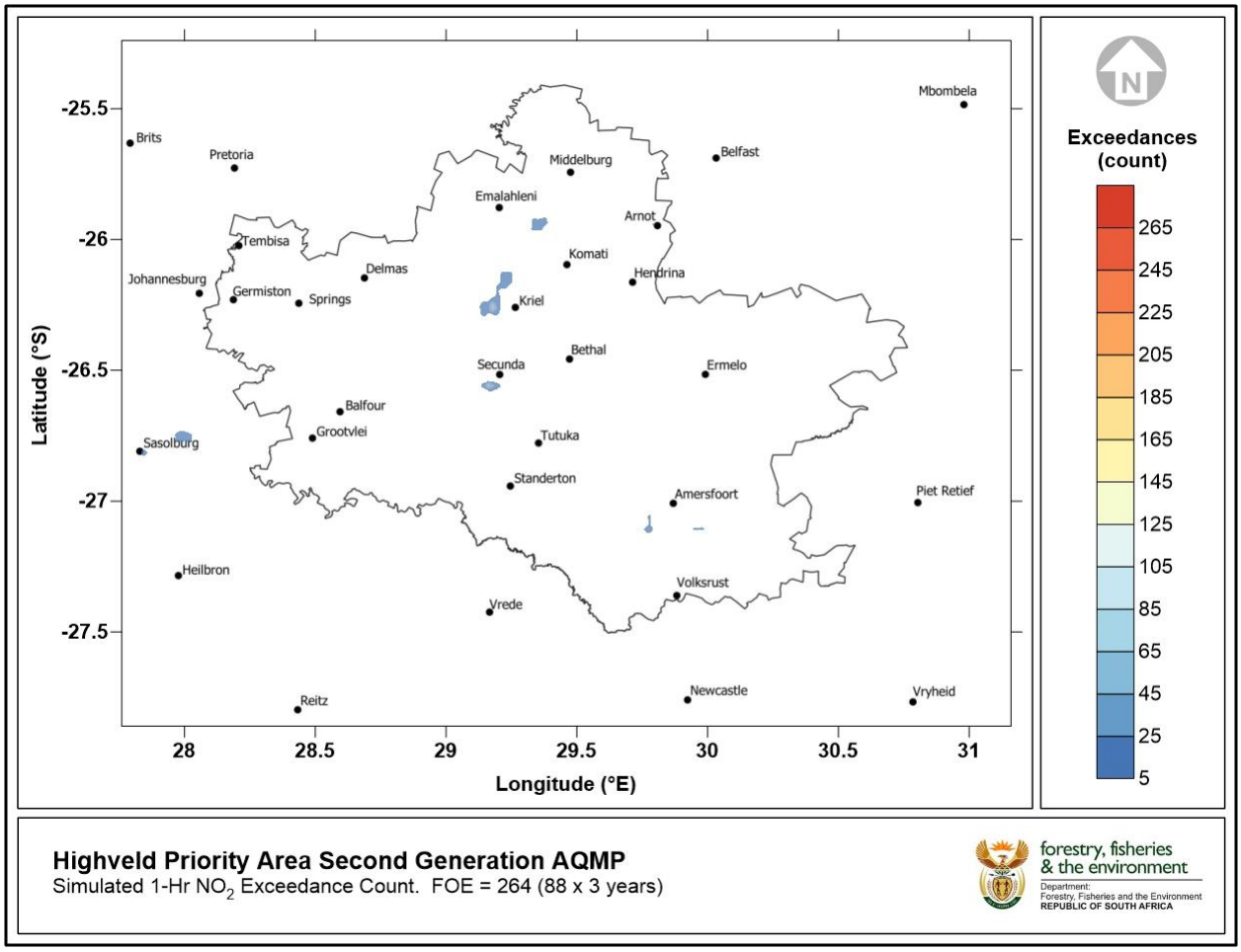


Figure 6-24: Map illustrating simulated 1-Hr NO_2 concentration exceedance counts.

6.6.1.5 Ozone (O_3)

Figure 6-25 illustrates the simulated annual O_3 concentrations over the modelling domain. Figure 6-25 indicates a generally lower O_3 concentration towards the centre of the HPA region, with distinct elevated concentrations towards the outer border of the modelling domain.

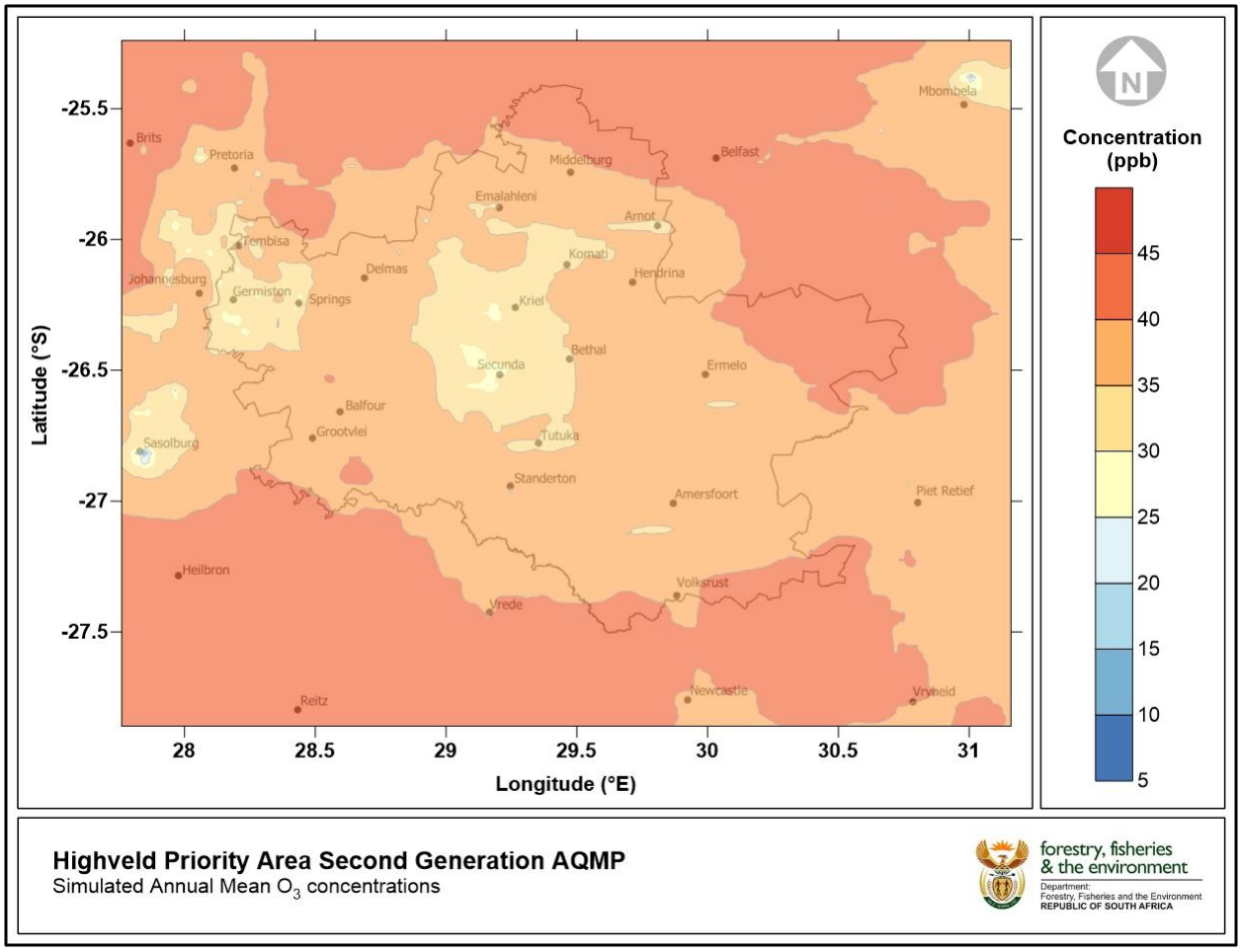


Figure 6-25: Map showing simulated annual O_3 concentrations.

Figure 6-26 highlights the frequency of exceedances for the 8-Hr time averaging period for the three-year simulation period for O_3. The permissible number of exceedances is 33. Simulated results, as illustrated in Figure 6-26, indicate that the complete modelling domain is exceeding the permissible number of exceedances. Again, elevated exceedances are accounted for towards the boundary of the modelling domain, with fewer exceedances towards the centre of the HPA region.

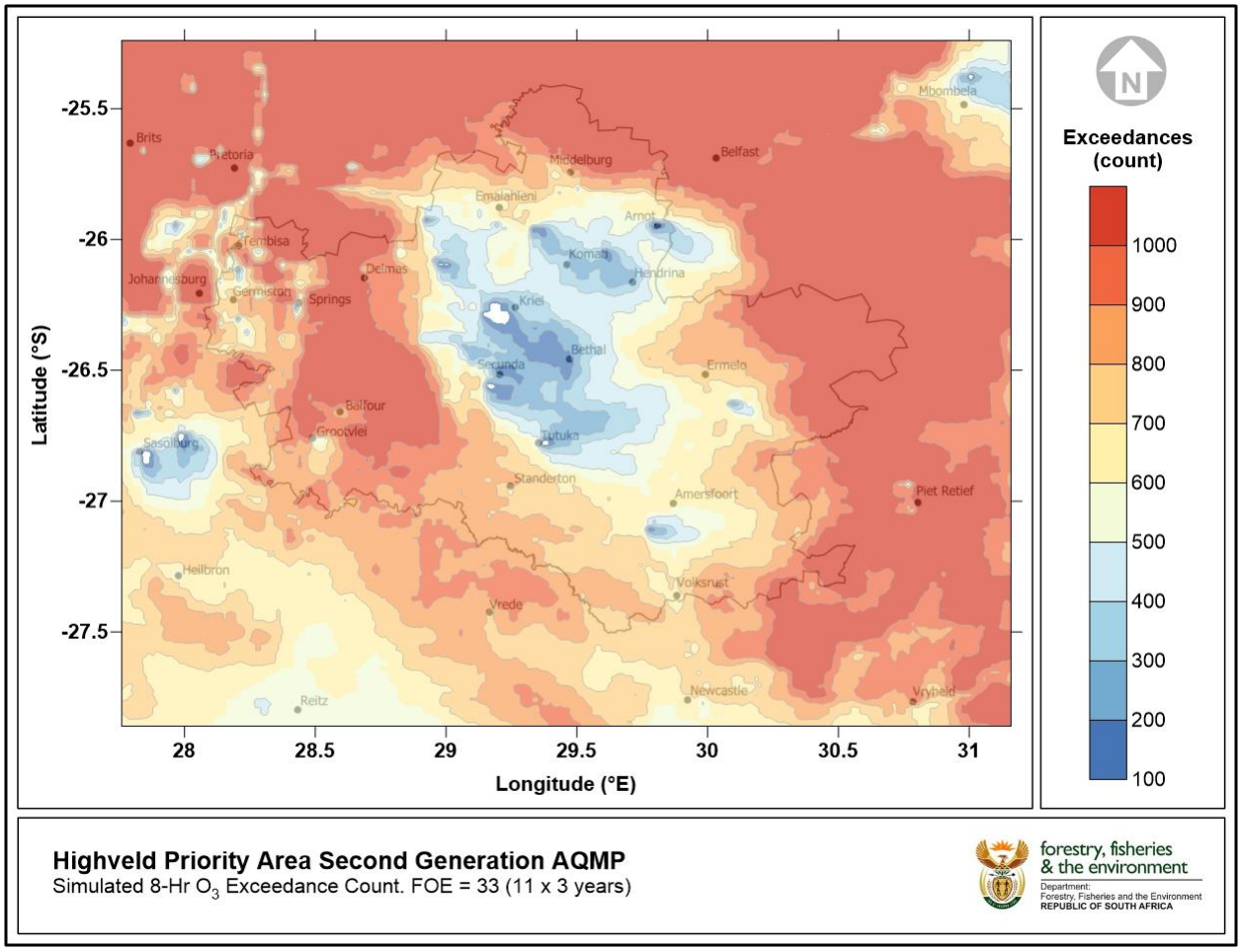


Figure 6-26: Map showing simulated 8-Hr O_3 concentration exceedance counts.

6.6.2 Parent Domain Model output as time averaged concentration maps

Figures 6-27 to 6-31 illustrate preliminary modelling results for the outer (parent) domain (~6 km resolution).

Annual particulates (PM_{10} and $PM_{2.5}$) concentration maps (Figures 6-27 and 6-28) only show a squeezed shape of what is observed in the nest domain, confirming that the spatial extent of simulated exceedance areas is limited in the parent domain simulations.

Relatively few SO_2 hotspots (having limited spatial extent) are predicted to exceed the guidelines of SO_2 for all average periods, revealing that some of the areas with exceedances may be missed by the model at this resolution (Figure 6-29).

A similar pattern is also observed for NO_2 and O_3, illustrating similar trends highlighted in Figures 6-30 and 6-31, respectively.

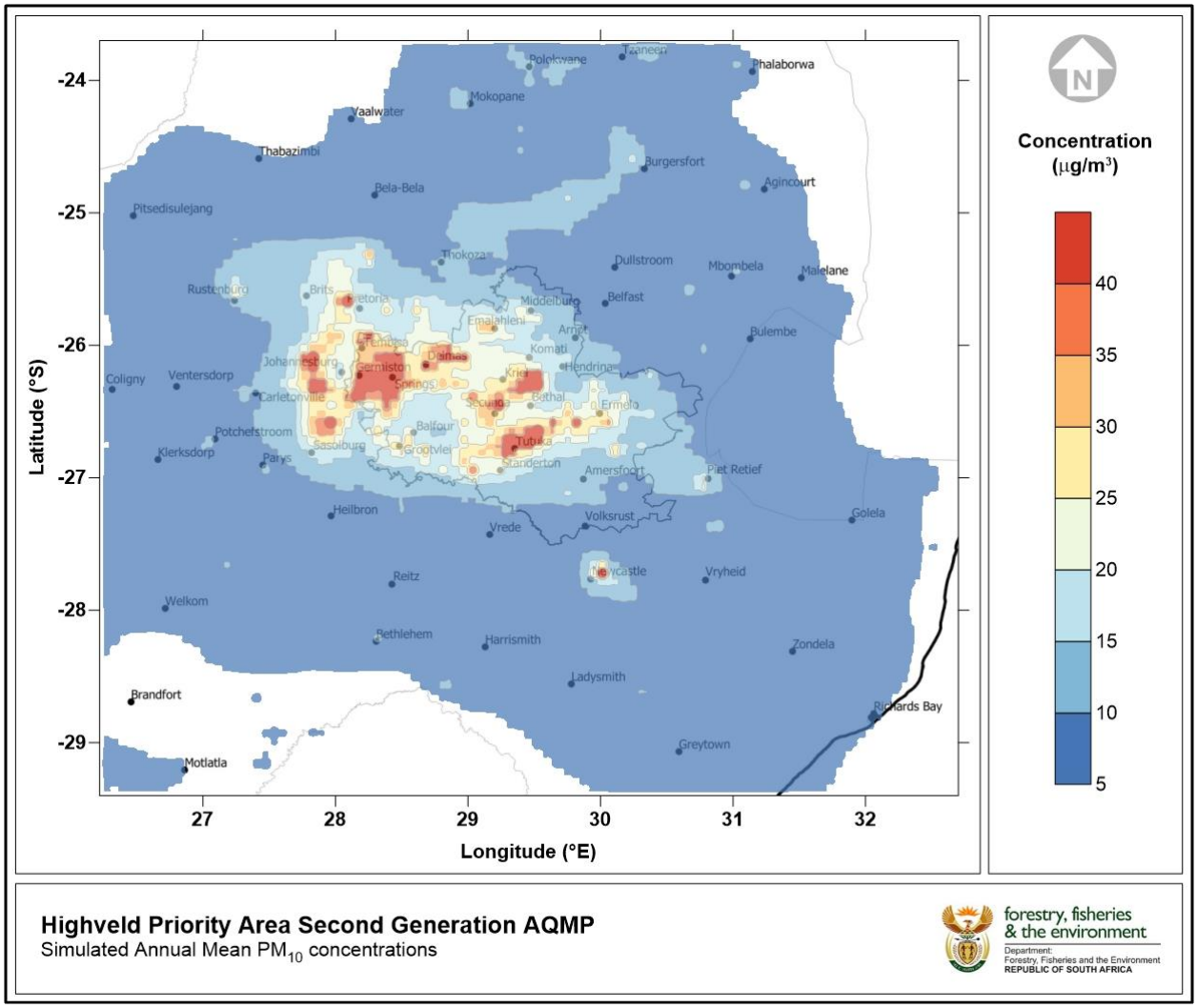


Figure 6-27: Map showing simulated annual PM_{10} concentrations.

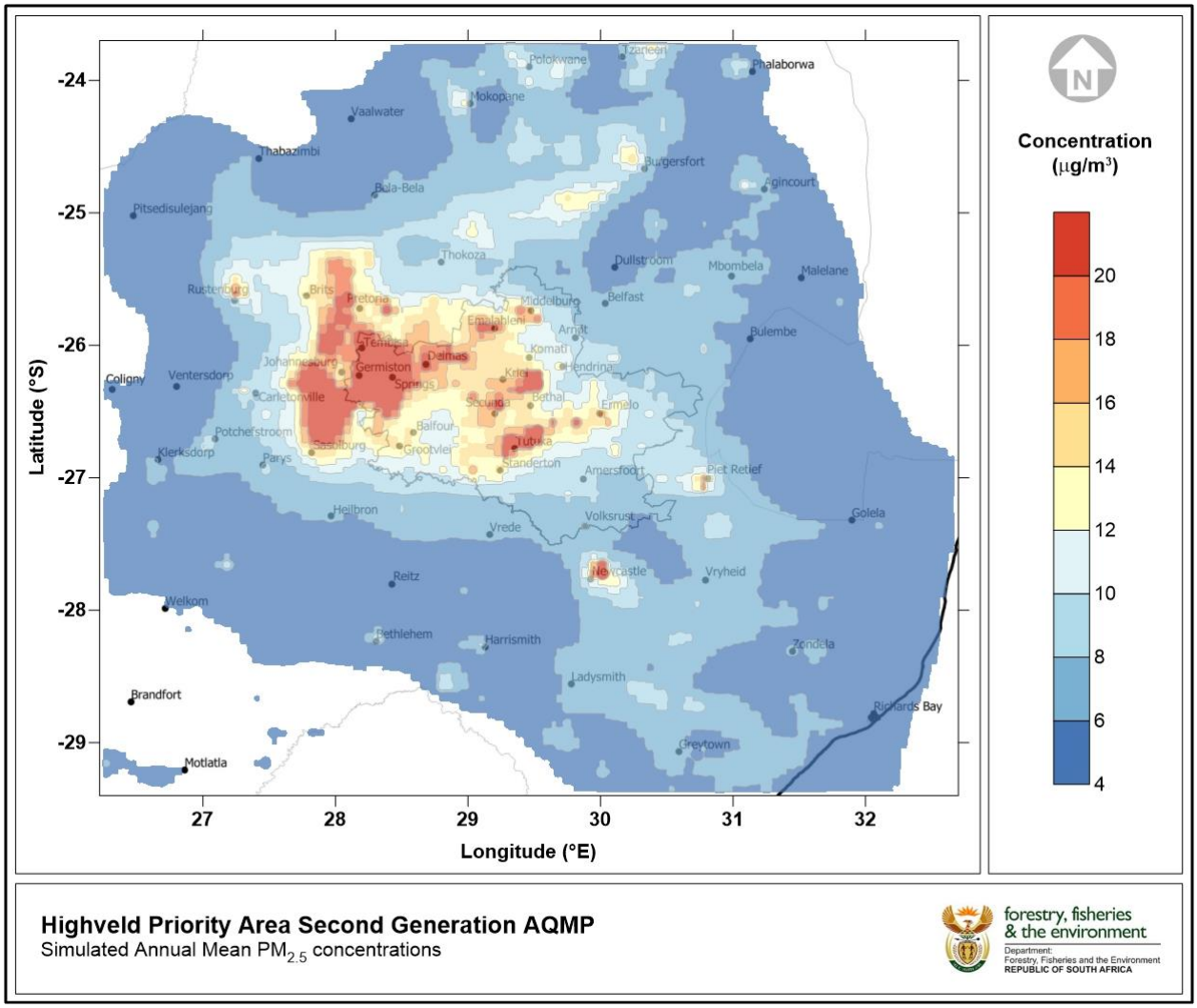


Figure 6-28: Map showing simulated annual $PM_{2.5}$ concentrations.

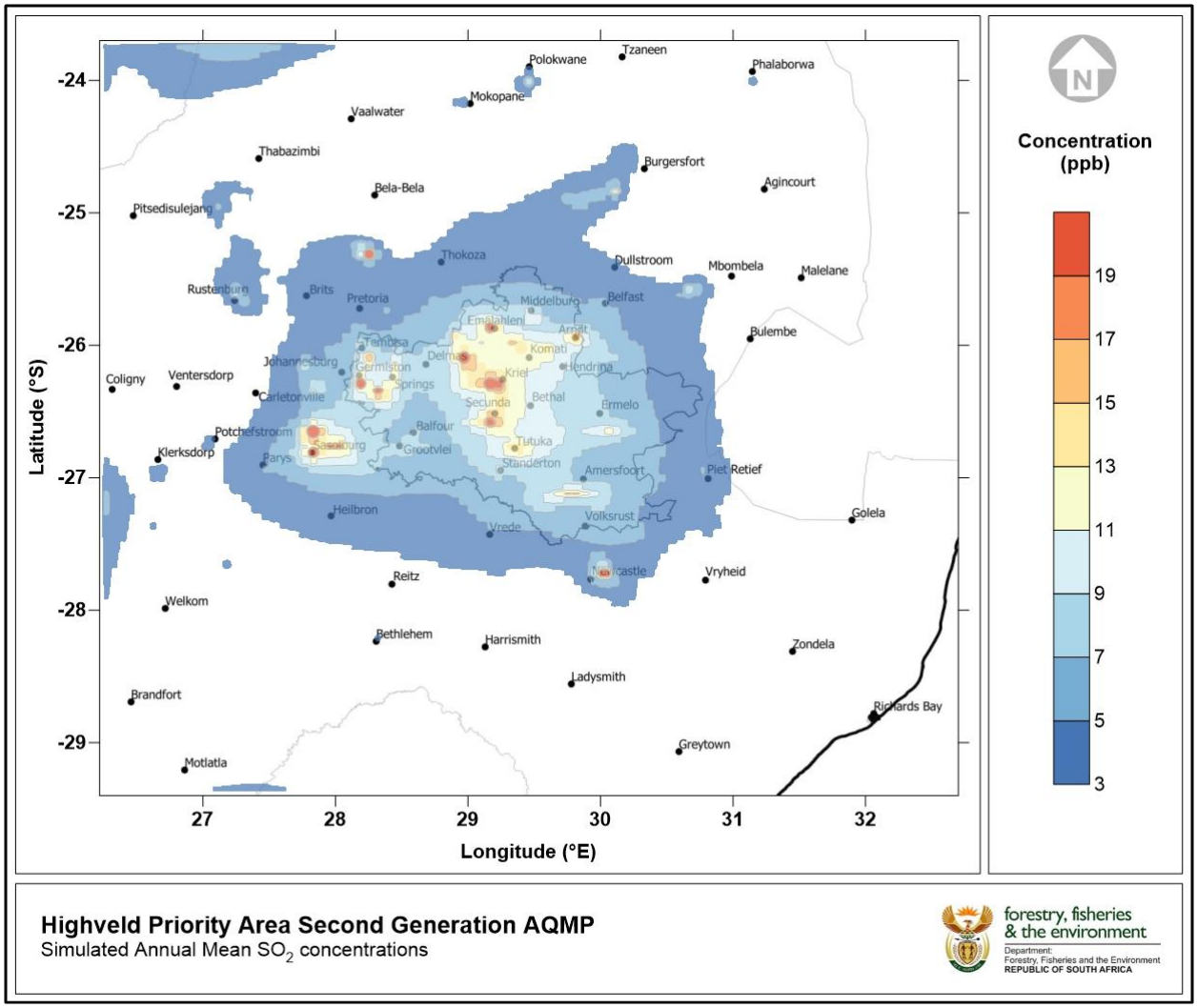


Figure 6-29: Map showing simulated annual SO_2 concentrations.

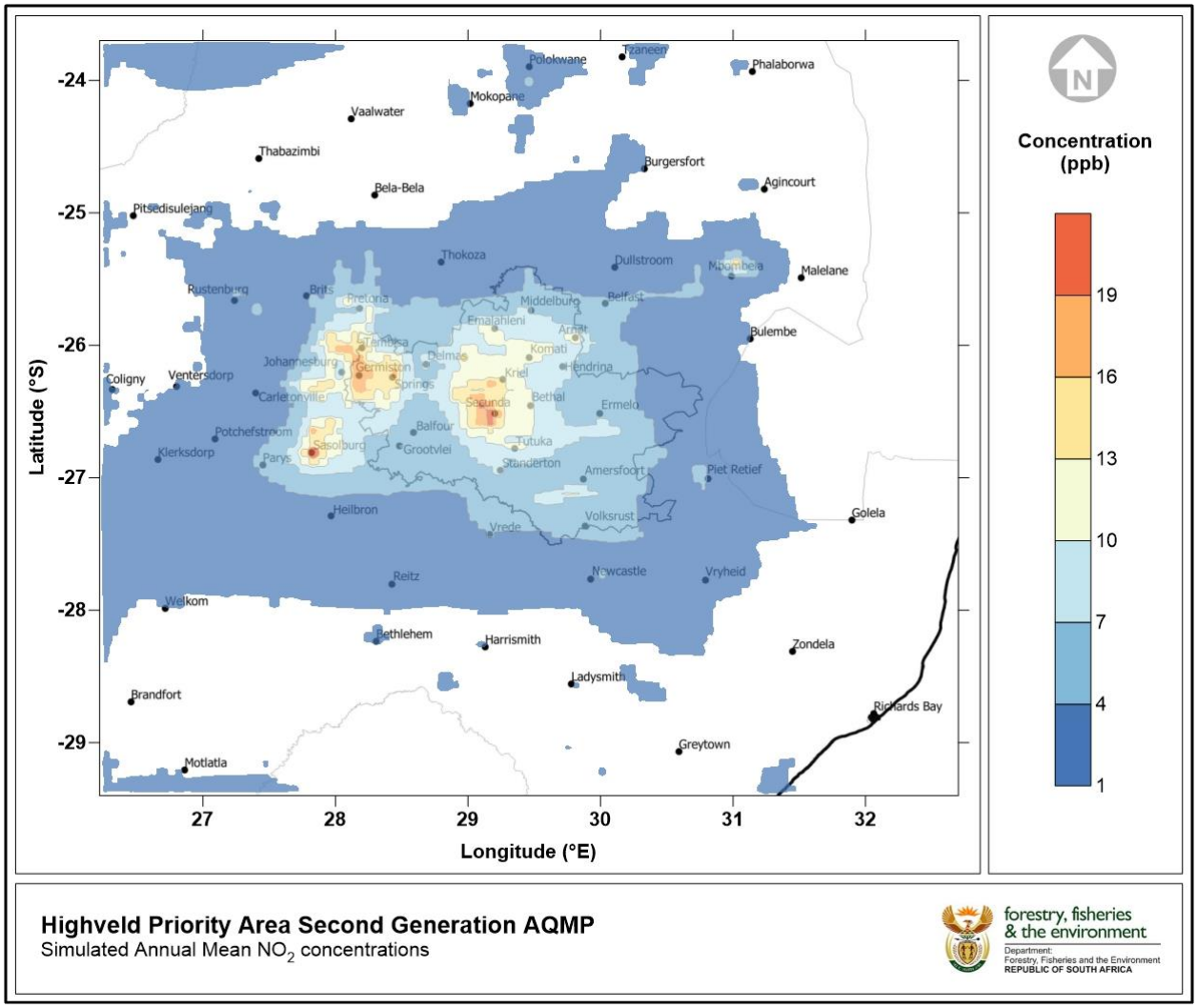


Figure 6-30: Map showing simulated annual NO_2 concentrations.

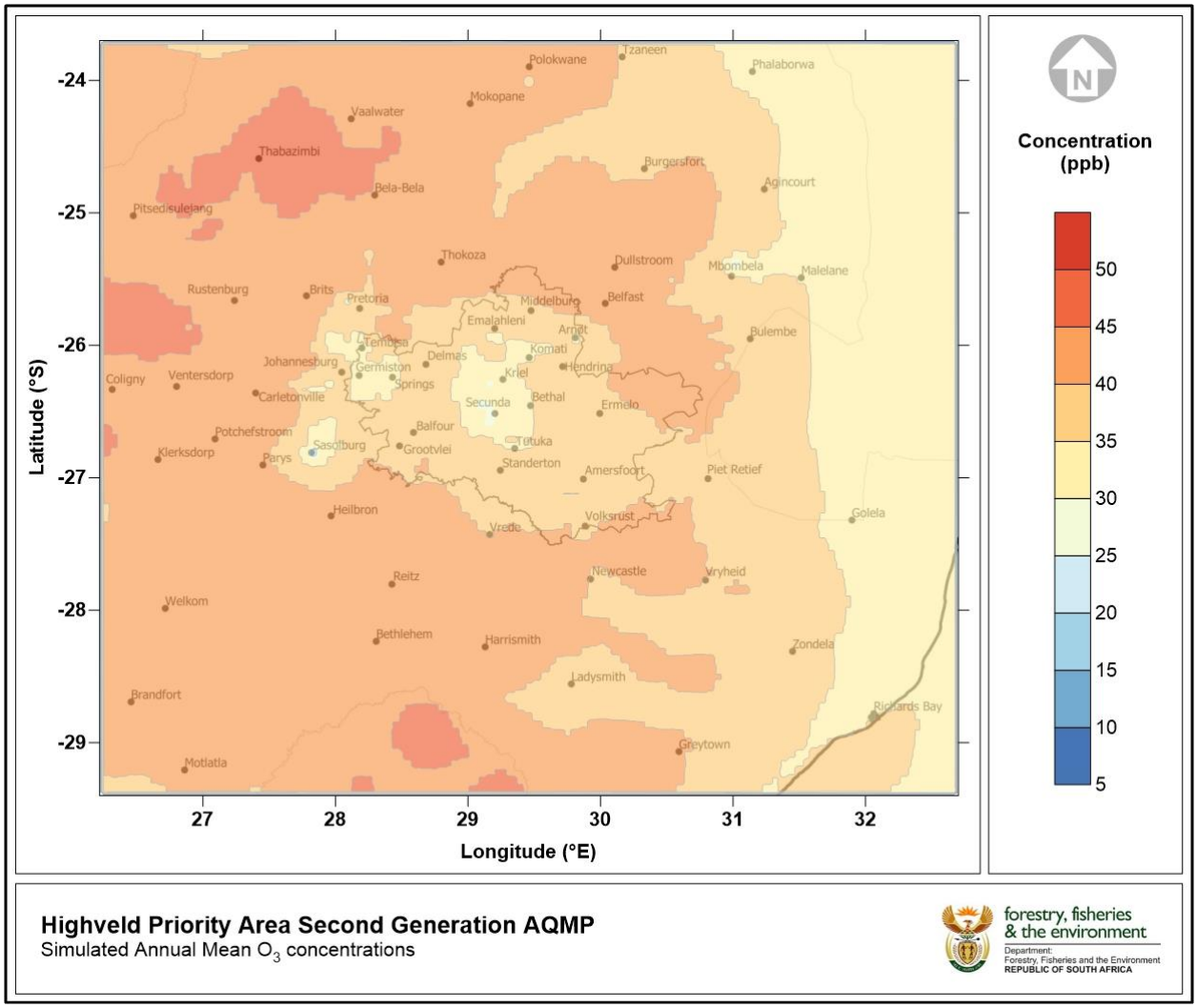


Figure 6-31: Map showing simulated annual O_3 concentrations.

Figure 6-31 indicates the same trend as the higher resolution nested domain. Relative lower concentrations are simulated over the HPA regions, while high concentration regions are simulated towards the north-east and south of the HPA region.

6.6.3 Model output applicability

As the CAMx model output is intended to be utilised in the generation of possible emission reduction strategies for the HPA, it is necessary to do a further evaluation with regards to performance in detecting exceedances of the NAAQS.

It should be noted that, as with the meteorological model comparison with observations (Section 6.2.1, and Annexure A), performance can only be evaluated at a specific location and only if a representative amount of data is available. It is possible that the model may perform better or worse outside regions near the stations.

In this section simulated concentrations are compared with the NAAQS at ten selected air quality stations per Annexure B. Observations for a station are not given if data coverage for the averaging period was below 70% (see Table B-1). The values are estimated similarly to those generated in the concentration maps, i.e., the 99th percentile of an average is used to represent the potential for exceedance during the year.

6.6.3.1 Sulphur Dioxide (SO_2)

Figure 6-32 and Figure 6-33 show the comparison for SO_2 (simulated annual mean and simulated 99th percentile 1-Hr concentrations, respectively), whilst Figures 6-34 and 6-35 indicate a simulated 24-hr mean and simulated 99th percentile 24-Hr concentrations, respectively.

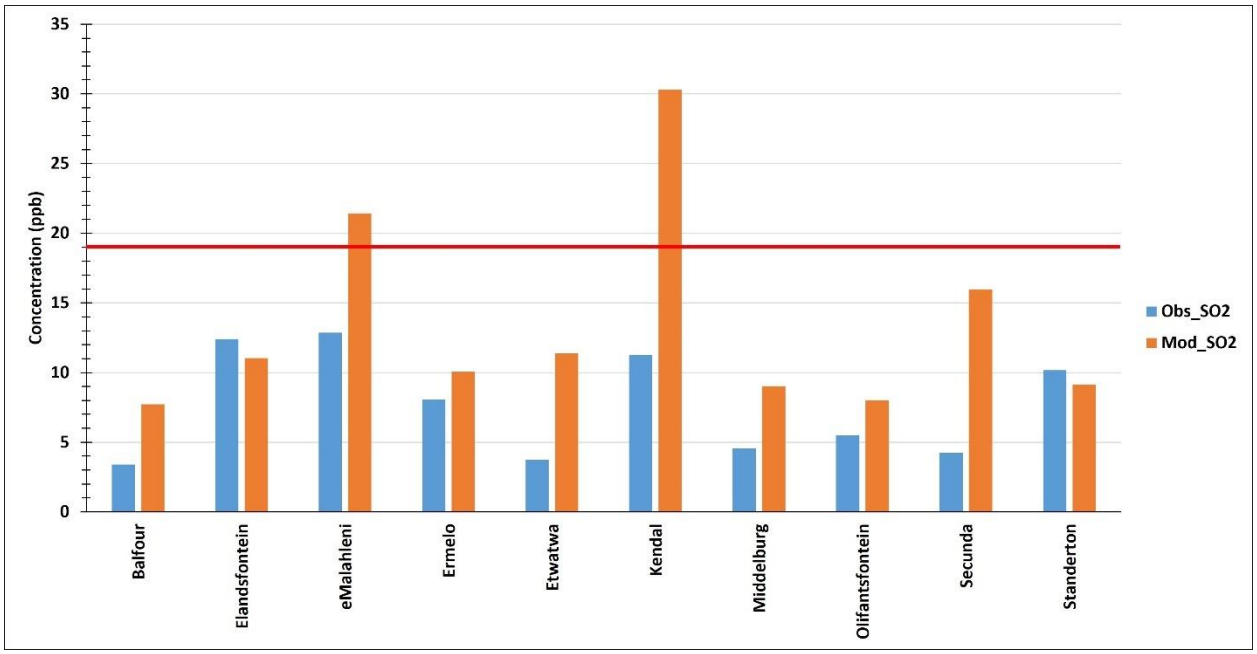


Figure 6-32: Comparison of observed (blue) vs simulated (orange) of annual average SO_2 concentrations (1-Hr averages). Red line is the annual SO_2 NAAQS (19ppb).

From Figure 6-32 it is noted that the observed annual SO_2 concentrations are below the annual NAAQS (19 ppb) at all monitoring sites. With regards to modelled annual average SO_2 concentration, although the modelled annual SO_2 concentrations are generally higher in magnitude compared to the observed values but they are still below the annual NAAQS (19 ppb) for SO_2 at most stations, only at eMalahleni and Kendal monitoring stations where exceedances are experienced.

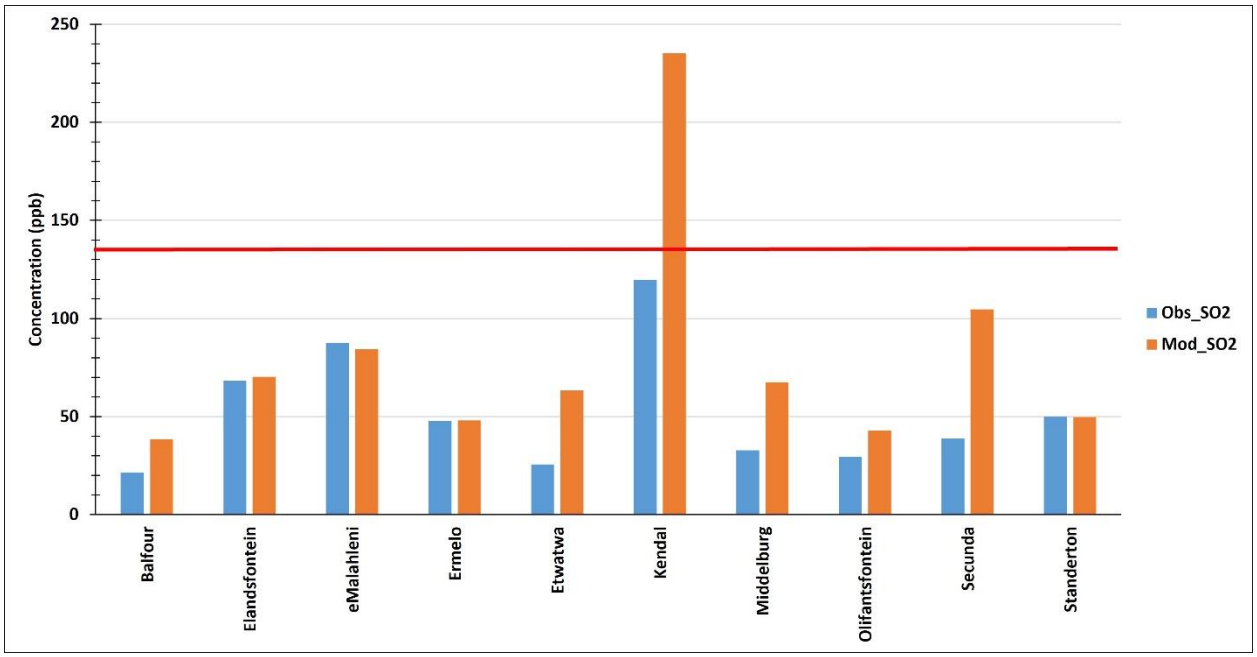


Figure 6-33: Comparison of observed (blue) vs simulated (orange) 99th percentile of 1-Hr averaged SO_2 concentrations. Red line is 1-Hr SO_2 NAAQS (134ppb).

From Figure 6-33 it can be derived that the 99th percentile 1-Hr average concentrations of SO_2 are below 1-Hr NAAQS (134 ppb) for both observations and model predicted values, only at Kendal station where modelled SO_2 hourly concentrations may exceed the stipulated threshold value. The modelled consistent exceedances at Kendal may be influenced by the significant overprediction of hourly SO_2 concentrations (> 600 ppb in some instances) by the model as was noted in Annexure B.

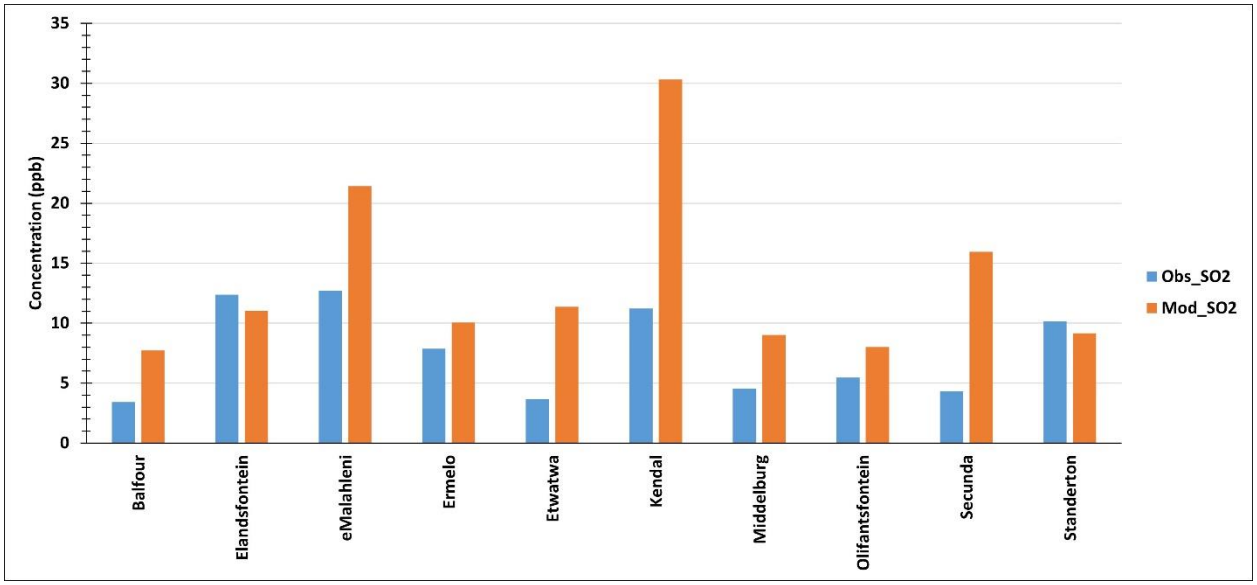


Figure 6-34: Comparison of observed (blue) vs simulated (orange) of 24-Hr average SO_2 concentrations. 24-Hr SO_2 NAAQS is 48ppb.

From Figure 6-34 it is not that both observed and modelled 24-Hr average SO_2 concentrations are below the NAAQS value of 48 ppb at all monitoring stations, even though the modelled SO_2 concentrations were found to be overpredicted.

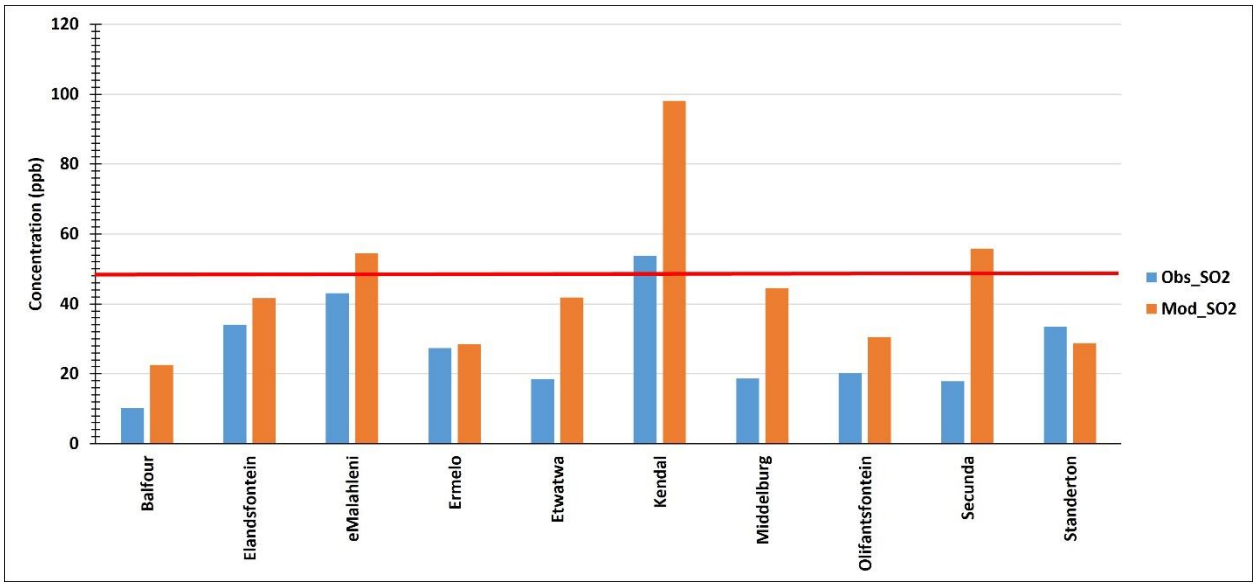


Figure 6-35: Comparison of observed (blue) vs simulated (orange) 99th percentile of 24-Hr averaged SO_2 concentrations. Red line is 24-Hr SO_2 NAAQS (48ppb).

From Figure 6-35 it is noted that the observed 99th percentile of 24-Hr average SO_2 is exceeded at one station (Kendal). On the other hand, modelled concentrations were exceeded at three stations including eMalahleni, Kendal, and Secunda.

6.6.3.2 Nitrogen Dioxide (NO_2)

Figure 6-36 and Figure 6-37 illustrates the comparison for NO_2 (annual mean and simulated 99th percentile 1-Hr concentrations, respectively).

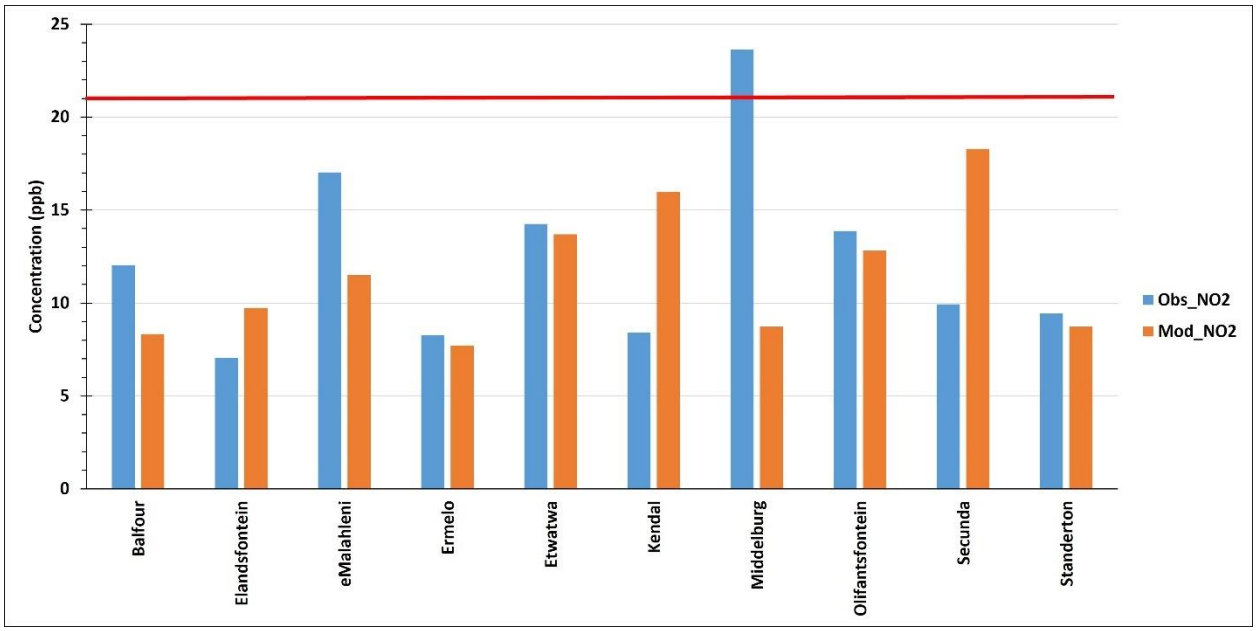


Figure 6-36: Comparison of observed (blue) vs simulated (orange) of annual average NO_2 concentrations (1-Hr average). Red line is annual NO_2 NAAQS.

From Figure 6-36 it is noted that observed 1-Hr annual average concentrations of NO_2 show to exceed the NAAQS value of 21 ppb at only one station (Middelburg). For the modelled concentrations no exceedances were found at any of the monitoring stations presented here. However, it must also be recalled that the model results analysis (Annexure B) indicated that the model tends to underestimate the NO_2 concentrations.

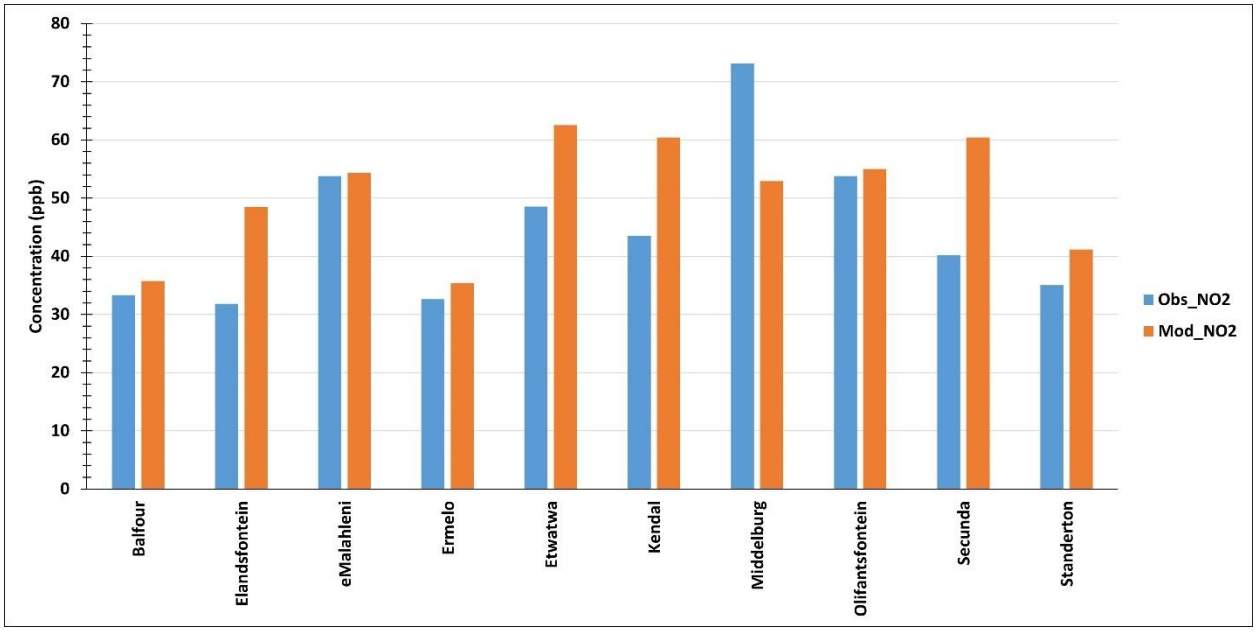


Figure 6-37: Comparison of observed (blue) vs simulated (orange) 99th percentile of 1-Hr averaged NO_2 concentrations. NO_2 NAAQS is 106ppb.

From Figure 6-37 it is noted that no exceedances of the NAAQS (106 ppb) for both observed and modelled 99th percentile of 1-Hr averaged NO_2 concentrations. The concentrations of the 99th percentiles are below 60 ppb on average for both modelled and observed concentrations, with relatively higher values obtained in the modelled dataset.

6.6.3.3 Particulate Matter (PM_{10})

Figure 6-38 illustrates the comparison for PM_{10} annual mean, whilst Figures 6-39 and 6-40 indicate a simulated 24-Hr mean and simulated 99th percentile 24-Hr concentrations, respectively.

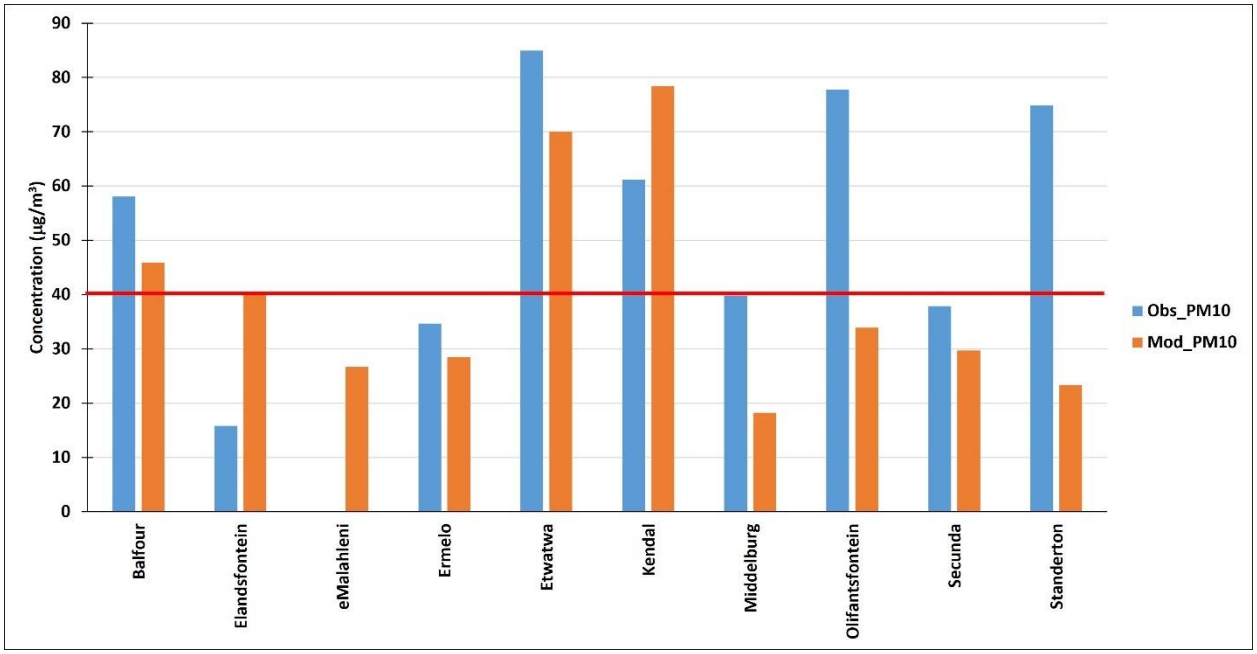


Figure 6-38: Comparison of observed (blue) vs simulated (orange) of annual average PM_{10} concentrations (1-Hr average). Red line is annual PM_{10} NAAQS (40µg/m³).

For Figure 6-38 it is noted that the observed annual average PM_{10} exceed the PM_{10} NAAQS value of 40 µg/m³ at Balfour, Etwatwa, Kendal, Olifantsfontein, and Standerton stations. For Balfour, Etwatwa and Kendal stations both observed and modelled concentrations indicate PM_{10} NAAQS are exceeded in these areas. The modelled annual average concentrations of PM_{10} are generally lower in magnitude at most stations.

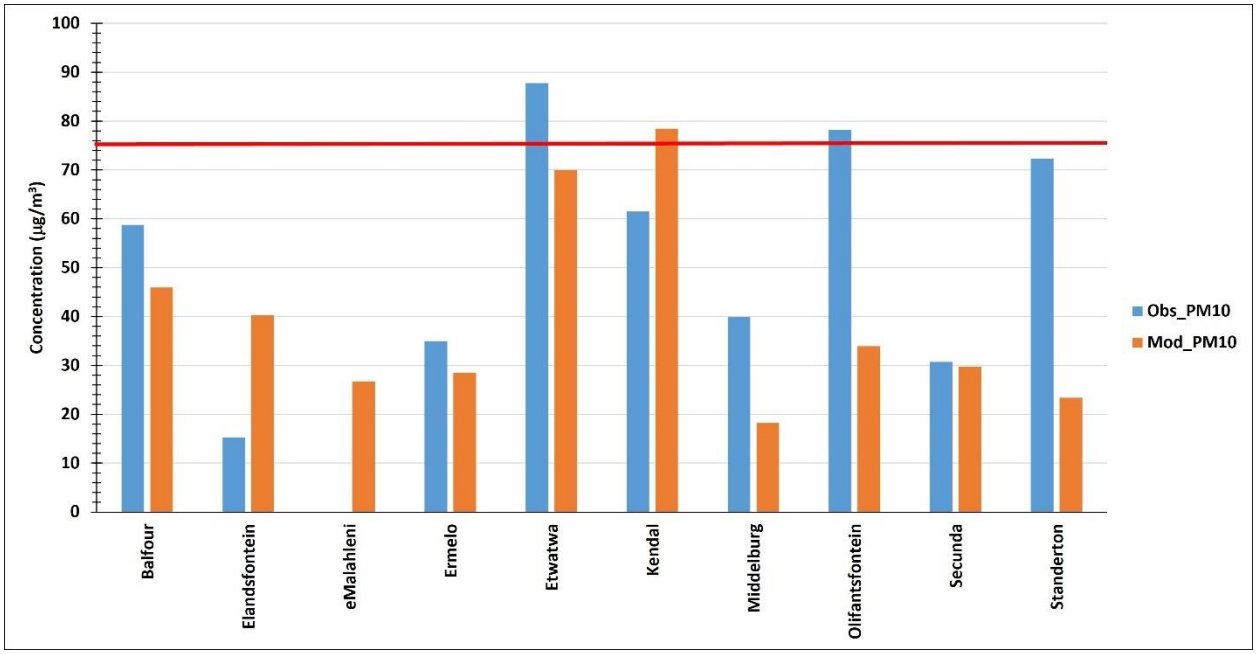


Figure 6-39: Comparison of observed (blue) vs simulated (orange) of 24-Hr average PM_{10} concentrations. Red line is 1-Hr PM_{10} NAAQS (75µg/m³).

Figure 6-39 presents the observed and modelled 24-Hr average concentration of PM_{10} at various monitoring sites. It is noted from Figure 6-39 that observed 24-Hr average PM_{10} concentrations exceed the NAAQS value of 75µg/m³ at two sites, Etwatwa and Olifantsfontein while the modelled 24-Hr concentrations only show exceedances at Kendal monitoring station. It must be noted that the modelled PM_{10} concentrations were found to be generally underpredicted when compared to the observed values.

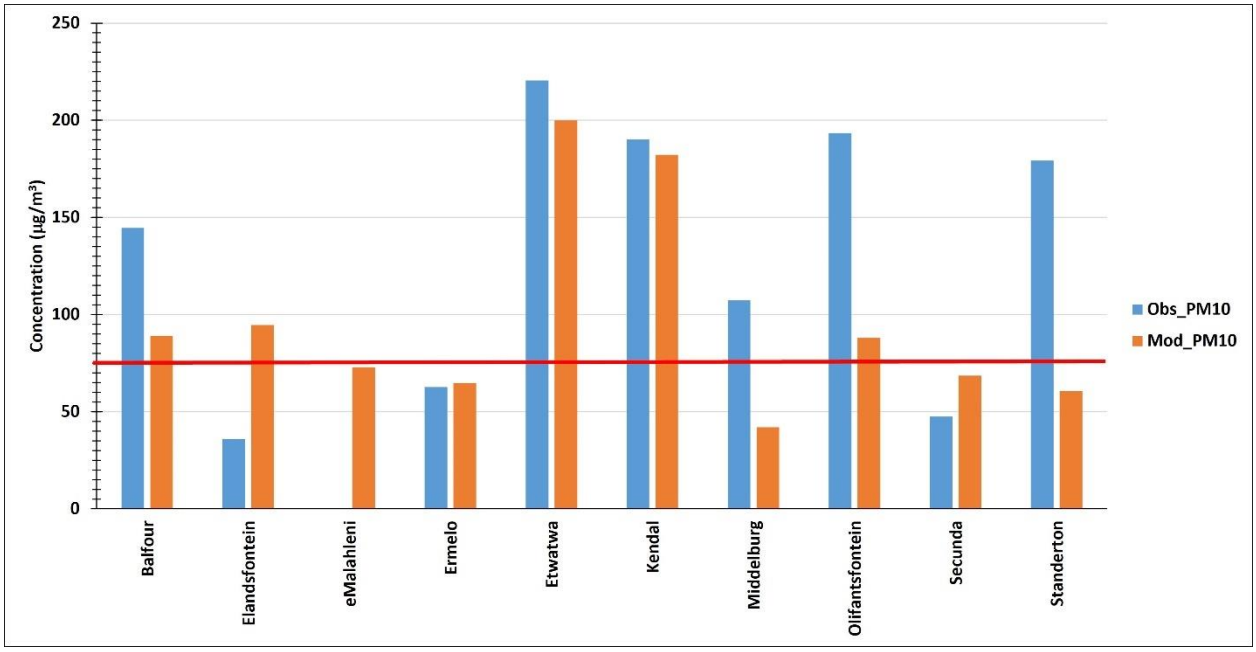


Figure 6-40: Comparison of observed (blue) vs simulated (orange) 99th percentile of 24-Hr averaged PM_{10} concentrations. Red line is 1-Hr PM_{10} NAAQS.

Regarding the 99th percentile of 24-Hr averaged PM_{10}, Figure 6-40 illustrates that 6 of the monitoring sites experience exceedances of PM_{10} (75µg/m³), these include Balfour, Etwatwa, Kendal Middelburg Olifantsfontein as well as Standerton. For the modelled concentrations only 50% of the stations are predicted to experience PM_{10} exceedances namely Balfour, Elandsfontein, Etwatwa, Kendal and Olifantsfontein. Again, it must be noted that the modelled PM_{10} concentrations were found to be generally underpredicted when compared to the observed values.

6.6.3.4 Particulate Matter ($PM_{2.5}$)

Figure 6-40 show the comparison for $PM_{2.5}$ (annual mean concentrations), whilst Figures 6-41 and 6-42 indicate a simulated 24-Hr mean and simulated 99th percentile 24-Hr concentrations, respectively.

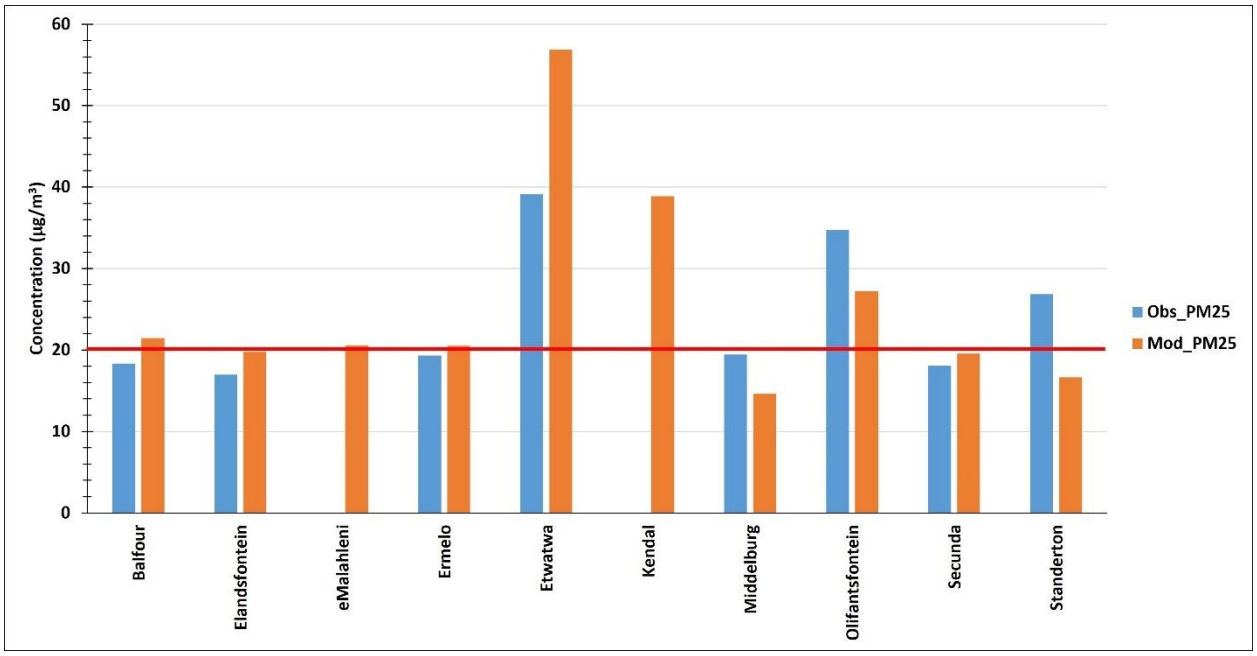


Figure 6-41: Comparison of observed (blue) vs simulated (orange) of annual average $PM_{2.5}$ concentrations (1-Hr averages). Red line is annual $PM_{2.5}$ NAAQS.

For $PM_{2.5}$ (Figure 6-41), observed annual average concentrations are exceeded at only 30% of the monitoring stations though is important to note that no observed data was captured for some of the stations that have been shown to be consistent with exceedances (e.g., Kendal) for other pollutants. The NAAQS is 20$\mu g/m^3$ as indicated by the red line. With respect to the modelled annual concentrations, NAAQS values are predicted to be exceeded at least 6 stations (60%). These including Balfour, Elandsfontein, Ermelo, Etwatwa, Kendal and Elandsfontein.

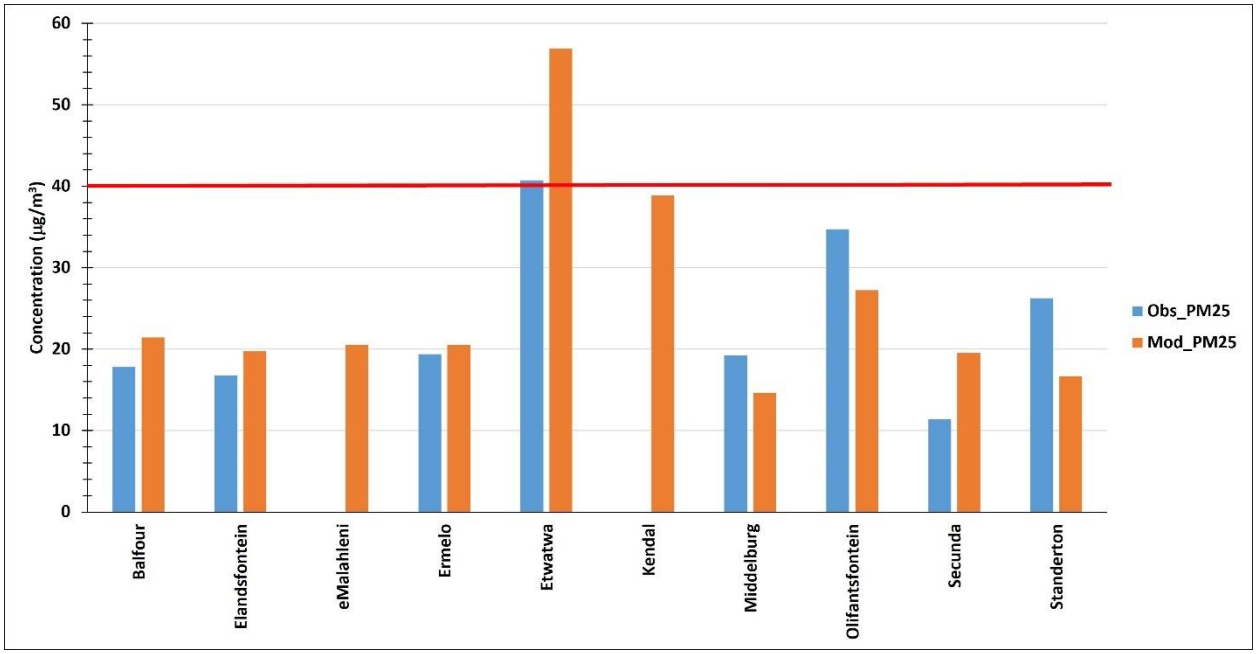


Figure 6-42: Comparison of observed (blue) vs simulated (orange) of 24-Hr average $PM_{2.5}$ concentrations. Red line is annual $PM_{2.5}$ NAAQS.

For 24-Hr average $PM_{2.5}$ concentrations, Figure 6-42 suggests that both observed and modelled concentrations are below the 40µg/m³ NAAQS limit. Etwatwa monitoring station is the only site that may experience exceedances for both observation and simulated concentrations.

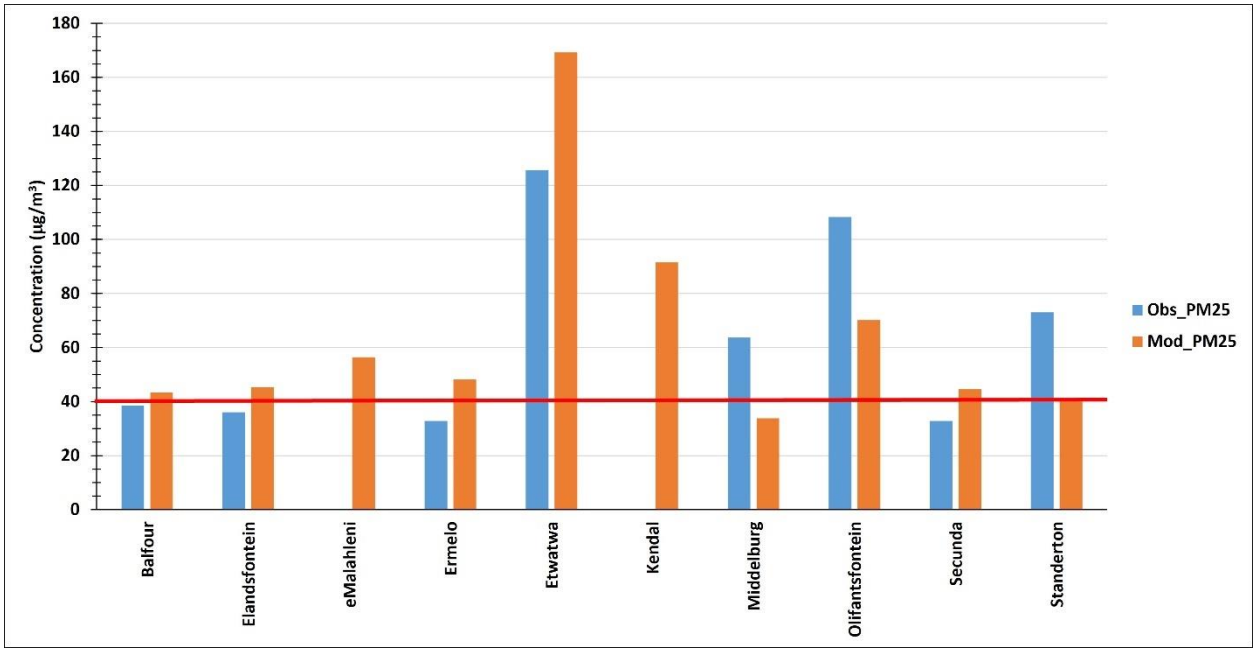


Figure 6-43: Comparison of observed (blue) vs simulated (orange) 99th percentile of 24-Hr averaged $PM_{2.5}$ concentrations. Red line is annual $PM_{2.5}$ NAAQS.

For the 99th percentile of 24-Hr average $PM_{2.5}$ concentrations, Figure 6-43 illustrates that all the monitoring stations presented here are predicted to experience exceedances of the 40µg/m³ NAAQS. For observed concentrations only Middelburg, Olifantsfontein and Secunda experience exceedances. The Etwatwa monitoring site exhibits to be the worst station for $PM_{2.5}$ exceedances.

6.6.3.5 Ozone (O_3)

Figure 6-44 show the comparison for O_3 (annual mean), whilst Figures 6-45 and 6-46 indicate a simulated 8-Hr mean and simulated 99th percentile 8-Hr concentrations, respectively.

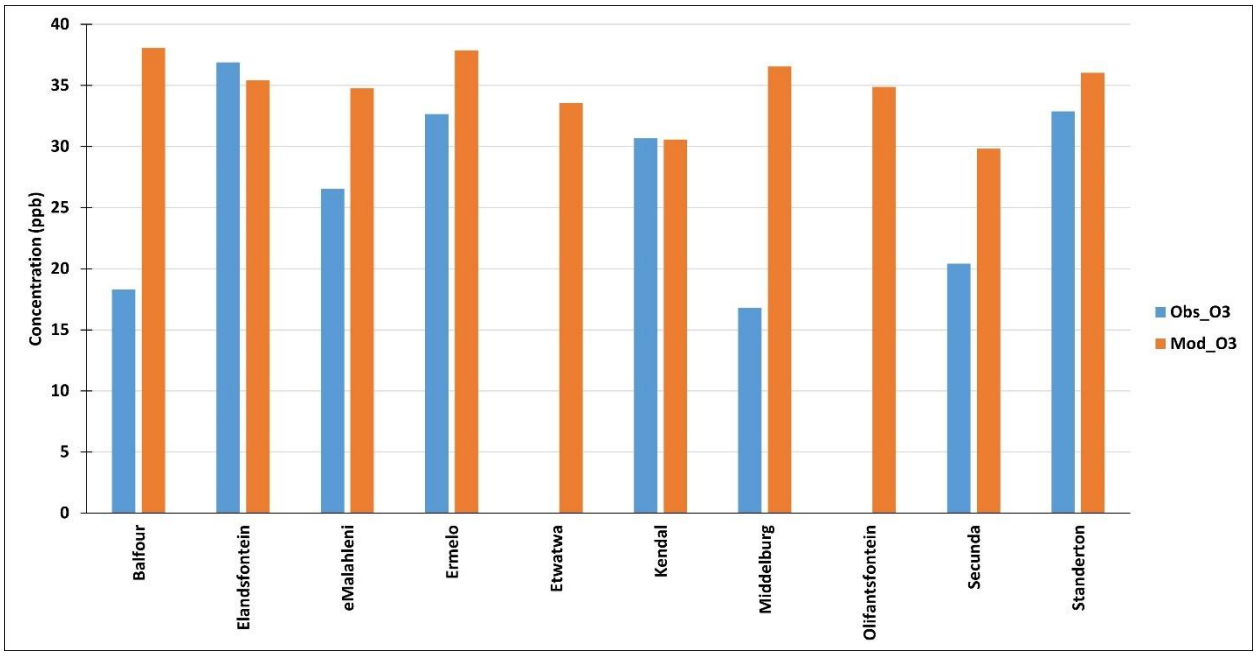


Figure 6-44: Comparison of observed (blue) vs simulated (orange) of annual average O_3 concentrations (1-Hr averages).

It can be noted from Figure 6-44 that annual predicted O_3 concentrations are between 30 and 40ppb. No annual NAAQS for O_3 is available and the analysis is purely for comparison purposes.

Figure 6-44 demonstrates that no O_3 exceedances (NAAQS 61 ppb) are experienced at all stations for both modelled and observed 8-Hrr average O_3. Regarding the 99th percentile of 8-Hr O_3 concentrations (Figure 6-45), O_3 concentrations are predicted to be exceeded at almost all stations except for Kendal. In terms of observed concentrations about 50% of the stations (Elandsfontein, eMalahleni, Ermelo, Kendal and Standerton).

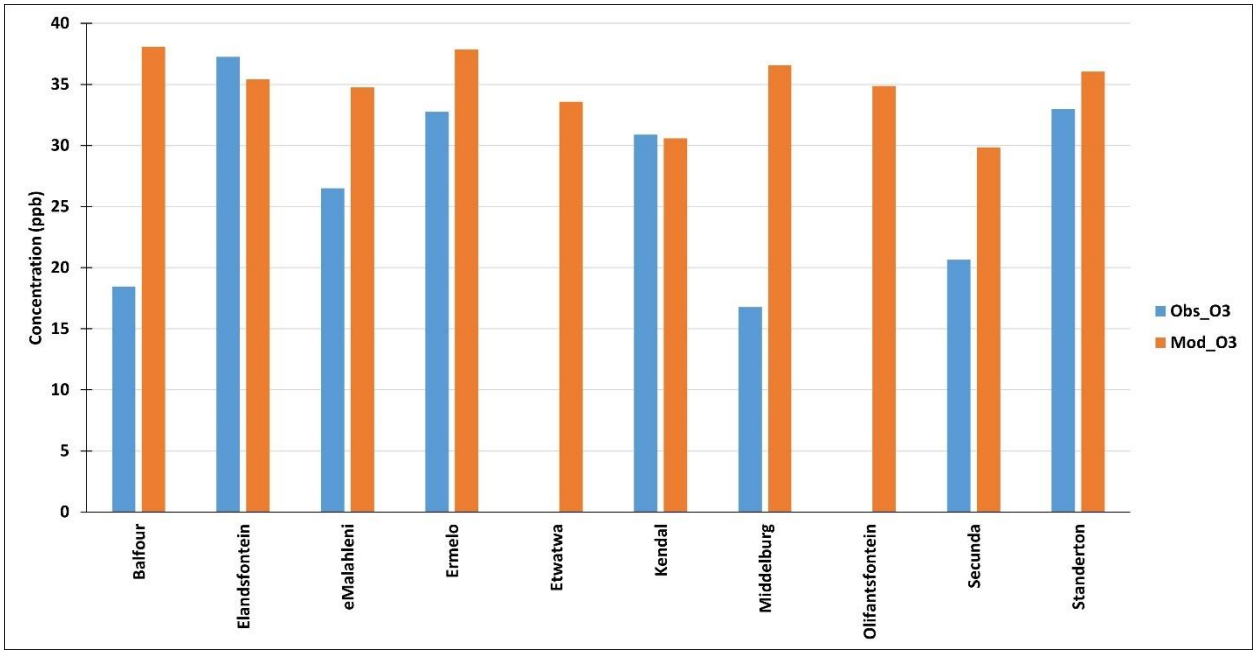


Figure 6-45: Comparison of observed (blue) vs simulated (orange) of 8-Hr average O_3 concentrations.

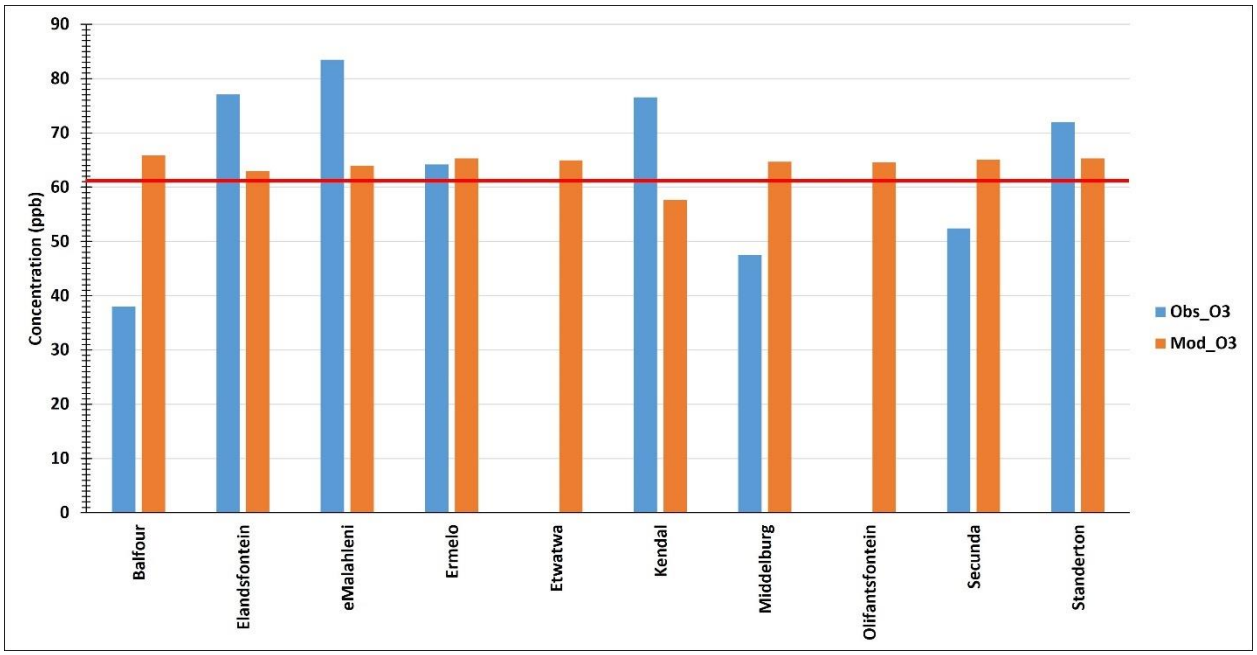


Figure 6-46: Comparison of observed (blue) vs simulated (orange) 99th percentile of 8-Hr averaged O_3 concentrations.

7. MAIN FINDINGS AND WAY FORWARD

The objective of the baseline characterisation was two-fold, namely, to determine the current state of air quality in the HPA and to assess whether the interventions set by the 2012 HPA AQMP resulted in AAQ improvements, and if not, the reason for this. The main findings set out in this section are primarily based on the background assessment, the evaluation of AAQ in the HPA, the 2019 emission inventory and the associated dispersion modelling. These provided a good understanding of the current state of air quality within the HPA and, to some extent, the source contributions to the ambient pollution levels.

7.1 Ambient Air Quality

Since the declaration of the HPA and subsequent development of the AQMP, there has been an improvement in AAQ monitoring. The number of monitoring stations have increased from 23 to 49 (reporting on SAAQIS) since the gazetting of the 2012 Air Quality Management Plan. An assessment of historical AAQ data (2007-2020) was conducted for the Gert Sibande DM, Nkangala DM, as well as the CoE, to determine dispersion conditions and to assess AAQ trends in the region.

The main findings are as follows:

Surface Wind Field:

- Wind rose analyses based on hourly data obtained from 6 AQMSs in the HPA indicate that there is a predominance of northerly and north-easterly winds at these stations, with average speeds varying between 2 m/s and 7 m/s.

Particulate matter:

- Daily averages: The analysis of the available monitored data (2007-2020) illustrates that while there was a clear improvement in AAQ monitoring since the development of the HPA AQMP and implementation of the HPA AQMP, in other words, 2013, ambient PM_{10} concentrations are still elevated over many areas in the HPA with exceedances of the PM_{10} daily NAAQS of 75 µg/m³ These elevated concentrations typically coincide with periods of low temperatures and stable atmospheric conditions associated with the winter months.
- Annual trends: The inception of AQMP implementation in 2013 has resulted in variations in the status of compliance with the annual NAAQS of 40 across the entire region. The analyses of the annual trends illustrate that some areas have witnessed significant improvements, in other words, Club, Camden and Elandsfontein from 2012 to 2020.
- With this in mind, it is evident that the development of the priority area AQMP and the subsequent implementation from 2012 has an important bearing on the observed improvements. On the other hand, very little-to-no improvement and even further deterioration has taken place at some sites, in other words, Komati, Bosjesspruit and Majuba. It is, therefore, recommended that these areas require more focused and strategic attention and intervention in terms of compliance and enforcement in respect of all regulated activities, including communities.

Sulphur dioxide (SO_2):

- Hourly averages: While there was a clear improvement in AAQ monitoring since the development of the HPA AQMP and implementation of the HPA AQMP, in other words, 2013, the hourly averages for SO_2 monitored data still show a number of exceedances of the hourly NAAQS of 134 ppb. These exceedances occur at a large majority of stations for most of the years under review. What is also evident is a clear decrease in the level of monitoring in 2020 with only three stations with useable data.

- Daily averages: Unlike the hourly concentration detailed above, an increased level of compliance with the daily NAAQS of 48 ppb is noted. What is also clear is a pronounced increase in compliance from 2014 to 2020 with consistent compliance noted at Club, Bosjesspruit, Camden and Majuba. Again, what is also evident is a clear decrease in the level of monitoring in 2020 with only three stations with useable data.
- Annual trends: Annual average ambient SO_2 concentrations recorded at the AQMS of concern indicate adequate compliance with the annual NAAQS of 19 ppb, which was evident even prior to the development and implementation of the 2012 HPA AQMP.

Nitrogen dioxide (NO_2):

- Hourly averages: The hourly NO_2 National Ambient Air Quality Standard (NAAQS) of 106 ppb was seldom exceeded after 2012 with these exceedances taking place at the Elandsfontein and Club AQMSs. It is also important to note that consistent exceedances of the NAAQS were noted at the Club AQMS prior to 2012 with a clear improvement thereafter, again speaking to the development of the priority area AQMP and the subsequent implementation from 2012 having an important bearing on the observed improvements.
- Annual trends: Annual average ambient NO_2 concentrations recorded at the AQMS of concern were well within the annual average NAAAQS of 21 ppb, with the exception of a single exceedance taking place at the Elandsfontein AQMS in 2014, which was most likely an extreme event. Slightly increased annual average ambient NO_2 concentrations were also noted in 2017. However, the average concentrations are still well below the annual NAAQS.

Ozone (O_3):

- Eight-hour running averages: A clear improvement in ambient monitoring from 2012 onwards. While this clear improvement is evident, exceedances of the eight-hour O_3 running average NAAQS of 61 ppb was evident prior to 2012 with exceedances occurring at the Club and Bosjesspruit AQMSs. Improved measurements are noted from 2016 to 2019. However, these measurements are still above the eight-hour running average O_3 NAAQS.

7.2 Highveld Priority Area Emissions Inventory

Emissions were quantified for all main sources within the HPA, as well as sources from the surrounding areas to form input into air quality modelling. The emission inventory reported here is for the sources within the HPA. These include the following:

- Industrial sources: Sources of air pollutants represent mostly stationary facilities operating under licences or registration, of which the emissions are reported to the authorities annually (Section 21 and Section 23 sources). A total of 866 individual point sources were identified across 117 facilities in the HPA, mostly in the CoE and the Nkangala DM.
- Windblown Particulate Emissions: Particulates are the typical form of pollutants associated with mining activities. Open-cast mining which forms the bulk of mining activities in the Mpumalanga region can emit pollutants near ground-level over (potentially) large areas. Additionally, Windblown particulate emission rates were quantified using the Airborne Dust Dispersion Model from Area Sources (ADDAS) developed by Airshed Planning Professionals (Burger, 2011). The sources of windblown particulates include exposed topsoil areas.
- Mobile sources: Accounting for vehicles travelling on arterial and main roads, national freeways, secondary roads, slipways, off- and onramps and streets. Use was made of SANRAL national counts for 2016 and the Mpumalanga Road Assets Management System (MP RAMS) traffic count data (2019 update). A top-down and bottom-up approach was followed

- Residential fuel burning: Fuel combustion for energy use in the residential environment in the HPA. Both a top-down (for gas and paraffin) and bottom-up (for wood and coal) approach was used for residential fuel use emissions. Community Survey 2016 data were used to proportionally disaggregate national fuel consumption to provincial and then SAL geographic units.
- Residential waste burning: Residential waste combustion for energy use in the residential environment in the HPA. A bottom-up approach was used for residential waste burning emissions. Community Survey 2016 data were used to proportionally disaggregate national fuel consumption to provincial and then SAL geographic units.
- Biogenic VOCs: The CAMS global emissions dataset was used to provide biogenic VOC emission estimates. These emissions were simulated using MEGAN.
- Agricultural ammonia: The CAMS global emissions dataset was used to provide NH_3 emission estimates from agriculture (livestock [animal excreta], soils [fertiliser application] and agricultural waste burning).
- Biomass burning: Biomass burning emissions from large-scale agricultural burning and natural fires for 2019 were obtained from the Fire Inventory from NCAR (FINN). This dataset uses active fire count observations, landcover cover from MODIS sensors and estimated fuel consumption to quantify biomass burning emissions.
- Spontaneous combustion: Currently, there is no acceptable standard method for estimating emissions from spontaneous combustion. This is due to the difficulty in obtaining reliable measurements in coal mining areas. For the HPA, emissions emanating from spontaneous combustion were estimated by multiplying emission rates obtained from Cook and Lloyd (2012), with the area of each coal mine operating in the HPA.

A comparison was made between the initial 2012 AQMP Emission Inventory to the recently developed 2019 emission inventory, which is the foundational input for the development of the Second Generation HPA AQMP.

Based on this comparison the main findings are:

- There are significant changes in emissions volumes between the initial 2012 HPA AQMP Inventory with the 2019 emission inventory, resulting in significantly less total emission quantified for SO_2 and NO_x in 2019.
- For PM_{10}, changes in emissions volumes between the initial 2012 HPA AQMP Inventory with the 2019 emission inventory are minimal, with only a 6% reduction being experienced. This is due to increased emissions from industries, residential fuel burning; and biomass burning, with industries noted to have the most pronounced increase (14% increase or 15 388 tpa). At the same time, significant reductions in estimated PM_{10} emissions are also noted for on-road vehicle emissions and windblown particulates with 85% and 23% reductions respectively.
- It is also important to note that the 2019 emission inventory incorporates both emission sources and pollutants previously not quantified in the 2012 emission inventory, yet clear emission reductions were still noted across all three pollutants.

7.3 Photochemical Modelling

The CAMx chemical air quality model was used to simulate current ambient concentrations of pollutants within the HPA to assess AAQ on a more comprehensive spatial scale than what can be provided with monitoring stations. Areas of elevated concentrations can be identified for expanded monitoring and when viewed within the context of the emission inventory, likely contributing sources are targeted for intervention strategies.

A summary of the main finding for each pollutant is detailed below.

Particulate matter (PM_{10} and $PM_{2.5}$):

- For PM, both the simulated PM_{10} and $PM_{2.5}$ concentrations tend to have similar characters in the spatial distribution of exceedances.
- For annual NAAQS, the same areas are also predicted to be impacted though the spatial extent is reduced for $PM_{10,}$ while it has become even more extended for $PM_{2.5}$ exceedances (Figures 6-16 and 6-18).
- In terms of 24-hour exceedances, the central HPA region in areas such as Secunda and west of Ermelo, as well as the north (Emalahleni) to north-west regions, the concentrations for PM_{10} and $PM_{2.5}$ are exceeding the permissible number of exceedances, with a large portion of Gauteng (including the VTAPA region) predicted to be impacted by both pollutants (see Figures 6-17 and 6-19).

Sulphur Dioxide (SO_2):

- It is noted that annual SO_2 NAAQS (19 ppb) is exceeded primarily over the west (Sasolburg area, part of the VTAPA) with Secunda, eMalahleni, Witbank and the CoE also illustrating pronounced areas of exceedance.
- A hotspot to the north of Secunda seems to stand out from the other spots within the HPA and occurs for all average periods, with daily impact having the largest spatial extent bulging northward towards the HPA boundaries (see Figure 6-22).
- Other HPA bounded hotspots, such as areas around Amersfoort, eMalahleni and the CoE, become more significant with regard to the 24-hour Frequency of Exceedance as they become more spatially extended.
- Various other hotspots are also predicted at the edges of the modelling domain over the west (Sasolburg area, part of the VTAPA) and the north-western region, which are outside the HPA region.

Nitrogen Dioxide (NO_2):

- For annual NAAQS of NO_2 (21 ppb), limited number of areas were simulated to be impacted by the exceedances of the annual standard, including Secunda and in the north-western part of the HPA where a few numbers of hotspots were predicted in areas around Gauteng, as indicated by the red spots (Figure 6-23).

Ozone (O_3)

- The simulated annual O_3 concentrations over the modelling domain indicate a generally lower O_3 concentration towards the centre of the HPA region, with distinct elevated concentrations towards the outer border of the modelling domain (Figure 6-25).

7.6 Summary of the HPA Health study

The HPA health study conducted by DFFE comprised of local and regional assessments to have a better understanding of the risk and impacts of air pollution on human health in the HPA. For this purpose, the report investigated the exposure of communities living in close proximity to AQMSs and to sources of SO_2 and NO_2. Particulate matter PM_{10} and $PM_{2.5}$ were considered. The study had three main assessments undertaken, as follows:

- HHRA;
- Vulnerability Assessment (including a focus on children); and
- Impact Assessment.

The main findings of this study are summarised below:

- Based on simulated HQs, the central and towards the eastern parts of the HPA are at risk to the negative health impacts of exposure to SO_2. Within these areas, the communities most at risk are primarily located near intense industrial SO_2 emitters.
- Based on simulated HQs, a large portion of the western part of the HPA is at risk to the negative health impacts of exposure to PM_{10}. Within this western region, the communities most at risk are primarily located in the CoE Metropolitan Municipality, the Govan Mbeki LM, and the Msukaligwa LM.
- The CoE Metropolitan Municipality and the Govan Mbeki LM are the main vulnerable areas in the HPA. The main conditions affecting vulnerability to the effects of air pollution in these areas are population characteristics and socio-economic conditions.
- If the annual NAAQS for PM_{10} and $PM_{2.5}$ are met, estimated attributable mortality in the HPA is expected to decrease to 5 125 people for PM_{10} and 4 881 people for $PM_{2.5}$.
- The largest percentage attributable deaths from not meeting PM_{10} annual NAAQS occur in the CoE Metropolitan Municipality and the Govan Mbeki LM. If the annual NAAQS for PM_{10} is met, all-cause mortality in the CoE Metropolitan Municipality is expected to decrease by 18,75%
- For $PM_{2.5}$, the largest percentage attributable deaths from not meeting $PM_{2.5}$ annual NAAQS occur in the City of Ekurhuleni. If the annual NAAQS for $PM_{2.5}$ are met, all-cause mortality in the CoE Metropolitan Municipality is expected to decrease by 16,62%

The abovementioned results are consistent with the health impacts detailed in the initial 2012 HPA AQMP, which found that the CoE Metropolitan Municipality, Emalahleni, Steve Tshwete, and Secunda are areas with large populations possibly at risk from the ambient concentrations of SO_2 and PM_{10}. Hospital admissions with respiratory conditions were estimated to be significantly higher in the Johannesburg and CoE Metropolitan Municipality conurbation (more than 34 000 cases) when compared to admissions in the Mpumalanga Highveld as a whole (more than 8 600 cases).

7.6 Way forward

The baseline assessment assessed compliance with ambient air quality standards within the HPA while exploring the potential risk to human health and the degradation of the environmental medium air. Moreover, this baseline assessment is intended to form the basis of the development of the Second Generation HPA AQMP. The information contained in this document will be used to lay the foundation for comprehensive strategies assessment and focus on specific interventions informed by cost-effective pollution control measures (in other words, Pollution Preventative Programme) for targeted emission reductions in line with the NAAQS objectives within a set timeframe. The next step in the Second Generation HPA AQMP development process is the formulation of targeted emission reductions that are aligned to a set of intervention scenarios based on the same emission inventory used in this baseline assessment and are expected to bring AAQ into compliance with the NAAQS.

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ANNEXURE A: WEATHER RESEARCH AND FORECASTING RESULTS COMPARED TO MEASURED METEOROLOGICAL PARAMETERS

Table A-1 summarises the locations of the AQMS assessed for comparison to the simulated meteorological data from the WRF Model. Please refer to Figure 4-1 for the placement of these stations in the HPA.

Table A-1: Simulated data obtained from the Weather Research and Forecasting Model run

Number	Monitoring Station	District	Municipality	Location	
				Latitude	Longitude
1	Etwatwa	Ekurhuleni	CoE	-26.116633	28.475386
2	Kendal	Nkangala	eMalahleni	-26.107927	28.974442
3	eMalahleni (SAWS)	Nkangala	eMalahleni	-25.877861	29.186472
4	Komati	Nkangala	Steve Tswete	-26.097463	29.450600
5	Elandsfontein	Gert Sibande	Govan Mbeki	-26.245481	29.417328
6	Secunda	Gert Sibande	Govan Mbeki	-26.550639	29.079028
7	Ermelo	Gert Sibande	Msukaligwa	-26.493348	29.968054
8	Standerton	Gert Sibande	Lekwa	-26.964112	29.2232
9	Balfour	Gert Sibande		-26.662851	28.584703
10	Middelburg (SAWS)	Nkangala	eMalahleni	-25.796056	29.462823
11	Olifantsfontein	Ekurhuleni	CoE	-25.973743	28.236044

A wide variety of indexes can be found in literature and are proposed for different fields of applications (meteorology, air quality, etc.), different scopes (for example, forecast, episode study) or different type of applications (for example, regulatory). This section discusses some of the statistical indexes that are commonly used in air quality studies.

For this study, hourly average observed and modelled meteorological and concentration values are used to calculate their comparison. Consequently, in following best practices for model evaluation, data from the AQMS were first processed for quality control. This exercise provided a picture of the data capture for the period of analysis across the HPA monitoring network, with the resulting data completeness being poor for the Etwatwa station with 0%, and Middelburg (SAWS) demonstrating the highest at 97% Table A-2 summarises the data capture (%) for the meteorological parameters at each station for the period 2018 to 2020.

Table A-2: Percentage meteorological data capture at air quality monitoring station for the period 2018 to 2020

Number	Monitoring Station	Wind Speed (%)	Wind Direction (%)	Temperature (%)	Rainfall (%)
1	Etwatwa	0	0	0	4
2	Kendal	46	44	48	48
3	eMalahleni (SAWS)	65	60	97	97
4	Komati	55	55	55	55
5	Elandsfontein	76	76	74	76
6	Secunda	87	83	88	88
7	Ermelo	79	79	89	89
8	Standerton	87	87	82	87
9	Balfour	94	94	93	91
10	Middelburg (SAWS)	97	97	97	97
11	Olifantsfontein	17	17	0	0

The statistical parameters used for the assessment include the following:

1. Mean Bias (MB) (model minus observation) is the mean over- or underestimate. The higher the number, the bigger the difference between the observed data and the modelled data. A negative number will indicate underestimation, while a positive number shows overestimation.

$$Mean\ Bias = \frac{1}{n}\sum_{1}^{n}(M - O)$$

2. Mean Gross Error (MGE) ignores whether it is an over- or underestimate and gives the gross error. This indicates the absolute average of the errors.

$$Mean\ Gross\ Error = \frac{1}{n}\sum_{1}^{n}|M - O|$$

3. Normalised Mean Bias (NMB) is the MB normalised by the observed value such that over- or underestimates can be compared across sites and parameters.

$$Normalised\ Mean\ Bias = \frac{\sum_{1}^{n}(M - O)}{\sum_{1}^{n}(O)}$$

4. NMGE - Normalised Mean Gross Error. Similar to the NMB, but ignores whether there is an over- or underestimate.

$$Normalised\ Mean\ Gross\ Error = \frac{\sum_{1}^{n}|M - O|}{\sum_{1}^{n}(O)}$$

5. Root Mean Square Error (RMSE) compares prediction errors of different models or model configurations for a particular variable and not between variables. Indicates how concentrated the data is around the line of best fit (data spread) (larger number = higher spread). Wind direction will be high due to the nature of wind direction being quite dynamic.

$$Root\ Mean\ Square\ Error = \sqrt{\frac{\sum_1^n\ (M-O)^2}{n}}$$

6. Index of Agreement (IOA). Used to measure how well model-produced estimates simulate observed data. Measure of the degree of model prediction error which varies between 0 and 1, where 1 is perfect prediction and 0 shows no agreement between observed and modelled data.

$$Index\ of\ Agreement = 1 - \left[\frac{\sum_1^n (O-M)^2}{\sum_1^n\ (\left|M-\overline{O}\right| + |O-\overline{O}\ |)^2}\right]$$

IOA, the Index of Agreement based on Willmott et al. (2011), which spans between -1 and +1 with values approaching +1 representing better model performance.

An IOA of 0.5, for example, indicates that the sum of the error-magnitudes is one half of the sum of the observed-deviation magnitudes. When IOA = 0.0, it signifies that the sum of the magnitudes of the errors and the sum of the observed-deviation magnitudes are equivalent. When IOA = -0.5, it indicates that the sum of the error-magnitudes is twice the sum of the perfect model-deviation and observed-deviation magnitudes. Values of IOA near -1.0 can mean that the model-estimated deviations about O are poor estimates of the observed deviations, but they can also mean that there simply is little observed variability. Some caution is, therefore, needed when the IOA approaches -1.

7. Pearson correlation (r). The Pearson correlation coefficient is a measure of the strength of the linear relationship between two variables. Indicates the relationship between the data with -1 showing a strong negative correlation, 1 showing a positive strong correlation, and 0 showing no relationship between observed and modelled data.

$$r = \frac{1}{(n-1)}\sum_{i=1}^{n}\left(\frac{M_i-\overline{M}}{\sigma_M}\right)\left(\frac{O_i-\overline{O}}{\sigma_O}\right)$$

8. COE, the Coefficient of Efficiency based on Legates and McCabe (1999, 2012). There have been many suggestions for measuring model performance over the years, but the COE is a simple formula which is easy to interpret.

A perfect model has a COE = 1. As noted by Legates and McCabe, although the COE has no lower bound, a value of COE = 0.0 has a fundamental meaning. It implies that the model is no more able to predict the observed values than does the observed mean. Therefore, since the model can explain no more of the variation in the observed values than can the observed mean, such a model can have no predictive advantage.

For negative values of COE, the model is less effective than the observed mean in predicting the variation in the observations.

As data completeness greatly varies for the period over the 11 selected AQMSs, it would not be of great benefit to compare each station against the other, and rather look at the overall observations compared to the WRF output. Cognizance should be taken that each area will have its own wind speed and direction variation due to local geography.

Table C-3 below presents the statistical metrics generated from a quantitative comparison of model-observation datasets for winds and temperature at various locations from 2018 to 2020. n indicates the number of complete pairs of data. FAC_2, fraction of predictions within a factor of two. All statistics are based on complete pairs of mod and obs.

Overall, the modelled meteorology values are in good agreement with the observations. The analysis indicates that the model was able to reproduce the observed pattern of the meteorological fields investigated with the FAC_2 value generally above 0.5 for almost all the parameters. The statistics also reveal that, among the evaluated meteorological fields, the modelled 2m temperature had the greatest (> 80%) correlation, R values and smallest bias values.

On the other hand, the wind direction is the only parameter with R values that are below 0.5. In the case of temperature, the general model tendency was to underestimate the observed ambient temperature at all stations, with mean bias values ranging between -0.47 °C to -2.52 °C across the stations except for Olifantsfontein station (MB ~ 23.61) where data completeness was very poor (0,2%) for this parameter.

The overall mean bias is within the range of -5 °C ≥ MB ≤ +5 °C performance criteria as proposed by Chemel & Sokhi (2012), suggesting a good model performance in predicting HPA ambient temperature. For wind speed, WRF tends to both overestimate and underestimate the observed wind speed depending on the station location, the MB values varies between -1.27 to 0.93 with a larger bias (~ 47%) occurring at Olifantfontein station (~17% data completeness).

The simulated wind speed also correlates well with observations having a correlation coefficient, R greater than ~ 0.58 at all stations when Olifantsfontein is excluded. The observed wind direction was not well represented by the model, with large variability in MB values (-29.29 to 0.98 degrees) and with the closest acceptable correlation coefficient, R found to be 043.

Table A-3: Statistics from comparison of Weather Research and Forecasting temperature and wind fields with air quality monitoring station measurements

Station	Variable	n	%	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA
Balfour	Wind Speed	24608	93.6	0.66	0.73	1.34	0.30	0.56	1.73	0.69	-0.02	0.49
	Wind Direction	24608	93.6	0.61	-29.29	90.68	-0.15	0.47	129.97	0.33	0.03	0.52
	Temperature	24534	93.3	0.96	-0.52	2.48	-0.03	0.15	3.22	0.90	0.57	0.79
Elandsfontein	Wind Speed	20021	76.1	0.69	-1.27	1.79	-0.28	0.39	2.26	0.58	-0.13	0.43
	Wind Direction	19963	75.9	0.52	25.97	113.72	0.18	0.77	148.27	0.01	-0.30	0.35
	Temperature	19367	73.6	0.91	-2.54	3.45	-0.15	0.20	4.33	0.86	0.28	0.64
EMalahleni	Wind Speed	17109	65.0	0.68	0.64	1.16	0.28	0.52	1.49	0.68	0.01	0.51
	Wind Direction	15881	60.4	0.66	27.09	81.01	0.16	0.48	125.57	0.41	0.23	0.61
	Temperature	25448	96.7	0.99	-0.79	1.94	-0.04	0.11	2.44	0.94	0.60	0.80
Ermelo	Wind Speed	20829	79.2	0.79	-0.40	1.40	-0.10	0.34	1.77	0.62	-0.05	0.47
	Wind Direction	20842	79.2	0.67	9.98	77.26	0.06	0.45	120.95	0.43	0.28	0.64
	Temperature	23458	89.2	0.96	-0.92	2.56	-0.06	0.16	3.20	0.89	0.49	0.74
Kendal	Wind Speed	12183	46.3	0.69	-0.36	1.45	-0.11	0.42	1.86	0.59	0.15	0.57
	Wind Direction	11513	43.8	0.61	0.98	91.32	0.01	0.50	133.83	0.30	0.12	0.56
	Temperature	12568	47.8	0.97	-0.64	2.15	-0.04	0.13	2.74	0.92	0.60	0.80
Komati	Wind Speed	14489	55.1	0.67	0.70	1.44	0.26	0.54	1.81	0.62	-0.03	0.48
	Wind Direction	14481	55.1	0.48	-25.06	117.87	-0.13	0.59	148.36	0.18	-0.09	0.46
	Temperature	14589	55.5	0.97	-0.77	2.17	-0.05	0.13	2.83	0.92	0.61	0.80
Middelburg	Wind Speed	25521	97.0	0.63	0.93	1.36	0.47	0.68	1.75	0.65	-0.25	0.38
	Wind Direction	25521	97.0	0.70	-7.45	81.54	-0.04	0.42	121.28	0.32	0.14	0.57
	Temperature	25516	97.0	0.98	-0.47	2.12	-0.03	0.12	2.71	0.92	0.59	0.80
Olifantsfontein	Wind Speed	4439	16.9	0.62	0.51	1.35	0.28	0.74	4.48	0.09	-0.25	0.37
	Wind Direction	4466	17.0	0.62	12.00	92.48	0.07	0.57	128.70	0.14	-0.34	0.33

	Temperature	42	0.2	0.00	-23.61	30.00	-0.69	0.88	35.64	0.31	-0.24	0.38
Secunda	Wind Speed	22901	87.1	0.72	0.31	1.14	0.12	0.44	1.49	0.69	0.18	0.59
	Wind Direction	21800	82.9	0.64	3.36	88.24	0.02	0.48	130.98	0.32	0.14	0.57
	Temperature	23180	88.1	0.95	-0.45	2.33	-0.03	0.14	2.98	0.92	0.60	0.80
Standerton	Wind Speed	23013	87.5	0.72	0.72	1.33	0.28	0.52	1.73	0.68	-0.05	0.47
	Wind Direction	23013	87.5	0.66	3.73	78.10	0.02	0.47	113.81	0.38	0.14	0.57
	Temperature	21477	81.6	0.93	-1.18	2.76	-0.07	0.17	3.53	0.90	0.55	0.78

ANNEXURE B: TIME-SERIES PLOTS OF MODEL VS MEASURED CONCENTRATIONS

Model time series of CO, NO_2, SO_2, O_3, $PM_{2.5}$ and PM_{10} were compared with available measurements from monitoring stations in the HPA for model verification. The same eleven stations were utilised as referenced in Annexure A of this report. Monitoring data (for the year 2019) was received for the stations in the CAMx 2km model domain. Annexure C shows R-statistics OpenAir package summary plots for this data; and illustrates completeness (to an extent) for all 11 stations. The summary plots show daily average time series and a daily average is shown regardless of for example 24 (100%) or 1 (~4%) data points are available. Table B-1 summarises the data coverage percentage for the eleven air quality monitoring stations.

Table B-1: Percentage meteorological data capture at air quality monitoring station for the period 2019 (<70% in red)

Number	Monitoring Station	SO_2	NO_2	O_3	CO	$PM_{2.5}$	PM_{10}
4	Etwatwa	92	81	0	47	81	81
6	Olifantsfontein	80	32	0	36	80	79
12	Balfour	93	85	15	77	38	87
18	eMalahleni (SAWS)	94	95	88	94	0	0
21	Kendal	88	23	54	0	0	74
23	Elandsfontein	71	72	71	0	69	40
28	Secunda	89	87	89	89	0	1
34	Standerton	48	75	77	89	82	45
36	Ermelo	85	76	90	82	6	6
43	Middelburg (SAWS)	95	84	86	92	73	74
46	Komati	64	62	7	0	56	50

Only ten stations exhibited data coverage over 70% or partially above 70% for any single pollutant. These ten stations were used in the model comparison, and Komati was excluded from this comparison. Figure 4-1 indicates the locations stations.

Time variation plots

R-Statistics OpenAir package was used to generate time series and time-variation plots for model and observations at each station for each pollutant. The time-series plots give a good overview of the model and observations, showing periods without observations clearly and giving context to the time-variation plots. The time-variation plots are useful in that they can display simulated and observed diurnal, seasonal and weekly variation in one figure such that relative comparisons can be made visually regarding model performance. However, it is very important to look at these within the context of both the station's location (and thus impact from emission sources). Figures 9-1 to 9-4 illustrate time-series and time-variation plots for SO_2 at the specific stations. For each plot, the red line represents the model predicted concentration values while the blue/light blue line show concentrations measured at a specific monitoring station.

B.1 Sulphur Dioxide (SO_2)

The model generally performs reasonably well in reproducing the observed pattern in the evolution of SO_2 concentrations, though there is a tendency for over-prediction of hourly concentration values at most stations (Figure B-1 to B-2). The observed SO_2 concentrations are generally limited to 200 ppb while the model predicts that SO_2 concentrations may reach up to more than 600 ppb depending on the station location. One of the possible reasons for model overprediction of SO_2 could be due to underestimation of the SO_2-sulphate conversion rate in the model which is a well-known issue in regional models.

The observed diurnal pattern of SO_2 concentrations is characterised by bimodal (morning and evening) peaks at most monitoring stations suggesting a strong influence of local emissions sources. The concentrations measured at Kendal and Elandsfontein stations exhibit a different diurnal character with only one broad peak occurring between late morning and 12 PM which is indicative of influence from long range transport of high stack emissions mixing down the surface, the model was able to reproduce these important features. Regarding seasonal variation of SO_2, maximum (Figure B-3 to -B-4) concentrations are more prominent during colder winter months and with minimum values occurring during summer months at most stations with the exception of Kendal and Balfour where there is no clear distinction on monthly averaged concentration values. Again, the model was able to capture the observed seasonal variation of SO_2 concentration at most stations.

Statistically (Annexure C, Table C-1), low correlation, R values ($R < 0.5$) were dominant in the model-observation hourly SO_2 concentrations comparison. The lowest positive mean bias value of 2.20 ppb was obtained at Ermelo and the highest positive mean bias value of 18.70 ppb was found at Kendal station.

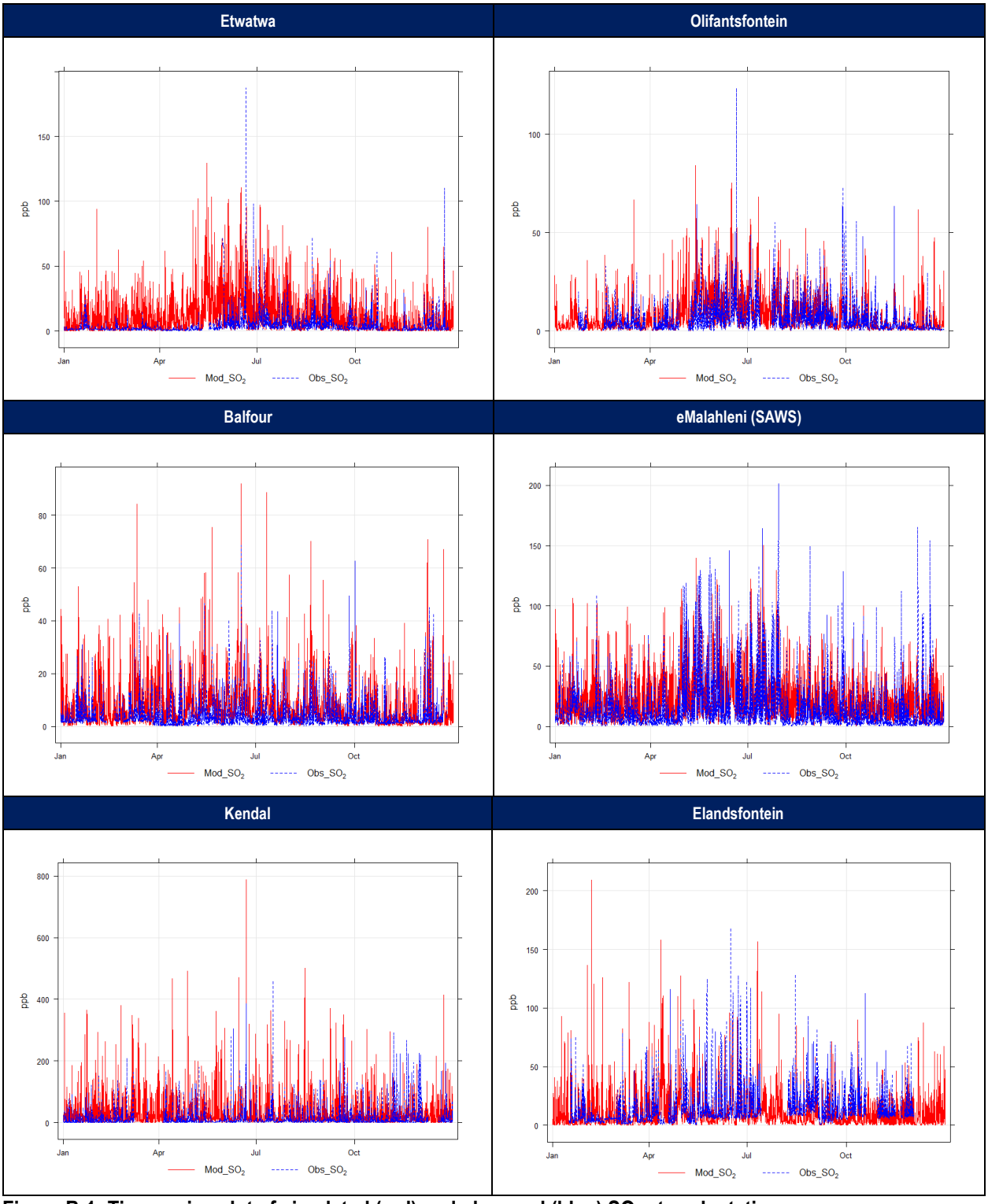

Figure B-1: Time-series plot of simulated (red) and observed (blue) SO_2 at each station

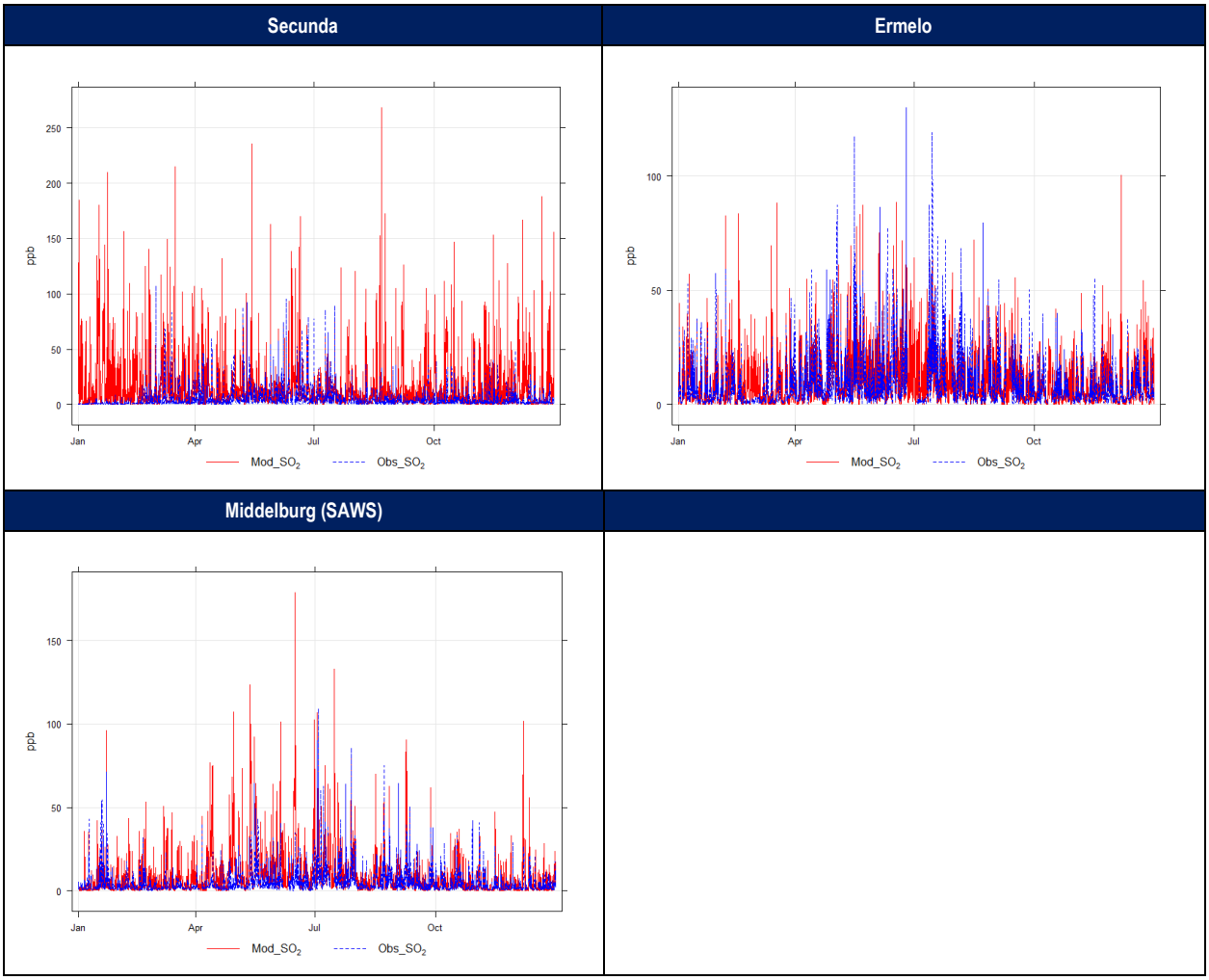

Figure B-2: Time-series plot of simulated (red) and observed (blue) SO_2 at each station

Figure B-3: Time-variation plot of simulated (red) and observed (blue) SO_2 at each station

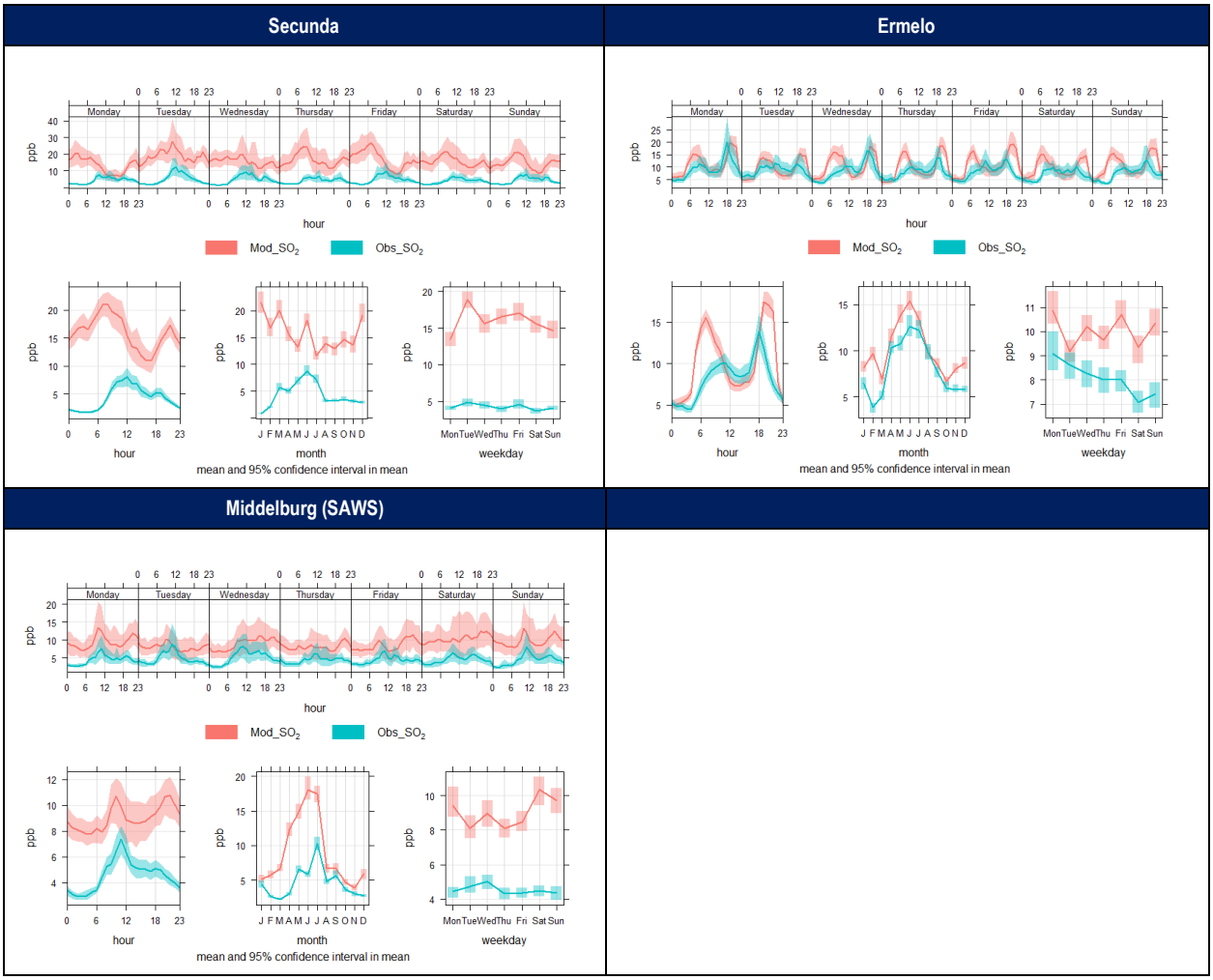

Figure B-4: Time-variation plot of simulated (red) and observed (blue) SO_2 at each station

B.2. Nitrogen Dioxide (NO_2)

Figure B-5 to B-8 represents hourly and monthly averaged model-observed concentrations of NO_2 at various monitoring stations. As shown in Figures B-5 and B-6 the modelled hourly NO_2 concentrations values overlap well with the corresponding observed values. However, the modelled minimum hourly concentrations tend to be smaller in magnitude than that of the observed minimum values at all locations. In addition, the modelled monthly average NO_2 concentrations (Figures B-7 and B-8) tend to be systematically underestimated in all seasons, suggesting an under-representation of NOx emissions in the model. Both the observed average diurnal and seasonal patterns are captured by the model.

The observed diurnal character of NO_2 is composed of two peaks occurring in the morning between 06:00 to 09:00 and in the evening around 6:00 pm and this is well reproduced by the model, though it is noted that the daytime NO_2 concentration is generally underestimated while the maximum peaks are overestimated in the model, particularly the evening peak. The extended modelled evening peaks may be attributed to the temporal profiles applied to disaggregate the annual emissions. The seasonal modelled NO_2 concentration is also well in line with the corresponding observed seasonal variation with maximum concentrations observed during winter periods. The observed-modelled NO_2 concentrations' degree of agreement varies with station location and the closest match was obtained at the Ermelo station and the largest gap was found at Middelburg station.

The statistical analysis (Annexure C, Table C-1) of model performance for NO_2 prediction exhibits some variability depending on the observation station. The correlation, R values range between 0.22 at Standerton to 0.61 at eMalahleni monitoring stations. The bias values range between 0.25 ppb (Etwatwa) to -15.65 (Middelburg). However, in most of the stations, the FAC2 values exceeded the prescribed threshold (FAC > 3) recommended for dispersion model performance COST ES1006. (2015).

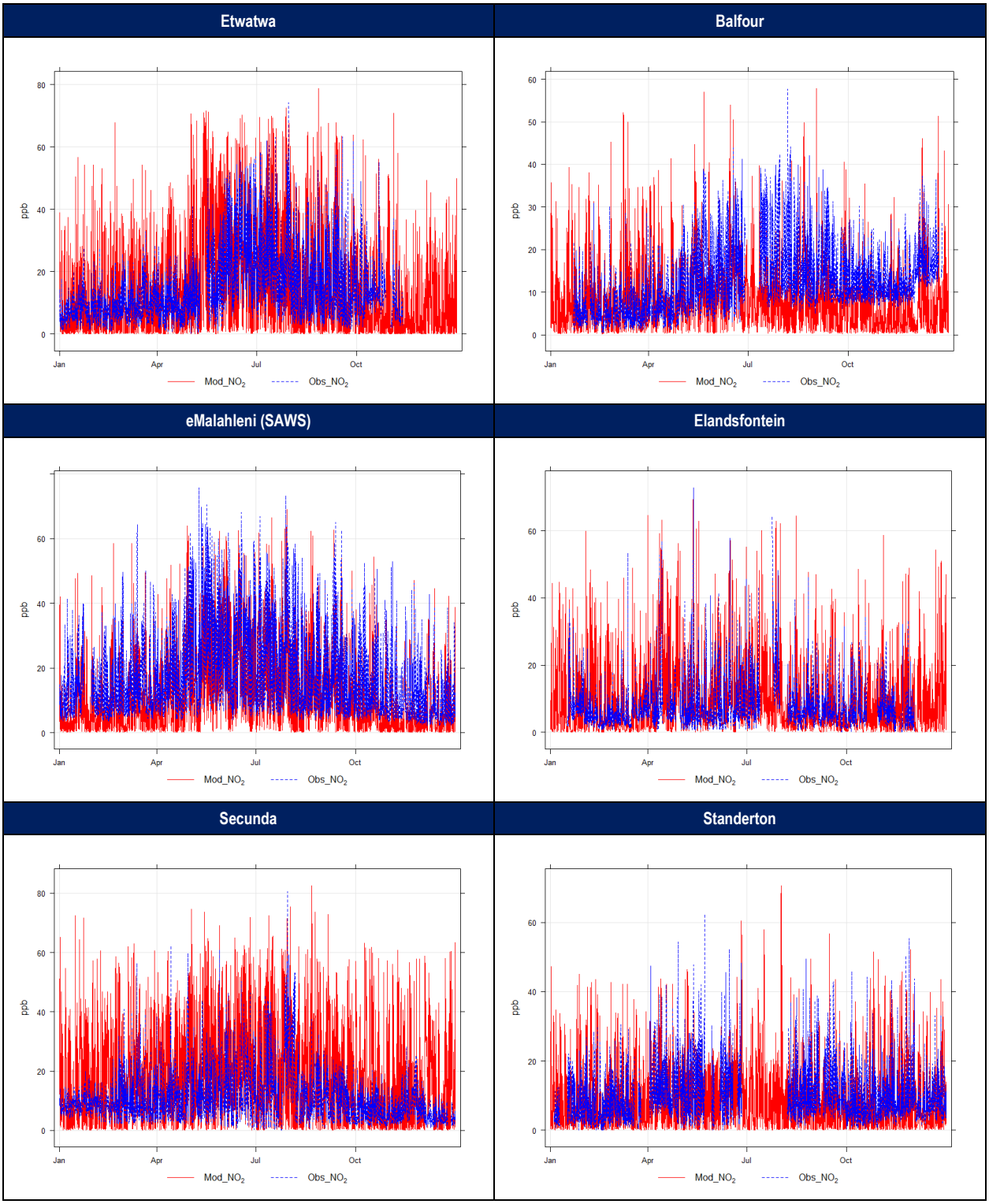

Figure B-5: Time-series plot of simulated (red) and observed (blue) NO_2 at each station

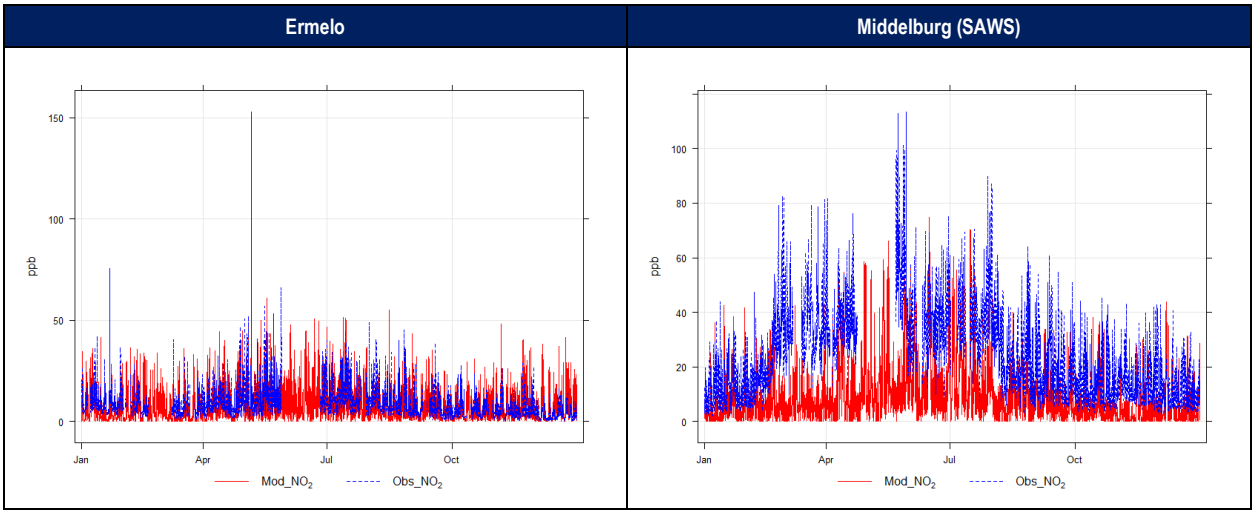

Figure B-6: Time-series plot of simulated (red) and observed (blue) NO_2 at each station.

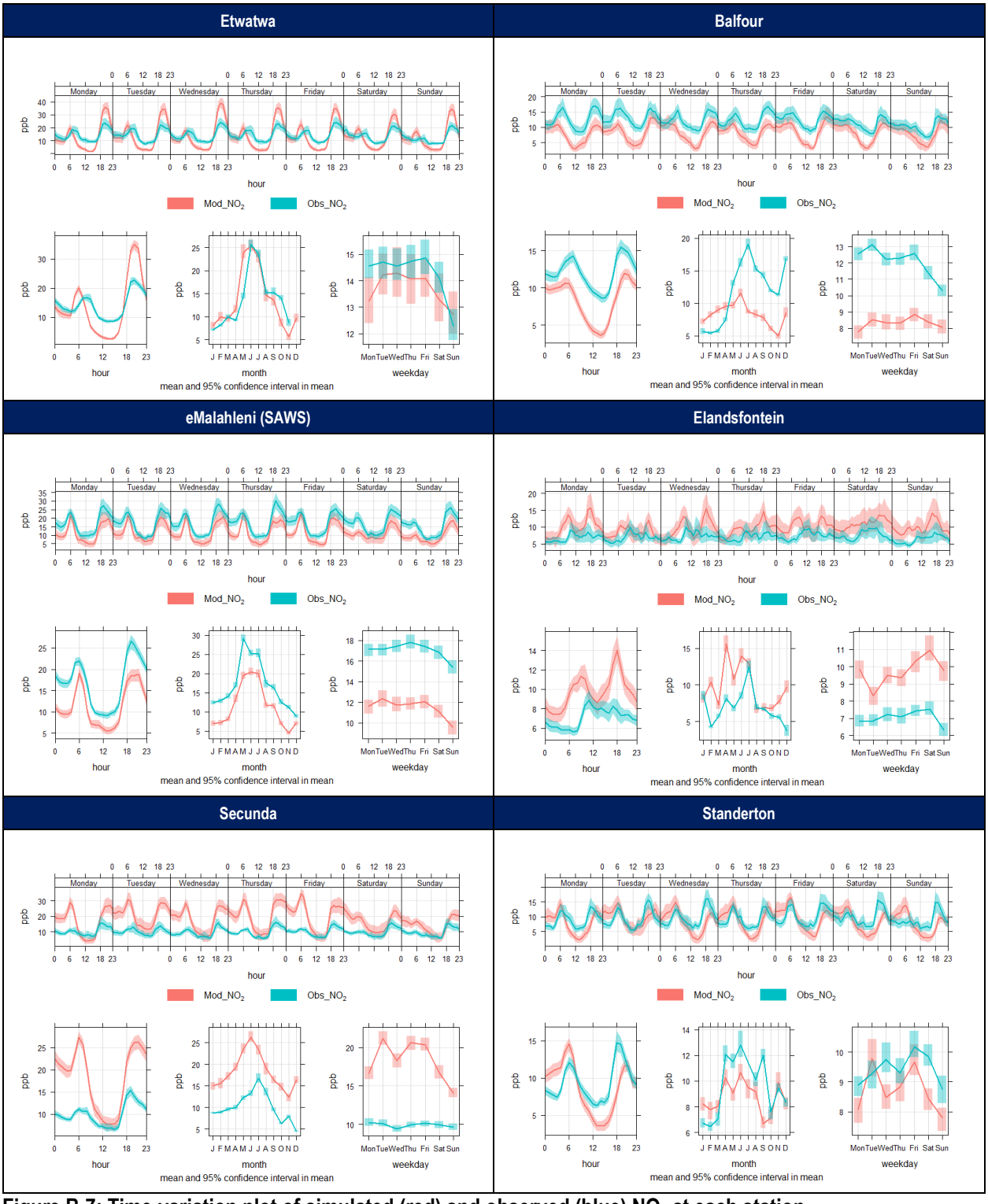

Figure B-7: Time-variation plot of simulated (red) and observed (blue) NO_2 at each station.

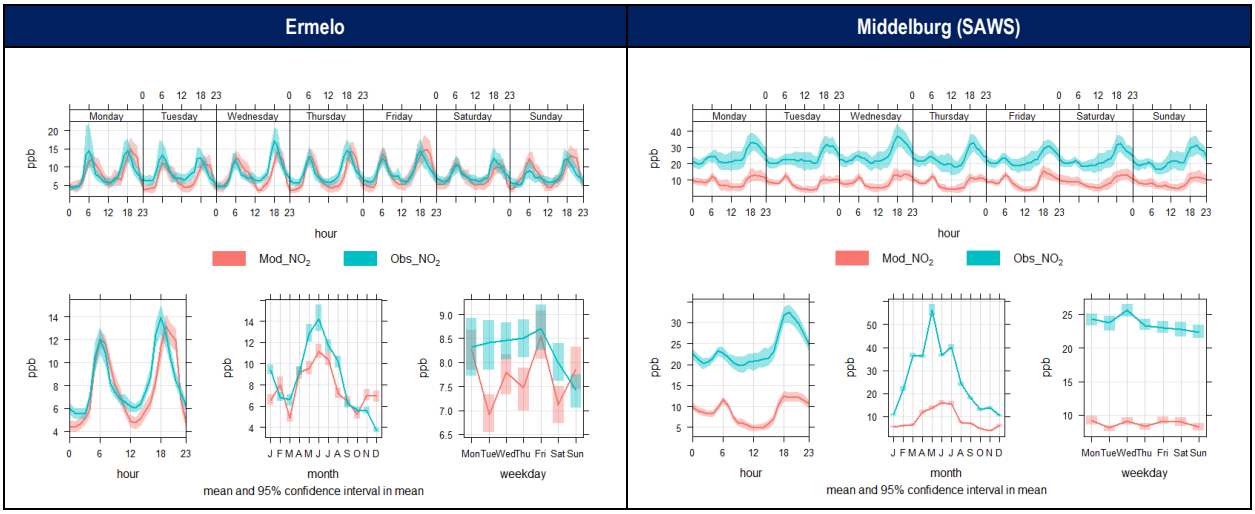

Figure B-8: Time-variation plot of simulated (red) and observed (blue) NO_2 at each station.

B.3. Particulate Matter (PM_{10})

Figures B-9 to B-10 represent hourly and monthly averaged model-observed concentrations of PM_{10} at various monitoring stations. As shown in Figure B-9 the modelled hourly PM_{10} concentrations values overlap well with the corresponding observed values. However, the modelled PM_{10} concentrations are generally lower in magnitude to that of the observed concentration values at all locations and throughout the day. This may suggest an under-representation of PM_{10} emissions used in the model. Both the observed average diurnal and seasonal patterns are captured by the model. The observed diurnal bimodal peaks character of PM_{10} is also well reproduced by the model, though the modelled peaks are generally underestimated. The seasonal modelled PM_{10} concentrations are also well in line with the corresponding observed seasonal variation with maximum concentrations observed during winter periods. Similarly, with the NO_2 above, the observed-modelled PM_{10} concentrations show significant deviation at Middelburg station this may confirm the poor representation of emissions sources that exist in this area.

In terms of statistical metrics analysis modelled- observed PM_{10} correlation (Annexure C, Table C-1), R values are generally lower with only Etwatwa and Olifantsfontein exhibiting greater (> 0.5) observed-modelled correlations of PM_{10} concentrations. The mean bias values vary depending on the station location but are generally above 10 ppb and the largest bias (> 50 ppb) is found at the Standerton monitoring station. However, the FAC2 is above 0.3 at all stations.

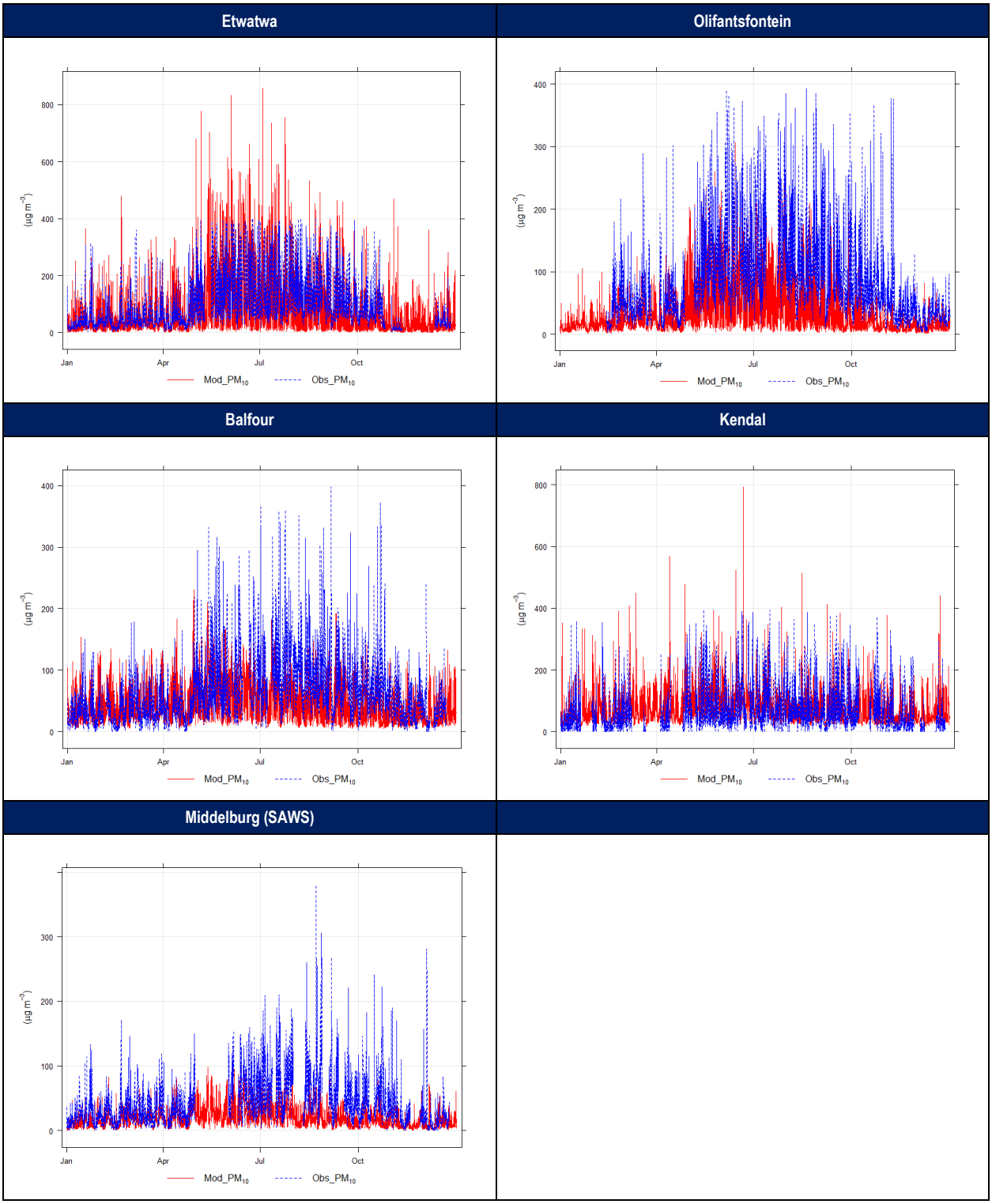

Figure B-9: Time-series plot of simulated (red) and observed (blue) PM_{10} at each station.

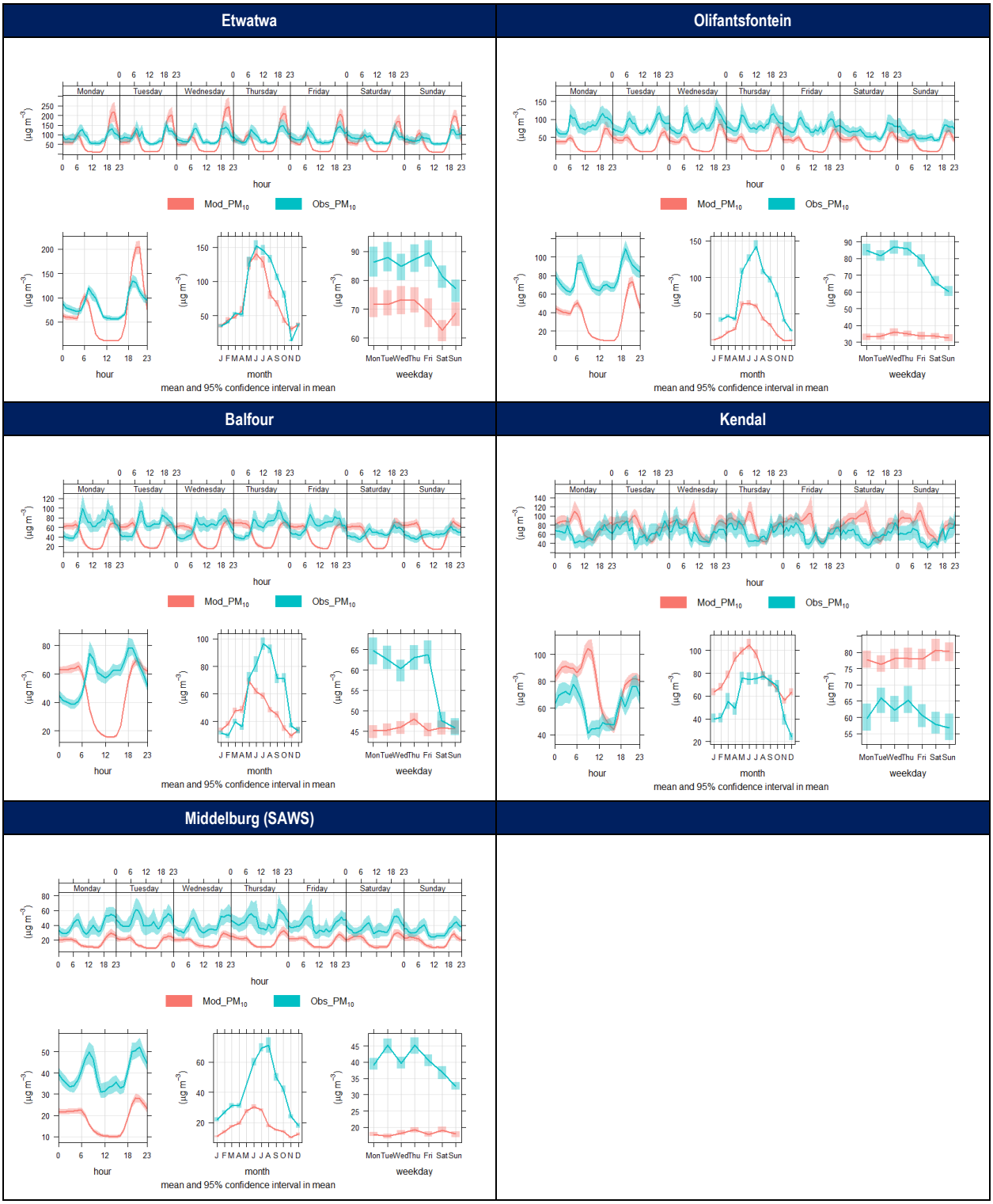

Figure B-10: Time-variation plot of simulated (red) and observed (blue) PM_{10} at each station.

B.4. Particulate Matter ($PM_{2.5}$)

Figures B-11 to B-12 represent hourly and monthly averaged model-observed concentrations of $PM_{2.5}$ at various monitoring stations. The modelled hourly modelled-observed $PM_{2.5}$ concentrations relatively overlap with each other. The temporal variation of $PM_{2.5}$ has a similar tendency to that of PM_{10} with two diurnal peaks and seasonal maximum and minimum peaks during winter and summer respectively which is well reproduced by the model. The predicted $PM_{2.5}$ concentrations values are generally underpredicted by the model except for the Etwatwa monitoring station where predicted average peak concentrations in the evening are 4 times as much as the observed peak. The general tendency of the model underestimating $PM_{2.5}$ may be likely due to 1) inaccurate representation of emissions and 2) the underestimation of the SO_2 conversion rate mentioned above may also reduce the formation of $PM_{2.5}$ in the model.

Similarly, for $PM_{2.5,}$ low correlation values (Annexure C, Table C-1) are calculated for most of the stations with only three stations (Etwatwa, Olifantsfontein and Middelburg. showing better (> 0.5) correlation values. Mean bias values are also high for $PM_{2.5}$ but better than in PM_{10}.

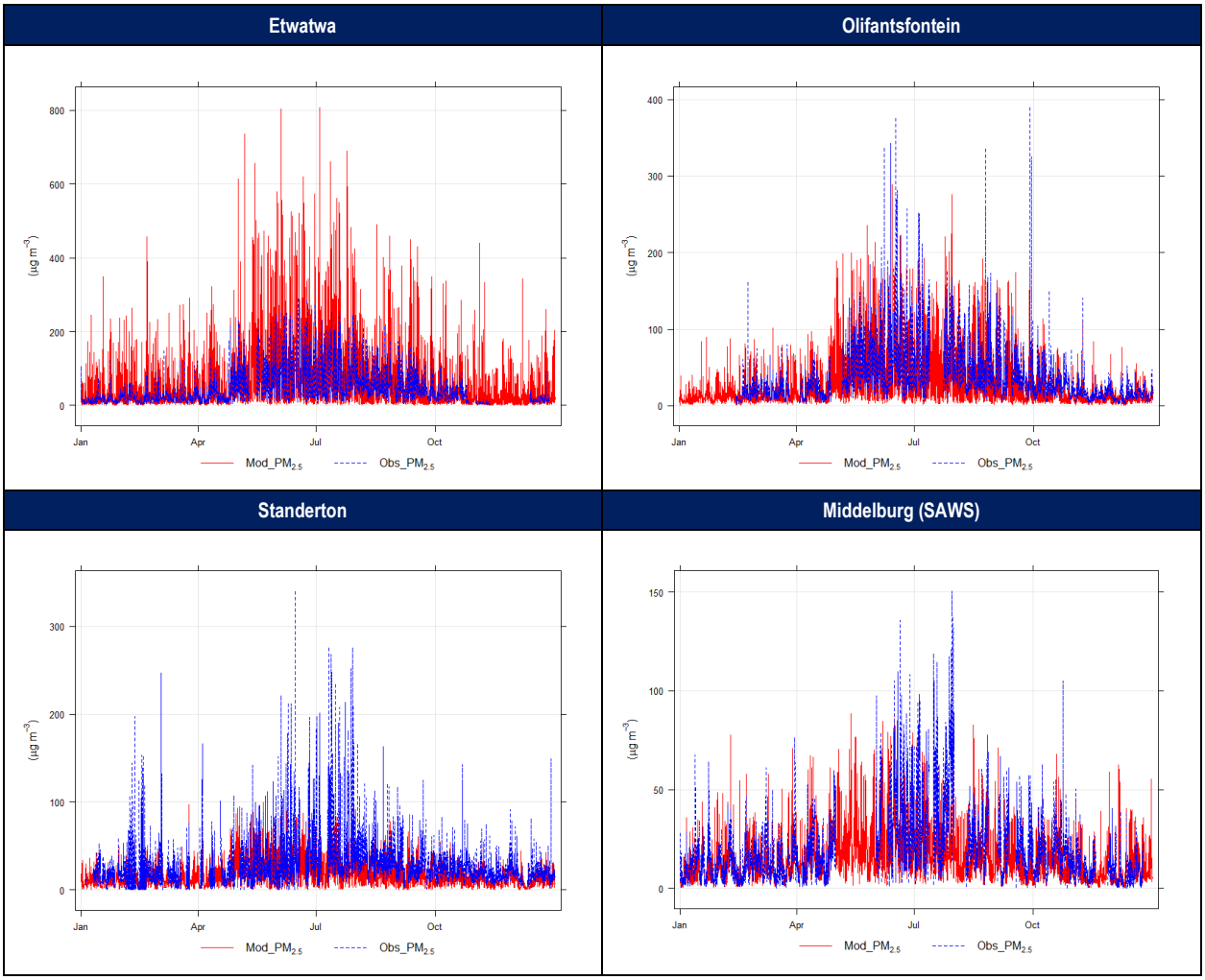

Figure B-11: Time-series plot of simulated (red) and observed (blue) $PM_{2.5}$ at each station.

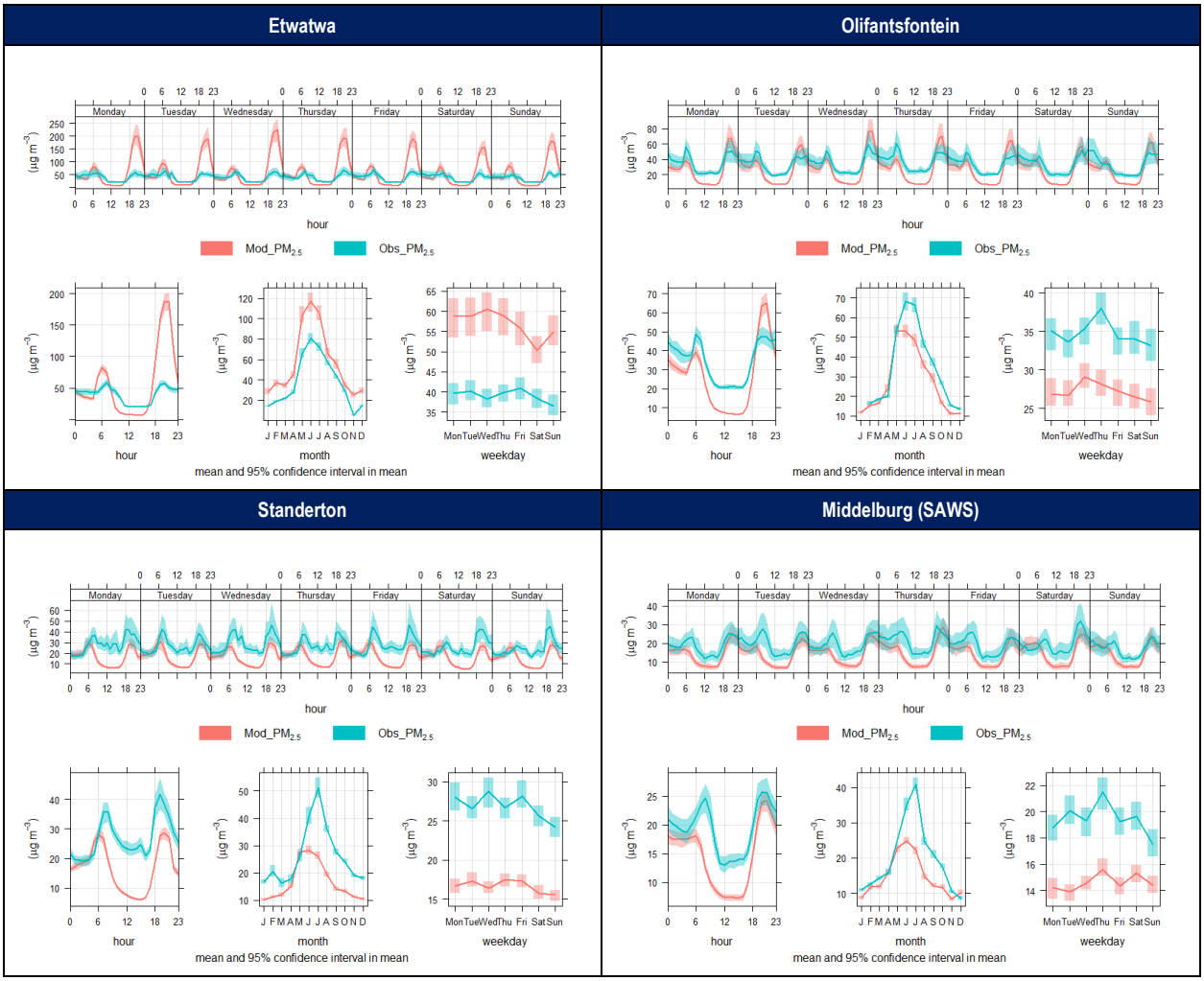

Figure B-12: Time-variation plot of simulated (red) and observed (blue) $PM_{2.5}$ at each station.

B.5. Ozone (O_3)

Figures B-13 to B-14 represent hourly and monthly averaged model-observed concentrations of O_3 at various monitoring stations. Temporal variability of observed O_3 concentrations was well captured by the model. Exploratory analysis of model-observation comparison of the average O_3 diurnal pattern (Figure B-14) reveals that both the model and observation show a clear distinction of daytime and night-time O_3 concentrations with maximum concentrations occurring during the day and lower values during night-time for all stations. While the observed-modelled hourly O_3 concentrations (Figure B-13) seem to overlap quite well at most stations, modelled maximum O_3 peaks at Middelburg station tend to show relatively larger deviations from that of measurements. Observed average O_3 concentrations show a monthly variability with higher concentration values during warmer months (up to 50 ppb depending on the station location) and lower concentrations during colder months (<10 ppb). This monthly trend was also captured well by the model. The model's general tendency is to systematically overpredict O_3 concentrations, the modelled diurnal profile of O_3 shows that concentrations are overestimated almost throughout the day and more significant from late evening until early morning. The night-time overestimation of modelled O_3 concentrations may be attributed to poor titration of O_3 which largely is due to limited NO_X concentrations available.

The O_3 statistical analysis (Annexure C, Table C-1) exhibits that there is a strong correlation between modelled concentrations of O_3 and that of the observed O_3. The correlation coefficient, R is above 0.5 with relatively lower mean bias values (< 10 ppb) at most stations. The FAC2 values may reach up to more than 90% (0.9) depending on the stations.

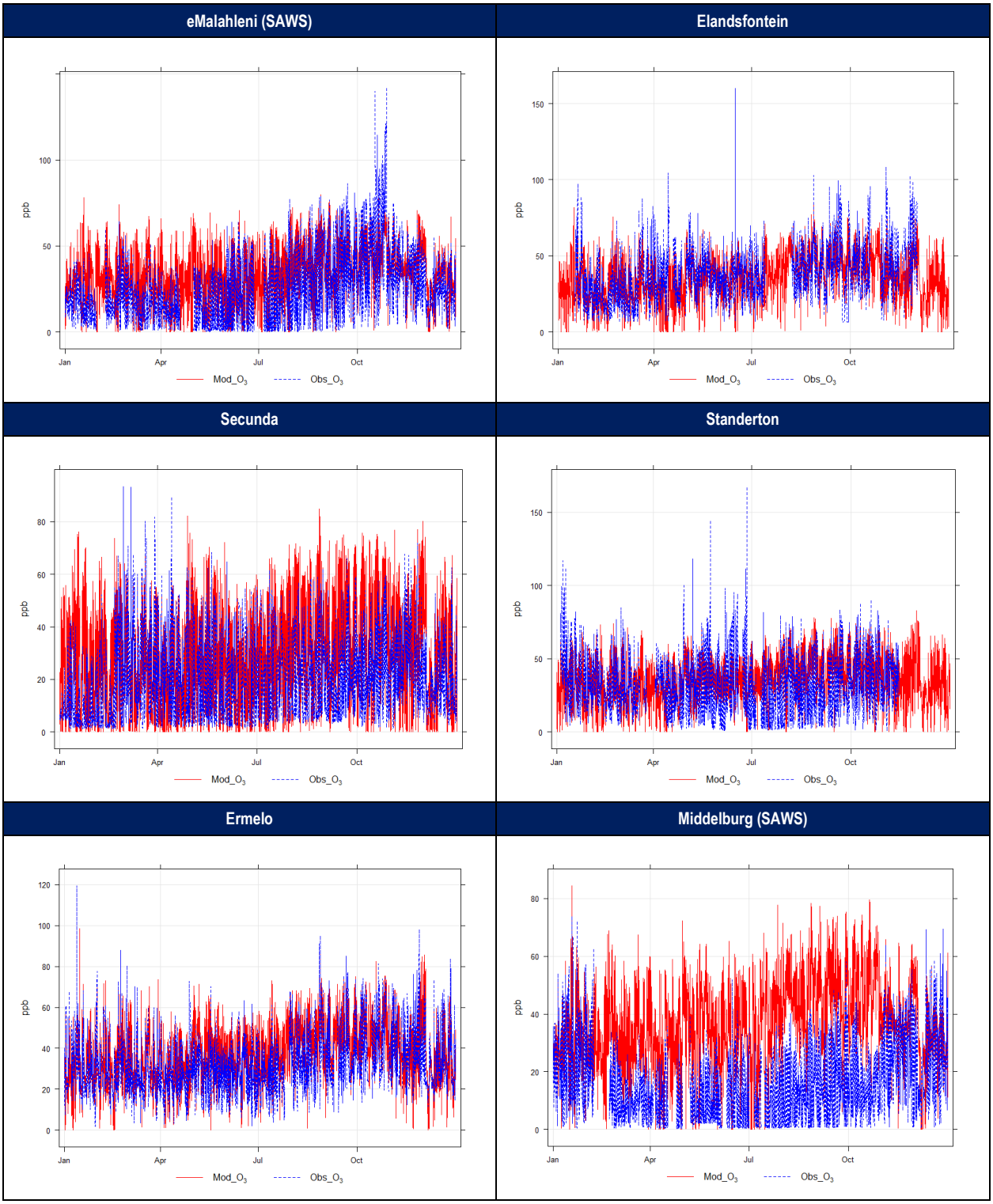

Figure B-13: Time-series plot of simulated (red) and observed (blue) O_3 at each station.

Figure B-14: Time-variation plot of simulated (red) and observed (blue) O_3 at each station.

B.6. Carbon Monoxide (CO)

Figures B-15 to B-16 represent hourly and monthly averaged model-predicted concentrations of CO at various monitoring stations. Though the temporal variability of observed CO concentrations was captured with success by the model, there is very little overlap between the observed-modelled hourly CO concentrations. The model was not able to predict maximum CO concentrations. The modelled diurnal and seasonal peak concentration values were significantly lower at all monitoring stations.

The statistical analysis of CO (Annexure C, Table C-1) exhibits low correlation in modelled and observed CO concentrations with the R values below 0.5 at most stations, except for Olifants (0.6) and Etwatwa (0.5) where the R values are greater than 0.5. It is also important to note that the two stations had low data recovery for CO during the period of analysis.

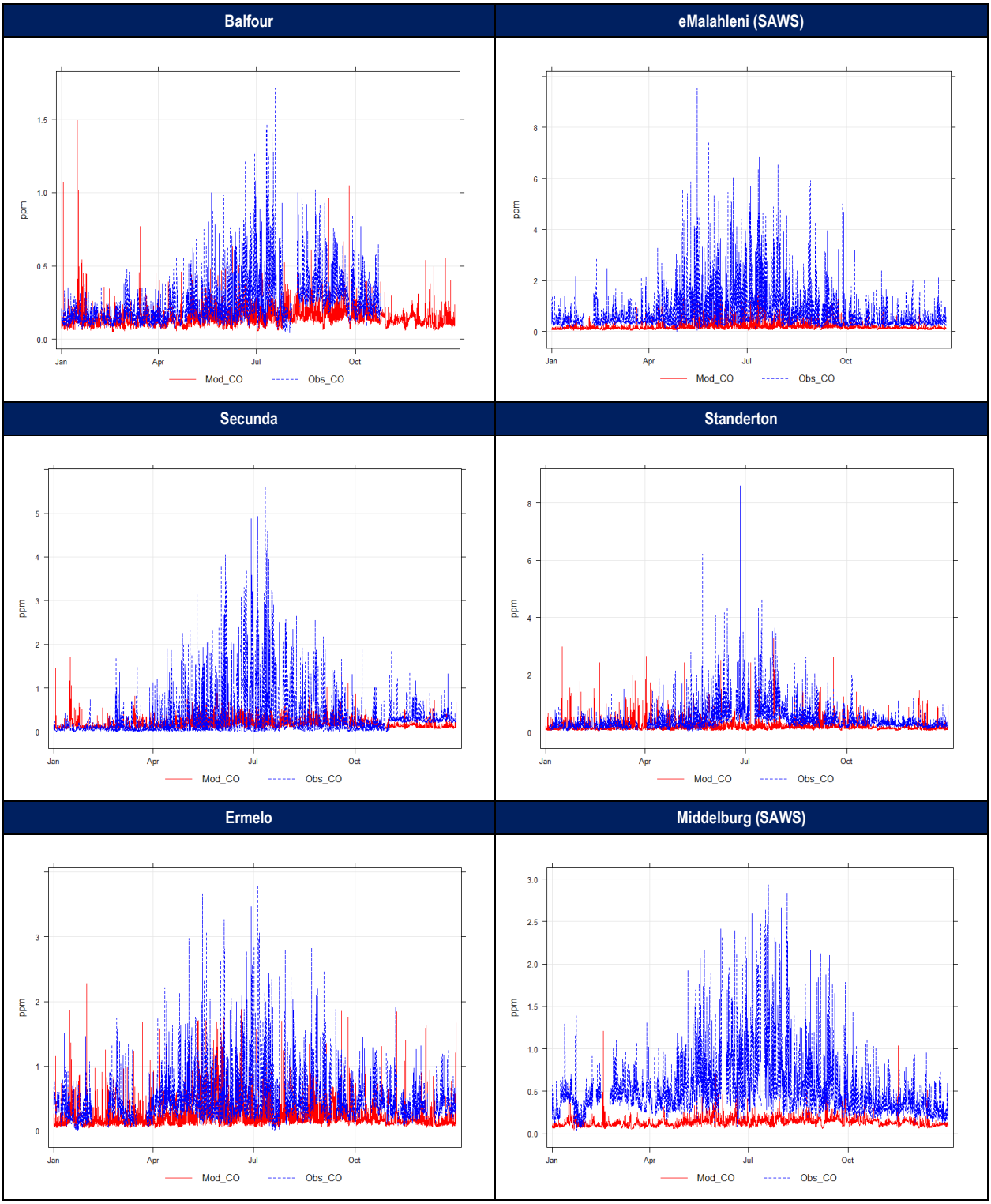

Figure B-15: Time-series plot of simulated (red) and observed (blue) CO at each station.

Figure B-16: Time-variation plot of simulated (red) and observed (blue) CO at each station.

ANNEXURE C: TIME-SERIES PLOTS OF MODEL VS MEASURED CONCENTRATIONS

A detailed description of the statistical parameters utilised for Table C-1 are contained in Annexure A.

Table C-1: Statistics from comparison of WRF temperature and wind fields with air quality monitoring station measurements

Station	Variable	n	%	FAC2	MB	MGE	NMB	NMGE	RMSE	R	COE	IOA
Balfour	SO_2	8115	93	0.36	4.37	5.84	1.28	1.71	9.39	0.28	-1.44	-0.18
	NO_2	7476	85	0.43	-3.71	7.75	-0.31	0.64	9.83	0.25	-0.41	0.29
	O_3	1356	15	0.54	14.32	16.06	0.78	0.88	18.89	0.52	-1.10	-0.05
	CO	6746	77	0.69	-0.10	0.12	-0.39	0.49	0.18	0.32	-0.07	0.46
	PM_{10}	7599	38	0.48	-12.50	38.06	-0.22	0.66	52.99	0.16	-0.14	0.43
	$PM_{2.5}$	3359	87	0.56	-0.81	10.95	-0.04	0.60	14.24	0.28	-0.33	0.34
Elandsfontein	SO_2	6197	71	0.37	-1.42	10.52	-0.11	0.85	17.62	0.25	-0.26	0.37
	NO_2	6320	72	0.41	2.75	7.15	0.39	1.01	10.97	0.33	-0.82	0.09
	O_3	6189	71	0.86	-0.97	11.53	-0.03	0.31	15.55	0.49	0.10	0.55
	CO	0	0	NA	NaN	NaN	NaN	NaN	NaN	NA	NaN	NaN
	PM_{10}	3546	69	0.34	28.50	33.76	1.81	2.14	53.20	0.16	-2.52	-0.43
	$PM_{2.5}$	6009	40	0.48	3.54	13.53	0.21	0.80	19.35	0.33	-0.33	0.34
EMalahleni	SO_2	8257	94	0.35	8.59	16.09	0.67	1.25	22.86	0.24	-0.51	0.25
	NO_2	8333	95	0.42	-5.27	9.34	-0.31	0.55	12.16	0.61	0.05	0.53
	O_3	7665	88	0.66	8.69	13.73	0.33	0.52	17.20	0.66	0.11	0.56
	CO	8212	94	0.16	-0.52	0.52	-0.72	0.73	0.84	0.44	-0.15	0.43
	PM_{10}	0	0	NA	NaN	NaN	NaN	NaN	NaN	NA	NaN	NaN
	$PM_{2.5}$	0	0	NA	NaN	NaN	NaN	NaN	NaN	NA	NaN	NaN
Ermelo	SO_2	7483	85	0.43	2.20	7.03	0.27	0.87	11.17	0.43	-0.09	0.46
	NO_2	6663	76	0.46	-0.60	5.53	-0.07	0.67	8.18	0.42	-0.18	0.41
	O_3	7900	90	0.91	4.81	10.06	0.15	0.31	12.55	0.64	0.02	0.51

Station	Variable	n	%	FAC2	MB	MGE	NMB	NMGE	RMSE	R	COE	IOA
	CO	7222	82	0.34	-0.24	0.32	-0.50	0.68	0.46	0.19	-0.33	0.34
	PM_{10}	507	6	0.46	-16.08	21.60	-0.46	0.62	30.05	0.28	-0.13	0.43
	$PM_{2.5}$	494	6	0.51	-6.10	11.24	-0.32	0.58	15.65	0.35	-0.07	0.47
Etwatwa	SO_2	8047	92	0.30	7.50	9.11	2.01	2.45	15.13	0.25	-1.94	-0.32
	NO_2	7060	81	0.42	0.25	9.64	0.02	0.68	12.77	0.60	-0.20	0.40
	O_3	0	0	NA	NaN	NaN	NaN	NaN	NaN	NA	NaN	NaN
	CO	4077	47	0.52	-0.18	0.35	-0.32	0.64	0.67	0.50	0.21	0.60
	PM_{10}	7129	81	0.44	-20.34	53.28	-0.24	0.63	78.58	0.53	0.07	0.53
	$PM_{2.5}$	7129	81	0.46	12.60	34.96	0.32	0.89	61.19	0.52	-0.21	0.39
Kendal	SO_2	7665	88	0.29	18.70	26.17	1.66	2.32	50.92	0.19	-1.23	-0.10
	NO_2	2009	23	0.29	8.16	13.70	0.97	1.63	18.42	-0.03	-1.27	-0.12
	O_3	4694	54	0.60	-3.50	16.46	-0.11	0.54	20.79	0.28	-0.06	0.47
	CO	0	0	NA	NaN	NaN	NaN	NaN	NaN	NA	NaN	NaN
	PM_{10}	6452	0	0.49	19.92	54.00	0.33	0.88	77.34	0.16	-0.26	0.37
	$PM_{2.5}$	0	74	NA	NaN	NaN	NaN	NaN	NaN	NA	NaN	NaN
Middelburg	SO_2	8297	95	0.40	4.44	6.63	0.98	1.46	13.08	0.42	-0.73	0.14
	NO_2	7372	84	0.22	-15.65	16.89	-0.66	0.71	21.91	0.40	-0.28	0.36
	O_3	7507	86	0.37	20.32	21.75	1.21	1.30	25.47	0.36	-1.08	-0.04
	CO	8056	92	0.15	-0.36	0.36	-0.72	0.73	0.47	0.23	-0.66	0.17
	PM_{10}	6492	73	0.41	-22.01	24.78	-0.55	0.62	37.42	0.41	-0.01	0.49
	$PM_{2.5}$	6394	74	0.58	-5.09	10.24	-0.26	0.53	15.55	0.54	0.15	0.58
Olifantsfontein	SO_2	6999	80	0.44	2.72	6.03	0.50	1.10	9.89	0.31	-0.48	0.26
	NO_2	2797	32	0.33	-5.88	9.26	-0.42	0.67	12.47	0.43	-0.03	0.48
	O_3	0	0	NA	NaN	NaN	NaN	NaN	NaN	NA	NaN	NaN

Station	Variable	n	%	FAC2	MB	MGE	NMB	NMGE	RMSE	R	COE	IOA
	CO	3154	36	0.42	-0.34	0.38	-0.59	0.65	0.61	0.60	0.17	0.58
	PM_{10}	6905	80	0.35	-43.15	48.25	-0.55	0.62	67.30	0.53	-0.05	0.47
	$PM_{2.5}$	6988	79	0.54	-6.49	19.01	-0.19	0.55	29.96	0.62	0.17	0.59
Secunda	SO_2	7808	89	0.30	11.85	13.79	2.79	3.25	25.65	0.15	-2.53	-0.43
	NO_2	7610	87	0.40	8.07	12.03	0.81	1.21	17.02	0.35	-1.26	-0.12
	O_3	7828	89	0.49	9.54	15.39	0.47	0.75	18.84	0.56	-0.26	0.37
	CO	7758	89	0.39	-0.11	0.23	-0.39	0.80	0.47	0.27	0.15	0.57
	PM_{10}	69	0	0.35	-12.14	25.33	-0.32	0.67	31.71	0.12	-0.39	0.30
	$PM_{2.5}$	14	1	0.71	6.30	10.83	0.35	0.60	14.01	0.85	0.19	0.60
Standerton	SO_2	4203	48	0.43	-1.36	8.06	-0.13	0.79	12.57	0.25	-0.17	0.41
	NO_2	6530	75	0.40	-0.76	7.24	-0.08	0.77	10.03	0.22	-0.42	0.29
	O_3	6726	77	0.74	3.81	13.46	0.12	0.41	17.26	0.52	0.10	0.55
	CO	7825	89	0.37	-0.21	0.31	-0.48	0.73	0.52	0.04	-0.27	0.36
	PM_{10}	3970	82	0.19	-57.09	59.18	-0.76	0.79	81.28	0.14	-0.40	0.30
	$PM_{2.5}$	7140	45	0.50	-9.65	16.03	-0.36	0.60	25.98	0.39	-0.04	0.48