Activity 12: Atmospheric Dispersion Modelling

Eskom

Activity 12.4: Dispersion modelling for year 2024 – KwaZamokuhle

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Eskom's Air Quality Offset (AQO) programme in KwaZamokuhle, Ezamokuhle, and Sharpeville is centred on reducing emissions from domestic solid fuel combustion and curbing waste burning. The implementation of Eskom's AQO interventions in 2,250 qualifying households in KwaZamokuhle was successfully completed by July 1, 2024. The principal indicator for the success of the intervention is related to a change in exposure to air pollution and nett emissions avoided as result of Eskom AQO interventions. This is quantified as the theoretical decrease in ambient particulate matter (PM) concentrations. Accordingly, the focus of this study is to assess the impact of Eskom's household-level AQO interventions in KwaZamokuhle.

2. Study Aim & Objectives

The study aims to assess the impact of the 2250 household AQO interventions implemented by Eskom in KwaZamokuhle, through the application of dispersion modelling to evaluate subsequent changes in ambient air quality.

The objectives of this study are:

1) To calculate the nett reductions in: PM, sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) emissions achieved through Eskom's KwaZamokuhle AQO Project interventions for residential fuel burning.
2) To evaluate the nett benefit in ambient air quality due to Eskom's KwaZamokuhle AQO Project for residential fuel burning.

3) Study Methodology

➢ Calculation of nett reductions of PM, SO_2 and NO_2

The methodology employed in this study is consistent with the Department of Forestry, Fisheries and the Environment's (DFFE) Second-Generation Highveld Priority Area Air Quality Management Plan (HPA AQMP) (DFFE, 2024). Household-level coal usage was estimated by multiplying the number of households by this per-household consumption figure, thereby enabling calculation of total coal usage for KwaZamokuhle. Subsequently, pollutant-specific emission factors were applied to these coal usage estimates to quantify the resultant emissions for each pollutant of interest. To ensure consistency, the emissions factors employed in this study are identical to those used in the recently published DFFE HPA Second-Generation AQMP Baseline Report.

Evaluating the nett benefit in ambient air quality for Eskom's AQO Project in KwaZamokuhle

Based on the output from the calculated PM, SO_2 and NO_2 emissions inventory for KwaZamokuhle, a dispersion modelling assessment aligned to the Code of Practice for Air Dispersion Modelling in Air Quality Management in South Africa (Gazette No 37804, 2014) was utilised to determine the potential nett ambient air quality benefit of Eskom's KwaZamokuhle AQO Project. For this study, a level 3 tier modelling assessment, the US-EPA approved California Puff (CALPUFF) modelling suite was utilised.

4) Study Results

Calculated nett reductions of PM, SO_2 and NO_2

The nett reductions in PM, SO_2 and NO_2 emissions attributable to Eskom's KwaZamokuhle AQO Project for the 2250 households is provided in Table i and illustrated in Figure i.

Table i: Emission Inventory for the residential fuel burning emission source category for KwaZamokuhle, representing the total nett reduction in emissions attributable to Eskom's Phase 1 AQO Project (tonnes) in KwaZamokuhle

Number of households that received Eskom AQO intervention in KwaZamokuhle	Estimated air quality benefit (tonnes)			
	SO_2	NO_x (as NO_2)	PM_{10}	$PM_{2.5}$
2250	53.51	24.57	69.71	64.85

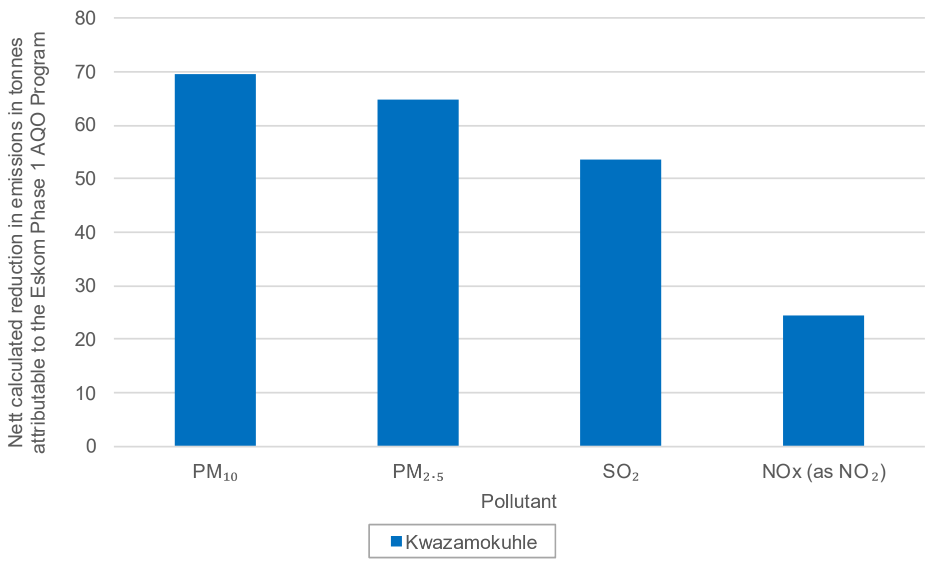


Figure i: Total nett reduction in emissions attributable to Eskom's Phase 1 AQO Project (tonnes) for KwaZamokuhle

Quantification of the nett ambient air quality for Eskom's KwaZamokuhle Residential Fuel Burning AQO Project

The study results demonstrate AQO interventions resulted in a notable reduction in PM, SO_2 and NO_2 levels in the Kwazamokuhle airshed. Table ii presents the net ambient air quality benefit of Eskom's KwaZamokuhle AQO Project, which targets residential fuel burning, showing the modelled improvements across discrete residential receptors in Ezamokuhle. Its further noted that in dispersion modelling, annual average concentrations provide a more reliable measure of air quality than hourly predictions because they smooth out short-term fluctuations caused by changing weather and emission conditions. This long-term view better reflects population exposure, regulatory compliance, and overall environmental impact.

Table iii: Improvement in ambient air quality due to Eskom's Kwazamokuhle AQO Project at the discrete receptors located in the KwaZamokuhle airshed

Model predicted maximum concentration range in μg/m³ at discrete receptors			
Pollutant	Averaging Period		
	1-hour	24-hour	Annual
SO_2	149 to 333	45 to 101	10 to 33
NO_2	55 to 122		3 to 12
PM_{10}		59 to 132	13 to 43
$PM_{2.5}$		55 to 122	12 to 40

The resulting improvements in ambient air quality attributable to Eskom's KwaZamokuhle AQO Project at the various discrete receptors are presented in Figure ii to iv for SO_2 ambient concentrations, Figure v to vi for NO_2 ambient concentrations, Figure vii to viii for PM_{10} ambient concentrations and in Figure ix to x for $PM_{2.5}$ ambient concentrations.

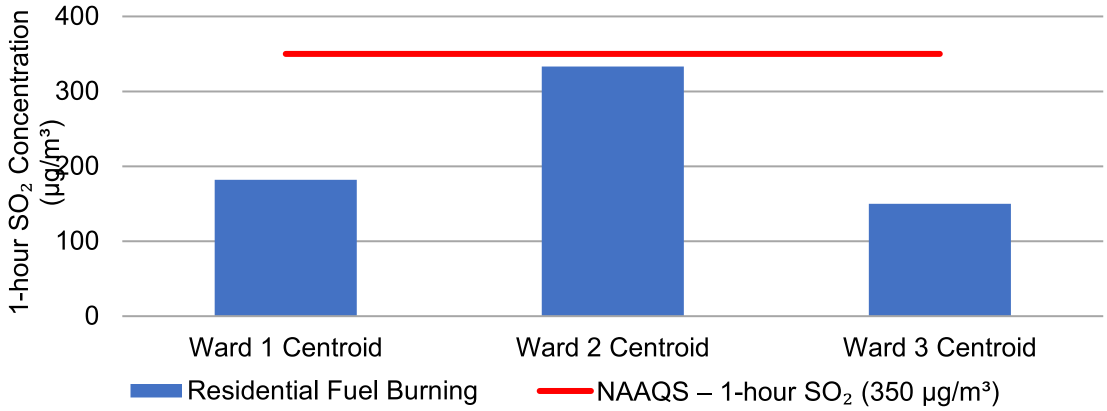


Figure ii: Model predicted improvement in the 1-hour SO_2 ambient concentrations (99th percentile) in µg/m^3 at discrete receptors

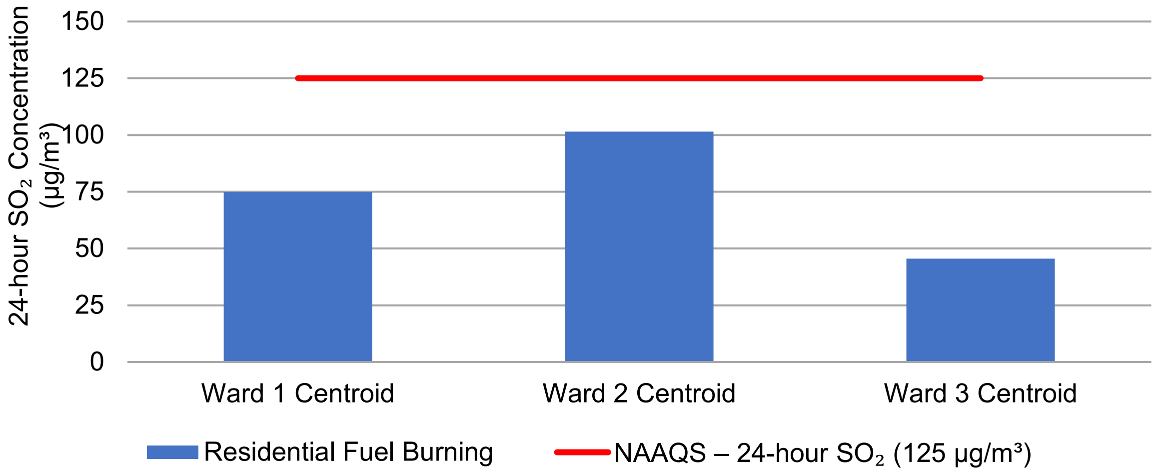
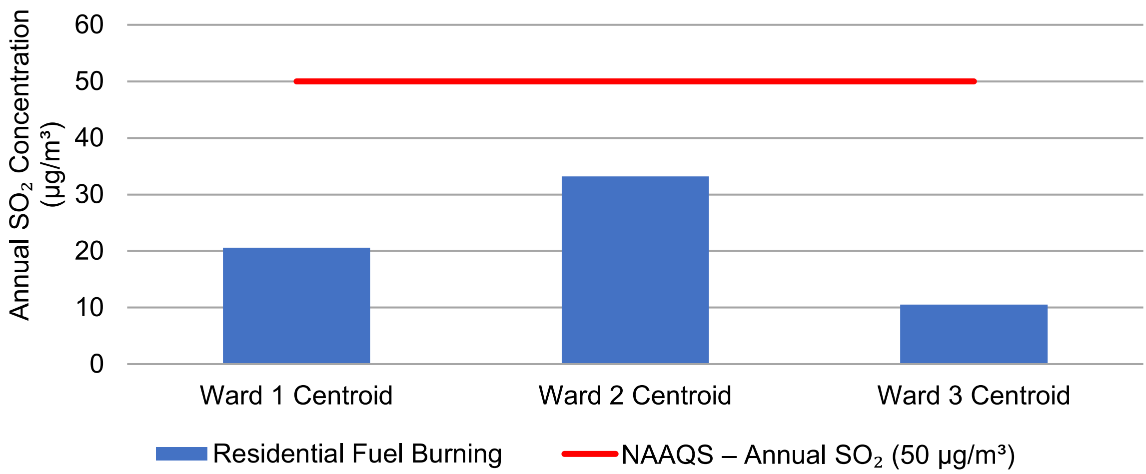


Figure iii: Model predicted improvement in the 24-hour SO_2 ambient concentrations (99th percentile) in µg/m^3 at discrete receptors



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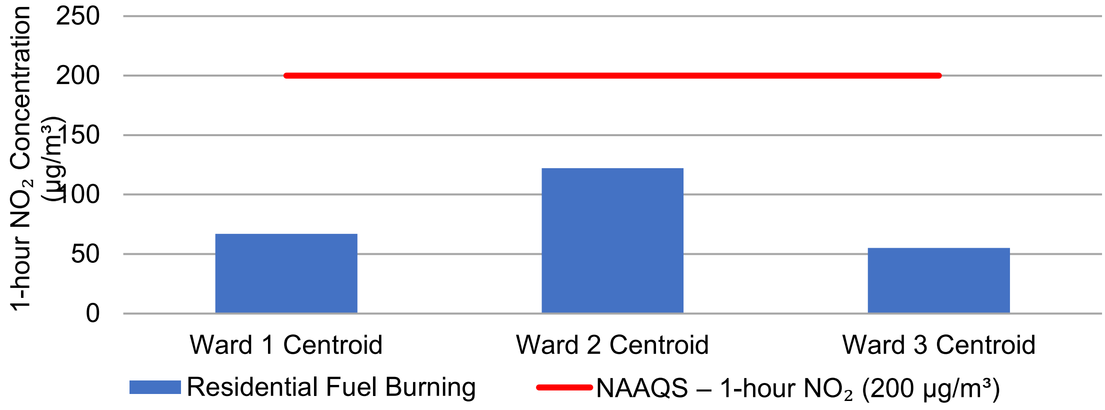

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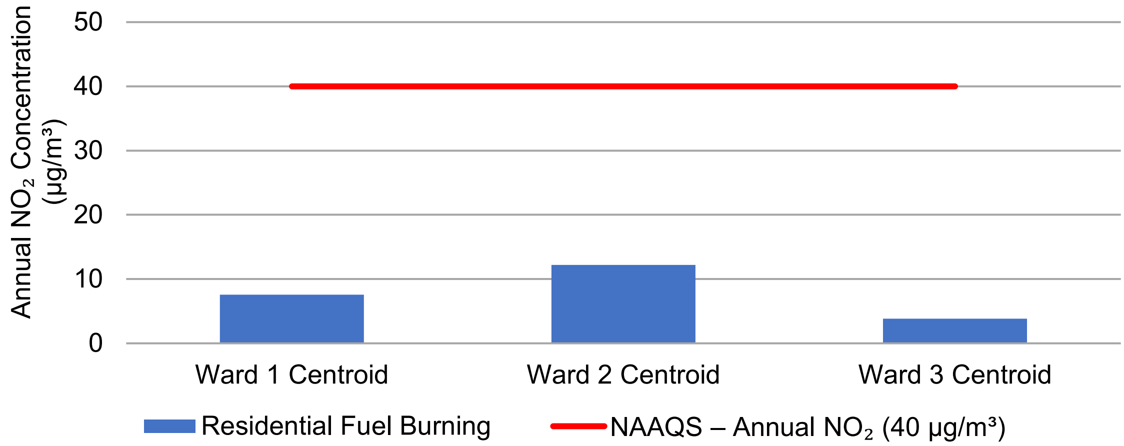

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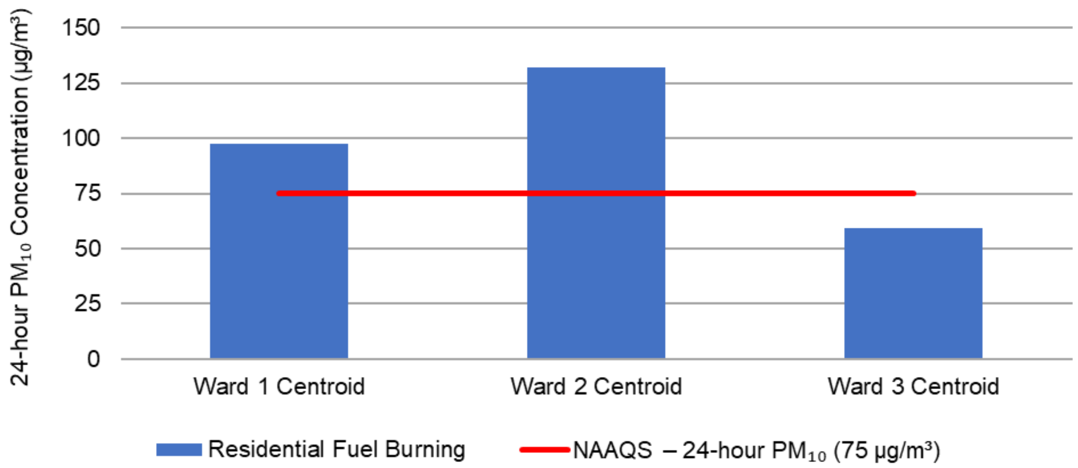
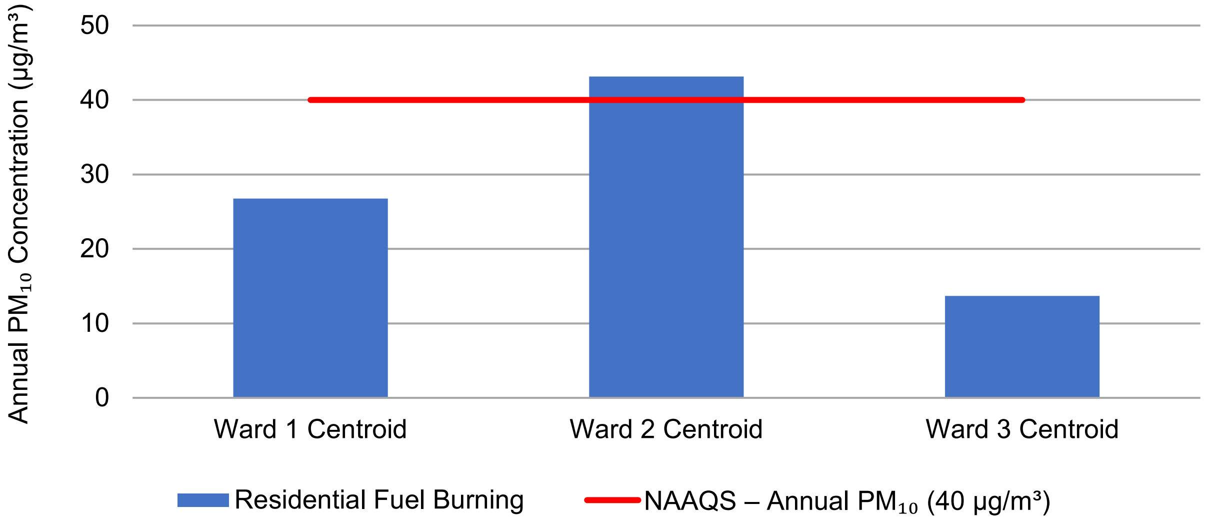


Figure vii: Model predicted improvement in the 24-hour PM_{10} ambient concentrations (99th percentile) in µg/m^3 at discrete receptors



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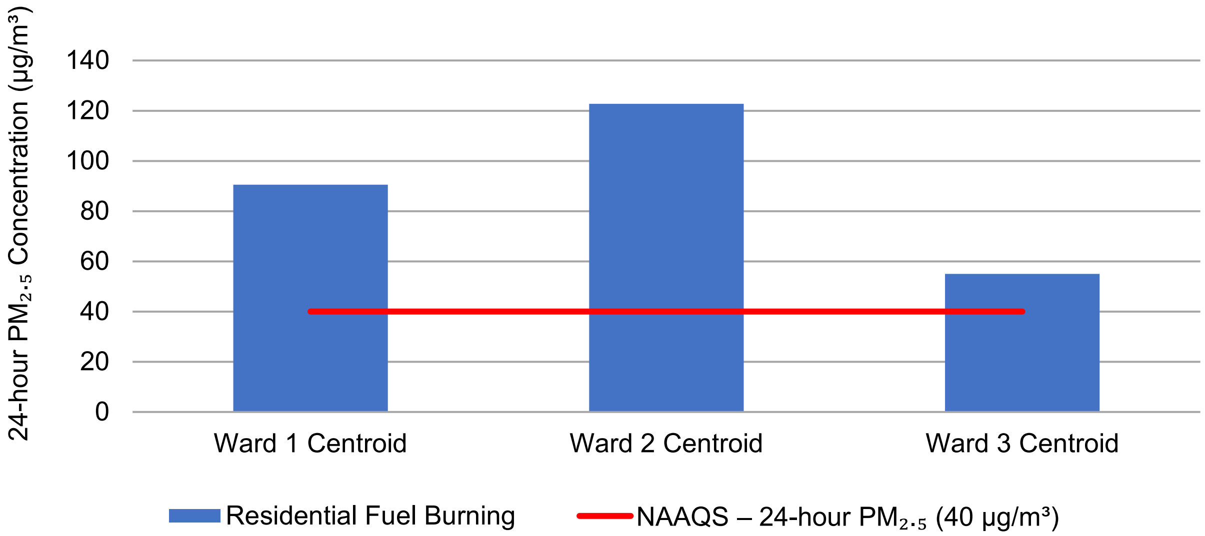

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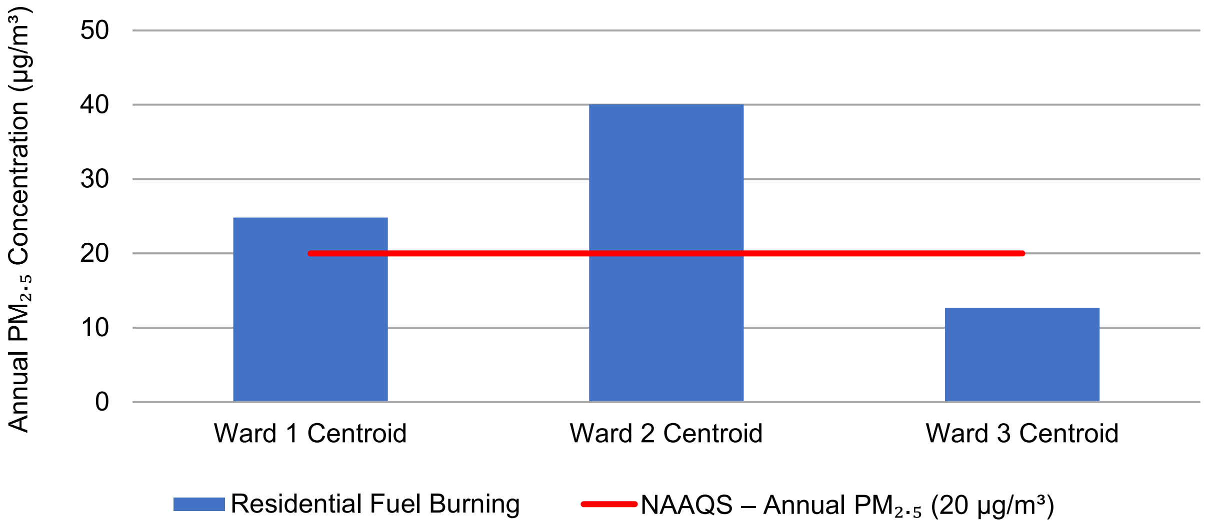

Figure x: Model predicted improvement in the $PM_{2.5}$ ambient concentrations annual concentrations in µg/m³ at discrete receptors

5. Conclusion

The study results indicate that Eskom's AQO Project at Kwazamokuhle has led to a significant reduction in emissions and corresponding improvements in ambient air quality. The project achieved net reductions of SO_2 (53 tonnes), NO_2 (24 tonnes), PM_{10} (69 tonnes), and $PM_{2.5}$ (64 tonnes). The long-term (annual) maximum ambient concentration improvements observed across receptors range between: (i) 10–33 µg/m³ for SO_2, (ii) 3–12 µg/m³ for NO_2, (iii) 13–43 µg/m³ for PM_{10}, and (iv) 12–40 µg/m³ for $PM_{2.5}$. By addressing one of the most widespread sources of urban air pollution in low-income communities, Eskom not only enhanced local air quality but also established a scalable model for similar interventions elsewhere. The KwaZamokuhle case study serves as a powerful illustration of how scientifically informed AQO initiatives can play a pivotal role in advancing air quality management and safeguarding public health in regions disproportionately affected residential fuel combustion. Scaling up such interventions will be essential to achieving national air quality targets, particularly within the Highveld and Vaal Priority Areas.

1. INTRODUCTION

1.1 AIR QUALITY OFFSETS GUIDELINE

An environmental offset is an action(s), designed to compensate for a negative environmental impact of resource use, a discharge, emission, or other activity. The Department of Environment, Forestry & Fisheries (DEFF) defines air emission offsets as an intervention, or interventions, specifically implemented to counterbalance the adverse and residual environmental impact of atmospheric emissions in order to deliver a nett ambient air quality benefit within, but not limited to, the affected airshed where ambient air quality standards are being or have the potential to be exceeded and whereby opportunities and need for offsetting exist (Notice 333 of 2016).

1.2 ESKOM'S APPROACH TO AIR QUALITY OFFSETS

DEFF's Air Quality Offset Guideline has shaped and informed Eskom's Air Quality Offsets Implementation Plan. This Plan has been based on a scientific process of feasibility studies, testing and demonstration, and on consultation with key stakeholders. Figure 1-1 illustrates the concept schedule for the phased implementation of Eskom's air quality offsets.

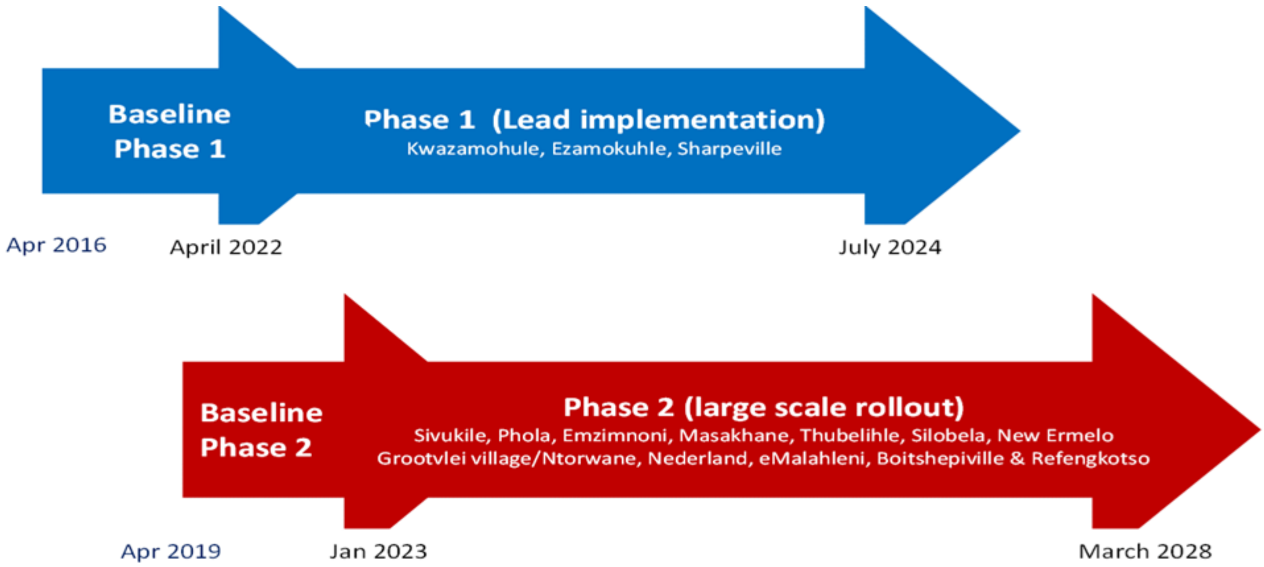

Figure 1-1: Concept Schedule for the implementation of Eskom's air quality offsets (Matimolane, 2023)

Eskom has adopted the phased approach (Figure 1-2) herein to increase the probability of success and to ensure that learnings from early phases are incorporated into the large-scale roll-out. (Matimolane, 2020).

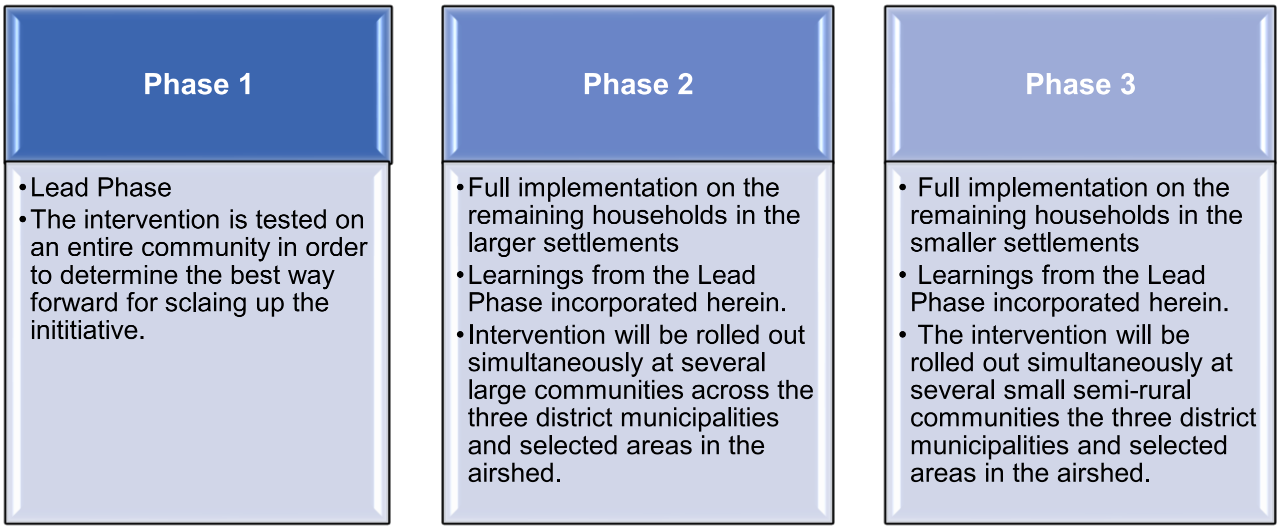

Figure 1-2: Eskom's Phased approach to the rollout of air quality offset interventions (Matimolane, 2020)

Eskom's air quality offsets programme is designed to reduce human exposure to harmful levels of air pollution by reducing emissions from local sources, like domestic coal burning and waste burning. Thus, air quality offsets can improve ambient air quality in low-income communities in the vicinity of Eskom's power stations. Eskom has developed air quality offset (AQO) implementation plans for Majuba Power Station (Ezamokuhle township), Hendrina Power Station (KwaZamokuhle township) and Lethabo Power station (Sharpeville).

1.3 ESKOM'S PLANNING, MONITORING AND VERIFICATION (PMV) PROJECT

For Eskom's PMV Project, interventions to reduce household emissions from domestic coal/wood burning will be rolled out in KwaZamokuhle and Ezamokuhle in the Mpumalanga Highveld. For formal dwellings the intervention will be a thermal insulation retrofit and an electricity starter pack and installation. The intervention for informal dwellings still needs to be selected and tested. Interventions also need to be identified and implemented to improve air quality in Sharpeville, Gauteng. Since domestic coal burning is less prevalent in Sharpeville, it is expected that a community-scale intervention, like reducing waste burning, will be more suitable there.

Air Resource Management (ARM) (Pty) Ltd has been appointed by Eskom to support the PMV services in support of the *Phase 1: Lead implementation* at: KwaZamokuhle; Ezamokuhle and Sharpeville. It's ARM (Pty) Ltd understanding that the overall objective *Lead Implementation Phase* is to benefit the specific local communities, minimize implementation risk, increase practical and scientific knowledge, and develop and refine monitoring, reporting and verifications processes. To achieve this, Eskom has included sixteen targeted work package Activities (Table 1-1) for these respective communities. This report focuses on Activity 12.4: Dispersion Modelling for the year 2024 for KwaZamokuhle.

Table 1-1: Eskom PMV Activity Schedule (Eskom PMV NEC Contract, 27082020)

Activities	Kwazamokuhle	Ezamokuhle	Sharpeville
Activity 1: Preliminary air quality assessment		✓	
Activity 2: Gather Area intelligence		✓	
Activity 3: Rapid in situ assessment		✓	
Activity 4: Obtain ethical clearance		✓	
Activity 5: Census	✓	✓	✓
Activity 6: Community source survey		✓	
Activity 7: Fuel source survey		✓	
Activity 8: Household surveys		✓	
Activity 9: Annual (household/community) surveys and monitoring of project effectiveness	✓	✓	✓
Activity 10: Ambient air quality monitoring	✓	✓	✓
Activity 11: Conduct indoor air quality monitoring	✓	✓	
Activity 12: Atmospheric Dispersion Model	✓	✓	✓
Activity 13: Design of Intervention		✓	✓
Activity 14: Development of Database Reporting	✓	✓	✓
Activity 15: Strategic Assistance and offsets methodology	✓	✓	✓
Activity 16: Research and Development	✓	✓	✓

1.4 Key metrics recorded for Eskom's AQO PMV Project

Three indicator domains will be monitored before, during and after the Eskom AQO implementation, namely the emissions, state of ambient air and quality of life. Over every monitoring period, the project scenario (as it actually took place) will be compared to a credible baseline scenario (i.e. the situation that would have been the case if the project was not implemented). The principal indicator for the success of the intervention will be related to a change in exposure to air pollution and nett emissions avoided as a result of Eskom AQ offsets interventions. This will be expressed as the theoretical reduction in the ambient concentration of PM (Figure 1-3).

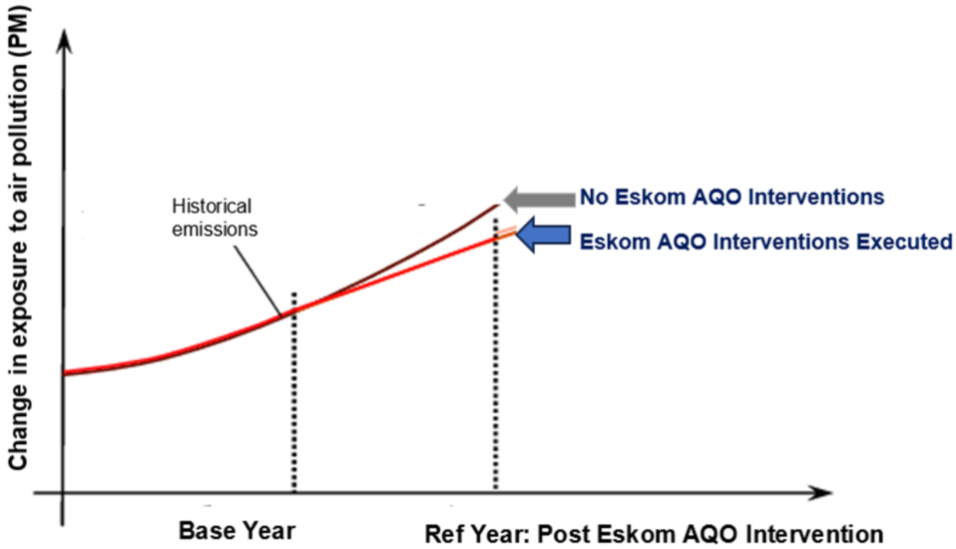

Figure 1-3: Principal indicator of success for Eskom AQO Project

1.5 Implementation of Eskom's Phase 1 AQO interventions

The implementation of Eskom's AQO interventions in 2005 qualifying households in Ezamokuhle was successfully completed in September 2024 (Mandavha, 2024). Similarly, the Eskom AQO interventions for 2250 qualifying households in KwaZamokuhle were finalized in July 1, 2024 (Nxumalo, 2024). Further, as part of Eskom's AQO programme for Lethabo power station, six waste interventions have been undertaken in Sharpeville. A total volume of 9035m^3 of waste has been collected to date in the Vaal (Nkungwana, 2024).

1.6 Scope of Work

In accordance with the scope of work, for *Activity 12: Atmospheric Dispersion Modelling* (Table 1-1) ARM must compile emission inventories of all sources affecting air quality in the three communities. ARM shall then develop and run appropriate dispersion model(s) to predict ambient SO_2, NO_2 and particulate matter (PM_{10} and $PM_{2.5}$) levels in the selected settlements to an acceptable level of accuracy. ARM will run the dispersion models on an annual basis to determine the impact of the interventions on ambient air quality. It's noted that Eskom has successfully implemented the roll-out of 2250 household AQO interventions in KwaZamokuhle (Mandavha, 2024). Thus, the focus of this study is determining the impact of Eskom's AQO household interventions at KwaZamokuhle.

1.7 Study Objective

This study aims to assess the impact of the 2250 household AQO interventions implemented by Eskom in KwaZamokuhle, through the application of dispersion modelling to evaluate subsequent changes in ambient air quality.

The objectives of this study are:

1) To calculate the nett reductions in particulate matter (PM), sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) emissions achieved through Eskom’s KwaZamokuhle AQO Project interventions for residential fuel burning.
2) To evaluate the nett benefit in ambient air quality due to Eskom's KwaZamokuhle AQO Project for residential fuel burning.

2. METHODOLOGY

To thoroughly evaluate impacts and potential improvements, this study implemented a structured three-phase approach (Figure 2-1):

- **Phase 1: Roll-out of AQO interventions for residential fuel burning in KwaZamokuhle:** The first phase involved the identification of households in KwaZamokuhle that were willing to participate in the Eskom AQO Project and subsequent rollout of interventions at these households. These interventions included a ceiling retrofit, rewiring, stove replacement and LPG heaters.
- **Phase 2: Determining the nett emissions avoided for Eskom's KwaZamokuhle AQO Residential Fuel Burning Project**: The methodology utilised herein is aligned with the DFFE Second-Generation HPA AQMP (DFFE, 2024). The DFFE Second-Generation HPA AQMP (DFFE, 2024) estimated 2.4 tonnes of coal being assumed to be burned at the household (HH) level which was also informed by the HPA Health Study (CSIR, 2017). By multiplying the number of households by the coal combustion at the household level, an estimate of the amount of coal usage at household (ward) level is calculated. Appropriate emission factors were then applied to the coal usage value to determine the resultant emissions per pollutant.
- **Phase 3: Quantification of the nett ambient air quality for Eskom's KwaZamokuhle AQO Residential Fuel Burning Project:** Aligned to the South African Dispersion Modelling Regulations, was the application of the USEPA CALPUFF modelling suite, driven by meteorological inputs from The Air Pollution Model (TAPM), to simulate ambient concentrations of PM (PM_{10}, $PM_{2.5}$), SO_2 and NO_2 across the KwaZamokuhle modelling domain.

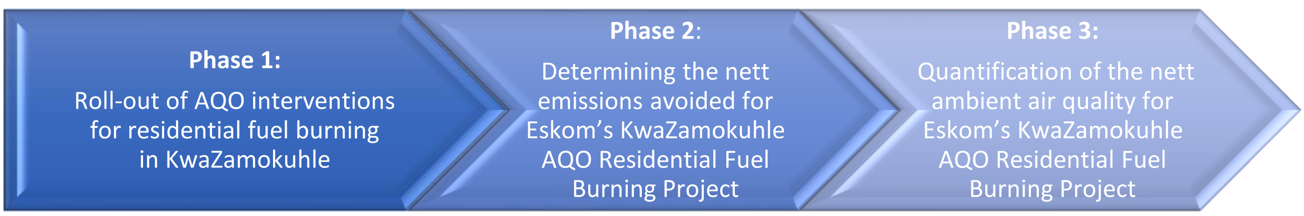

Figure 2-1: Approach to Study

2.1 Phase 1: Roll-out of AQO interventions for residential fuel burning in KwaZamokuhle

The first phase involved the identification of households in KwaZamokuhle that were willing to participate in the Eskom AQO Project and subsequent rollout of interventions at these households.

Since 2022, some 2250 households (pers comm, Matimolane, 2024) have received interventions in KwaZamokuhle. These interventions include the ceiling retrofit, rewiring, stove replacement and LPG heaters. Hence Phase 1 of the study has been completed (ARM, 2024a).

In this study, Google Earth satellite imagery was used to map out the location of residential households as these would correspond to areas where residential fuel burning would primarily occur in KwaZamokuhle. Area sources corresponding with residential fuel burning, which has been used in the modelling is presented in Figure 2-2.

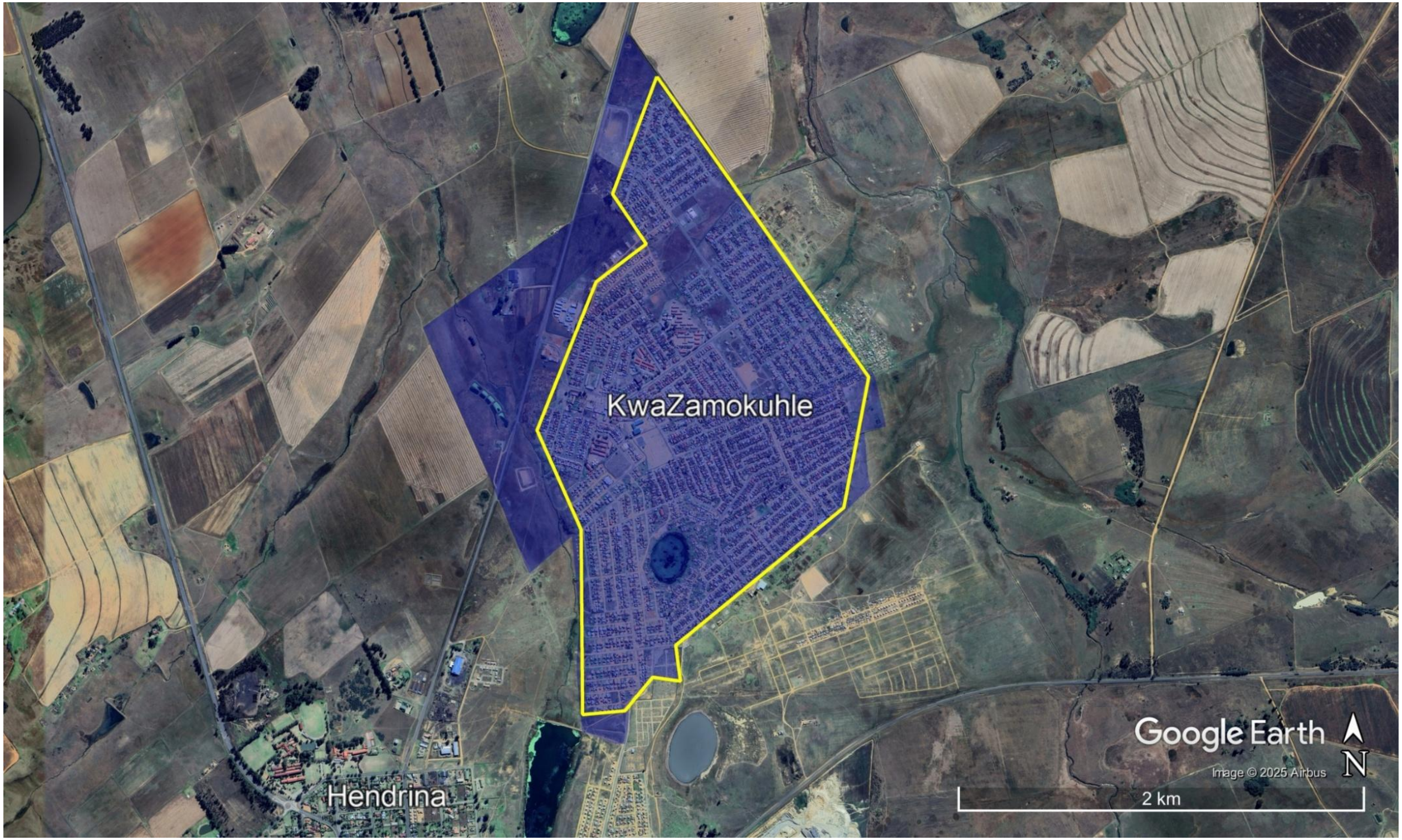

Figure 2-2: Location of KwaZamokuhle residential fuel burning sources (yellow polygon outline) used in the modelling study

2.2 Phase 2: Determining the nett emissions avoided for Eskom's KwaZamokuhle AQO Residential Fuel Burning Project

This section provides an overview of the methodology to calculate the nett emission avoided from household fuel combustion due to Eskom's AQO Project in KwaZamokuhle.

Methodology

The methodology utilised herein is aligned with the DFFE Second-Generation HPA AQMP (DFFE, 2024). The DFFE Second-Generation HPA AQMP (DFFE, 2024) estimated 2.4 tonnes of coal being assumed to be burned at the household (HH) level which was also informed by the HPA Health Study (CSIR, 2017). By multiplying the number of households by the coal combustion at the household level, an estimate of the amount of coal usage at household (ward) level is calculated. Appropriate emission factors were then applied to the coal usage value to determine the resultant emissions per pollutant.

Emission Factors

An emission factor (EF) is a quantity of a pollutant emitted relative to an activity metric, such as the quantity of fuel or material burned. It is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere, with an activity associated with the release of that pollutant. For instance, an EF for the release of SO_2 from combustion of coal would be expressed in grams (g) SO_2 emitted per kilogram (kg) of coal combusted. EFs are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant. EFs are generally used in calculating the rate at which a pollutant is being released from a source (emission rate), which can be used to simulate the concentration of the pollutant at a receptor. The general equation (1) for emissions estimation is:

$$E_i = F_B \times EF_i \qquad \text{Equation 1}$$

Where:

- E_i: The emission of pollutant i
- F_B: The amount of fuel burned
- EF_i: Emission factor of the fuel burned

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 (Amann et al., 2011), Ballard-Tremeer (1997), Britton (1998), Scorgie (2012) and Makonese et al. (2015). Many of the South African studies focused on coal. A hybrid selection from these studies is considered in this household fuel combustion emissions methodology and are presented in Table 2-1.

Table 2-1: Emission factors used for residential fuel combustion

Pollutant	LPG		Paraffin		Coal		Wood	
	Emission Factor (g/kg)	Source	Emission Factor (g/kg)	Source	Emission Factor (g/kg)	Source	Emission Factor (g/kg)	Source
SO_2	0.01	FRIDGE	0.851	FRIDGE	11.6	Scorgie, 2012	0.123	Ballard-Tremeer, 1997
NO_X	1.4	FRIDGE	1.5	FRIDGE	3.95	Makonese et al., 2015	1.224	AP-42
PM_{10} (a)	0	NA	0	NA	12.91	Makonese et al., 2015	1.035	AP-42
$PM_{2.5}$	0.068	AP-42	0.359	AP-42	16.146	Makonese et al., 2015	13.745	AP-42

Note: (a) PM_{10} represents only the coarse fraction (i.e., PM with a diameter 2.5 µm to 10 µm)

For alignment with the recently published HPA Second-Generation AQMP Baseline Report (DFFE, 2024), Table 2-2 is a summary of the EFs utilised in this study.

Table 2-2: Emission factors used for residential coal combustion

Fuel	$PM_{2.5}$	PM_{10}	SO_2	NO_2 as (NO_X)
Coal (g/kg)	12.01	12.91	9.91	4.55

2.3 Phase 3: Quantification of the nett ambient air quality for Eskom's KwaZamokuhle AQO Residential Fuel Burning Project

Based on the emissions inventory, a dispersion modelling assessment aligned to the *Code of Practice for Air Dispersion Modelling in Air Quality Management in South Africa* (DEA, 2014) is utilised to determine the potential nett ambient air quality benefit of Eskom's KwaZamokuhle AQO Project. For this study, a level 3 tier modelling assessment, the US-EPA approved California Puff (CALPUFF) modelling suite has been utilised. The CALPUFF model is an integrated modelling system which can simulate the effects of time and space-varying meteorological conditions for pollutant dispersion, transformation and deposition. The modelled predicted concentrations for SO_2, NO_2, PM_{10} and $PM_{2.5}$ are assessed against the respective National Ambient Air Quality Standards (NAAQS) (Table 2-3).

Table 2-3: NAAQS in µg/m³ for SO_2, NO_2, PM_{10} (DEA, 2009) and $PM_{2.5}$ (DEA, 2012)

Pollutant	Averaging Period	Limit value (µg/m³)	Permitted frequency of exceedance	Compliance Date
Sulphur Dioxide (SO_2)	10 minutes	500	526	Immediate
	1-hour	350	88	Immediate
	24-hour	125	4	Immediate
	1 year	50	0	Immediate
Nitrogen Dioxide (NO_2)	1 hour	200	88	Immediate
	1 year	40	0	Immediate
Inhalable particulate matter less than 10 µm in diameter (PM_{10})	24-hour	75	4	Immediate
	1 year	40	0	Immediate
Inhalable particulate matter less than 2.5 µm in diameter ($PM_{2.5}$)	24-hour	40	0	Immediate
	24-hour	25	0	1 January 2030
	1 year	20	0	Immediate
	1 year	15	0	1 January 2030

3. GENERAL DESCRIPTION OF AREA

3.1 LOCATION

The township of KwaZamokuhle lies adjacent to the town of Hendrina within the Steve Tshwete Local Municipality in the Mpumalanga Province, South Africa. According to the Census 2011 data, KwaZamokuhle has an area of 3.79 km^2 with a population of 20,427 (5,395.09 per km^2) and has 5,874 households (1,551.42 per km^2) (StatsSA, 2012).

3.2 TOPOGRAPHY AND LAND USE

3.2.1 TOPOGRAPHY

The Australian CSIRO Atmospheric Research Division, The Air Pollution Model (TAPM) was used to determine the topographical terrain map for the study area (Figure 3-1). The global terrain height and land use datasets are sourced from the US Geological Survey (USGS), Earth Resources Observation Systems (EROS) Data Center Distributed Active Archive Center (EDC DAAC). The topography of the area is relatively flat with a generally uniform terrain.

3.2.2 LAND USE

For atmospheric dispersion modelling an understanding of the land use information is critical. Based on this information, appropriate chemical transformation mechanisms, dispersion coefficients, albedo, surface moisture and surface roughness are selected for the modelling assessment. The classification of a site as urban or rural is based on the Auer method specified in the United States Environmental Protection Agency (USEPA) guideline on air dispersion models (USEPA, 2005). The classification scheme is based on activities within a 3 km radius of the emitting source.

From the Auer's method, areas typically defined as rural include residences with grass lawns and trees, large estates, metropolitan parks and golf courses, agricultural areas, undeveloped land and water surfaces. An area is defined as urban if it has less than 35% vegetation coverage or the area falls into one of the land use types in Table 3-1.

A land cover map of the study area is presented in Figure 3-2. Based on the Auer's assessment method detailed above, the study area is classified as rural as the emitting sources are located throughout the modelling domain.

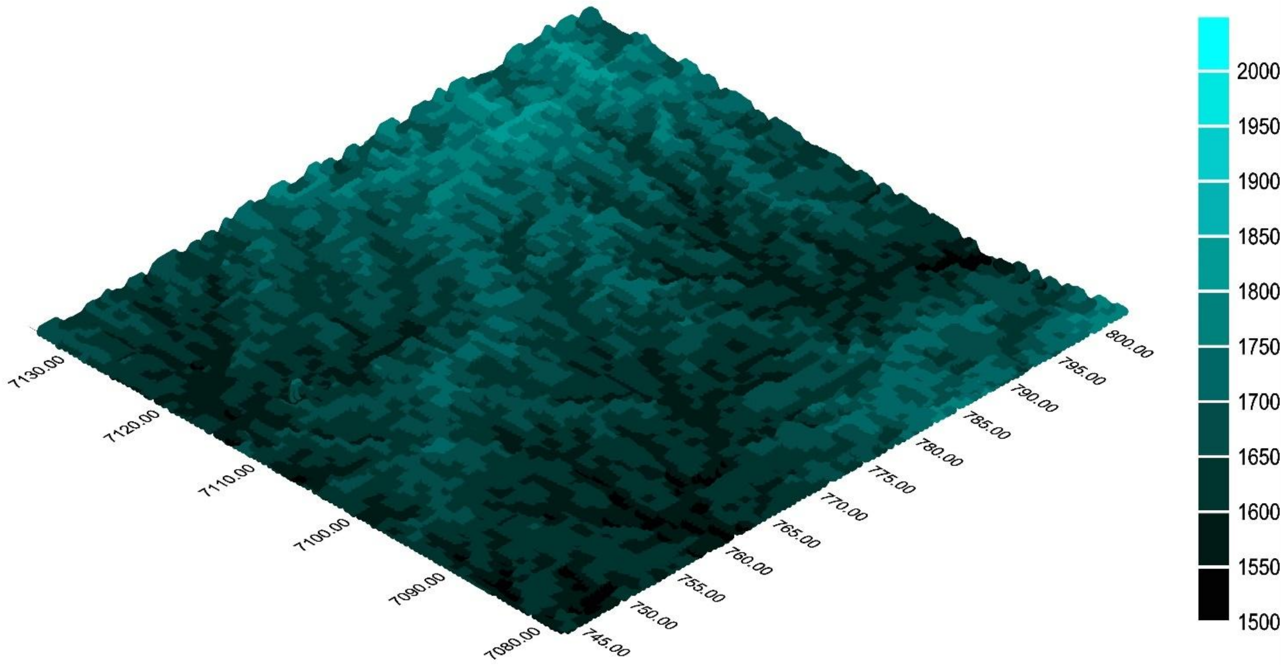

Figure 3-1: Topography of the Study Area

Table 3-1: Land types, use and structures and vegetation cover

Urban Land Use		
Type	**Land Use and Structures**	**Vegetation**
I1	Heavy industrial	Less than 5 %
I2	Light/moderate industrial	Less than 5 %
C1	Commercial	Less than 15 %
R2	Dense single / multi-family	Less than 30 %
R3	Multi-family, two-story	Less than 35 %

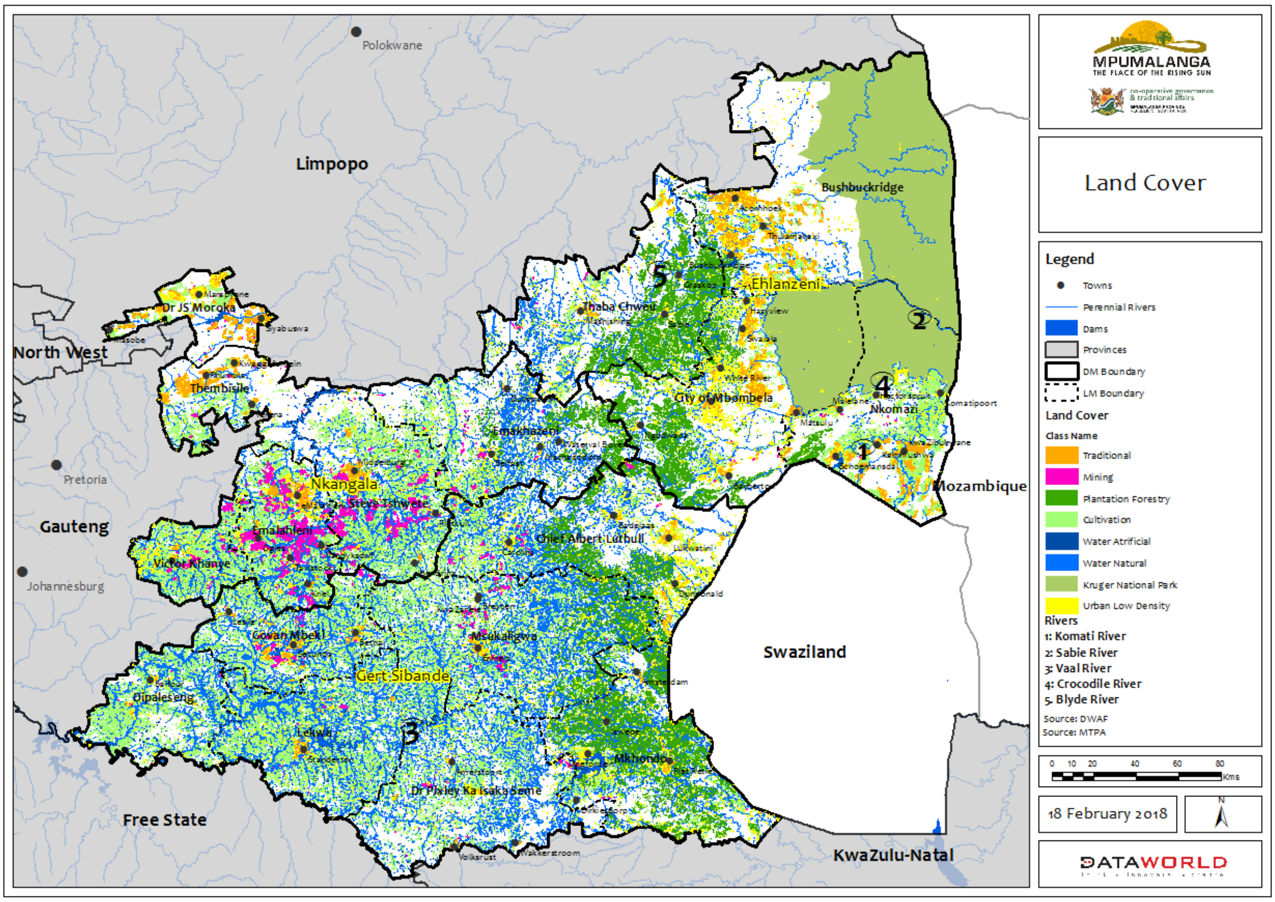

Figure 3-2: Land cover for Mpumalanga (Source: Mpumalanga Tourism and Parks Agency, extracted from Mpumalanga Spatial Development Framework (2019))

3.3 Climate and Meteorology

The Highveld experiences a temperate climate with dry winters according to the Köppen Climate Classification system (Köppen, 1884). The winters are mild and dry, but cold at night. Rainfall occurs in summer. The rain is largely due to the development of low-pressure troughs over the central plateau in summer whilst the dry winters are due to the dominant subtropical high-pressure system. The temperate temperatures are attributed to the relatively high altitude.

3.3.1 Rainfall and Temperature

The mean monthly rainfall totals recorded at the Eskom Hendrina Air Quality Monitoring Station (AQMS) for the period 2020 to 2022 is presented in Figure 3-3. It is noted that rainfall occurs predominantly from October to April, with the maximum in summer (December). The region received a mean annual rainfall of ~101 mm for the period 2020 to 2022. Average temperatures for the area are mild throughout the year with slightly cooler temperatures in winter. The long-term average (2020-2022) maximum temperature is 30°C in summer and 20.2°C in winter, with extreme maxima of 33.8°C in summer and 25.5°C in winter. The long-term minimum, maximum and mean temperatures observed at the Eskom Hendrina AQMS station is presented in Figure 3-3.

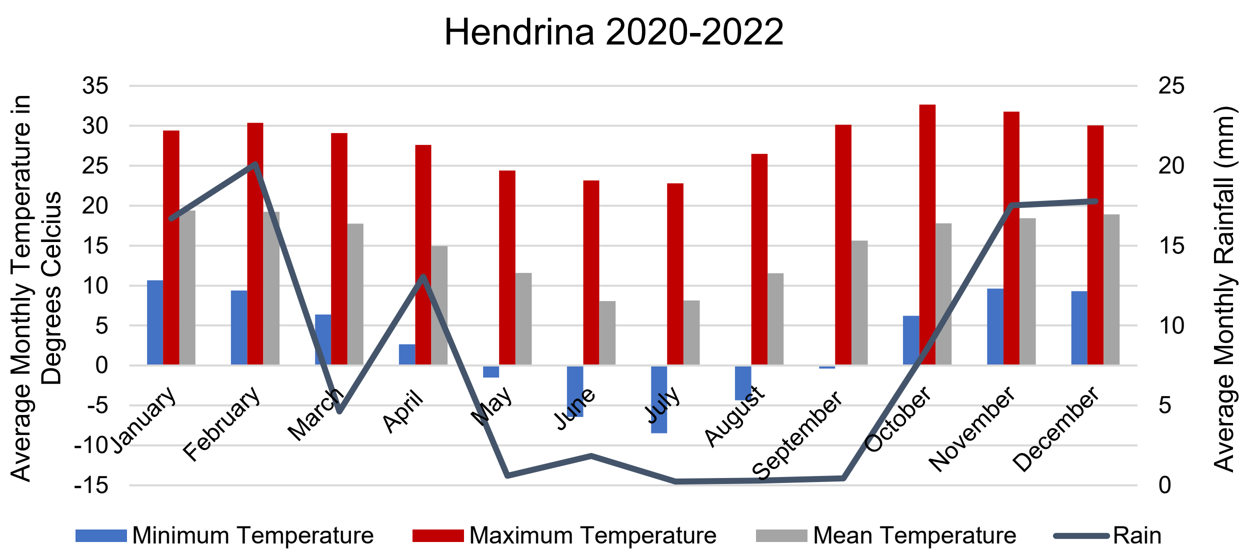

Figure 3-3: Average monthly maximum, minimum and mean temperatures and average monthly rainfall recorded at the Eskom Hendrina AQMS

3.3.2 Surface and Near-Surface Winds

Air quality is strongly influenced by meteorology. Meteorological mechanisms govern the dispersion, transformation, and eventual removal of pollutants from the atmosphere (Seaman, 2000). The analysis of hourly average meteorological data is necessary to facilitate a comprehensive understanding of the dispersion potential of the site. The horizontal dispersion of pollution is largely a function of the wind field. The wind speed determines both the distance of downward transport and rate of pollutant dilution. The wind rose is a useful way of showing how wind speed and wind direction conditions vary by year.

Wind Direction

At the Eskom Hendrina AQMS, the average wind speed for the period 2020-2022 was recorded at 2.6 m/s with calm condition at 0.2% (Figure 3-4). Calm condition means that wind speed is recorded at 0 m/s (Carlaw, 2015). The predominant wind directions were both easterly (~13% frequency of occurrence) followed by northeasterly and southerly (~15% frequency of occurrence) with maximum wind speeds of 8-11 m/s in the easterly direction.

The wind speed and direction data for the period 2020-2022 also demonstrates a seasonal signal at the Eskom Hendrina AQMS (Figure 3-5). For the spring and summer months, the average wind speed was recorded at ~2.9 m/s, with predominant wind directions of easterly winds (~15%

frequency of occurrence) followed by northeasterly and northwesterly winds (~15% frequency of occurrence). For the autumn and winter months, the average wind speed was recorded at ~2.5 m/s with predominant wind directions of southerly winds (~20% frequency of occurrence) followed by easterly winds (~10% frequency of occurrence).

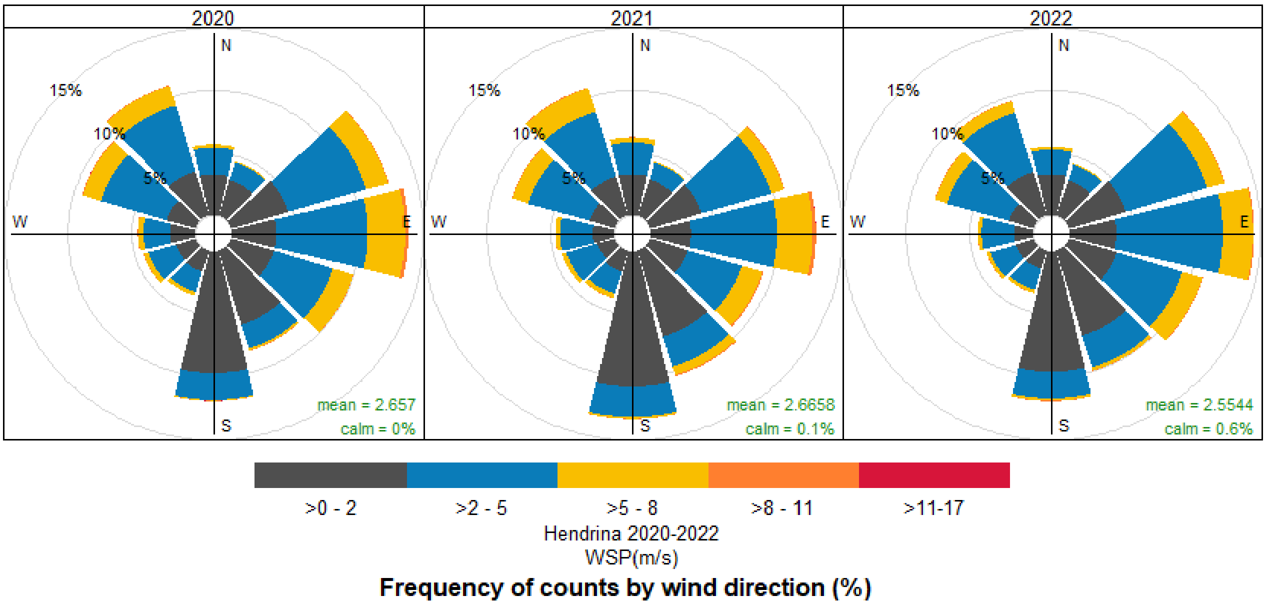

Figure 3-4: Annual wind rose for the Eskom Hendrina AQMS for the period 2020 to 2022

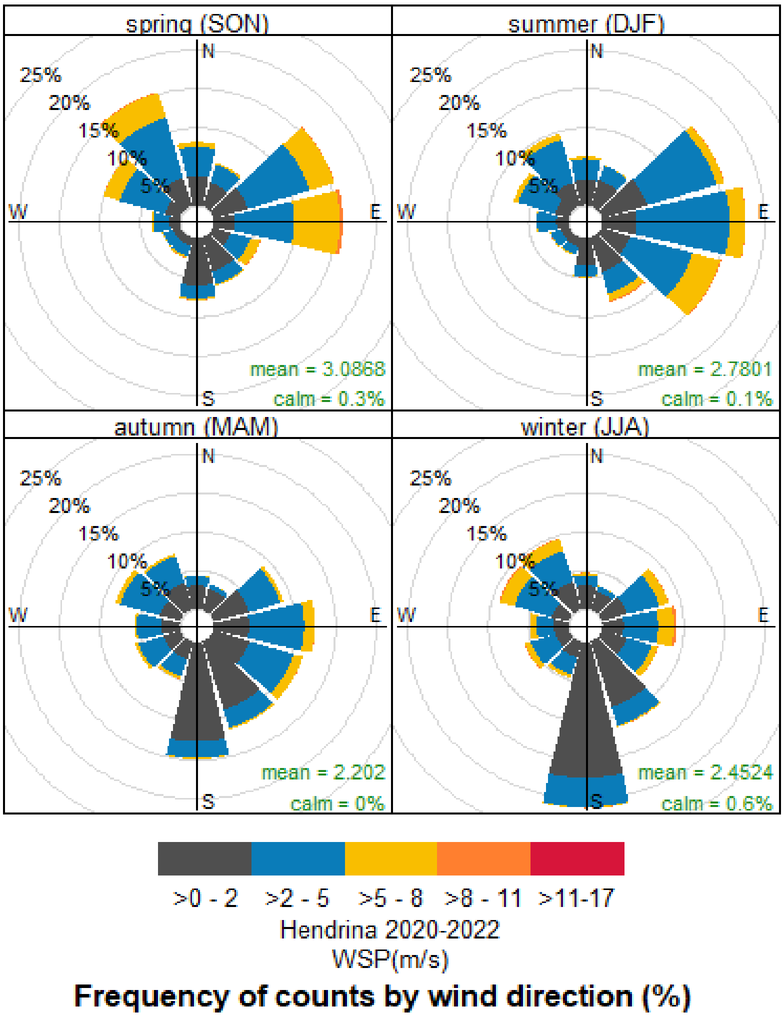

Figure 3-5: Seasonal wind rose for the Eskom Hendrina AQMS for the period 2020 to 2022

WIND SPEED

Wind drives the atmospheric transport and strongly affects vertical mixing and thus the ventilation of the urban air (Grundstrom et al., 2015). Stagnant atmospheric conditions with calm, clear weather often leads to stable atmospheric stratification which then leads to poor air quality (Delaney and Dowding, 1998; Janhall et al., 2006; Olofson et al., 2009). Low wind speeds leads to restricted air ventilation and may cause ambient air quality to deteriorate particularly when pollutants are emitted near ground level (Jones et al., 2010). In contrast, high wind speeds are associated with increased dispersion and mixing of atmospheric pollutants which may result in low ambient pollution concentrations.

Monthly wind speed averages for the Eskom Hendrina AQMS is presented in Figure 3-6. For the period January to May, the wind speed pattern shows a general decrease in values with low averages recorded until July. This is associated with less mixing and dispersion of pollutants which may result in elevated ambient concentrations particularly during winter (Liebenberg, 1999). Conversely, there is an increase in wind speeds from August to December. This is associated with increased dispersion and mixing of atmospheric pollutants which may result in lower ambient pollution concentrations during this period.

Diurnal wind speed averages for the Eskom Hendrina AQMS is presented in Figure 3-7. Lower wind speeds are logged from 19h00 to 05h00. This is associated with elevated atmospheric pollution concentrations due to less mixing and dispersion. The wind speeds then increase from 06h00 to 15h00. This is associated with lower pollution concentrations influenced by an increase in the mixing and dispersion of atmospheric pollutants (Liebenberg, 1999).

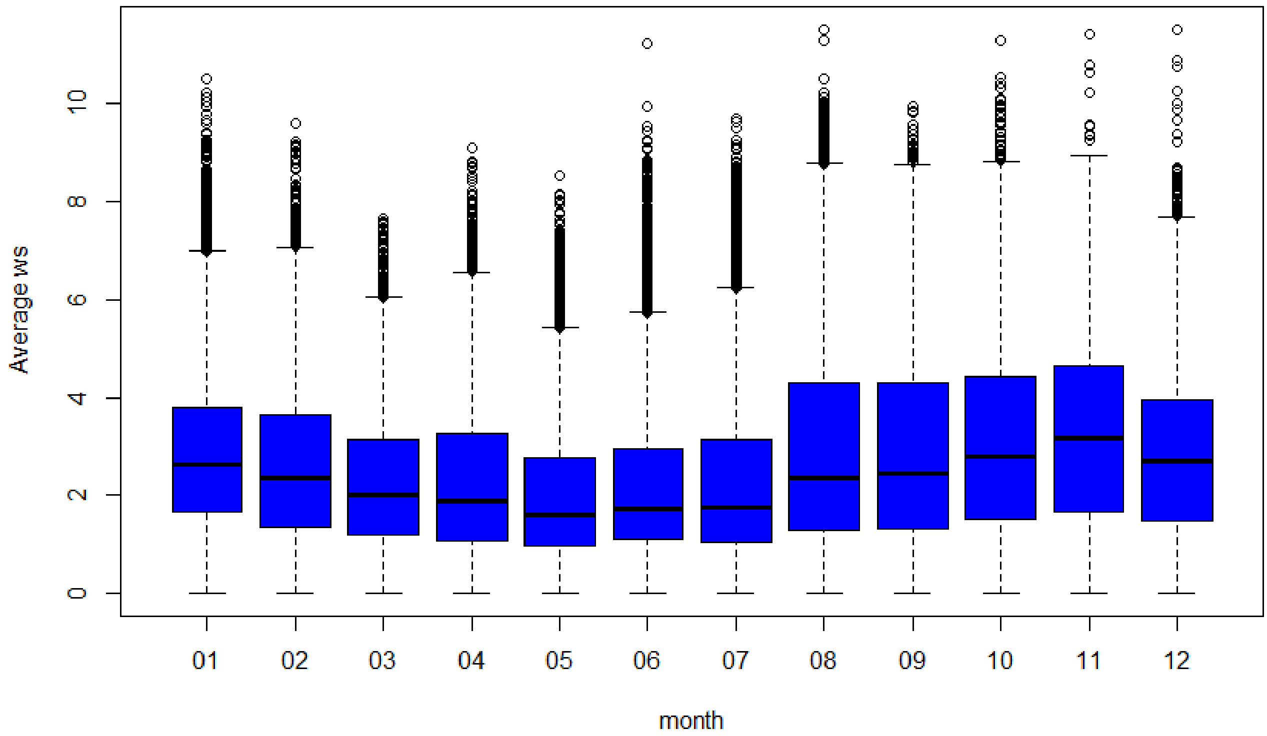

Figure 3-6: Monthly wind speed averages for the Eskom Hendrina AQMS (box and whisker plot indicates interquartile range, diamond indicate outliers and bars indicate the min and max value)

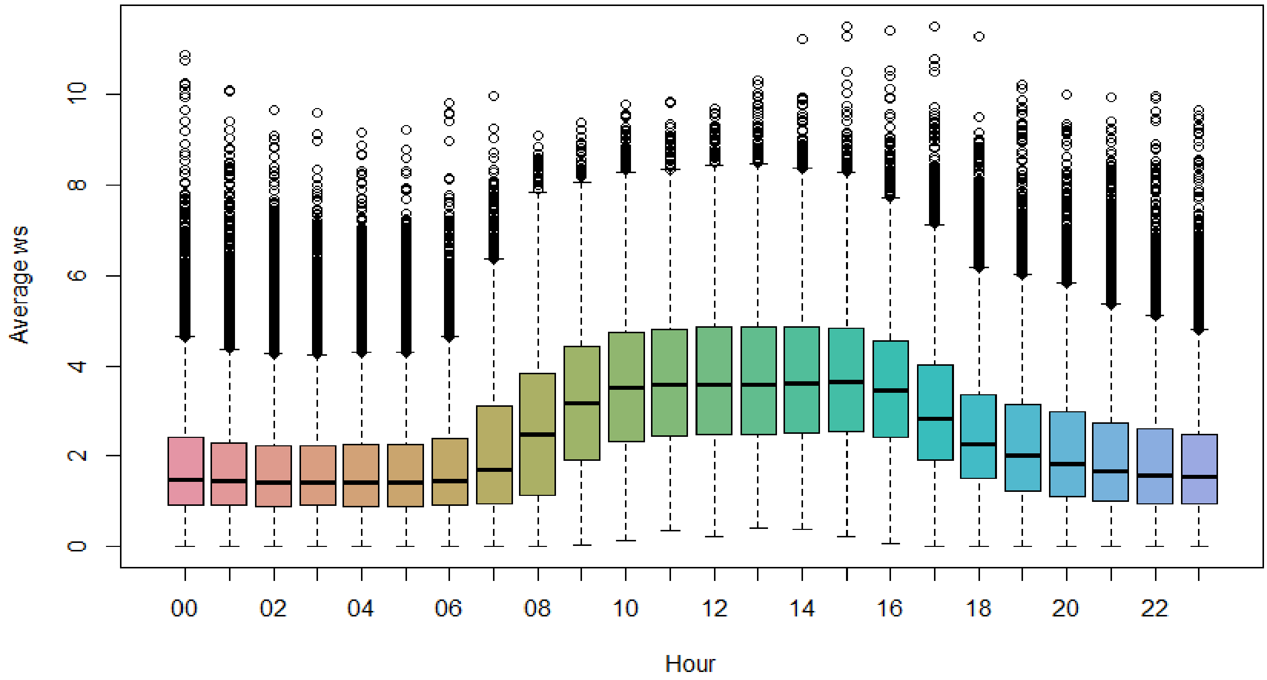

Figure 3-7: Diurnal wind speed averages for the Eskom Hendrina AQMS (box and whisker plot indicates interquartile range, diamond indicate outliers and the bars indicate the min and max value)

3.3.3 Dispersion Potential

The extent to which synoptic systems and weather disturbances impact on the dispersion potential of the atmosphere depends on the height and persistence of elevated temperature inversions. Elevated inversions reduce the height at which pollutants are able to mix, and consequently results in the accumulation of pollutants between the surface and the base of the inversion layers. These inversions therefore play a key role in the recirculation of pollutants as well as controlling long-range transport.

The southern African subcontinent is under the influence of a semi-permanent sub-tropical anticyclone. They are dominant in mid-winter with a frequency of occurrence of 80% as opposed to 20% in summer (Garstang et al., 1996). These high-pressure systems are associated with large-scale subsidence inversions which has a considerable influence on the accumulation of trace gases and aerosols in the troposphere (Garstang et al., 1996; Swap and Tyson, 1999). The presence of subsidence induced semi-permanent absolutely-stable layers at altitudes of approximately 700 hPa (~3 km), 500 hPa (~5 km) and 300 hPa (~7 km) (Figure 3-8), were identified over southern Africa by Cosijn and Tyson (1996) and Freiman and Tyson (2000). The horizontal and vertical transport of aerosols between the surface and the tropopause is controlled by these stable layers (Garstang et al, 1996). The lower level elevated subsidence inversion is significant in that it represents a persistent cap impeding the upward mixing of air pollutants (DEFF, 2007).

Convective activity hinders the formation of inversions. Whilst cyclonic disturbances are usually associated with the dissipation of inversions, pre-frontal conditions tend to lower the base of the elevated inversion, thus reducing the mixing depth. After the passage of a cold front, there is a gradual increase in the mixing depth (Scott and Diab, 2000).

For KwaZamokuhle, the dispersion potential is anticipated to be better during the day due to higher daytime temperatures and a higher frequency of moderate wind speeds. In addition, summer months will have a better dispersion potential than the winter months due to a higher frequency of stronger winds, higher rainfall, stronger thermal mixing, weaker and less persistent night-time temperature inversions.

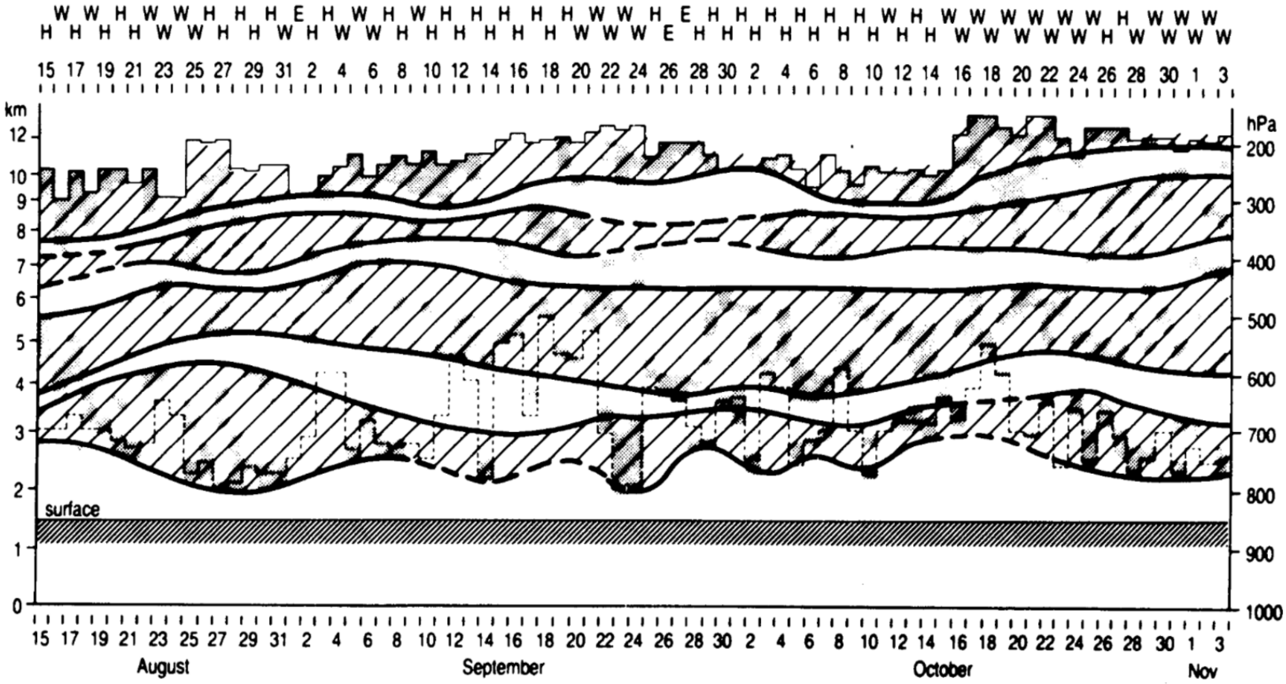

Figure 3-8: Daily variation of absolutely stable layers over Pretoria (southern Africa) during SAFARI-92. Stippled boxes indicate the height and depth of stable layers. Envelopes of continuous and discontinuous stable layers are indicated by cross-hatched regions enclosed by solid and dashed lines respectively. Light dashed lines depict the height of the 1200UT mixing depth. Circulation class for each day is shown by H (continental high), W (westerly disturbance) and E (easterly disturbance) (Source: Garstang et al., 1996: p 23724)

4. MODELLING PROCEDURE

4.1 BACKGROUND

Models have been used for decades to approximate physical systems and make estimates about the nature of a system under study (USEPA, 2004). Graedel and Crutzen (1997) have shown that it has become common practice in the environmental science field to describe complex systems of interacting physical, chemical and biological processes through the design of numerical models. For example, mathematical models are often used for assessing air pollution impacts in order to gain a better insight into this multidimensional (Denzer, 2004) and multidisciplinary (Wang, 2005) challenge.

Atmospheric dispersion models use mathematical equations that simulate the physics (Briggs, 1975; Gifford, 1960; Pasquill, 1983; Turner, 1970) and chemistry (Seinfeld and Pandis, 1998) that control the transport and transformation of pollutants in the atmosphere. They provide a means of estimating air pollutant concentrations and particle deposition in the ambient environment based on information on emissions and the prevailing meteorology (Chen et al., 2001; NSW, 2004).

4.2 ASSESSMENT LEVEL PROPOSED AND JUSTIFICATION

A number of dispersion models are used for regulatory applications in South Africa. The suitability of a particular model for an air quality assessment will vary depending on the complexity and scope of the study; the objectives of the modelling; technical factors and the level of risk associated with the project. According to the Regulations Regarding Air Dispersion Modelling (DEA, 2014), a tiered approach in the selection of a suitable air dispersion model is recommended. According to the regulations, it is recommended that simple screening models (Level 1) are considered first before the application of more advanced models (Level 2 and 3).

In this study, a detailed understanding of the air quality impacts (time and space variation of the concentrations) is required. Additionally, this modelling study must be able to account for causality effects, calms, non-linear plume trajectories, spatial variations in turbulent mixing, multiple source types and chemical transformations. In light of the above, and in accordance with recommendations provided in the Regulations, a Level 3 modelling assessment was regarded as most appropriate for application in this study.

4.3 MODELS USED IN STUDY

4.3.1 METEOROLOGICAL MODEL

Air quality is strongly influenced by meteorology which covers an array of atmospheric processes that determines the evolution of emissions, chemical species, aerosols and particulate matter (Seaman, 2000). The performance of atmospheric dispersion models depends critically on the meteorological data to simulate the fate and transport of air pollution (Busillo et al., 2005; Davakis et al., 2007; Pielke and Uliasz, 1998). The representativeness of meteorological data is a key factor in accurately modelling the dispersion of these pollutants since meteorological conditions are not uniform over larger distances or in complex terrain, coastal environments, or in urban areas (Alapaty, 1994; Moschandreas et al., 2002).

South Africa is constrained by the lack of an adequate network of surface and upper air meteorological stations that are representative of the atmospheric boundary layer near the surface or at higher levels (Zunckel, 2007). Further, spatially and temporally representative wind flow statistics are not widely available for South Africa (Raghunandan et al., 2008). In this study, no upper air meteorological data is recorded within the modelling domain and the nearest upper air station is located at Irene in Pretoria. Due to the scarcity of surface and upper air meteorological stations available for the study area, TAPM was used to provide site-specific and representative meteorological data for the dispersion model.

TAPM

TAPM, developed by the Australian CSIRO Atmospheric Research Division, is an integrated 3-dimensional mesoscale prognostic meteorological and air pollution regulatory model that is controlled by a graphical user interface (Hurley et al., 2005a; Hurley, 2005b; Luhar and Hurley, 2004; Zawar-Reza et al., 2005).

The meteorological component of TAPM is an incompressible, optionally non-hydrostatic, primitive equation model which uses a terrain-following vertical coordinate system for 3-dimensional simulations (Zawar-Reza and Sturman, 2008). It includes comprehensive parameterisations for cloud/rain micro-physical processes, urban/vegetative canopy and soil, turbulence closure and radiative fluxes (Katzfey and Ryan, 1997; Lai and Chang, 2009; Mahrer and Pielke, 1977).

TAPM predicts local-scale flows, for instance sea breezes and terrain-induced circulations, by using meteorological fields obtained from larger scale synoptic analyses (Luhar and Hurley, 2004). TAPM is able to make use of fundamental fluid dynamics and scalar transport equations to predict the underlying meteorology of an area (Hurley, 2005c). It solves momentum equations to determine the mean horizontal wind components, the incompressible continuity equation for vertical velocity, and scalar equations for potential virtual temperature and moisture (Luhar and Hurley, 2004). The model allows for the option of observed wind data to be assimilated into the momentum equations as nudging terms (Luhar and Hurley, 2003; Raghunandan et al., 2008). Potential virtual temperature is determined from an equation combining the conservation of heat and water vapour. Pressure is determined by the application of a Poisson equation to the nonhydrostatic component (Luhar and

Hurley, 2003; Hurley 2005). A detailed description of the equations and parameterisations, including the numerical methods used to solve the model equations, used in the present study is given by Hurley et al. (2005a) and Hurley (2005b).

TAPM uses databases of global terrain height, land use, sea-surface temperature and synoptic meteorological analyses as input. The global terrain height and land use datasets are available at a grid space resolution of approximately 1 km and sea surface temperature and synoptic scale meteorological datasets are available at a 100 km resolution. The global terrain height and land use datasets are sourced from the US Geological Survey (USGS), Earth Resources Observation Systems (EROS) and the Data Center Distributed Active Archive Center (EDC DAAC) data (Hurley, 2005). Global long-term monthly mean sea surface temperatures are derived from the US National Center for Atmospheric Research (NCAR) and the synoptic scale analyses are obtained from the Australian Bureau of Meteorology.

TAPM has been verified for a number of Australian and international datasets, and results from these studies have shown good model performance for both meteorology and air pollution predictions, particularly for the study of annual extreme (high) concentrations important for environmental impact assessments. The meteorological results show that TAPM performs well in a variety of regions (e.g., coastal, inland and generally complex terrain for sub-tropical to mid-latitude conditions). The pollution results show that TAPM performs well for a range of important phenomena (e.g. nocturnal inversion break-up fumigation; stable, neutral, convective and building wake dispersion; shoreline fumigation; and general dispersion in complex rural and urban conditions). In particular, TAPM performs very well for the prediction of extreme pollution statistics, important for environmental impact assessments, for both non-reactive (tracer) and reactive (nitrogen dioxide, ozone and particulate) pollutants for a variety of sources (e.g. industrial stacks and/or general surface or urban emissions (Hurley et al., 2008).

TAPM has also been used extensively in South Africa for many dispersion modelling studies for AQMPs, Air Quality Impact Assessments, Atmospheric Impact Reports and Offsetting Projects. Some of the important AQMP studies include the first-generation Highveld Priority Area Air Quality Management Plan (DEA, 2011) and the Waterberg-Bojanala Priority Area Air Quality Management Plan: Baseline Characterisation (DEA, 2014). A TAPM verification study has also been conducted in South Africa at two coastal sites (Alexander Bay and Richards Bay) (Raghunandan et al., 2008). In this study, TAPM model output was compared with meteorological data measured at South African Weather Service (SAWS) meteorological stations at these locations. It was concluded that the TAPM model performed exceptionally well.

4.3.2 Dispersion Model

In this study, the US-EPA approved Californian Puff (CALPUFF) modelling suite was used for this Level 3 tier modelling assessment.

CALPUFF Modelling Suite

The CALPUFF model is an integrated modelling system which can simulate the effects of time- and space-varying meteorological conditions for pollutant dispersion, transformation and deposition (USEPA, 2005; Zhou et al., 2006). The CALPUFF modelling suite comprises of three main components: CALMET, CALPUFF and CALPOST (Figure 4-1). CALMET is a diagnostic meteorological model that generates hourly surface wind fields and micrometeorological variables on a three-dimensional gridded domain for CALPUFF (Elbir, 2006; Hao et al., 2007; Lopez et al., 2005; Song et al., 2006; Zhou et al., 2003). CALPUFF is a non-steady-state Gaussian based transport and dispersion model. It uses three-dimensional meteorological fields developed by CALMET and a series of overlapping puffs to represent the spatial and temporal distribution of emissions from a source (Scire et al., 2000b; Song et al., 2006). The CALPOST program is a powerful postprocessor used to average and report results based on data in the CALPUFF model output files. (Wang, 2006). A brief overview of the CALMET and CALPUFF models is presented in the sections below.

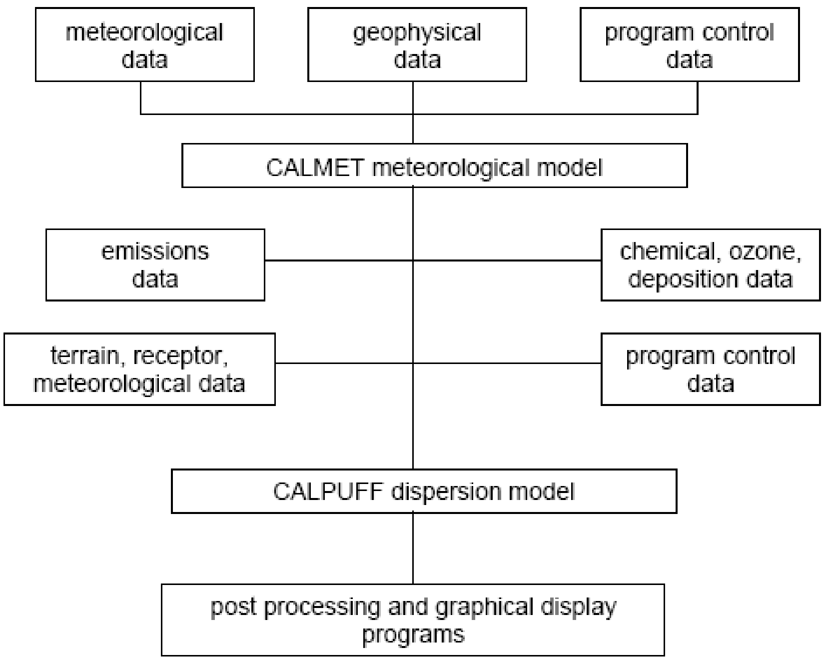

Figure 4-1: CALPUFF modelling system (Source: SRC, 2008)

CALMET

A three-dimensional wind field is computed by the CALMET meteorological model (USEPA, 2005). CALMET requires both geophysical data (terrain elevations and land use categories) and hourly meteorological data (wind speed, wind direction, temperature, cloud cover, ceiling height, surface pressure, relative humidity, precipitation and upper air sounding data) (USEPA, 2005; Scire and Robe, 2004).

CALMET consists of an advanced diagnostic wind field generator as well as a micrometeorological module for overwater and overland boundary layers. An initial guess wind field is modified to take account of kinematic effects of terrain, slope flows, valley flows and terrain blocking effects to create a Step 1 wind field. Observational data are then combined with this Step 1 wind field through an objective analysis procedure to generate the final Step 2 wind field (USEPA 2005; Scire 1999a; Scire 2000). CALPUFF advects and disperses along these wind vectors created by CALMET (Allwine et al., 1998).

CALPUFF

CALPUFF is a non-steady-state, time-and space-dependent Gaussian puff model which is designed to simulate the transport, dispersion, chemical reactions and deposition of gases and particles in the atmosphere (Ainslie and Jackson, 2009; Scire et al., 2000). CALPUFF treats emissions as a series of continuous puffs. Each puff is allowed to move with the ambient wind flow (Moschandreas et al., 2006). As the wind flow changes from hour to hour, the path of each puff is displaced in a Lagrangian fashion while undergoing Gaussian dispersion. The model predicted concentrations are calculated based on the contributions of each puff as it passes near or over a discrete receptor point in the modelling domain (Scire et al., 2000).

CALPUFF is able to model four different source types: point, line, volume and area sources within a single modelling domain. The model makes use of similarity theory to estimate the horizontal and vertical plume dispersion coefficients and contains comprehensive algorithms for both near-source stack and building effects (such as building downwash, partial penetration, plume rise) and long-range effects (chemical transformation, deposition, plume fumigation) (Ainslie and Jackson, 2009; Holmes and Morawska, 2006; USEPA, 2005).

The non-steady state approach of the CALPUFF model makes use of a full three-dimensional meteorological field which can account for spatial and temporal variability in the wind field and atmospheric stability (Scire and Robe, 2004). CALPUFF is able to take account of complex terrain effects, wind reversals, wind stagnation, and causality effects over large spatial scales (Beychok, 2005; Hao et al., 2007; Paradiz et al., 2008). These provide a more realistic simulation for dispersion and transport as opposed to steady-state Gaussian plume models (Elbir, 2003; Moschandreas et al., 2006).

4.4 Modelling domains and grid resolution

4.4.1 Meteorological Modelling Domains

TAPM

TAPM was used to model the hourly surface and upper air meteorology for the study area, for the period 2020 to 2022. TAPM was set-up in a nested configuration of three domains. The outer domain is 600 km by 600 km at a 24 km grid resolution, the middle domain is 300 km by 300 km at a 12 km grid resolution and the inner domain is 75 km by 75 km at a 3 km grid resolution (

Figure 4-2). The larger outer domains are used to initialise the inner fine-resolution modelling domains. The nesting configuration also ensures that topographical effects on meteorology are captured and that meteorology is well resolved and characterised across the boundaries of the inner domain. These simulations use default databases of global terrain height data, land use and synoptic scale meteorological analyses data as model input, as discussed in Section 4.3.

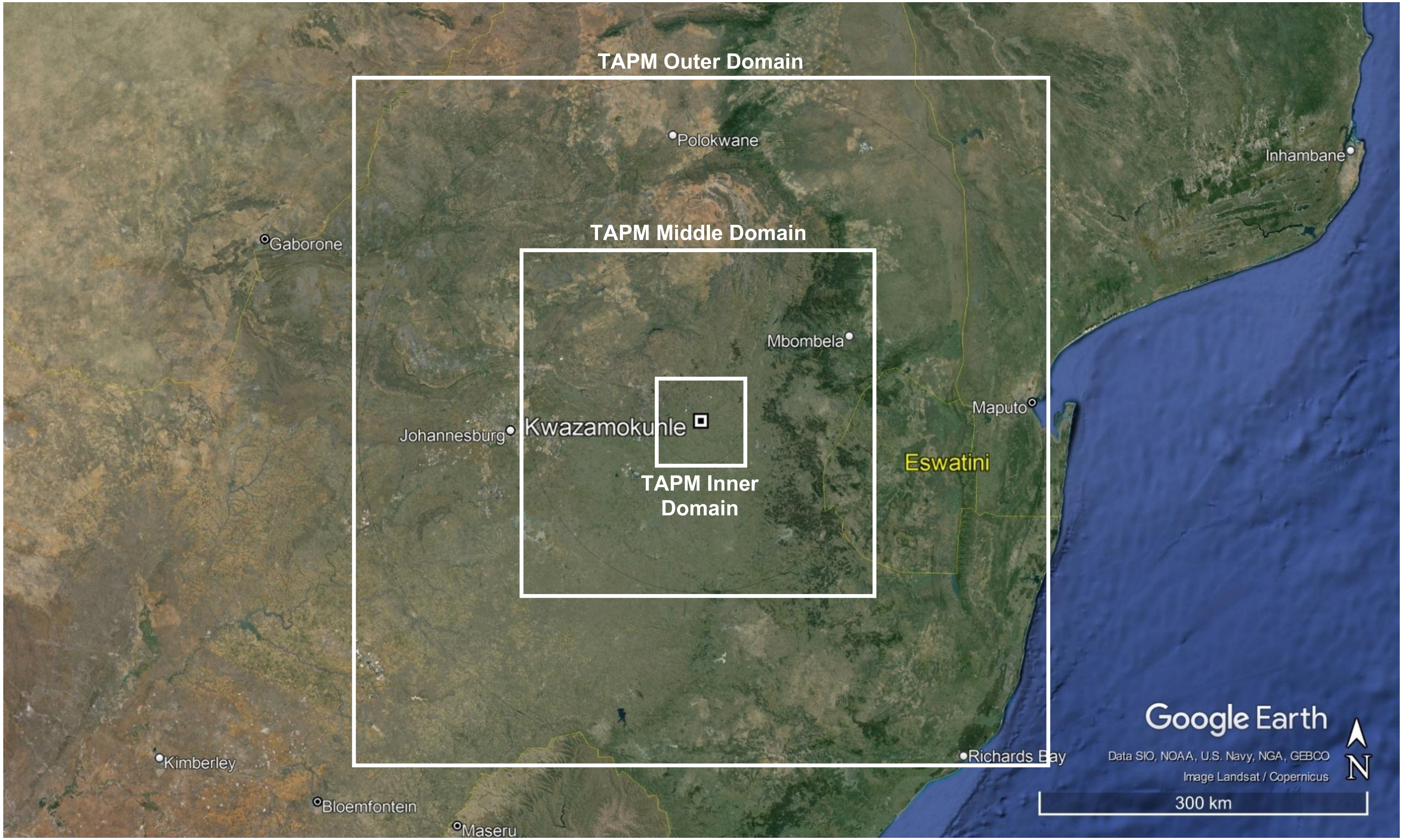

Figure 4-2: Nested grid domains used in the TAPM simulation

CALMET

The CALMET modelling domain for the study area has an extent of 65 km by 65 km with a uniformly spaced horizontal grid resolution of 1 km (Figure 4-2). The top of the domain was set at 5 km with 12 vertical levels.

4.4.2 Dispersion Modelling Domain

CALPUFF

A primary (coarse resolution) grid and a secondary (fine resolution) grid was used in the CALPUFF simulations (Figure 4-2**Error! Reference source not found.**). The grid specifications for each m odelling domain is specified in Table 4-1.

Table 4-1: CALPUFF modelling domain grid specifications

Variable	Primary Grid	Secondary Grid
Spatial Area (km^2)	3 721	64
Grid Distance (km) in x and y direction	61 x 61	8 x 8
Horizontal Grid resolution (m)	1 000	200
Number of grid cells in x and y direction	61 x 61	40 x 40
Total number of gridded receptors in domain	3 721	1 600

Primary Modelling Grid: Greater KwaZamokuhle Airshed

The domain extends 61 km (west-east) by 61 km (north-south) for a CALPUFF modelling domain of 3 721 km^2. It consists of a uniformly spaced Cartesian receptor grid with 1 000 m spacing, giving 3 721 grid cells (61 x 61 grid cells). This modelling domain caters for a range of emission source categories within a 30 km radius around KwaZamokuhle.

Secondary Modelling Grid: KwaZamokuhle Airshed

The domain extends 8 km (west-east) by 8 km (north-south) for a CALPUFF modelling domain of 64 km^2. It consists of a uniformly spaced Cartesian receptor grid with 200 m spacing, giving 1 600 grid cells (40 x 40 grid cells). This fine grid resolution ensures that dispersion characteristics and ambient concentrations are accurately captured within and in the immediate vicinity of KwaZamokuhle.

Modelling Grid used for the Residential Fuel Burning Study

The secondary modelling grid was used for the residential fuel burning study as it has a fine grid resolution and is large enough to capture dispersion characteristics and ambient concentrations a little beyond the area of focus.

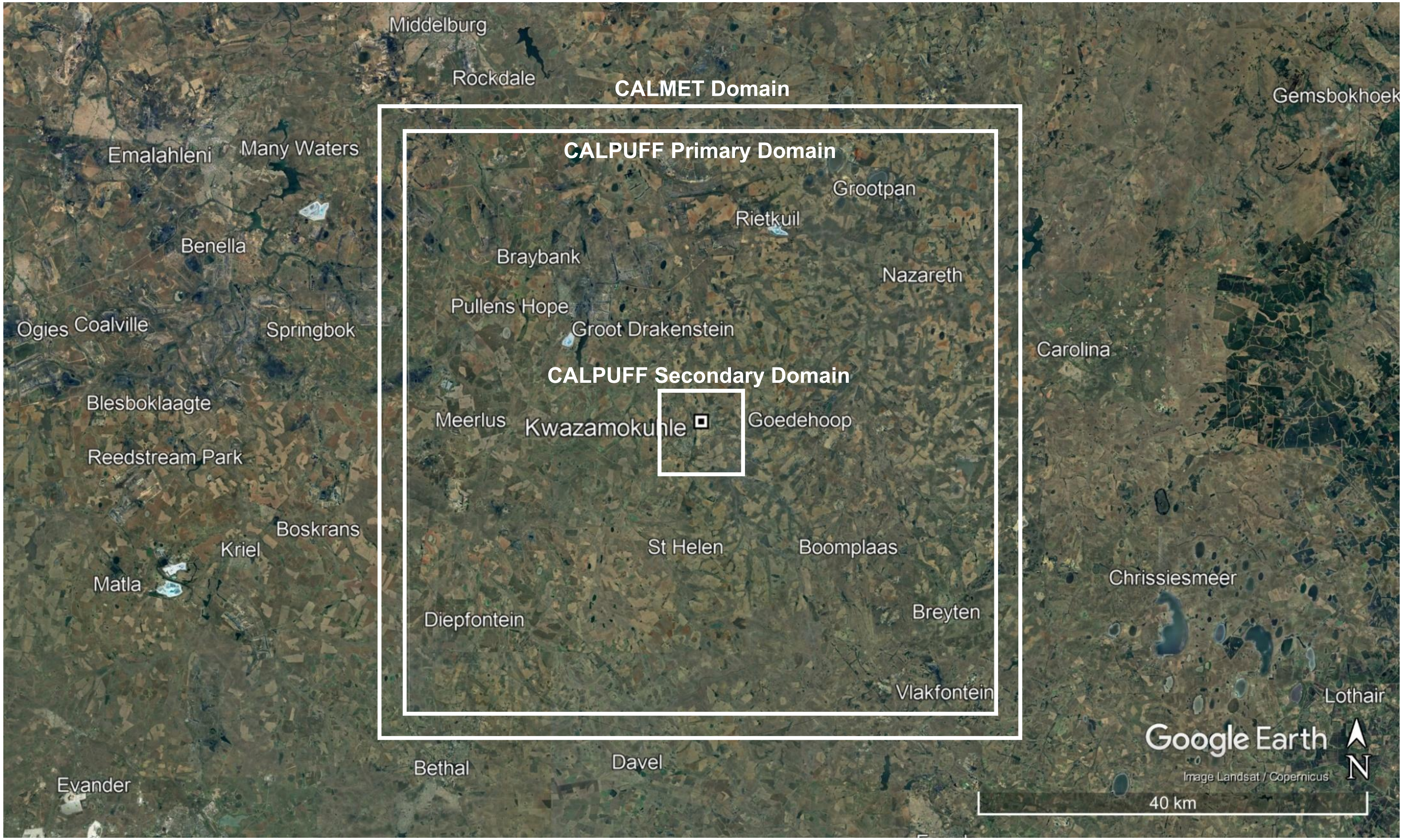

Figure 4-3: CALMET and CALPUFF Modelling Domains

4.5 Model Settings

A summary of model control options for CALMET and CALPUFF is presented in Table 4-2 and Table 4-3, respectively.

Table 4-2: Parameterization of key variables for CALMET

Parameter	Model value
12 vertical cell face heights (m)	0, 20, 40, 80, 160, 320, 640, 1000, 1500, 2000, 2500, 3000, 4000
Coriolis parameter (per second)	0.0001
Empirical constants for mixing height equation	Neutral, mechanical: 1.41 Convective: 0.15 Stable: 2400 Overwater, mechanical: 0.12
Minimum potential temperature lapse rate (K/m)	0.001
Depth of layer above convective mixing height through which lapse rate is computed (m)	200
Wind field model	Diagnostic wind module
Surface wind extrapolation	Similarity theory
Restrictions on extrapolation of surface data	No extrapolation as modelled upper air data field is used
Radius of influence of terrain features (km)	5
Radius of influence of surface stations (km)	Not applicable as continuous surface data field is used

Table 4-3: Parameterization of key variables for CALPUFF

Parameter	Model value
Chemical transformation	Default NO_2 conversion factor is applied
Wind speed profile	Rural
Calm conditions	Wind speed < 0.5 m/s
Plume rise	Transitional plume rise, stack tip downwash, and partial plume penetration is modelled
Dispersion	CALPUFF used in PUFF mode
Dispersion option	Pasquill-Gifford coefficients are used for rural and McElroy-Pooler coefficients are used for urban
Terrain adjustment method	Partial plume path adjustment

4.6 Pollutants Simulated

The CALPUFF suite of models was used to predict the dispersion of the following pollutants: SO_2, SO_4, NO_X, HNO_3, NO_3, PM_{10}, $PM_{2.5}$ and TPM (to calculate particulate/dust deposition rates) using the MESOPUFF II Scheme chemical transformation method. The MESOPUFF II Scheme is a pseudo-first-order chemical reaction mechanism for conversion of SO_2 to SO_4 and total NO_X to NO_3. Results of the modelling are presented for SO_2, NO_2, PM_{10} and $PM_{2.5}$.

The dispersion of the pollutants were simulated for the prevailing meteorological conditions for the period 1 January 2020 to 31 December 2022.

4.7 Total Particulate Calculation

Ambient particulate matter is a complex mixture of inorganic and organic compounds. The NAAQS regulates particulate matter for different size fractions (PM_{10} and $PM_{2.5}$) which are based on epidemiological evidence for mortality and cardiorespiratory health effects.

Sulphate and nitrate constitute a significant portion of the particle mass in the atmosphere. According to Reis *et. al* (2007) few epidemiological studies have included the sulphate content of particulate matter as a specific variable in health effect analyses. There is considerably less data for nitrates.

Reis *et. al* (2007) however demonstrated that epidemiologic and toxicological evidence provide little or no support for a causal association of particulate sulphate and health risk at ambient concentrations. Further, for nitrate-containing particulate matter, there is no epidemiological data and the toxicological evidence does not support a causal association between particulate nitrate compounds and excess health risks. There is insufficient evidence to include or exclude secondary organic processes for sulphates and nitrates as being potentially important to particulate matter associated health risk. (Reis *et. al*, 2007).

This baseline modelling study has taken a conservative approach (Scire, 2014) whereby the total concentrations of particulate matter (PM_{10} or $PM_{2.5}$) was computed as the sum of primary particulate matter concentrations (PM_{10} or $PM_{2.5}$) plus the contribution of concentrations from secondary particulate matter, including ammonium nitrate (NH_4NO_3) and ammonium sulphate ($(NH_4)_2SO_4$) as shown in the equation below:

Total PM_{10} or $PM_{2.5}$ = sum of (PM_{10} or $PM_{2.5}$) + $(NH_4)_2SO_4$ + NH_4NO_3

In this study, the total concentration of particulate matter (either PM_{10} or $PM_{2.5}$) was then compared to the applicable PM_{10} or $PM_{2.5}$ NAAQS (Table 2-3).

4.8 Emission Scenarios

In this study, only one emission scenario was considered: the residential fuel burning emission source category. A comprehensive emission inventory for this scenario is presented in Section 5.

4.9 Discrete Receptors

The location of discrete receptors that were selected for the KwaZamokuhle modelling domain is presented in Figure 4-4.

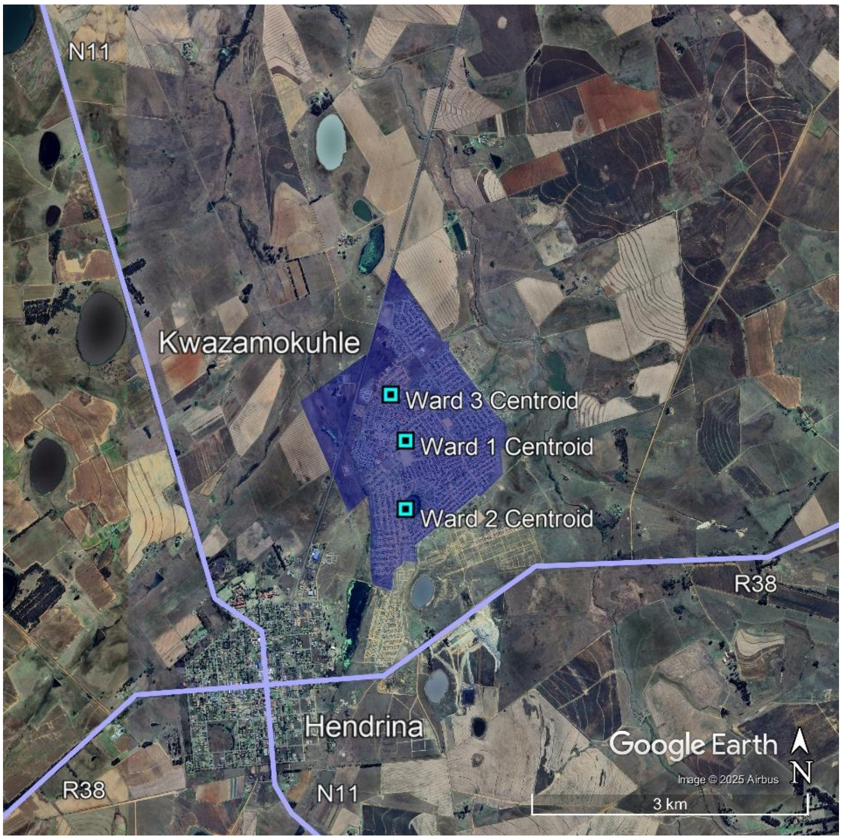

Figure 4-4: Location of discrete receptors for the modelling domain

5. EMISSION INVENTORY USED IN MODELLING

The identification of existing sources of emission in the modelling domain and the characterisation of existing ambient pollutant concentrations is fundamental to the assessment of the potential for cumulative impacts and synergistic effects given the existing operations and their associated emissions. In order to identify possible effects of reduction measures in an area it is necessary to prepare a representative emission inventory. In this study, an emission inventory was compiled for the residential fuel burning emission source category within the modelling domain.

The Emission Inventory for the residential fuel burning emission source category for KwaZamokuhle, representing the total nett reduction in emissions attributable to Eskom's Phase 1 AQO Project (tonnes) in KwaZamokuhle is presented in Table 5-1 and Figure 5-1 for SO_2, NO_2, PM_{10} and $PM_{2.5}$.

Table 5-1: Emission Inventory for the residential fuel burning emission source category for KwaZamokuhle, representing the total nett reduction in emissions attributable to Eskom's Phase 1 AQO Project (tonnes) in KwaZamokuhle

Indicative number of households for air quality offsets	Coal use per household (tonnes)	Coal use for all households (tonnes)	Estimated air quality benefit (based on ARM 2024 Study) (tonnes)			
			SO_2	NO_X (as NO_2)	PM_{10}	$PM_{2.5}$
2250	2.4	5400	53.51	24.57	69.71	64.85

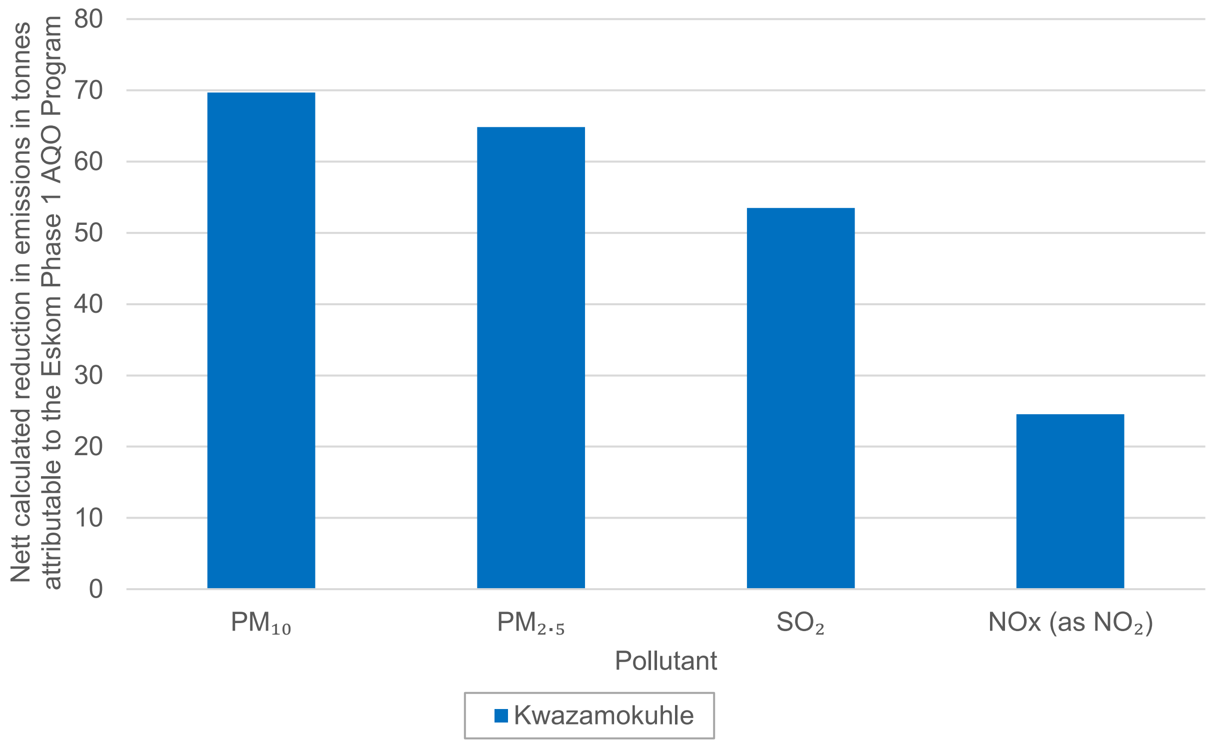

Figure 5-1: Total nett reduction in emissions attributable to Eskom's Phase 1 AQO Project (tonnes) for KwaZamokuhle

6. RESULTS & DISCUSSION

The CALPUFF dispersion model uses mathematical formulations to characterize the atmospheric processes that disperse a pollutant emitted by a source. In this study, the CALPUFF dispersion model was used to predict ambient concentrations of SO_2, NO_2, PM_{10} and $PM_{2.5}$ within the modelling domain, based on emissions from the residential fuel burning emission source category and meteorological data for a three-year period spanning from 2020 to 2022. Model predicted results for SO_2, NO_2, PM_{10} and $PM_{2.5}$ are assessed against the respective NAAQS.

This section is made up of several sub-sections as follows:

- Predicted SO_2 ambient concentrations
    - 1-hour SO_2
    - 24-hour SO_2
    - Annual SO_2
- Predicted NO_2 ambient concentrations
    - 1-hour NO_2
    - Annual NO_2
- Predicted PM_{10} ambient concentrations
    - 24-hour PM_{10}
    - Annual PM_{10}
- Predicted $PM_{2.5}$ ambient concentrations
    - 24-hour $PM_{2.5}$
    - Annual $PM_{2.5}$

In each subsection for SO_2, NO_2, PM_{10} and $PM_{2.5}$, model predicted ambient concentrations at each discrete receptor and at the point of maximum within the modelling domain, are presented in the form of a table. The 1-hour and 24-hour concentrations are based on the 99^{th} percentile.

This is then followed by bar graphs which graphically illustrate the respective predicted ambient concentrations at each of the discrete receptors. Below each graph is a corresponding contour plot representing the respective model predicted ambient concentrations for the KwaZamokuhle airshed.

6.1 Predicted SO_2 ambient concentrations

6.1.1 1-hour SO_2

Model predicted 1-hour SO_2 ambient concentrations at discrete receptors and at the point of maximum are presented in Table 6-1. If applicable, exceedances of the NAAQS are highlighted in red.

Bar graphs for model predicted 1-hour SO_2 ambient concentrations at discrete receptors and at the point of maximum are presented in Figure 6-1.

Contour plots for model predicted 1-hour SO_2 ambient concentrations are presented in Figure 6-2. With respect to contour plots, areas of exceedance of the NAAQS are coloured in red.

According to Table 6-1, model predicted 1-hour SO_2 ambient concentrations exceed the 1-hour SO_2 NAAQS of 350 µg/m³ at the point of maximum for the residential fuel burning emission source category.

Table 6-1: Model predicted 1-hour SO_2 ambient concentrations (99th percentile) in µg/m³ at discrete receptors and at the point of maximum for the residential fuel burning emission source category

Discrete Receptors	Residential Fuel Burning
Ward 1 Centroid	182.02
Ward 2 Centroid	333.29
Ward 3 Centroid	149.80
Maximum	566.57
	NAAQS – 1-hour SO_2 (350 µg/m³)

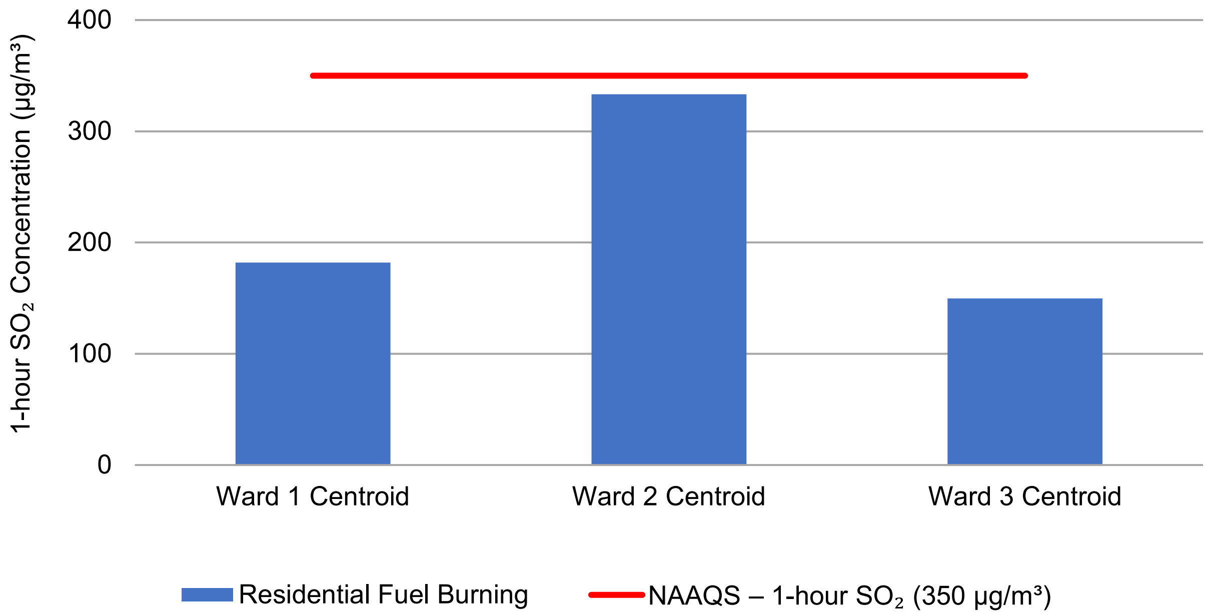

Figure 6-1: Model predicted 1-hour SO_2 ambient concentrations (99th percentile) in µg/m^3 at discrete receptors for the residential fuel burning emission source category

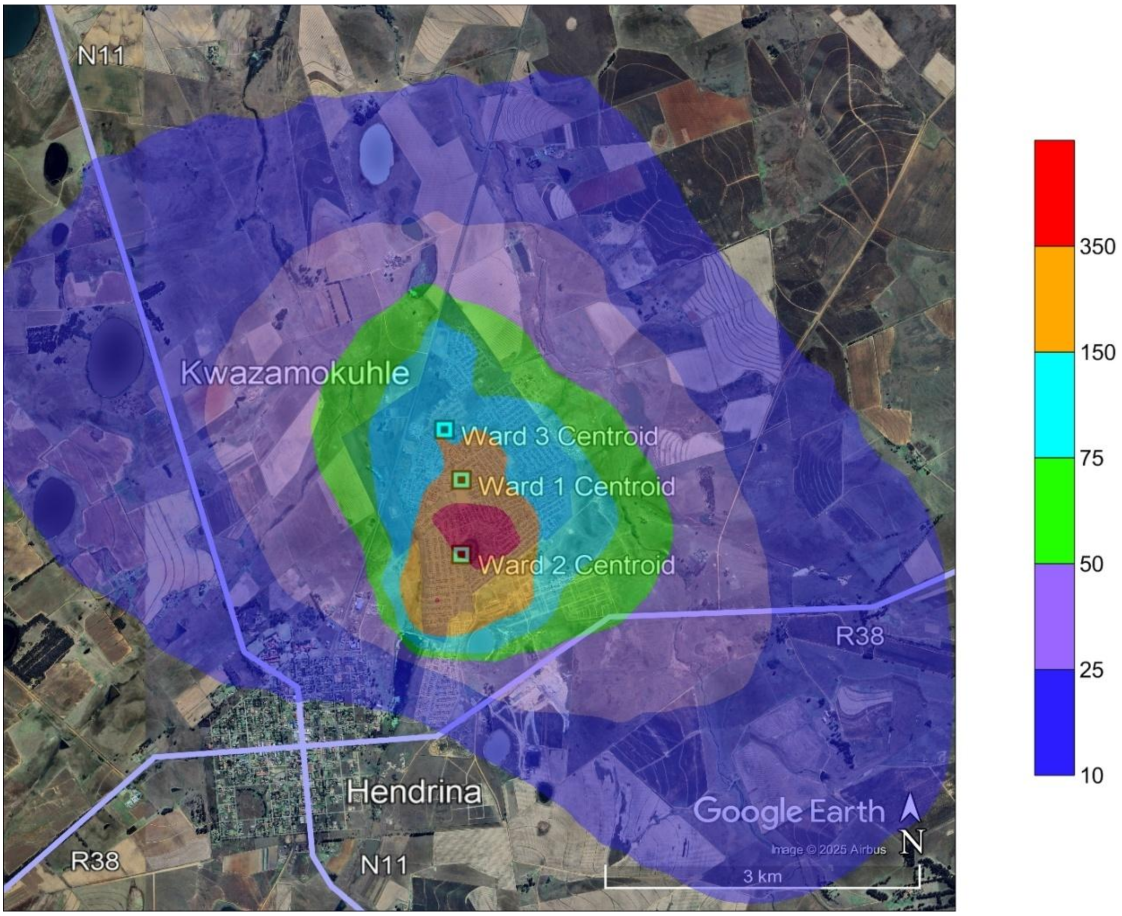

Figure 6-2: Model predicted 1-hour SO_2 ambient concentrations (99th percentile) in µg/m^3 for the residential fuel burning emission source category

6.1.2 24-HOUR SO_2

Model predicted 24-hour SO_2 ambient concentrations at discrete receptors and at the point of maximum are presented in Table 6-2. If applicable, exceedances of the NAAQS are highlighted in red.

Bar graphs for model predicted 24-hour SO_2 ambient concentrations at discrete receptors and at the point of maximum are presented in Figure 6-3.

Contour plots for model predicted 24-hour SO_2 ambient concentrations are presented in Figure 6-4. With respect to contour plots, areas of exceedance of the NAAQS are coloured in red.

According to Table 6-2, model predicted 24-hour SO_2 ambient concentrations exceed the 24-hour SO_2 NAAQS of 125 µg/m³ at the point of maximum for the residential fuel burning emission source category.

Table 6-2: Model predicted 24-hour SO_2 ambient concentrations (99th percentile) in µg/m³ at discrete receptors and at the point of maximum for the residential fuel burning emission source category

Discrete Receptors	Residential Fuel Burning
Ward 1 Centroid	74.82
Ward 2 Centroid	101.52
Ward 3 Centroid	45.48
Maximum	156.87
	NAAQS – 24-hour SO_2 (125 µg/m³)

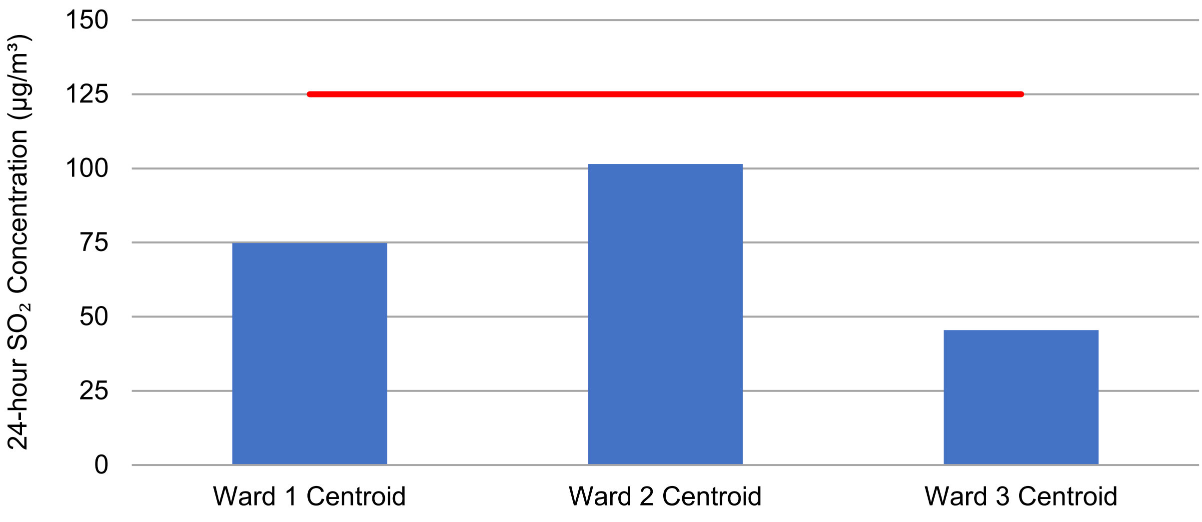

Figure 6-3: Model predicted 24-hour SO_2 ambient concentrations (99th percentile) in µg/m^3 at discrete receptors for the residential fuel burning emission source category

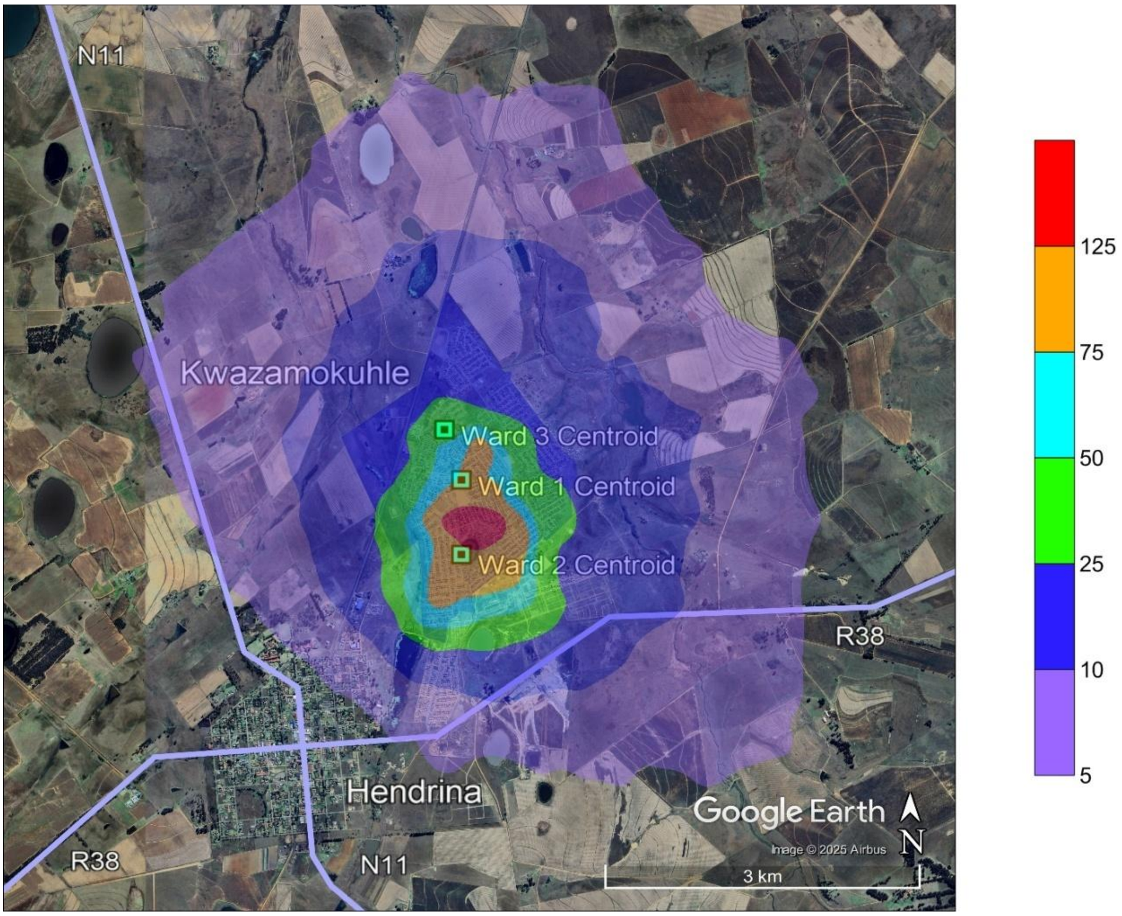

Figure 6-4: Model predicted 24-hour SO_2 ambient concentrations (99th percentile) in µg/m^3 for the residential fuel burning emission source category

6.1.3 Annual SO_2

Model predicted annual SO_2 ambient concentrations at discrete receptors and at the point of maximum are presented in Table 6-3. If applicable, exceedances of the NAAQS are highlighted in red.

Bar graphs for model predicted annual SO_2 ambient concentrations at discrete receptors and at the point of maximum are presented in Figure 6-5.

Contour plots for model predicted annual SO_2 ambient concentrations are presented in Figure 6-6. With respect to contour plots, areas of exceedance of the NAAQS are coloured in red.

According to Table 6-3, model predicted annual SO_2 ambient concentrations exceed the annual SO_2 NAAQS of 50 µg/m³ at the point of maximum for the residential fuel burning emission source category.

Table 6-3: Model predicted annual SO_2 ambient concentrations in µg/m³ at discrete receptors and at the point of maximum for the residential fuel burning emission source category

Discrete Receptors	Residential Fuel Burning
Ward 1 Centroid	20.59
Ward 2 Centroid	33.21
Ward 3 Centroid	10.52
Maximum	61.38
	NAAQS – annual SO_2 (50 µg/m³)

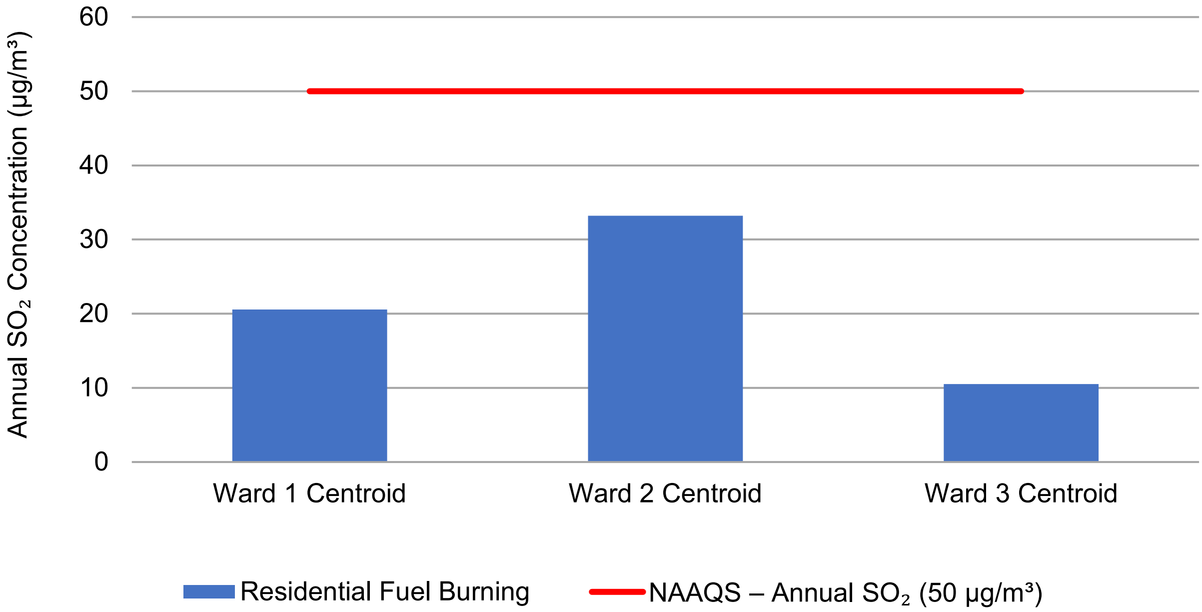

Figure 6-5: Model predicted annual SO_2 ambient concentrations in µg/m³ at discrete receptors for the residential fuel burning emission source category

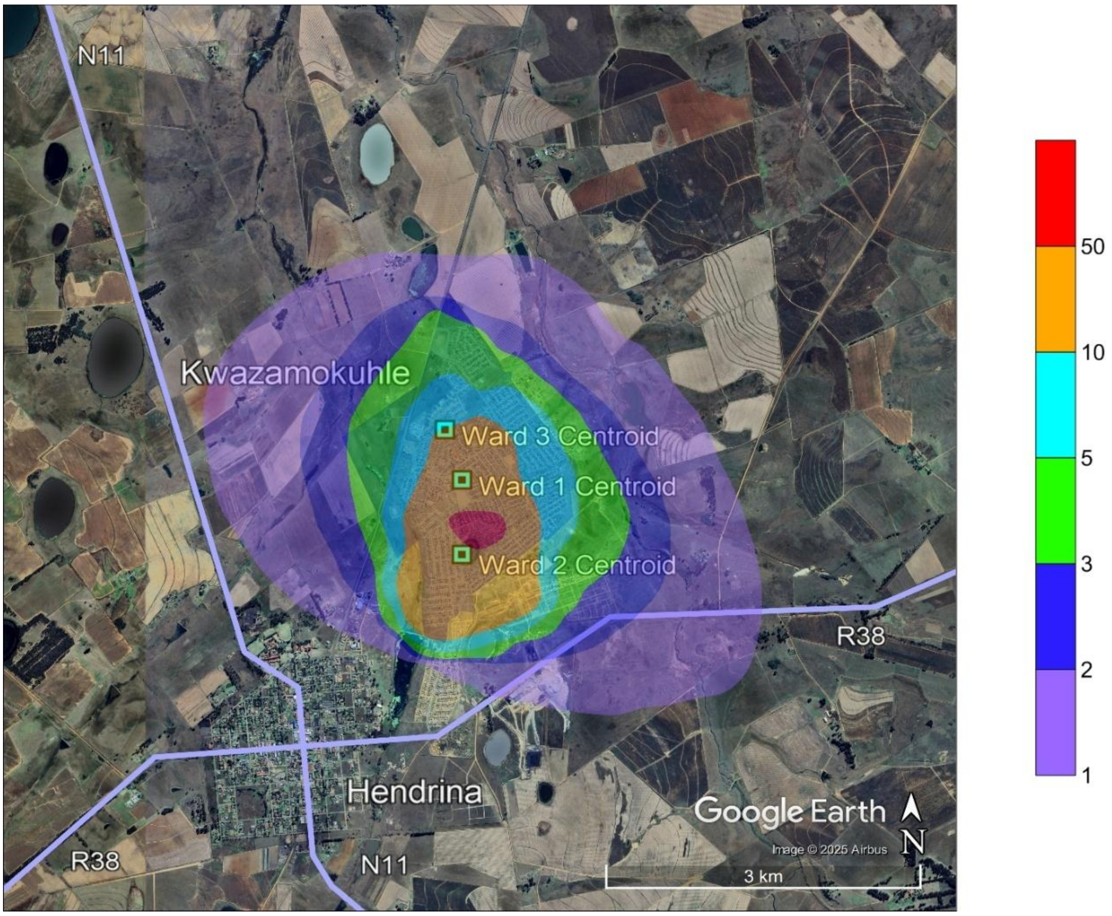

Figure 6-6: Model predicted annual SO_2 ambient concentrations in µg/m³ for the residential fuel burning emission source category

6.2 Predicted NO_2 ambient concentrations

6.2.1 1-hour NO_2

Model predicted 1-hour NO_2 ambient concentrations at discrete receptors and at the point of maximum are presented in Table 6-4. If applicable, exceedances of the NAAQS are highlighted in red.

Bar graphs for model predicted 1-hour NO_2 ambient concentrations at discrete receptors and at the point of maximum are presented in Figure 6-7.

Contour plots for model predicted 1-hour NO_2 ambient concentrations are presented in Figure 6-8. With respect to contour plots, areas of exceedance of the NAAQS are coloured in red.

According to Table 6-4, model predicted 1-hour NO_2 ambient concentrations exceed the 1-hour NO_2 NAAQS of 200 µg/m³ at the point of maximum for the residential fuel burning emission source category.

Table 6-4: Model predicted 1-hour NO_2 ambient concentrations (99th percentile) in µg/m³ at discrete receptors and at the point of maximum for the residential fuel burning emission source category

Discrete Receptors	Residential Fuel Burning
Ward 1 Centroid	66.95
Ward 2 Centroid	122.34
Ward 3 Centroid	55.05
Maximum	208.21
	NAAQS – 1-hour NO_2 (200 µg/m³)

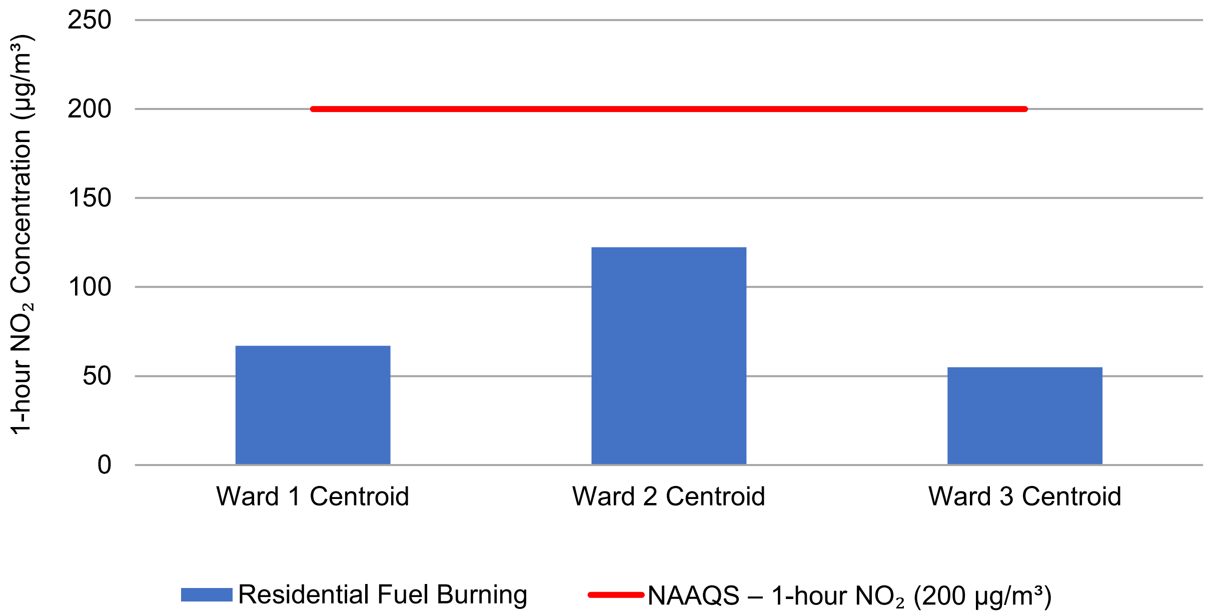

Figure 6-7: Model predicted 1-hour NO_2 ambient concentrations (99th percentile) in µg/m³ at discrete receptors for the residential fuel burning emission source category

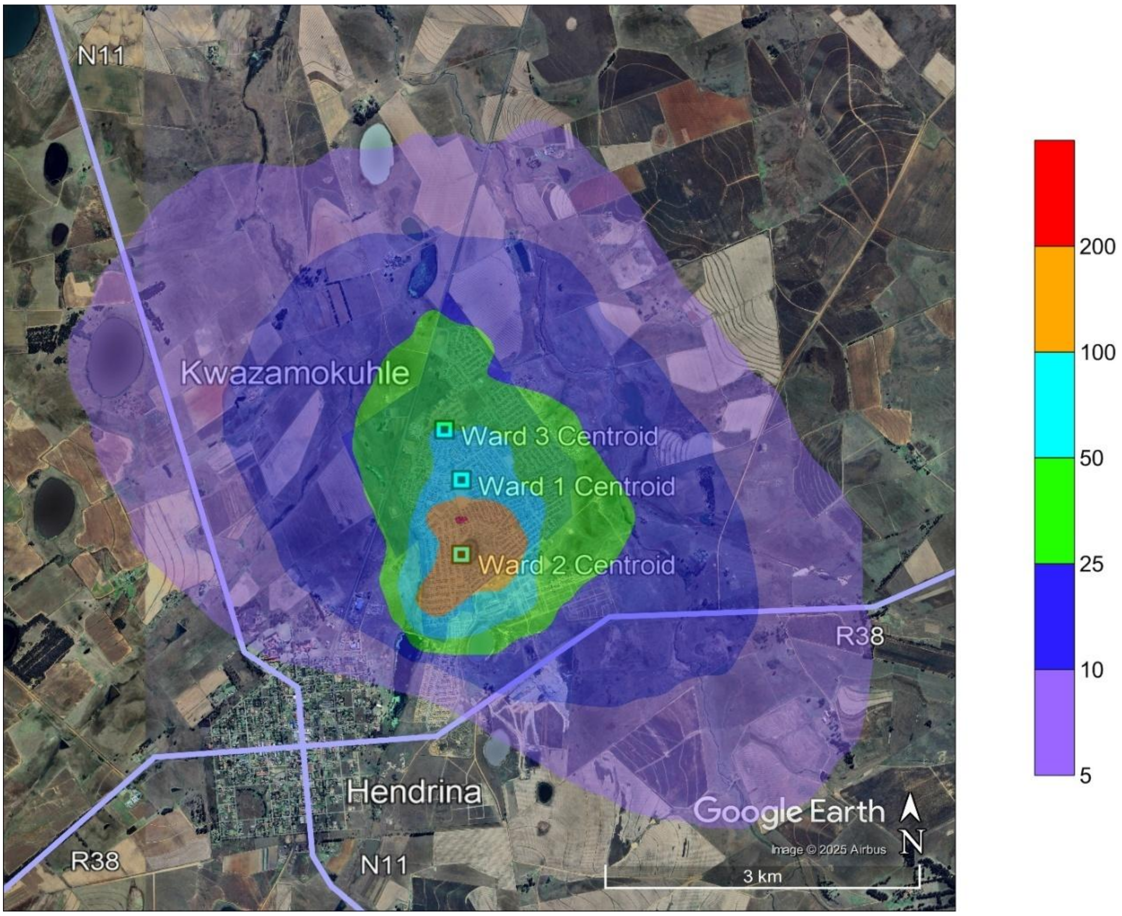

Figure 6-8: Model predicted 1-hour NO_2 ambient concentrations (99th percentile) in µg/m³ for the residential fuel burning emission source category

6.2.2 Annual NO_2

Model predicted annual NO_2 ambient concentrations at discrete receptors and at the point of maximum are presented in Table 6-5. If applicable, exceedances of the NAAQS are highlighted in red.

Bar graphs for model predicted annual NO_2 ambient concentrations at discrete receptors and at the point of maximum are presented in Figure 6-9.

Contour plots for model predicted annual NO_2 ambient concentrations are presented in Figure 6-10. With respect to contour plots, areas of exceedance of the NAAQS are coloured in red.

According to Table 6-5, model predicted annual NO_2 ambient concentrations do not exceed the annual NO_2 NAAQS of 40 µg/m³ at any of the discrete receptors or at the point of maximum for the residential fuel burning emission source category.

Table 6-5: Model predicted annual NO_2 ambient concentrations in µg/m³ at discrete receptors and at the point of maximum for the residential fuel burning emission source category

Discrete Receptors	Residential Fuel Burning
Ward 1 Centroid	7.55
Ward 2 Centroid	12.18
Ward 3 Centroid	3.85
Maximum	22.54
	NAAQS – annual NO_2 (40 µg/m³)

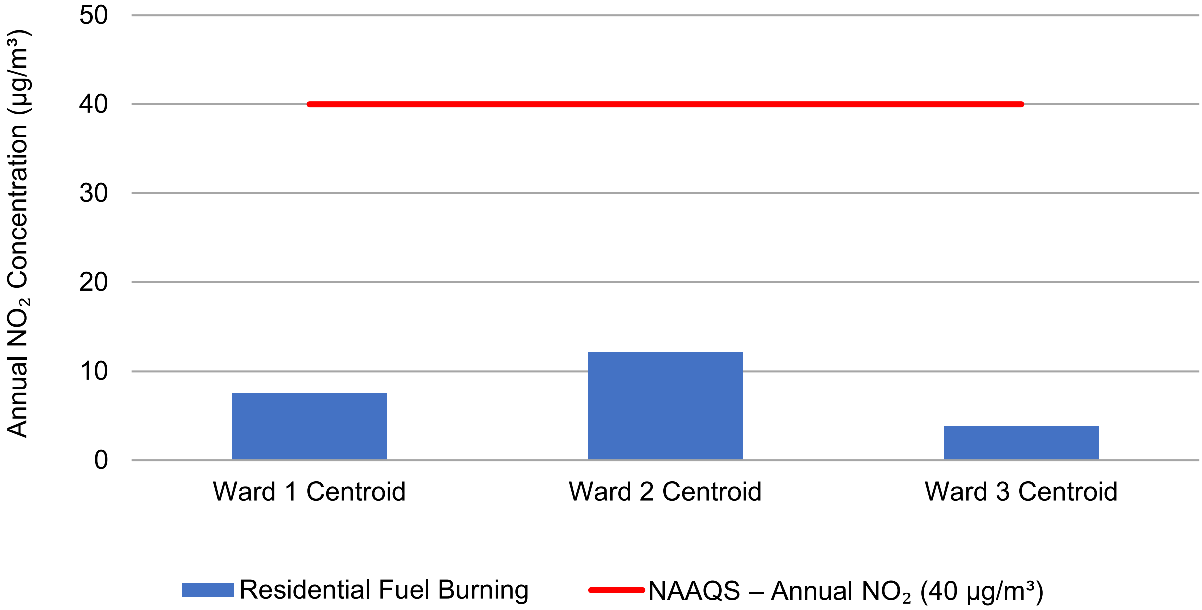

Figure 6-9: Model predicted annual NO_2 ambient concentrations in µg/m³ at discrete receptors for the residential fuel burning emission source category

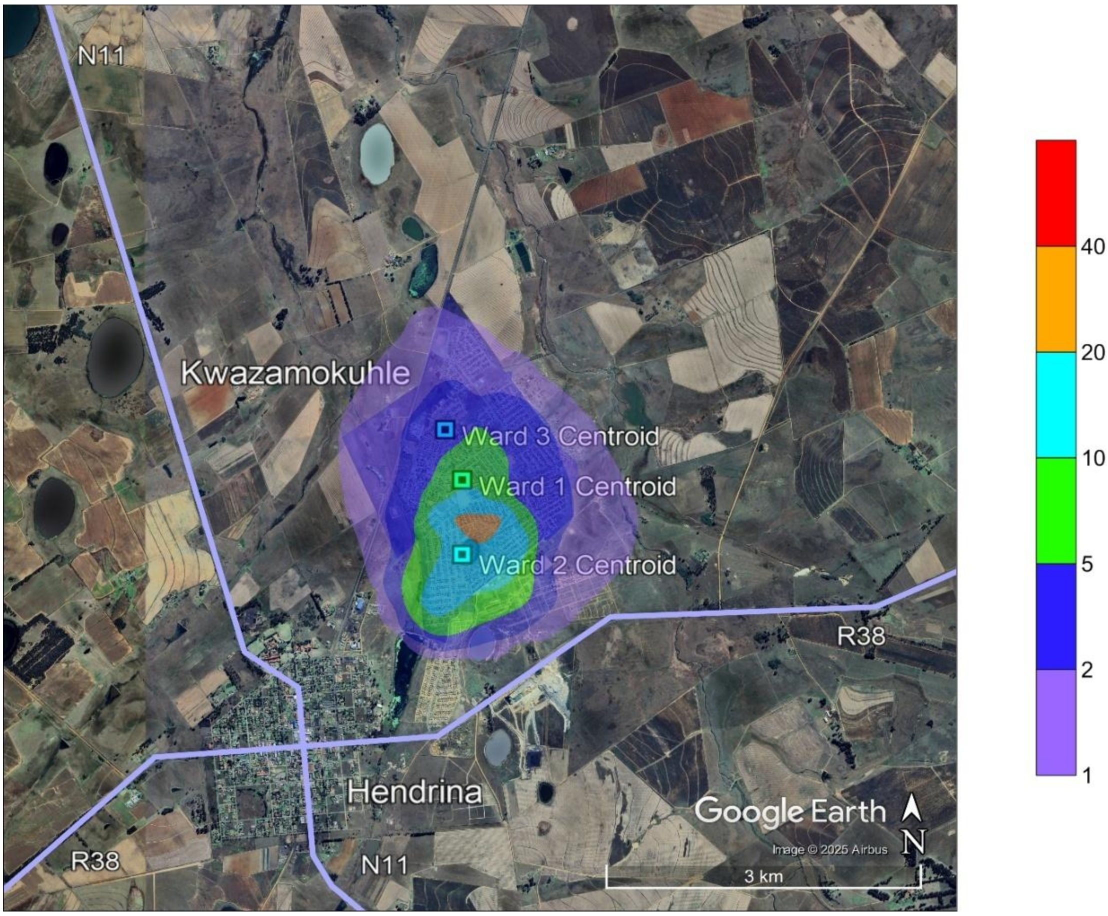

Figure 6-10: Model predicted annual NO_2 ambient concentrations in µg/m³ for the residential fuel burning emission source category

6.3 Predicted PM_{10} Ambient Concentrations

6.3.1 24-hour PM_{10}

Model predicted 24-hour PM_{10} ambient concentrations at discrete receptors and at the point of maximum are presented in Table 6-6. If applicable, exceedances of the NAAQS are highlighted in red.

Bar graphs for model predicted 24-hour PM_{10} ambient concentrations at discrete receptors and at the point of maximum are presented in Figure 6-11.

Contour plots for model predicted 24-hour PM_{10} ambient concentrations are presented in Figure 6-12. With respect to contour plots, areas of exceedance of the NAAQS are coloured in red.

According to Table 6-6, model predicted 24-hour PM_{10} ambient concentrations exceed the 24-hour PM_{10} NAAQS of 75 µg/m³ at the Ward 1 and Ward 2 Centroid discrete receptors and at the point of maximum for the residential fuel burning emission source category.

Table 6-6: Model predicted 24-hour PM_{10} ambient concentrations (99th percentile) in µg/m³ at discrete receptors and at the point of maximum for the residential fuel burning emission source category

Discrete Receptors	Residential Fuel Burning
Ward 1 Centroid	97.44
Ward 2 Centroid	132.09
Ward 3 Centroid	59.26
Maximum	204.11
	NAAQS – 24-hour PM_{10} (75 µg/m³)

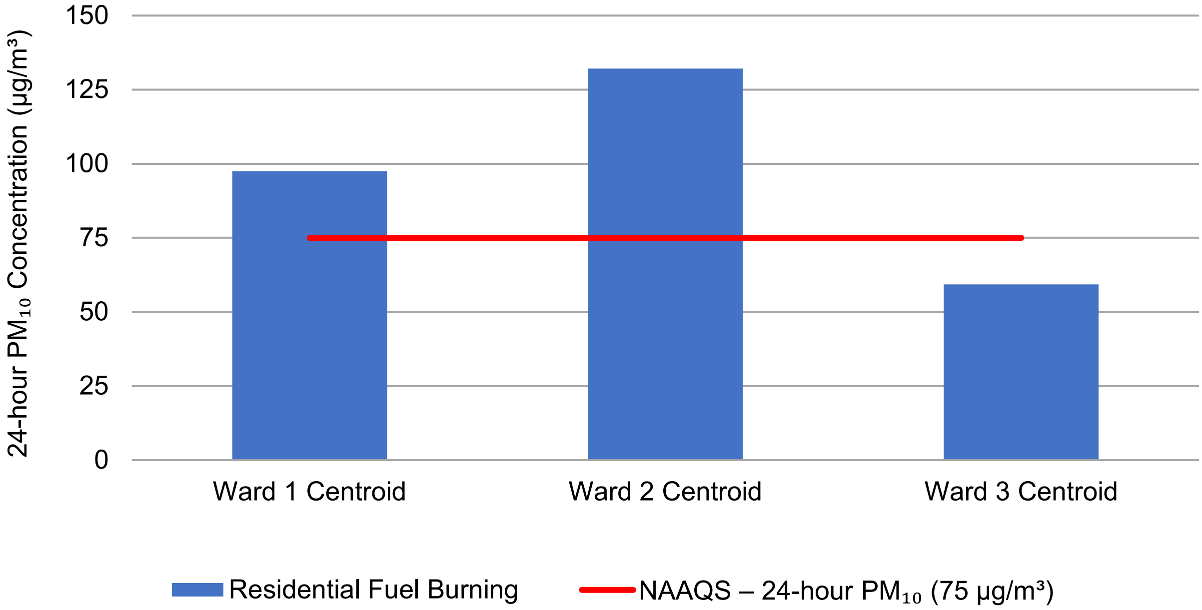

Figure 6-11: Model predicted 24-hour PM_{10} ambient concentrations (99th percentile) in µg/m³ at discrete receptors for the residential fuel burning emission source category

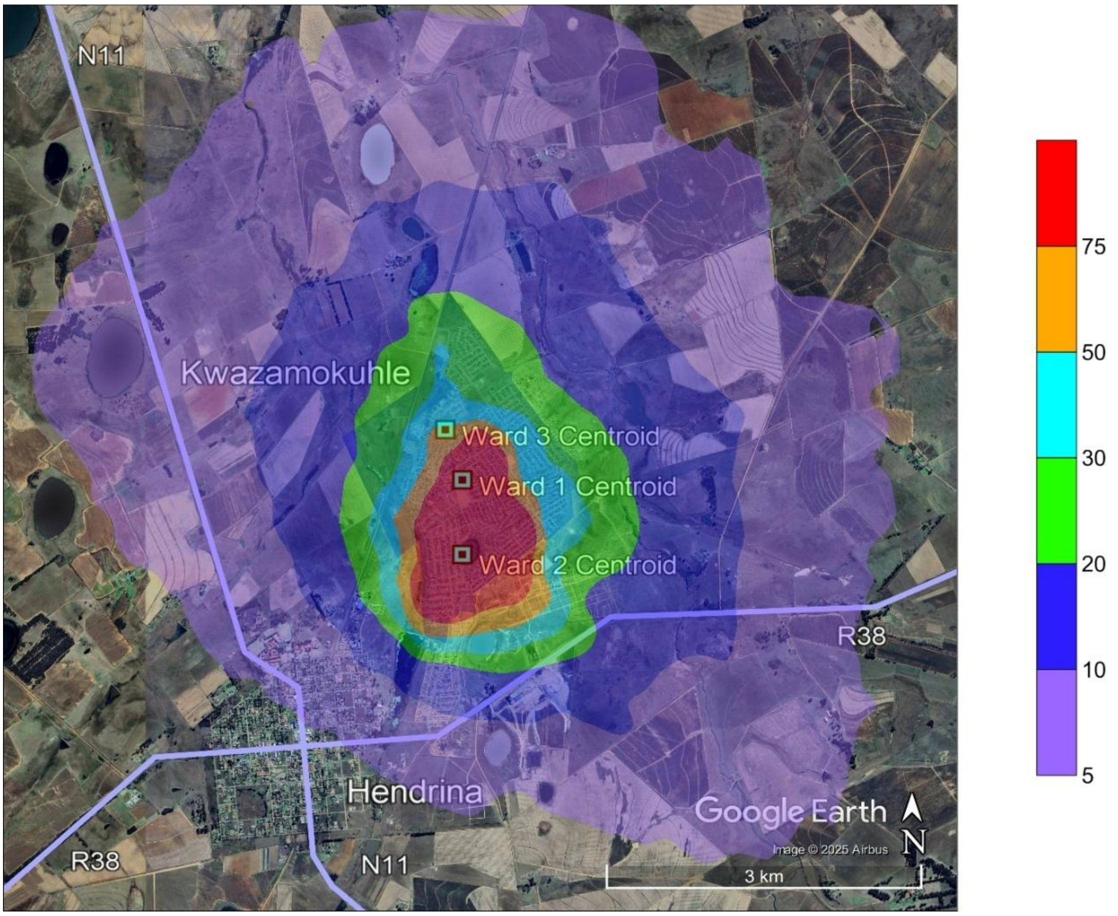

Figure 6-12: Model predicted 24-hour PM_{10} ambient concentrations (99th percentile) in µg/m³ for the residential fuel burning emission source category

6.3.2 ANNUAL PM_{10}

Model predicted annual PM_{10} ambient concentrations at discrete receptors and at the point of maximum are presented in Table 6-7. If applicable, exceedances of the NAAQS are highlighted in red.

Bar graphs for model predicted annual PM_{10} ambient concentrations at discrete receptors and at the point of maximum are presented in Figure 6-13.

Contour plots for model predicted annual PM_{10} ambient concentrations are presented in Figure 6-14. With respect to contour plots, areas of exceedance of the NAAQS are coloured in red.

According to Table 6-7, model predicted annual PM_{10} ambient concentrations exceed the annual PM_{10} NAAQS of 40 µg/m³ at the Ward 2 Centroid discrete receptor and at the point of maximum for the residential fuel burning emission source category.

Table 6-7: Model predicted annual PM_{10} ambient concentrations in µg/m³ at discrete receptors and at the point of maximum for the residential fuel burning emission source category

Discrete Receptors	Residential Fuel Burning
Ward 1 Centroid	26.75
Ward 2 Centroid	43.13
Ward 3 Centroid	13.68
Maximum	79.70
	NAAQS – annual PM_{10} (40 µg/m³)

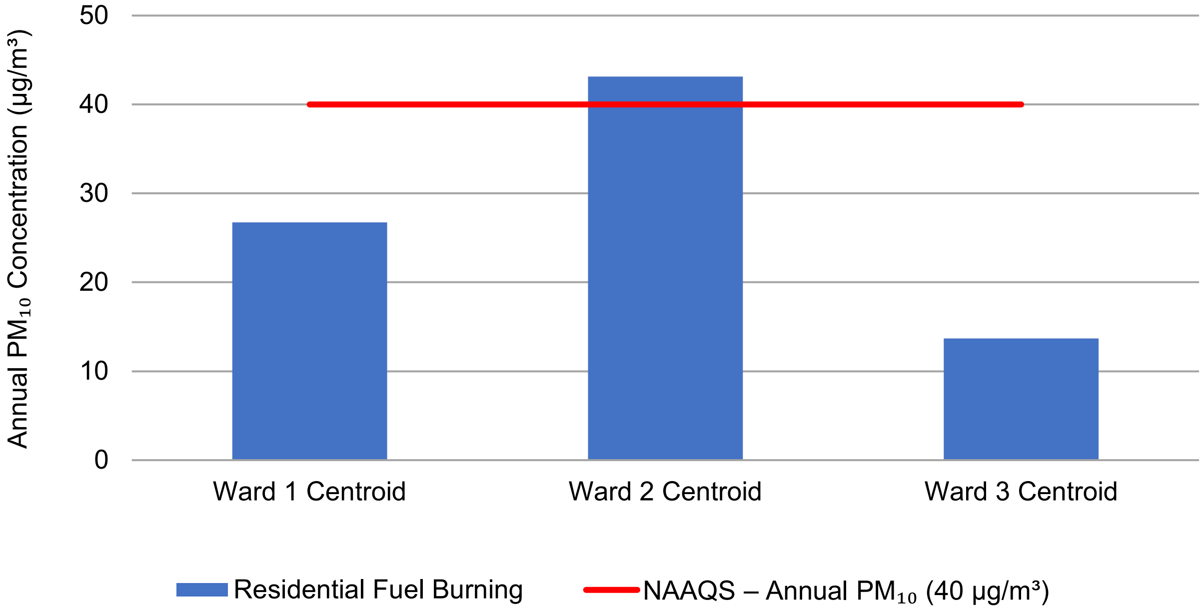

Figure 6-13: Model predicted annual PM_{10} ambient concentrations in µg/m^3 at discrete receptors for the residential fuel burning emission source category

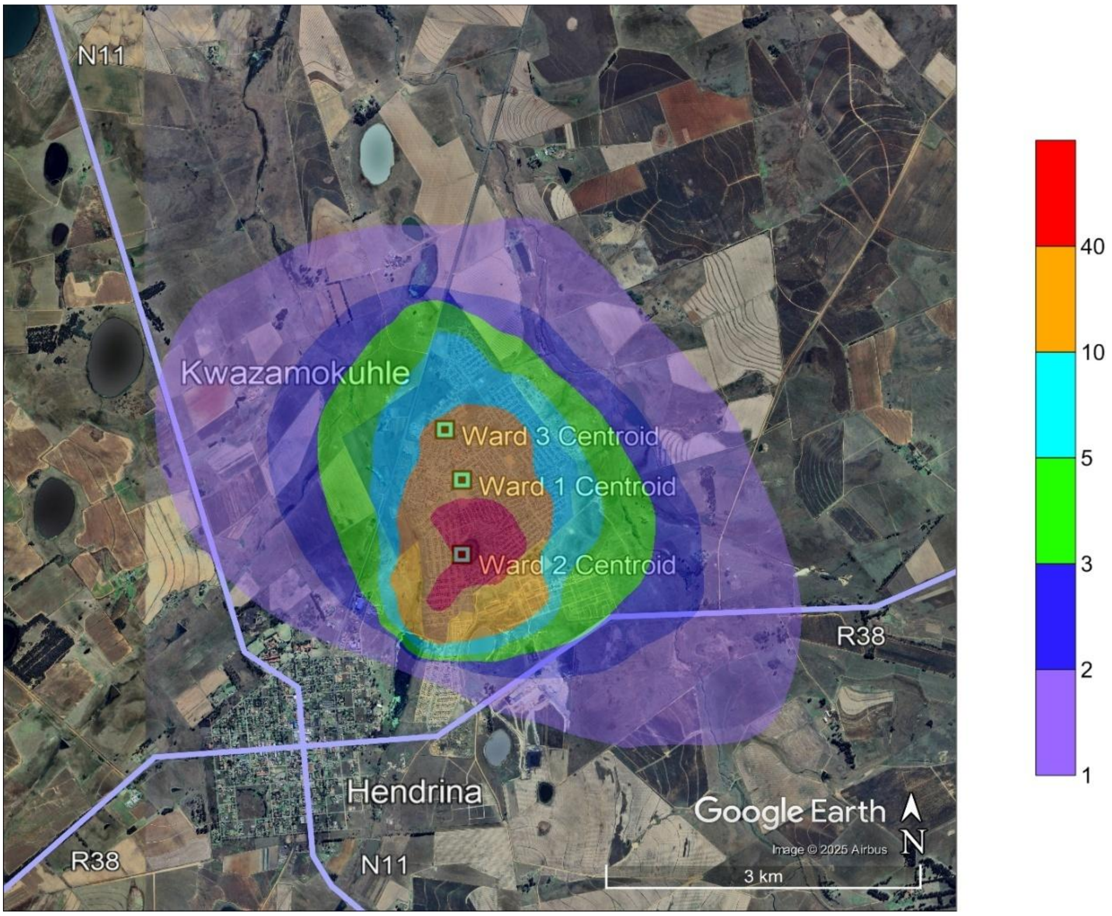

Figure 6-14: Model predicted annual PM_{10} ambient concentrations in µg/m^3 for the residential fuel burning emission source category

6.4 Predicted $PM_{2.5}$ ambient concentrations

6.4.1 24-hour $PM_{2.5}$

Model predicted 24-hour $PM_{2.5}$ ambient concentrations at discrete receptors and at the point of maximum are presented in Table 6-8. If applicable, exceedances of the NAAQS are highlighted in red.

Bar graphs for model predicted 24-hour $PM_{2.5}$ ambient concentrations at discrete receptors and at the point of maximum are presented in Figure 6-15.

Contour plots for model predicted 24-hour $PM_{2.5}$ ambient concentrations are presented in Figure 6-16. With respect to contour plots, areas of exceedance of the NAAQS are coloured in red.

According to Table 6-8, model predicted 24-hour $PM_{2.5}$ ambient concentrations exceed the 24-hour $PM_{2.5}$ NAAQS of 40 µg/m³ at the Ward 1, Ward 2 and Ward 3 Centroid discrete receptors and at the point of maximum for the residential fuel burning emission source category.

Table 6-8: Model predicted 24-hour $PM_{2.5}$ ambient concentrations (99th percentile) in µg/m³ at discrete receptors and at the point of maximum for the residential fuel burning emission source category

Discrete Receptors	Residential Fuel Burning
Ward 1 Centroid	90.50
Ward 2 Centroid	122.68
Ward 3 Centroid	55.05
Maximum	189.57
	NAAQS – 24-hour $PM_{2.5}$ (40 µg/m³)

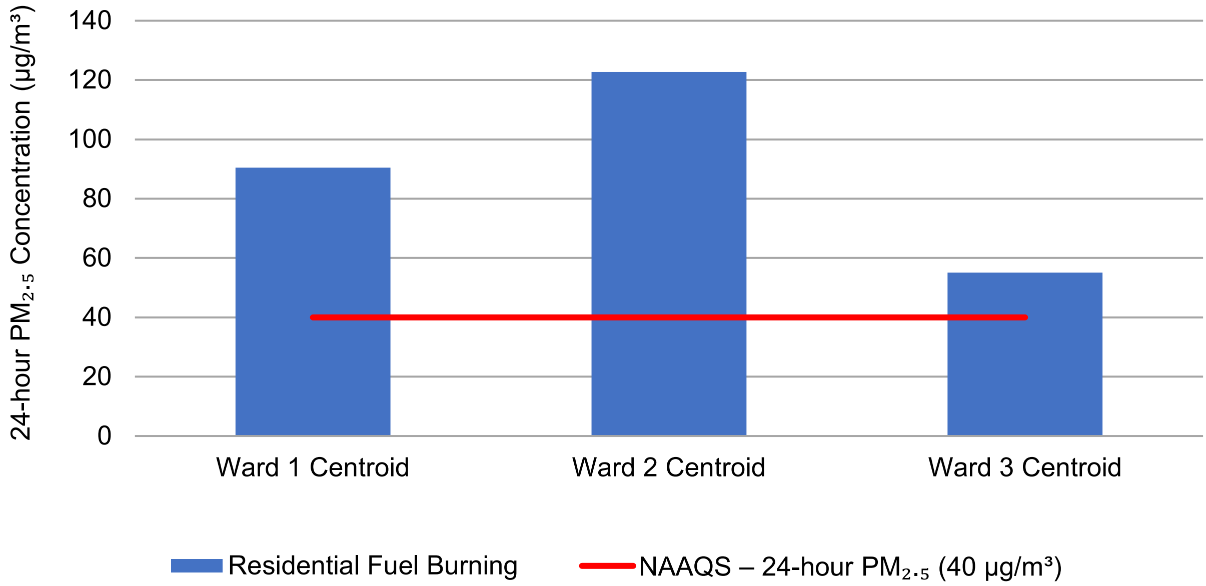

Figure 6-15: Model predicted 24-hour $PM_{2.5}$ ambient concentrations (99th percentile) in µg/m³ at discrete receptors for the residential fuel burning emission source category

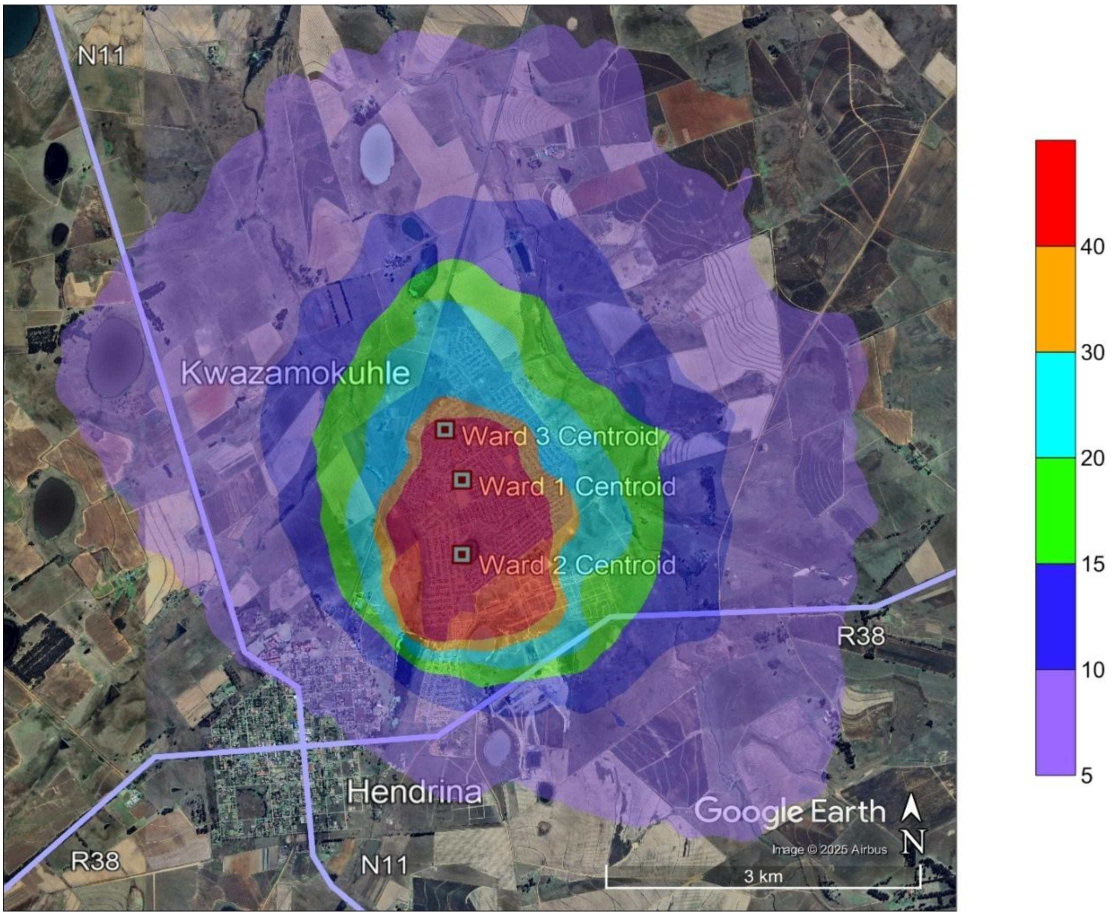

Figure 6-16: Model predicted 24-hour $PM_{2.5}$ ambient concentrations (99th percentile) in µg/m³ for the residential fuel burning emission source category

6.4.2 ANNUAL $PM_{2.5}$

Model predicted annual $PM_{2.5}$ ambient concentrations at discrete receptors and at the point of maximum are presented in Table 6-9. If applicable, exceedances of the NAAQS are highlighted in red.

Bar graphs for model predicted annual $PM_{2.5}$ ambient concentrations at discrete receptors and at the point of maximum are presented in Figure 6-17.

Contour plots for model predicted annual $PM_{2.5}$ ambient concentrations are presented in Figure 6-18. With respect to contour plots, areas of exceedance of the NAAQS are coloured in red.

According to Table 6-9, model predicted annual $PM_{2.5}$ ambient concentrations exceed the annual $PM_{2.5}$ NAAQS of 20 µg/m³ at the Ward 1, Ward 2 and Ward 3 Centroid discrete receptors and at the point of maximum for the residential fuel burning emission source category.

Table 6-9: Model predicted annual $PM_{2.5}$ ambient concentrations in µg/m³ at discrete receptors and at the point of maximum for the residential fuel burning emission source category

Discrete Receptors	Residential Fuel Burning
Ward 1 Centroid	24.84
Ward 2 Centroid	40.06
Ward 3 Centroid	12.70
Maximum	74.02
	NAAQS – annual $PM_{2.5}$ (20 µg/m³)

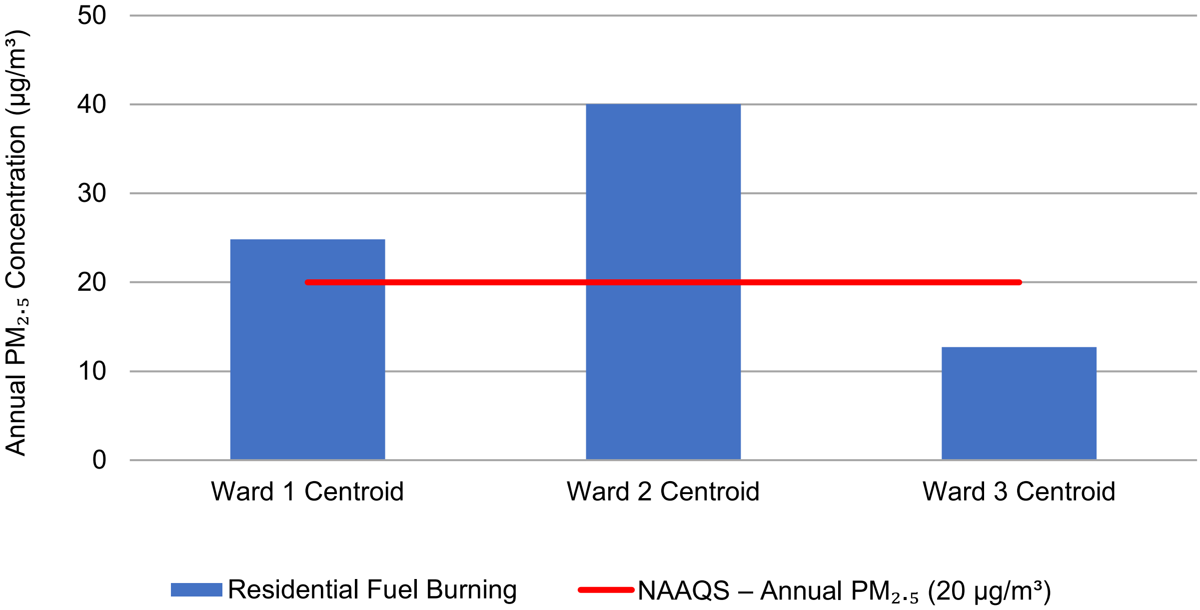

Figure 6-17: Model predicted annual $PM_{2.5}$ ambient concentrations in µg/m³ at discrete receptors for the residential fuel burning emission source category

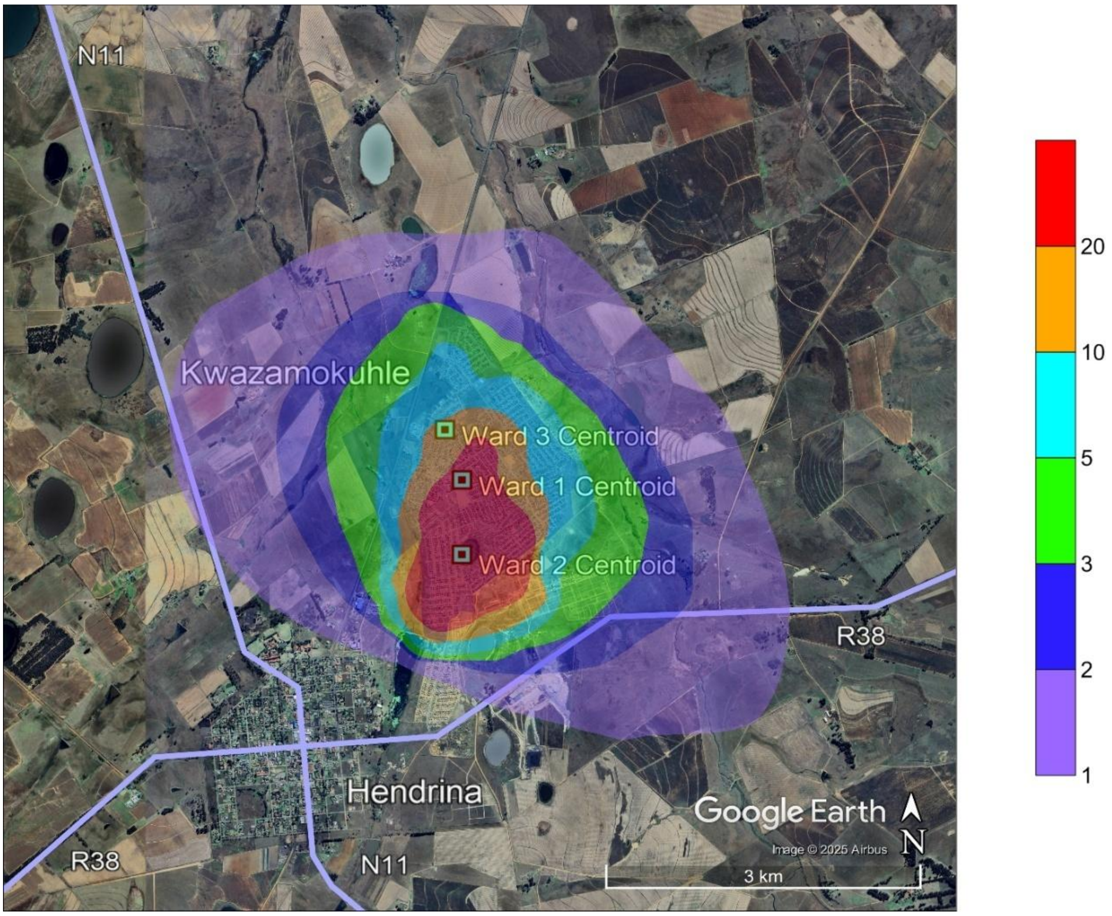

Figure 6-18: Model predicted annual $PM_{2.5}$ ambient concentrations in µg/m³ for the residential fuel burning emission source category

6.5 Ambient Air Quality Benefit Attributable To Eskom's KwaZamokuhle AQO Project

The following section provides a summary of the nett ambient air quality benefit of Eskom's KwaZamokuhle AQO Project, targeting residential fuel burning, and also evaluates compliance with the NAAQS.

Table 6-10 summarises the nett ambient air quality benefit of Eskom's KwaZamokuhle AQO Project. Where applicable, exceedances of the NAAQS are highlighted in red.

According to contour plots presented in the preceding sections, it is noted that the highest impacts are predicted to occur in the central parts of KwaZamokuhle. The maximum ambient air quality improvement are as follows:

- SO_2 ambient concentrations
  - 1-hour: 566.57 µg/m³ (above the standard by more than one times the NAAQS)
  - 24-hour: 156.87 µg/m³ (above the standard by more than one times the NAAQS)
  - Annual: 61.38 µg/m³ (above the standard by more than one times the NAAQS)
- NO_2 ambient concentrations
  - 1-hour: 208.21 µg/m³ (above the standard by more than one times the NAAQS)
  - Annual: 22.54 µg/m³ (below the NAAQS)
- PM_{10} ambient concentrations
  - 24-hour: 204.11 µg/m³ (above the standard by more than two times the NAAQS)
  - Annual: 79.70 µg/m³ (above the standard by approximately two times the NAAQS)
- $PM_{2.5}$ ambient concentrations
  - 24-hour: 189.57 µg/m³ (above the standard by more than four times the NAAQS)
  - Annual: 74.02 µg/m³ (above the standard by more than three times the NAAQS)

Table 6-10: Improvement in ambient air quality due to Eskom's KwaZamokuhle AQO Project for the residential fuel burning emission source category and comparison with the NAAQS in µg/m³ for SO_2, NO_2, PM_{10} and $PM_{2.5}$

Pollutant	Averaging Period	Limit value (µg/m³)	Model predicted maximum concentration for Residential Fuel Burning (µg/m³)	Comparison with NAAQS
Sulphur Dioxide (SO_2)	1-hour	350	566.57	> 1 x NAAQS
	24-hour	125	156.87	> 1 x NAAQS
	1 year	50	61.38	> 1 x NAAQS
Nitrogen Dioxide (NO_2)	1-hour	200	208.21	> 1 x NAAQS
	1 year	40	22.54	Below NAAQS
Inhalable particulate matter less than 10 µm in diameter (PM_{10})	24-hour	75	204.11	> 2 x NAAQS
	1 year	40	79.70	~ 2 x NAAQS
Inhalable particulate matter less than 2.5 µm in diameter ($PM_{2.5}$)	24-hour	40	189.57	> 4 x NAAQS
	1 year	20	74.02	> 3 x NAAQS

This analysis has clearly demonstrated that the nett ambient air quality benefit of Eskom's KwaZamokuhle AQO Project, targeting residential fuel burning, has resulted in a significant improvement of ambient air quality in the KwaZamokuhle airshed.

The fact that the project led to significant air quality improvements suggests it's effectively addressing one of the key contributors to poor ambient air quality – residential fuel burning, which often leads to high concentrations of particulate matter and other pollutants. By improving residential fuel burning practices or transitioning to cleaner fuels, the project likely reduced harmful emissions, particularly for $PM_{2.5}$ and SO_2.

Rolling out similar projects in other areas could help achieve widespread improvements in ambient air quality, especially in urban or densely populated regions where residential fuel burning contributes to pollution. $PM_{2.5}$ levels are a significant health concern. With more stringent NAAQS for $PM_{2.5}$ coming into effect in 2030, the need for projects like these becomes even more urgent. The 24-hour $PM_{2.5}$ NAAQS will drop from 40 µg/m³ to 25 µg/m³, a significant reduction aimed at lowering short-term exposure to harmful particles while the annual $PM_{2.5}$ NAAQS will drop from 20 µg/m³ to 15 µg/m³, making the target for long-term exposure even stricter. These changes in the NAAQS make air quality interventions like the KwaZamokuhle AQO Project even more crucial in meeting the stricter standards.

Potential Benefits of Expanding AQO Projects:

- Health Benefits:
    - Reducing $PM_{2.5}$ levels is critical for preventing respiratory diseases, cardiovascular issues, and other chronic health conditions that disproportionately affect vulnerable populations (e.g., children and the elderly)
    - These projects could significantly reduce hospital admissions related to air quality issues
- Environmental Benefits:
    - Lowering $PM_{2.5}$ and SO_2 concentrations can improve overall environmental quality, including reduced acid rain, which harms soil and water bodies, as well as reduced haze and better visibility
- Compliance with Future Standards:
    - Implementing AQO projects will help communities stay ahead of the curve and meet 2030 standards, which will require even more stringent pollution controls

Recommendation for consideration for Scaling Up:

- Adopting best practices from the KwaZamokuhle project can be useful for replicating the success in other communities, especially those with similar air quality issues from residential fuel burning
- A continued and recurring focus on community engagement and education will ensure that people understand the importance of switching to cleaner fuels and adopting cleaner burning technologies
- Partnerships with local governments and environmental agencies can also ensure that future interventions are well-coordinated and aligned with broader air quality goals
- Monitoring and Data Collection: Continuous monitoring of air quality in areas where these projects are implemented will be key to measuring success and making necessary adjustments

- Public Policy Support: Engaging with policymakers to support subsidies or incentives for adopting cleaner fuels and technologies will make these interventions more accessible to wider communities

In summary, expanding AQO projects like the one in KwaZamokuhle is not only beneficial from a current air quality perspective but is essential for meeting stricter air quality regulations in the near future, particularly in light of the 2030 NAAQS revisions for $PM_{2.5}$.

7. LIMITATIONS OF STUDY

7.1 Limitations and Potential Biases of the CALPUFF Model

Although the CALPUFF dispersion modelling system is very sophisticated and supports a wide range of modelling scenarios, it does have some limitations. One limitation of the system is that there is a finite number of sources that can be specified in the model input parameters. For example, CALPUFF can only accommodate a finite number of sources for each source type in a single model run. Each executable (e.g., CALMET, CALPUFF, CALPOST) has a corresponding parameterization file which defines these limits. If a project has one of these parameters which exceeds the model limit, the model executables need be recompiled in FORTRAN to accept higher limits; or multiple model runs can be built, and then CALSUM can be used to combine model runs together. Another limitation of the CALPUFF air dispersion model is that it can only be executed on a single processor (i.e., serially). Again, CALPUFF can be run with a single source to run faster, and then CALSUM can be used to combine single runs to assess the cumulative impacts.

The CALPUFF model is an objective dispersion modelling tool that uses mathematical formulations to characterize the atmospheric processes that disperse a pollutant emitted by a source and thereby predict ambient concentrations, based on emissions and meteorological inputs. The model does not favour and is not biased by any source or source type, and relies on the input parameters provided.

7.2 Uncertainties in the CALPUFF Model

Dispersion models are used to predict ambient concentrations based on certain measured parameters, such as wind speed, wind direction, temperature, relative humidity, pressure, solar radiation; and emission rates. Variations in model parameters that are not measured and which are inherent in the model (including complex atmospheric processes that are, by their nature, highly variable), can have an influence on the predicted concentrations. Uncertainties can also result from inadequate model physics and model formulations which are used to predict the ambient concentrations, as well as inaccuracies in model algorithms and input values. These include meteorological data and emission data which is unrepresentative, poor source characterisation in the model and errors in the concentrations measured at AQMS that are used for comparison with model predictions.

The primary areas of uncertainty relevant to this modelling study include uncertainties in the TAPM modelled meteorological data fields (i.e. how accurately the actual wind fields and other meteorological parameters are represented in the modelling), source emissions data and ambient air quality monitoring data. These data elements represent the most important sources of uncertainty in the model inputs. There may be some differences between the TAPM predicted wind speeds and temperature fields and values recorded at available observational stations, and in the modelling domain. These differences would be expected to increase the levels of uncertainty in the modelling results. The uncertainty of model predicted concentrations will scale directly with uncertainty in the emission estimates. Emission rates in this study are based on robust methodologies and are considered to be accurate.

Uncertainties can be minimised by using accurate input data, preparing the input files correctly, double checking for errors, correcting for odd model behaviour, ensuring that the errors in the measured data are minimised and applying appropriate model physics. The accuracy of model predictions in this assessment was done by ensuring that all uncertainties in the input data and model parameterisation were kept to a minimum.

8. CONCLUSION

This study assessed the nett reduction in emissions of PM, SO_2, and NO_2, as well as the resulting improvements in ambient air quality attributable to Eskom's KwaZamokuhle AQO Project. Aligned to the DFFE's Air Quality Offsets Guidelines, it is pivotal that an offset intervention is able to demonstrate a quantitative nett ambient air quality benefit in an airshed. The findings of this study have clearly demonstrated that the nett ambient air quality benefit of Eskom's KwaZamokuhle AQO Project, targeting residential fuel burning, has resulted in a significant improvement of ambient air quality in the KwaZamokuhle airshed.

The fact that the project led to significant air quality improvements suggests it's effectively addressing one of the key contributors to poor ambient air quality, viz, residential fuel burning, which often leads to high concentrations of particulate matter and other pollutants. By improving residential fuel burning practices or transitioning to cleaner fuels, the project likely reduced harmful emissions, particularly for $PM_{2.5}$ and SO_2. Rolling out similar projects in other areas could help achieve widespread improvements in ambient air quality, especially in urban or densely populated regions where residential fuel burning contributes to pollution.

In summary, expanding AQO projects like the one in KwaZamokuhle is not only beneficial from a current air quality perspective but is essential for meeting stricter air quality regulations in the near future, particularly in light of the 2030 NAAQS revisions for $PM_{2.5}$.

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11. ANNEXURE 1

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