Activity 1: Preliminary Air Quality Assessment

ACTIVE MEASUREMENT CAMPAIGN REPORT FOR EZAMOKUHLE

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EXECUTIVE SUMMARY

Environmental offsets are alternative actions (investments or initiatives) made to measurably mitigate the residual negative environmental impacts of an industrial activity. Thus, the use of offset mechanisms are important in the field of air quality management. The Department of Environment, Forestry and Fisheries *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. For Eskom's Planning Monitoring and Verification (PMV) project, interventions to reduce household emissions from domestic coal/wood burning will be rolled out in KwaZamokuhle and Ezamokuhle in the Mpumalanga Highveld. Interventions also need to be identified and implemented to improve air quality in Sharpeville, Gauteng.

Air Resource Management (ARM) (Pty) Ltd is supporting Eskom's PMV project. 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 for these respective communities.

In accordance with the scope of work, *Activity 1: Preliminary Air Quality Assessment* requires ARM to conduct a preliminary assessment to determine whether the Ezamokuhle community is in non-compliance with the National Ambient Air Quality Standards (NAAQS). ARM is utilising a phased three-pronged strategy of: firstly a *Status quo air quality trend analysis assessment*; secondly a *Baseline modelling assessment* and finally *Ambient air quality measurement study using both passive and active samplers* to evaluate compliance of the NAAQS at Ezamokuhle. The focus of this report is only on the *active sampling measurement campaign* for Ezamokuhle. The objective of this study was to undertake a preliminary air quality assessment for Ezamokuhle to quantify ambient air quality particulate matter (PM_{10}) concentrations & evaluate compliance to the NAAQS.

This study used MiniVOL samplers that were developed by the Lane Regional Air Pollution Authority and the US Environmental Protection Agency (USEPA) to characterize the spatial and temporal distributions of ambient PM_{10}. The location and the positioning of the MiniVOL samplers were chosen based on the results of the *Baseline Modelling Assessment Report for Ezamokuhle* (ARM, 2021a) which identified China 2 as the highest priority air quality hotspot in Ezamokuhle. Thus 5 MiniVOLS sampling sites were selected in Ezamokuhle. The sampling was conducted for the period 9th August 2021 to 20th August 2021. An accredited World Meteorological Organisation (WMO) atmospheric chemistry laboratory prepared and analysed the Whatman Teflon filter papers. ARM undertook a rigorous QA/QC process in support of the measurements. The collected filters showed a visible colour variation and varied from clear, light brown, dark brown to very dark grey. This trend was evident through-out the sampling campaign, indicating that the ambient PM_{10} pollutant concentrations varied both spatially and in magnitude for Ezamokuhle.

To map the measured PM_{10} concentrations, an interpolation was done using a Krigging algorithm. The measured PM concentrations were generally the highest at the centre of China 2, dominated by the influence of site 2. This finding of the MiniVOL sampling campaign was aligned to the previous ARM (2021b) passive sampling study which also had indicated that the highest concentrations were measured at the centre of China 2.

The measured PM_{10} concentrations at the 5 sites were generally in non-compliance with the daily NAAQS for PM_{10}. The PM morning and evening peaks were associated with residential fuel burning whilst the midday peak was indicative of a tall-stack emission source. A comparison of the trend level plot clearly indicated that the highest PM_{10} concentrations occurred in the mornings and evenings as opposed to midday. This indicates that residential fuel burning has a significant impact in terms of ambient PM_{10} loading for Ezamokuhle during winter.

Based on the results of the bivariate polar plots it was also apparent that there is a clear dependence of PM_{10} concentrations with decreasing ambient temperature. It was very interesting to note that on the coldest days over the entire sampling period of the study, elevated PM_{10} concentrations in Ezamokuhle were due primarily to residential fuel burning. This was also clearly visible in the field as for these coldest days, ARM noticed numerous: mbaula's burning, residential chimney stack emissions of both formal and backyard informal homes, coal merchants and wood merchants in Ezamokuhle.

Additionally, ARM noticed that the residential fuel burning emissions emitted from the household chimneys had a very low plume momentum and buoyancy which resulted in localised high ground level concentrations. Due to the poor dispersion of the chimneys, very often it was the adjacent neighbouring household that was directly impacted from this plume. Based on the field observations it was very clear to the team that although Ezamokuhle is a relatively small area, the PM_{10} pollutant concentration profile for the township is not homogenous but rather heterogenous. This was also confirmed by the spatial distribution of the MiniVOL PM_{10} pollutant concentration results.

A comparison was conducted between the closest MiniVOL sampling site and the Eskom Ezamokuhle air quality station. In general, there was a very good agreement between the measured MiniVOL results in comparison to the PM_{10} concentrations measured at the Eskom Ezamokuhle air quality station.

In summary the active measurement campaign has demonstrated that the ambient PM_{10} pollutant concentrations varied both spatially and magnitude in Ezamokuhle. Measured PM_{10} ambient concentrations were generally in non-compliance with the daily NAAQS for PM_{10}. The study results have indicated that residential fuel burning has a significant impact in terms of ambient PM_{10} loading for Ezamokuhle. This coupled with the colder temperatures & poor air pollution dispersion potential of Ezamokuhle in winter, results in elevated localised ambient PM_{10} concentrations. Hence there is an opportunity herein to reduce human exposure to harmful levels of air pollution by reducing emissions from residential burning. Thus, supporting the roll-out of Eskom's PMV air quality offset intervention project in Ezamokuhle. A long-term evaluation of PM_{10} loading in Ezamokuhle will be undertaken by ARM as part of Activity 10 of the Eskom PMV project.

1. BACKGROUND

1.1 ENVIRONMENTAL OFFSETS

Environmental offsets are alternative actions (investments or initiatives) made to measurably mitigate the residual negative environmental impacts of an industrial activity. An environmental offset is an action(s), designed to compensate for a negative environmental impact of resource use, a discharge, emission or other activity. Offsets should deliver a net sustainable development benefit, through an appropriately balanced assessment of the 5 Capitals: Natural/Environmental; Social, Human; Financial & Manufacture (Figure 1).

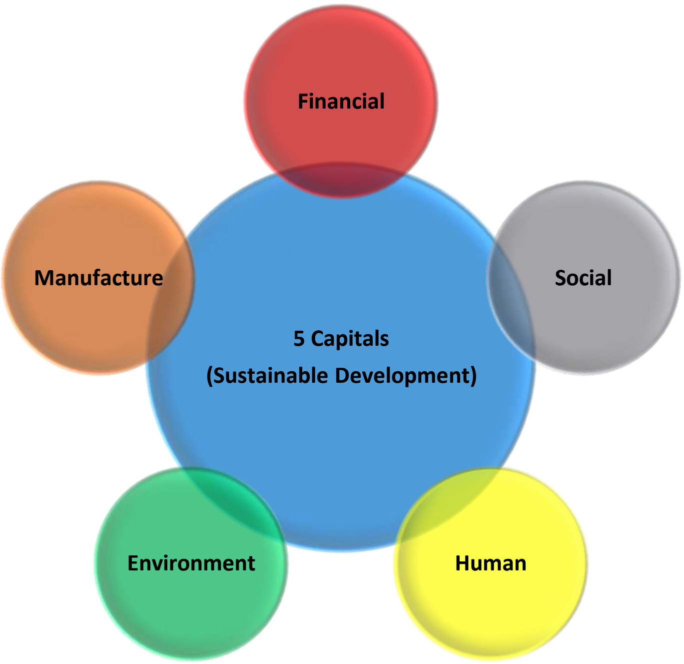

Figure 1: Five capitals approach to offsets

Offsets can be considered a form of mitigation, and part of a hierarchy of mitigation measures that should be applied to any development that has adverse environmental impacts. Proceeding from the top of the hierarchy, each measure must be fully considered before the next level of measures is considered. At the bottom of the hierarchy, offsets could be applied to mitigate the remaining adverse impact on the environment after appropriate avoidance, minimisation and rehabilitation measures have been taken. Thus, the use of offset mechanisms is important in the various areas of air quality improvement, water use (consumption and discharge), greenhouse gas mitigation and biodiversity.

1.2 AIR QUALITY OFFSETS GUIDELINE

The Department of Environment, Forestry & Fisheries (DEFF) defines air emissions offsets as an intervention, or interventions, specifically implemented to counterbalance the adverse and residual environmental impact of atmospheric emissions in order to deliver a net 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).

1.3 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 2 illustrates the concept schedule for the phased implementation of Eskom's air quality offsets.

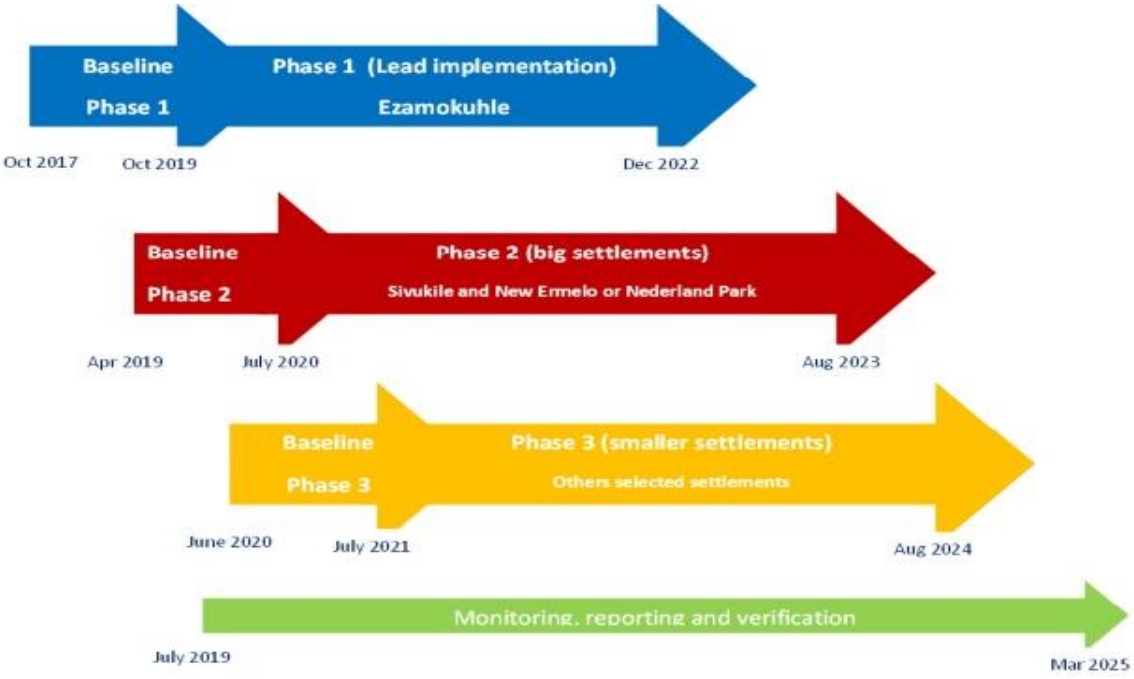

Figure 2: Concept Schedule for the implementation of Eskom's air quality offsets (Matimolane, 2020)

Eskom has adopted the phased approach (Figure 3) 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 3: Eskom’s Phased approach to the rollout of air quality offset interventions (Matimolane, 2020)

Phase 1	Phase 2	Phase 3
• Lead Phase • The intervention is tested on an entire community in order to determine the best way forward for sclaing up the inititiative.	• Full implementation on the remaining households in the larger settlements • Learnings from the Lead Phase incorporated herein. • Intervention will be rolled out simultaneously at several large communities across the three district municipalities and selected areas in the Vaal.	• Full implementation on the remaining households in the smaller settlements • Learnings from the Lead Phase incorporated herein. • The intervention will be rolled out simultaneously at several small semi-rural communities the three district municipalities and selected areas in the Vaal.

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).

1.4 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. Its 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) for these respective communities. This report focuses on Activity 1: Preliminary air quality assessment for Ezamokuhe.

Table 1: Eskom PMV Activity Schedule

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	✓	✓	✓

2. INTRODUCTION

2.1 ACTIVITY 1 - PRELIMINARY AIR QUALITY ASSESSMENT

In accordance with the scope of work, *Activity 1: Preliminary Air Quality Assessment* requires ARM to conduct a preliminary assessment to determine whether the Ezamokuhle community is in non-compliance with the National Ambient Air Quality Standards (NAAQS). The NAAQS limits are shown below in Table 2.

Table 2: NAAQS (DEFF, 2009)

Pollutant	Average Period	Concentration	Frequency of Exceedance	Compliance Date
Nitrogen Dioxide (NO_2)	1 hour	200 µg/m^3	88	Immediate
	1 year	40 µg/m^3	0	Immediate
Inhalable particulate matter less than 2.5 µm in diameter ($PM_{2.5}$)	24 hour	40 µg/m^3	4	Immediate until 31 December 2029
	24 hour	25 µg/m^3	4	1 January 2030
	1 year	20 µg/m^3	0	Immediate until 31 December 2029
	1 year	15 µg/m^3	0	1 January 2030
Inhalable particulate matter less than 10 µm in diameter (PM_{10})	24 hour	75 µg/m^3	4	Immediate
	1 year	40 µg/m^3	0	Immediate
Sulphur Dioxide (SO_2)	10 minutes	500 µg/m^3	526	Immediate
	1 hour	350 µg/m^3	88	Immediate
	24 hour	125 µg/m^3	4	Immediate
	1 year	50 µg/m^3	0	Immediate

ARM is utilising a phased three-pronged strategy of: firstly a *Status quo air quality trend analysis assessment*; secondly a *Baseline modelling assessment* and finally *Ambient air quality measurement study using both passive and active samplers* to evaluate compliance of the NAAQS at Ezamokuhle (Figure 4). This focus of this report is only on the active *sampling measurement campaign* for Ezamokuhle.

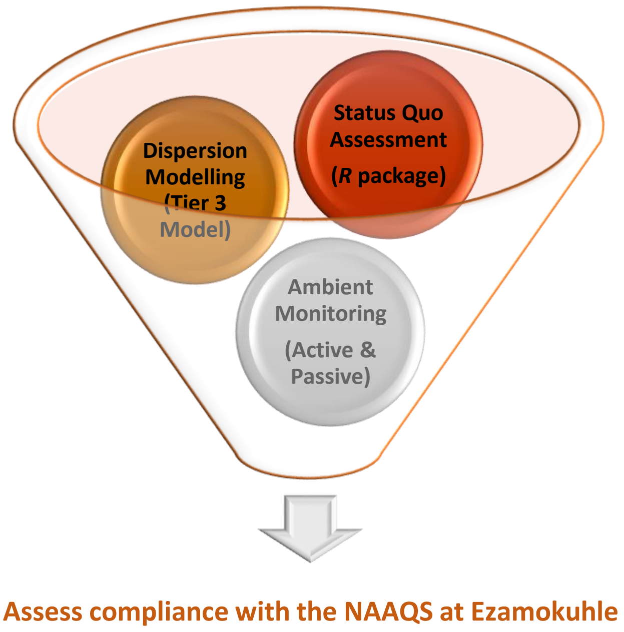

Figure 4: Phased approach to evaluate NAAQS non-compliance for Ezamokuhle

2.2 STUDY OBJECTIVE

As part of Eskom's Majuba Power Station amended Atmospheric Emission License (AEL), following postponement decisions, a condition is included for the Majuba Power Station to develop an AQO implementation plan to reduce particulate matter (PM) in the ambient/receiving environment of the Ezamokuhle township.

The objective of this study is to undertake a preliminary air quality assessment for Ezamokuhle to quantify PM_{10} ambient air quality concentrations as well to determine possible exceedances of the NAAQS for PM_{10} (Table 2).

3. METHODOLOGY

3.1 ACTIVE SAMPLING

Active sampling requires the use of a pumping device to actively pass air through an air sample container whereas passive sampling does not. Passive sampling relies on the kinetic energy of gas molecules and diffusion of the gases in an enclosed space onto a sorbent medium.

By using a pump, it is possible to collect gases and vapours by pumping air through a tube containing a bed of a sorbent, or it is possible to collect particulates (aerosols) by pumping air through a filter housed in a cassette or size-selective sampler. The flow rate for active samplers is typically in the range of millilitres per minute for gases and vapours or litres per minute for aerosols. The flow rate is set and verified using a calibrator designed for the purpose. There is a plethora of active sampling methods that have been validated and published by government agencies (Begum *et al*, 2006; Chow *et al*, 2006; Malm *et al*, 1994).

3.2 ACTIVE SAMPLERS USED IN STUDY

This study used five **MiniVOL** (Figure 5) samplers that were **developed by** the Lane Regional Air Pollution Authority and **the US Environmental Protection Agency** (USEPA) to characterize the spatial and temporal distributions of ambient particulate matter. The sampler’s portable design and ease of use have made it a popular choice for air quality assessments (Berg, 1990; Pleasant and Lumpkin, 1994; Chow et al., 1994; Baldauf et al., 1997; Lin and Kasprak, 1997; Cowherd and Grelinger, 1998).

Figure 5: MiniVOL Portable Air Sampler

3.2.1 MINIVOL

The MiniVOL is a portable particulate matter active sampler. The MiniVOL features a programmable timer, a constant flow control system, an elapsed time totaliser, rechargeable battery packs, and all-weather PVC construction. The MiniVOL consist of a pump that is controlled by a programmable timer. An elapsed time totalizer is linked in parallel with the pump to record the total time in hours of pump operation.

The sampler is equipped to operate from either AC or DC power sources. In the DC mode, the sampler operates from a battery pack, making the selection of a sampling site independent of line power supply. A charged battery pack is capable of operation the sampler for up to 24 sampling hours on a single charge. In the AC mode, the battery pack is connected to line power and mated to the sampler unit. This configuration charges the battery while using AC power (Airmetrics, 2001).

In the particulate matter sampling mode, air is drawn through a particle size selector (also referred to as an impactor) and then through a filter medium. Particle size separation is achieved by impaction. It is critical to the collection of the correct particle size that the correct flow rate move through the impactor. For the MiniVOL, the actual volumetric flow rate must be 5 litres per minute (Airmetrics, 2001). Impactors are available with a 10 micron cut point (PM_{10}) and a 2.5 micron cut point ($PM_{2.5}$). Operating the sampler without an impactor allows for the collection of total suspended particulate matter (TSP). The inlet tube downstream from the filter takes the air to the twin cylinder diaphragm pump. From the pump, air is forced through a standard flow meter where it is exhausted to the atmosphere inside the sampler body (Airmetrics, 2001).

The MiniVOL sampler is a popular choice of use in air quality assessments because it is portable and inexpensive relative to fixed site monitors. Advantages of the MiniVOL sampler include the flexibility to move or rotate monitoring sites, the ability to increase the number of monitoring sites to improve spatial distribution of data collected, and the ability to measure contaminant concentrations at almost any location (Baldauf et al., 2001).

- **MINIVOL VALIDATION STUDY**

Baldauf et al., (2001) conducted a performance evaluation of the MiniVOL Portable Air Sampler. They concluded that the MiniVOL operated reliably and yielded statistically similar concentration measurements when co-located with another MiniVOL. Also, the characterization of spatial distributions of $PM_{2.5}$ and PM_{10} mass concentrations can be accomplished with a high level of confidence. They also found that the MiniVOL produced statistically reliable results when co-located with a Versatile Air Pollutant Sampler (VAPS) and a Tapered Element Oscillating Microbalance (TEOM). Further, the authors mentioned that environmental factors such as ambient concentration, wind speed, temperature, and humidity influence the relative measurement comparability between these sampling systems (Baldauf et al., 2001).

3.3 SITE SELECTION

The location and the positioning of the MiniVOL samplers were chosen based on the results of the *Baseline Modelling Assessment Report for Ezamokuhle* (ARM, 2021a). Based on this study, the prioritisation of air quality hotspots for Ezamokuhe was ranked on the basis of highest predicted impacts. This ensured that the areas that potentially pose the greatest particulate matter risk to human health and the environment were identified for optimum placement of the active ambient air quality analysers.

The *Baseline Modelling Assessment Report for Ezamokuhle* demonstrated that the highest predicted model concentrations occurred in China 2 (ARM, 2021a). Thus China 2 was identified as the highest priority air quality hotspot in Ezamokuhle. Thus, for active measurement campaign, 5 MiniVOLS sampling sites were selected in Ezamokuhle (Figure 6). The samplers were distributed across the area to capture the spatial distribution of PM.

Figure 6: Location of MiniVOL Sampling Locations in Ezamokuhle

3.4 SAMPLING

The sampling campaigns were conducted for 11 days, from 9th August 2021 to 20th August 2021 at the 5 sites (Figure 7 to Figure 11). PM sampling was done using AirMetrics MiniVOL samplers collecting PM_{10}. The MiniVOL were programmed to sample at 5 lpm through PM_{10} particle size separators (impactors) and then through Whatman Teflon (2 µm pore size) filters. The actual flow rate was 5 lpm at ambient conditions for proper size fractionation. To ensure a constant flow of 5 lpm through the size separator at different air temperatures and ambient pressures, the sampler flow rates were adjusted for the ambient conditions at the sampling site. The sampling time was twenty-four hours per sample, with the samples been changed daily between 6:30am and 7:30am. The samplers were placed with nozzle at the height of the breathing zone.

Figure 7: MiniVOL Sampling Site 1

Figure 8: MiniVOL Sampling Site 2

Figure 9: MiniVOL Sampling Site 3

Figure 10: MiniVOL Sampling Site 4

Figure 11: MiniVOL Sampling Site 5

3.5 ANALYSIS OF SAMPLES

An accredited World Meteorological Organisation (WMO) atmospheric chemistry laboratory prepared and analysed the Whatman Teflon filter papers. The Whatman Teflon filter papers were supplied ready for use in a sealed petri dish. After sampling, the filter papers were retrieved and were placed in petri slides and sealed. The filters were then returned to the accredited WMO atmospheric chemistry laboratory for weighing and analysis. Only gravimetrical assessments were done on the filters (no chemical analysis was done on the particulate matter). The filters were weighed on a balance before the sampling and again after the sampling. The mass and the concentration of the particulate matter that was collected over a 24-hour period in the ambient air was then determined.

3.6 QUALITY ASSURANCE & QUALITY CONTROL (QA/QC) OF THE MEASUREMENTS

In support of the QA/QC of the measurements, ARM undertook the following steps:

1. An accredited World Meteorological Organization (WMO) atmospheric chemistry laboratory with its own quality assurance and control measures was used.
2. Operation and maintenance procedures utilized during the study conformed to the guidelines recommended by the Airmetrics manufacturer (Airmetrics, 2001).
3. Visual inspection of the filters was made over a light before each sampling period, to make sure that the filters did not have any contamination.
4. The filters were always handled with plastic tweezers and whilst wearing surgical gloves.
5. The filters were exchanged after each day of sampling on the site, taking care not to let any of the loose particles fall from the filter.
6. After the filters had been collected at the sites, the filters were placed in petri slides and sealed.

3.7 METEOROLOGICAL CONDITIONS FOR SAMPLING PERIOD

For the MiniVOL sampling period (9th to 20th August 2021) there were two periods of cool weather conditions (9-10 August & 13-17 August) which produced foggy and cool conditions in the Ezamokuhle township. The cool conditions experienced resulted from the passing cold fronts with the cool airmass being pulled into the interior as it pushes under the existing warm air. The first front to have passed in the interior was shallow and produced mild cold temperatures, whilst the second cold front event experienced on the 13th of August was a deep air mass with a deep ridging high pressure system that fed in moist air from the east coast and produced much colder conditions (Figure 12) compared to the previous cold front. The resultant high pressure also produced a relatively low inversion layer.

The fog experienced in Ezamokuhle during the second cold front can be defined as radiation fog. Radiation fog forms when the ground surface cools cooling the air just above the ground to its saturation temperature in stable atmospheric conditions. After sunset the sunlit area of the area do not receive solar radiation, and this allows the surface to cool and radiate the heat into the air. As the front passed through the area, cooling occurred and allowed for the air to be saturated and for condensation to occur. Due to the ridging high pressure, moisture was fed into the area and resulted in high humidity. At sunrise the heat of the sun allows for more mixing of the air and for evaporation to occur. This then leads to the fog banks to detach and cause low level clouds to occur and produce the thick fog that was experienced in Ezamokhule. The thickness of the fog can also be attributed to the presence of large nuclei in the form of fugitive dust and non-buoyant emission sources in the township as well as the lack of high winds that could have disturbed the mixing process of the air.

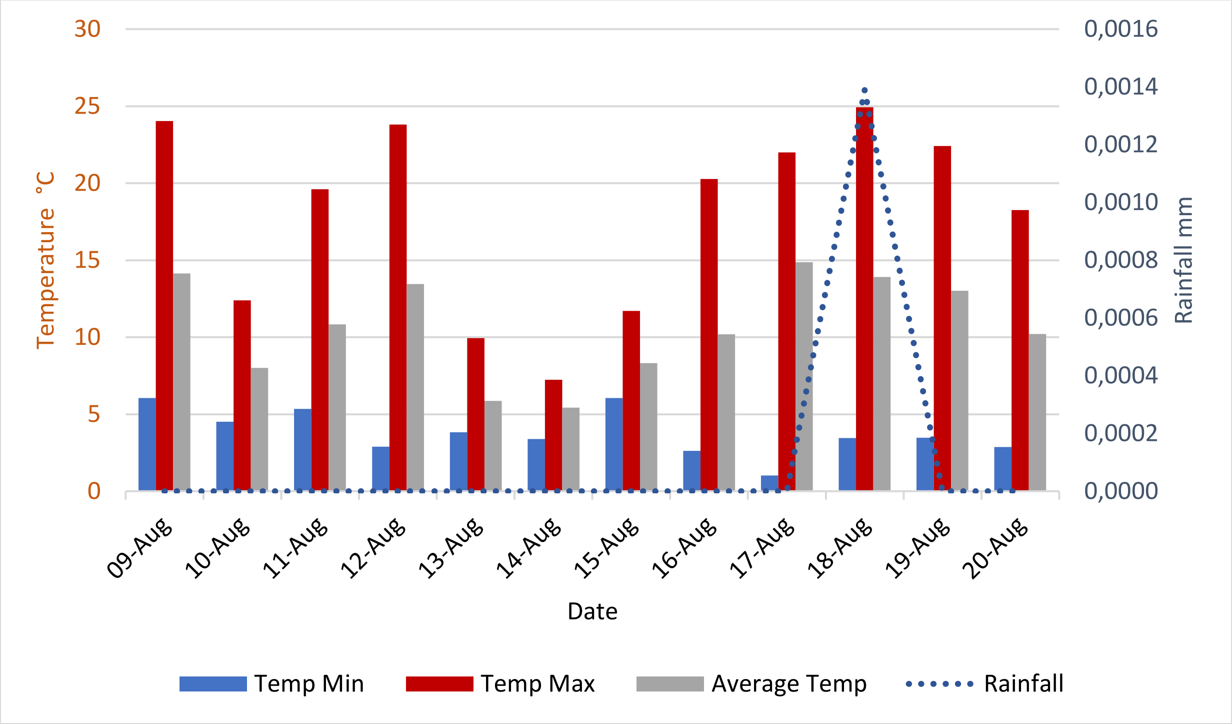

Figure 12: Average daily maximum and minimum temperatures and rainfall for the sampling period at Ezamokuhle (Source: Eskom Ezamokuhle Ambient Air Quality Station)

4. RESULTS & DISCUSSION

4.1 SPATIAL DISTRIBUTION OF POLLUTANTS IN EZAMOKUHLE

Figure 13 illustrates the colour variation of the filters which were collected for the same day. Colours varied from clear, light brown, dark brown to very dark grey. This trend was evident throughout the sampling campaign indicating that the ambient PM pollutant concentrations in Ezamokuhle varies both spatially and in terms of PM concentration levels.

Figure 13: Colour variation of collected filter samples for the same day of sampling

To map the PM_{10} concentrations that were measured at the 5 different locations in Ezamokuhle (Figure 6), an interpolation was done at the points of a grid that cover the studied area. In each point of this target grid, an estimation of the concentration was calculated using a Krigging algorithm that attaches weights to the concentrations measured at the sampling points. The basic idea of kriging is to predict the value of a function at a given point by computing a weighted average of the known values of the function in the neighbourhood of the point (John-Paul et. al, 2018).

4.1.1 INTERPOLATED PM_{10} CONCENTRATIONS IN EZAMOKUHLE

The spatial distribution of PM_{10} for the period of sampling are presented in Figure 14 to Figure 25 . The measured PM concentrations were generally the highest at the centre of China 2, dominated by the influence of site 2. This finding of the MiniVOL sampling campaign is aligned to the previous ARM (2021a) passive sampling study which also indicated that highest concentrations were measured at the centre of China 2.

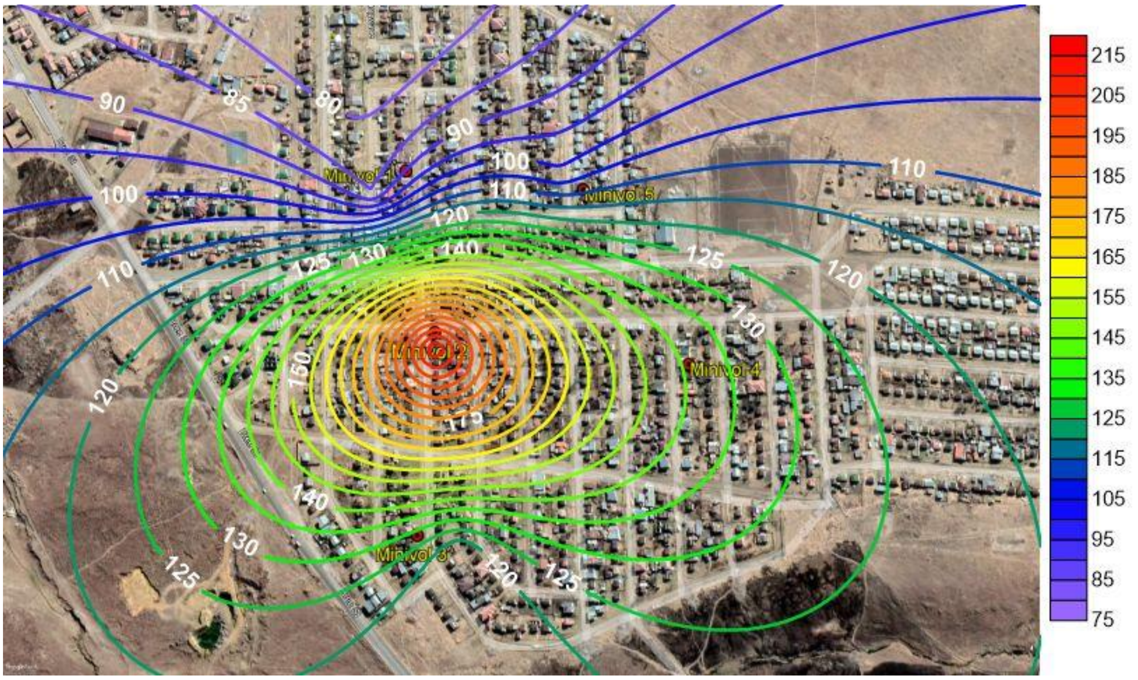

Figure 14: Isopleth map showing spatial distribution of measured PM_{10} concentrations in µg/m^3 for 9th August 2021

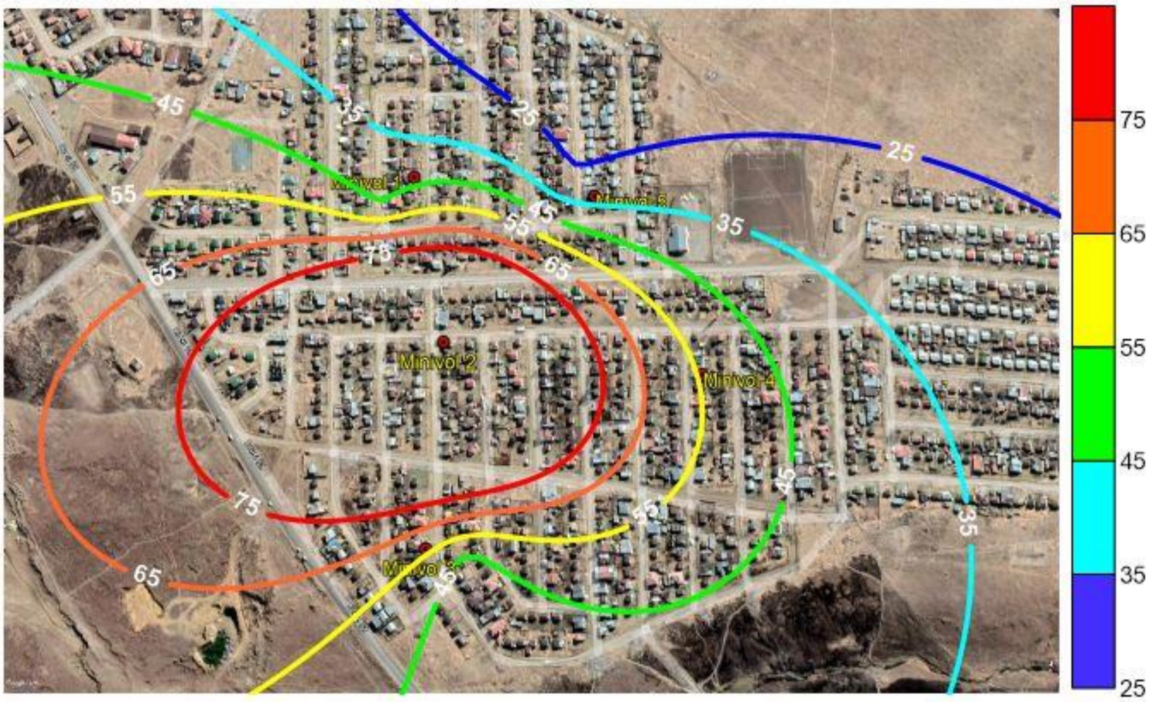

Figure 15: Isopleth map showing spatial distribution of measured PM_{10} concentrations in µg/m^3 for 10th August 2021

Figure 16: Isopleth map showing spatial distribution of measured PM_{10} concentrations in µg/m^3 for 11th August 2021

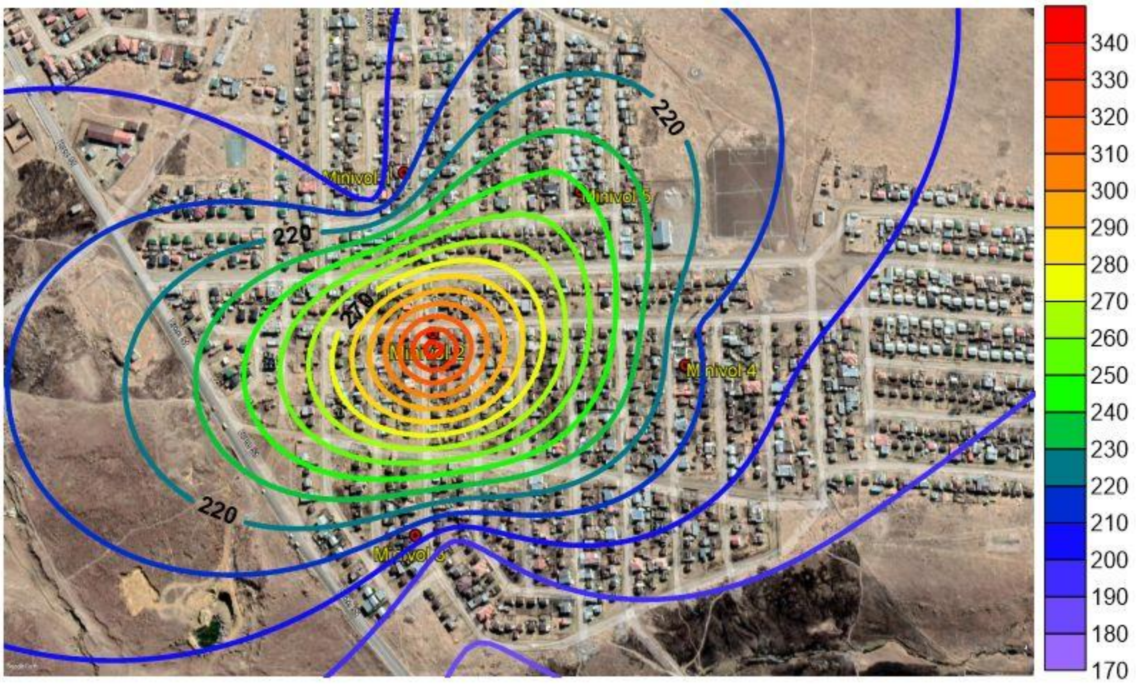

Figure 17: Isopleth map showing spatial distribution of measured PM_{10} concentrations in µg/m^3 for 12th August 2021

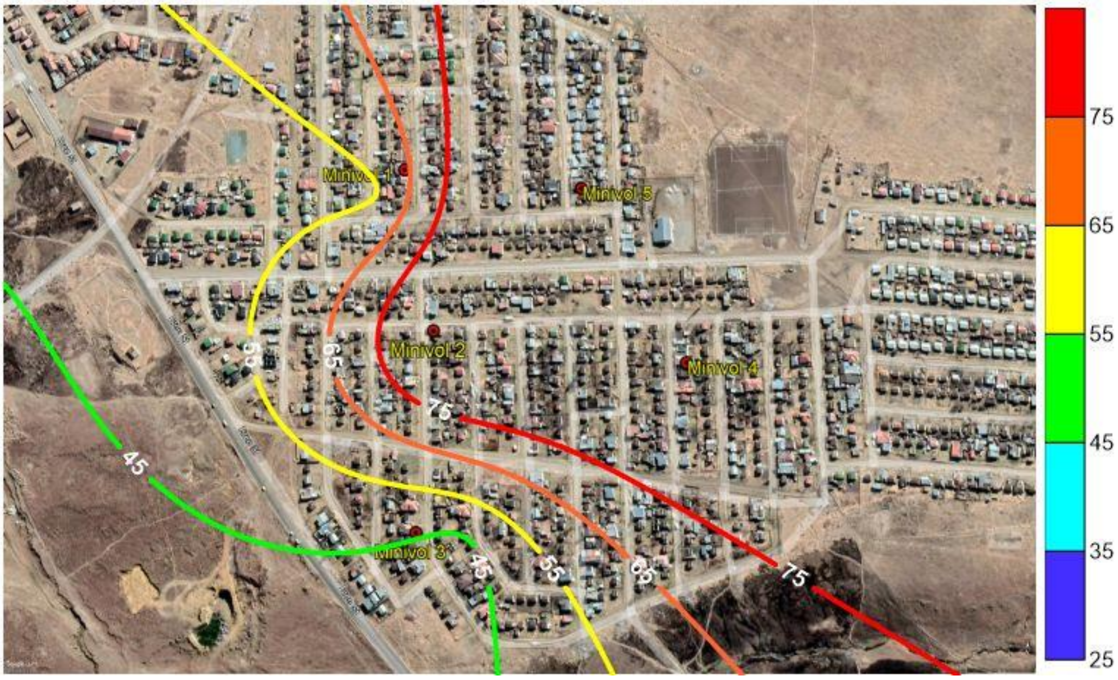

Figure 18: Isopleth map showing spatial distribution of measured PM_{10} concentrations in µg/m^3 for 13th August 2021

Figure 19: Isopleth map showing spatial distribution of measured PM_{10} concentrations in µg/m^3 for 14th August 2021

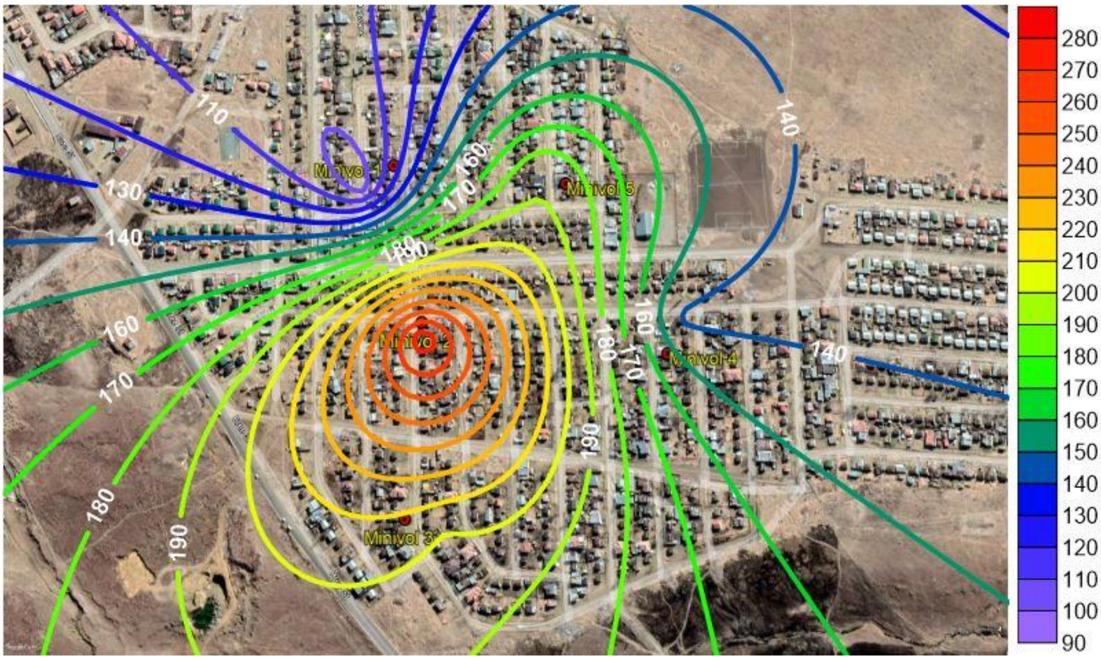

Figure 20: Isopleth map showing spatial distribution of measured PM_{10} concentrations in µg/m^3 for 15th August 2021

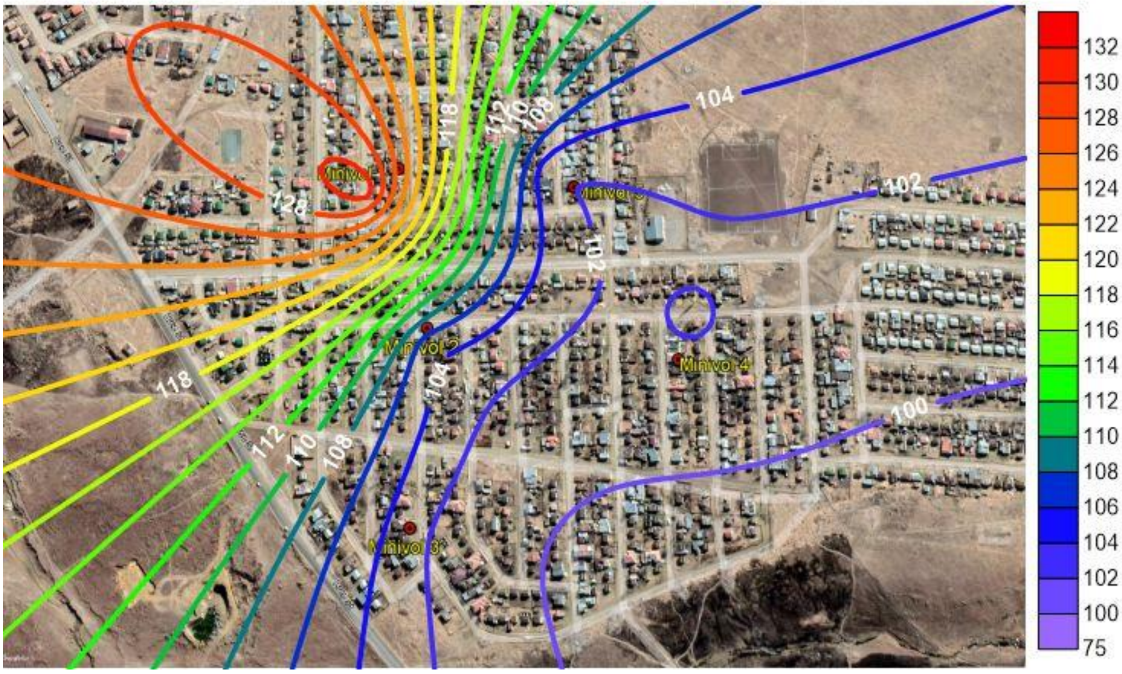

Figure 21: Isopleth map showing spatial distribution of measured PM_{10} concentrations in µg/m^3 for 16th August 2021

Figure 22: Isopleth map showing spatial distribution of measured PM_{10} concentrations in µg/m^3 for 17th August 2021

Figure 23: Isopleth map showing spatial distribution of measured PM_{10} concentrations in µg/m^3 for 18th August 2021

Figure 24: Isopleth map showing spatial distribution of measured PM_{10} concentrations in µg/m^3 for 19th August 2021

Figure 25: Isopleth map showing spatial distribution of measured PM_{10} concentrations in µg/m^3 for 20th August 2021

4.2 Comparison of MiniVOL measurements at Ezamokuhle to NAAQS

The PM_{10} concentrations that were measured at the 5 sites over the sampling campaign (9th to 20th August 2021) were compared to the daily NAAQS for PM_{10} (Table 2). Table 3 provides an overview of the NAAQS compliance status for each day that the PM_{10} measurements were undertaken. The actual measured PM_{10} concentrations are shown in Annexure 1.

Table 3: Compliance status of measured concentrations in Ezamokuhle to the NAAQS for PM_{10}

Date	Day	Site 1	Site 2	Site 3	Site 4	Site 5
09-Aug	**Monday**	Non-Compliant	Non-Compliant	Non-Compliant	Non-Compliant	Non-Compliant
10-Aug	**Tuesday**	Compliant	Non-Compliant	Compliant	Compliant	Compliant
11-Aug	**Wednesday**	Non-Compliant	Non-Compliant	Non-Compliant	Non-Compliant	Non-Compliant
12-Aug	**Thursday**	Non-Compliant	Non-Compliant	Non-Compliant	Non-Compliant	Non-Compliant
13-Aug	**Friday**	Compliant	Non-Compliant	Compliant	Non-Compliant	Non-Compliant
14-Aug	**Saturday**	Compliant	Non-Compliant	Compliant	Non-Compliant	Compliant
15-Aug	**Sunday**	Non-Compliant	Non-Compliant	Non-Compliant	Non-Compliant	Non-Compliant
16-Aug	**Monday**	Non-Compliant	Non-Compliant	Non-Compliant	Non-Compliant	Non-Compliant
17-Aug	**Tuesday**	Non-Compliant	Non-Compliant	Non-Compliant	Non-Compliant	Non-Compliant
18-Aug	**Wednesday**	Non-Compliant	Non-Compliant	Non-Compliant	Non-Compliant	Non-Compliant
19-Aug	**Thursday**	Non-Compliant	Non-Compliant	Non-Compliant	Compliant	Compliant
20-Aug	**Friday**	Compliant	Compliant	Compliant	Non-Compliant	Compliant

Figure 26 shows the time series (mean with 95% confidence interval) of ambient daily PM_{10} concentrations measured at the Eskom Ezamokuhle ambient air quality station for the period 9th to 20th August 2021. The particulate matter morning peak occurs at 07:00 whilst the evening peak occurs at 18:00. This is a typical profile for residential fuel burning. The morning peaks reduces towards midday as the inversion layer rises & improves the mixing height of the planetary boundary layer. It's evident there is a third less pronounced peak that occurs around midday due to the break-up of an elevated inversion layer, in addition to the development of daytime convective conditions causing the plume from tall stack emission sources to be brought down to ground level. A comparison of the trend level plot (Figure 27) for the period 9th to 20th August 2021, clearly indicates that the highest PM_{10} concentrations occur at 07:00 and at 18:00 (residential fuel burning) rather than at midday (tall stack emission source). This indicates that residential fuel burning had a significant impact in terms of ambient PM_{10} concentrations for Ezamokuhle for the winter sampling period.

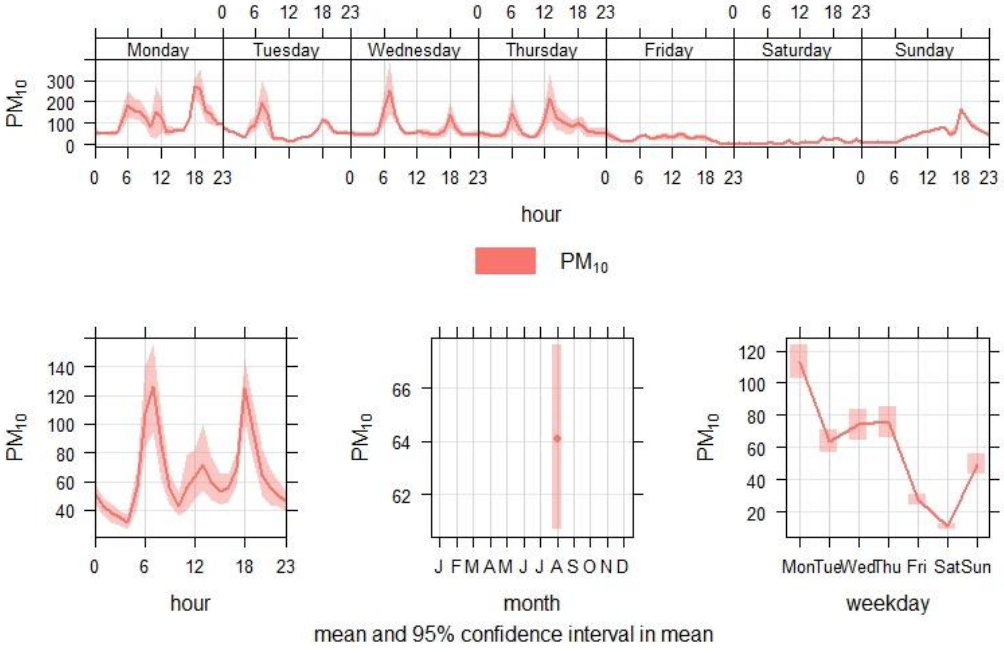

Figure 26: Mean daily PM_{10} pollutant concentrations for the period 9th August 2021 to 20th August 2021 in µg/m^3 for the Eskom Ezamokuhle ambient air quality station

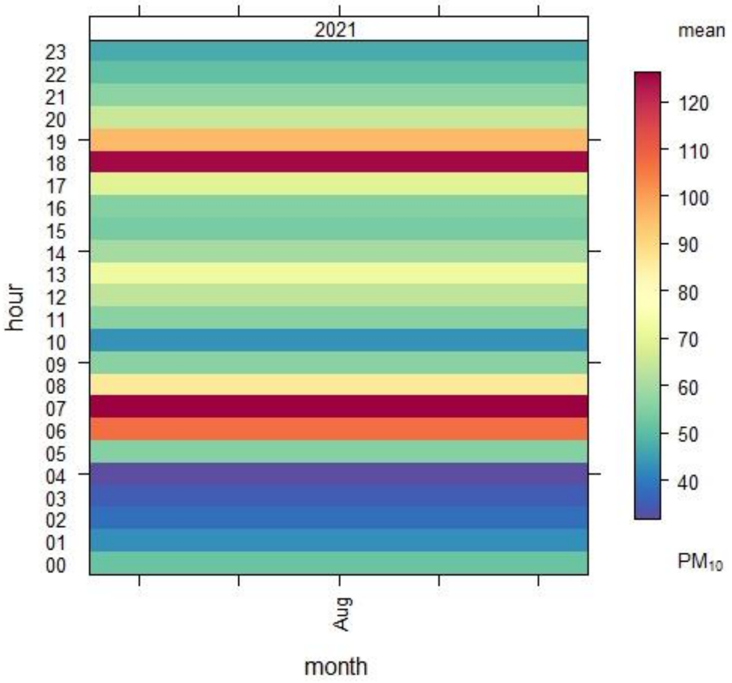

Figure 27: Trend level plot for PM_{10} measured at the Eskom Ezamokuhle ambient air quality station for the period 9th August 2021 to 20th August 2021

4.3 EMISSION SOURCE CONTRIBUTION

The emission performance of an individual air-pollution source can be inferred from an ambient record by isolating its signal of impacts. Numerous studies (Carslaw, 2007; Griffin et al., 2009; Malby et al., 2008; Shu et al., 2017) have demonstrated that these signals can successfully be used for source attribution. A common method for source characterisation is the use of bivariate polar plots (Carslaw et al., 2006; Westmoreland et al., 2007; Carslaw and Beevers, 2013; Uria Tellaetxe and Carslaw, 2014). Bivariate polar plots have proved to be extremely valuable for identifying and understanding sources of air pollution (Carslaw et al., 2006; Westmoreland et al., 2007). Bivariate polar plots provide an effective graphical means of discriminating different source types and characteristics as these plots show how the concentration of a pollutant varies by two different variables at a specific receptor.

4.3.1 BIVARIATE POLAR PLOT FOR MEAN CONCENTRATION

These plots show how the concentration of a pollutant varies by wind direction and wind speed at a receptor. The wind speed dependence of a source can provide important information concerning the source type and characteristics (Carslaw et al., 2006; Jones et al., 2010). High ground level concentrations from tall stack emissions are more prevalent during stronger wind speeds during stable conditions whilst conversely low-level emissions, and higher concentrations would normally be observed during weak-wind conditions.

Figure 28 to Figure 39 shows the bivariate plots for the Eskom Ezamokuhle station conditioned for the mean PM_{10} pollutant concentration for the period 9th to 20th August 2021. For the 10th, 13th to 17th August elevated PM_{10} pollutant concentrations are associated with only very low wind speeds, indicating a localised low-level emissions source. Figure 26 and Figure 27 has demonstrated that this low-level source is residential fuel burning signature. Whilst for the other days of the sampling its evident the elevated PM_{10} pollutant concentrations are associated with both high & low wind speeds. This is indicative of emissions from both tall stack emission and low-level residential burning sources.

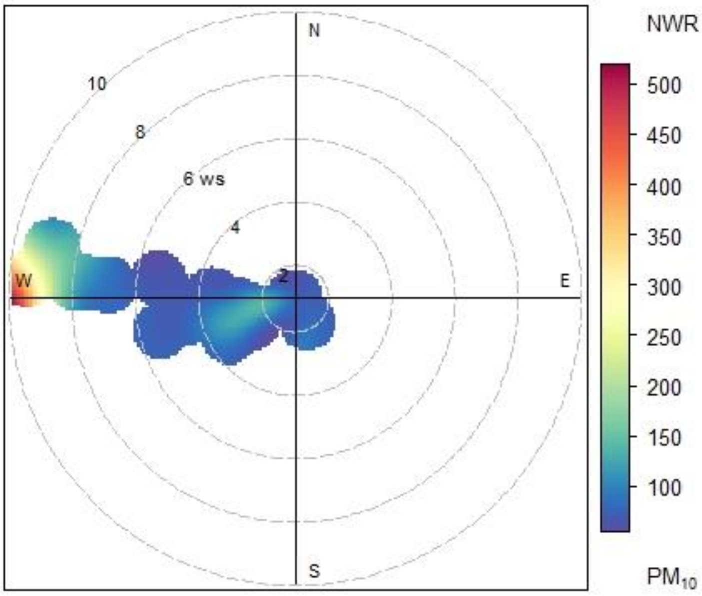

Figure 28: Polar plot of hourly mean PM_{10} concentration at the Eskom Ezamokuhle air quality station for 9th August 2021

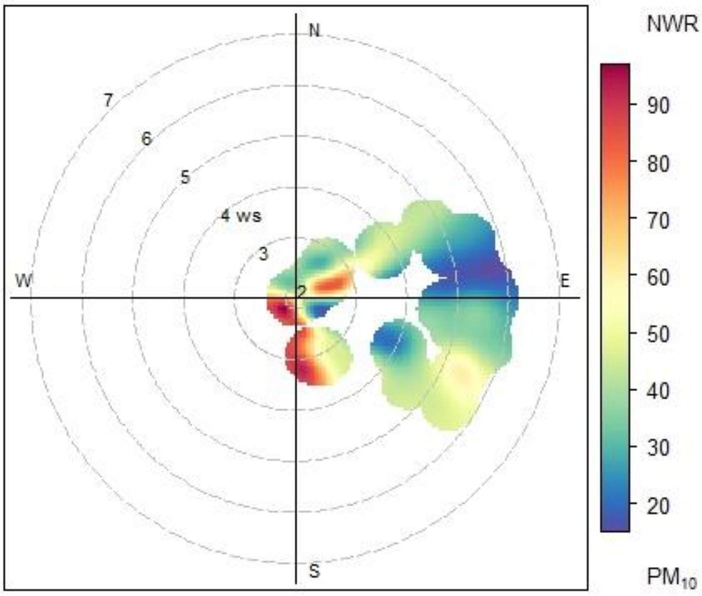

Figure 29: Polar plot of hourly mean PM_{10} concentration at the Eskom Ezamokuhle air quality station for 10th August 2021

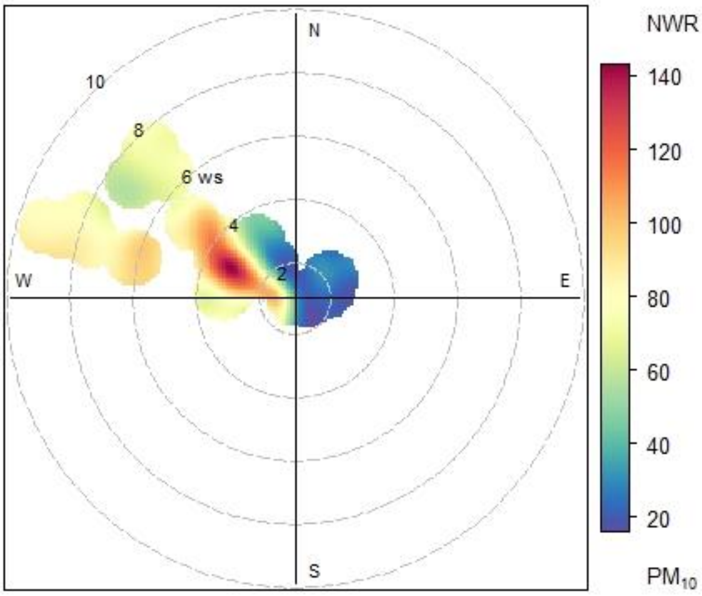

Figure 30: Polar plot of hourly mean PM_{10} concentration at the Eskom Ezamokuhle air quality station for 11th August 2021

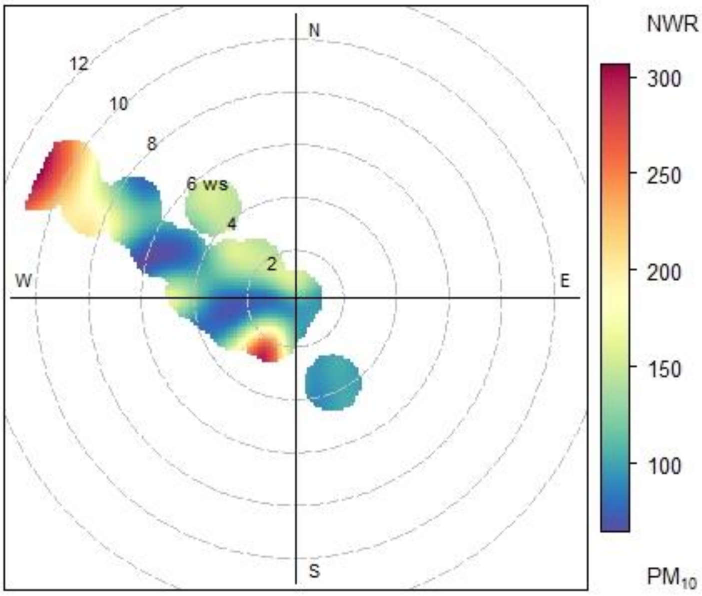

Figure 31: Polar plot of hourly mean PM_{10} concentration at the Eskom Ezamokuhle air quality station for 12th August 2021

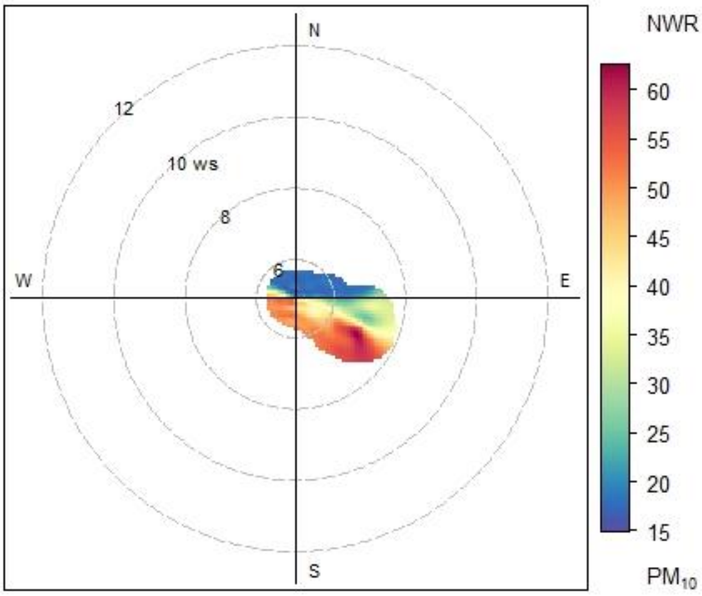

Figure 32: Polar plot of hourly mean PM_{10} concentration at the Eskom Ezamokuhle air quality station for 13th August 2021

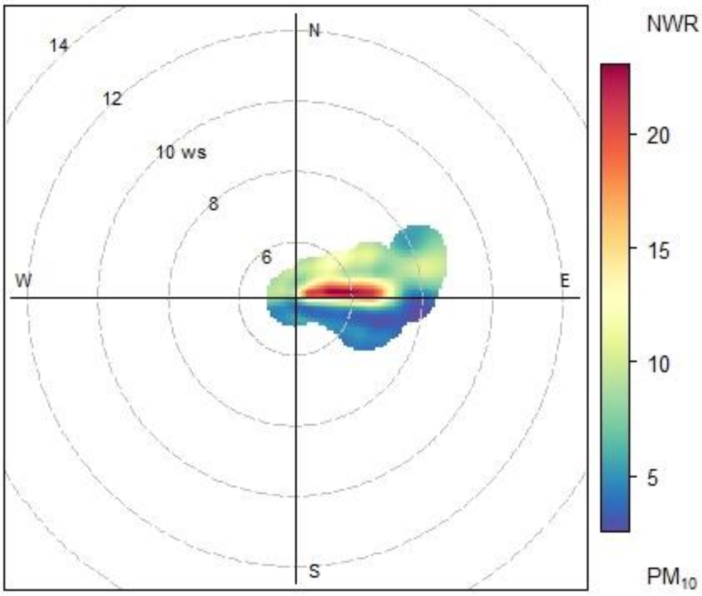

Figure 33: Polar plot of hourly mean PM_{10} concentration at the Eskom Ezamokuhle air quality station for 14th August 2021

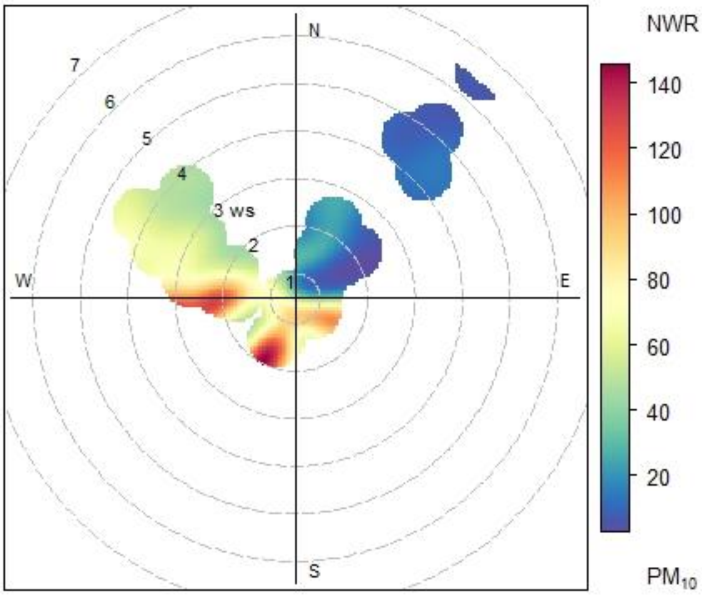

Figure 34: Polar plot of hourly mean PM$_{10}$ concentration at the Eskom Ezamokuhle air quality station for 15th August 2021

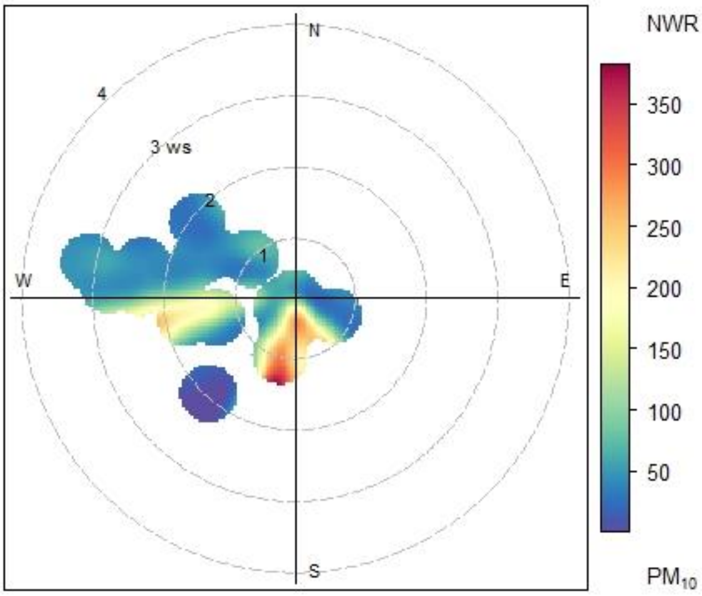

Figure 35: Polar plot of hourly mean PM$_{10}$ concentration at the Eskom Ezamokuhle air quality station for 16th August 2021

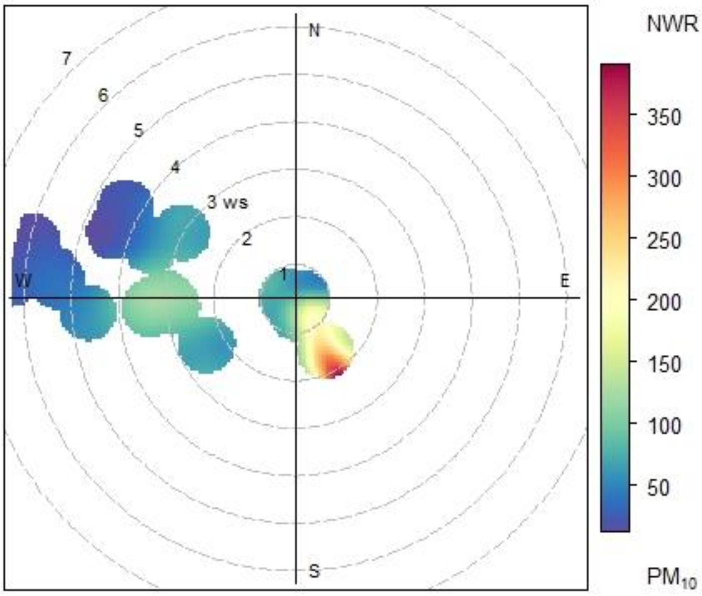

Figure 36: Polar plot of hourly mean PM_{10} concentration at the Eskom Ezamokuhle air quality station for 17th August 2021

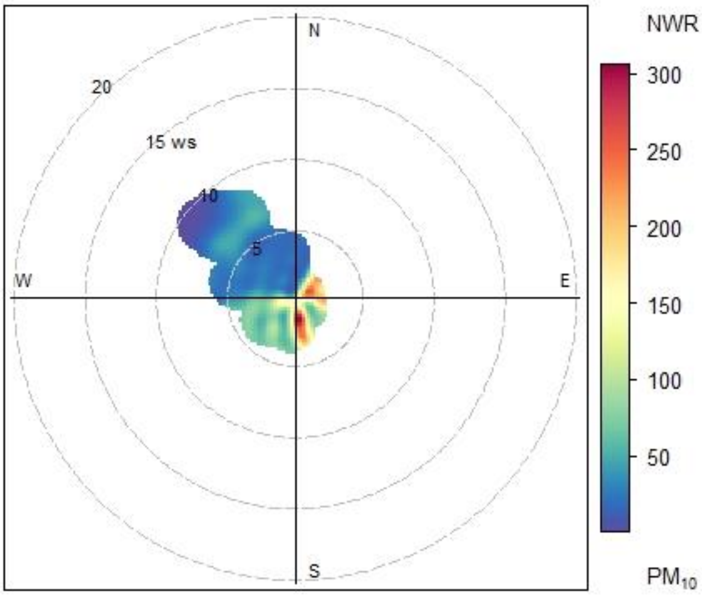

Figure 37: Polar plot of hourly mean PM_{10} concentration at the Eskom Ezamokuhle air quality station for 18th August 2021

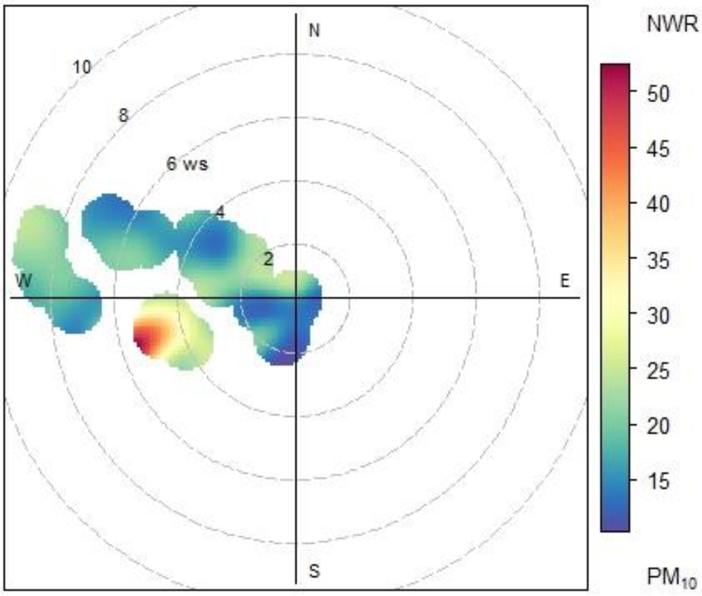

Figure 38: Polar plot of hourly mean PM$_{10}$ concentration at the Eskom Ezamokuhle air quality station for 19th August 2021

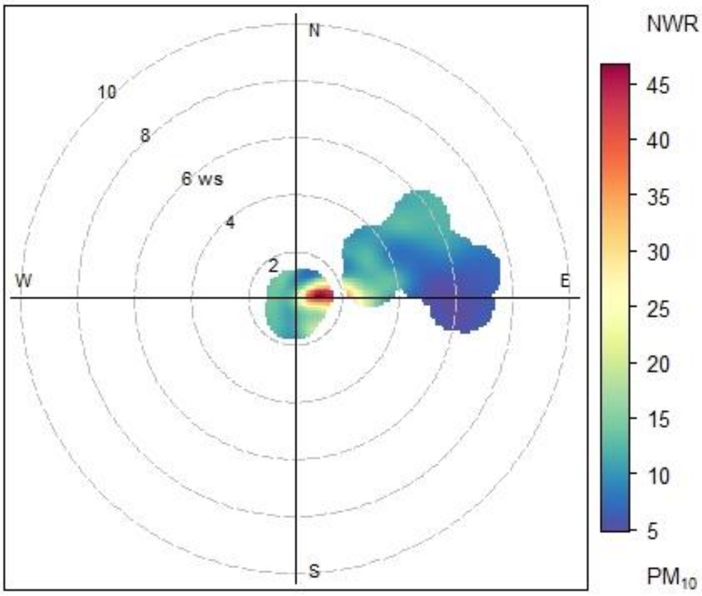

Figure 39: Polar plot of hourly mean PM$_{10}$ concentration at the Eskom Ezamokuhle air quality station for 20th August 2021

4.3.2 BIVARIATE POLAR PLOT FOR MEAN CONCENTRATION & TEMPERATURE

These plots show how the concentration of a pollutant varies by wind direction and temperature at a receptor. Temperature can help reveal high-level sources brought down to ground level in unstable atmospheric conditions or show the effect a source emission dependent on temperature e.g., residential burning for space heating.

Figure 40 to Figure 51 show the bivariate polar plots for PM_{10} pollutant concentration for the period 9th to 20th August 2021as a function of wind direction and surface temperature. It is apparent that there is a clear dependence of PM_{10} concentrations with decreasing ambient temperature. For the 10th, 13th, 14th and 15th August 2021, the highest PM_{10} concentrations occur during low temperatures (Figure 41,Figure 43,Figure 44, Figure 45) which results from residential fuel burning (Figure 26 and Figure 27).

Whilst for the other days of the sampling its evident the elevated PM_{10} pollutant concentrations are associated with both high & low temperatures. PM_{10} concentrations are elevated with increasing temperature as dispersing plumes from tall stacks are brought down to ground level under unstable atmospheric conditions when thermal turbulence is increased. Additionally elevated PM_{10} concentrations are associated for this period as well with low temperatures, which results from residential fuel burning.

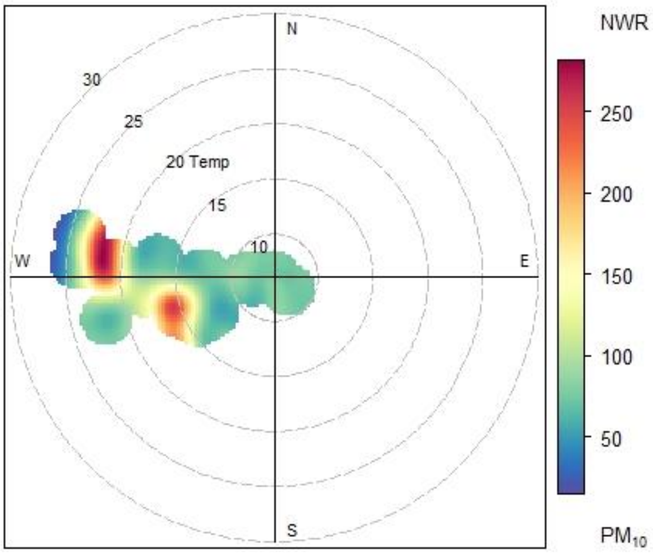

Figure 40: Polar plot function for the mean PM_{10} concentration plotted against temperature at the Eskom Ezamokuhle air quality s**tation for** 9th August 2021

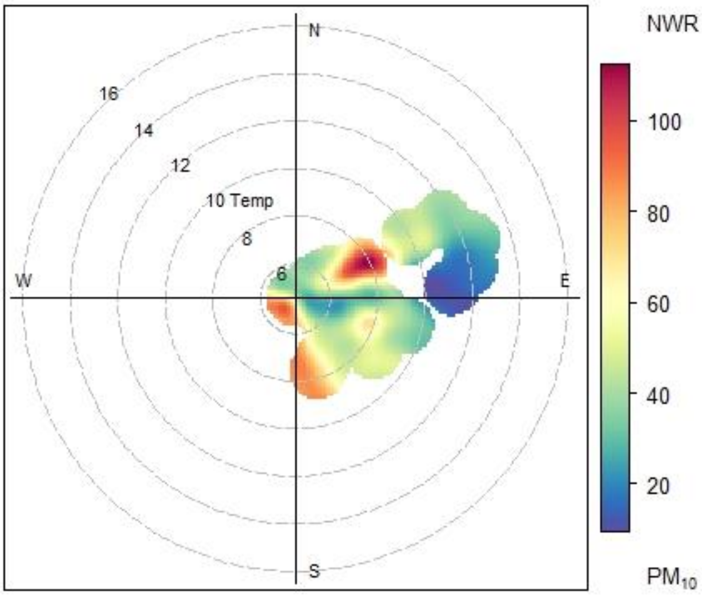

Figure 41: Polar plot function for the mean PM$_{10}$ **concentration plotted against temperature at the Eskom Ezamokuhle** air quality s**tation for** 10th August 2021

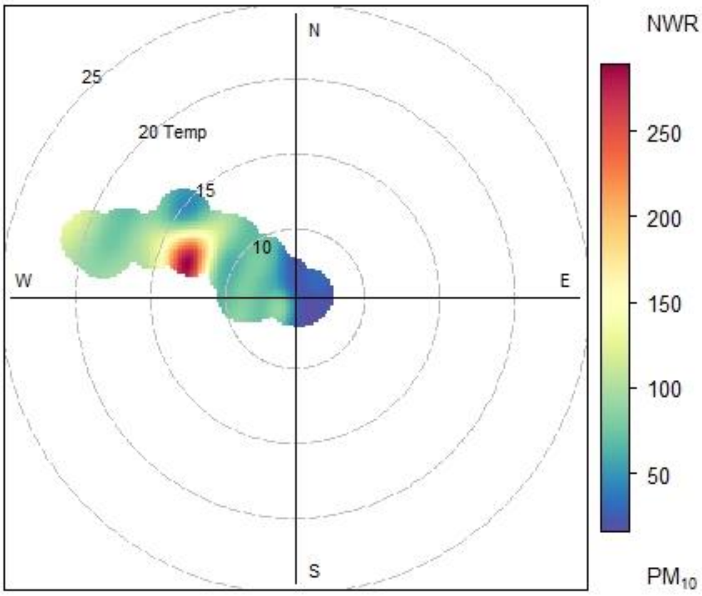

Figure 42: Polar plot function for the mean PM$_{10}$ **concentration plotted against temperature at the Eskom Ezamokuhle** air quality s**tation for** 11th August 2021

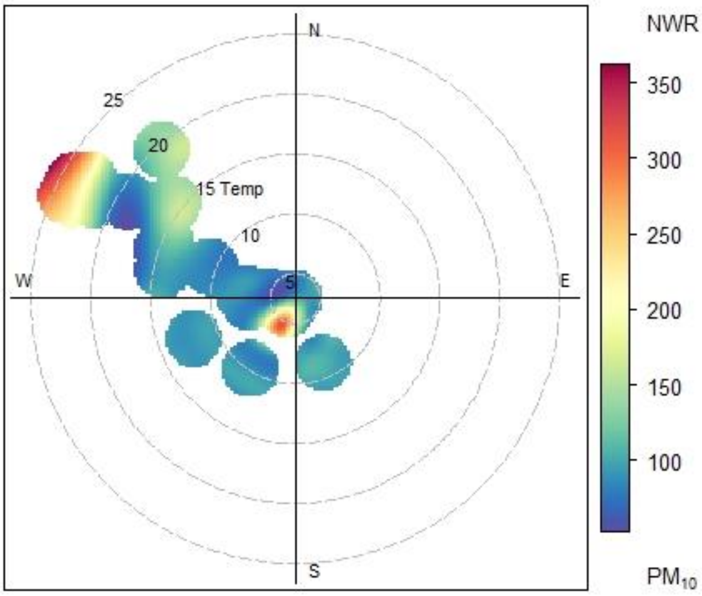

Figure 43: Polar plot function for the mean PM10 concentration plotted against temperature at the Eskom Ezamokuhle air quality s**tation for** 12th August 2021

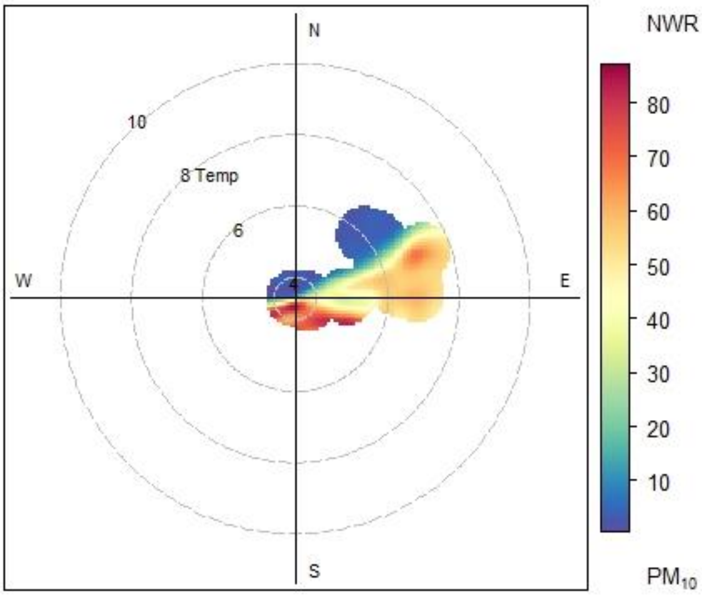

Figure 44: Polar plot function for the mean PM10 concentration plotted against temperature at the Eskom Ezamokuhle air quality s**tation for** 13th August 2021

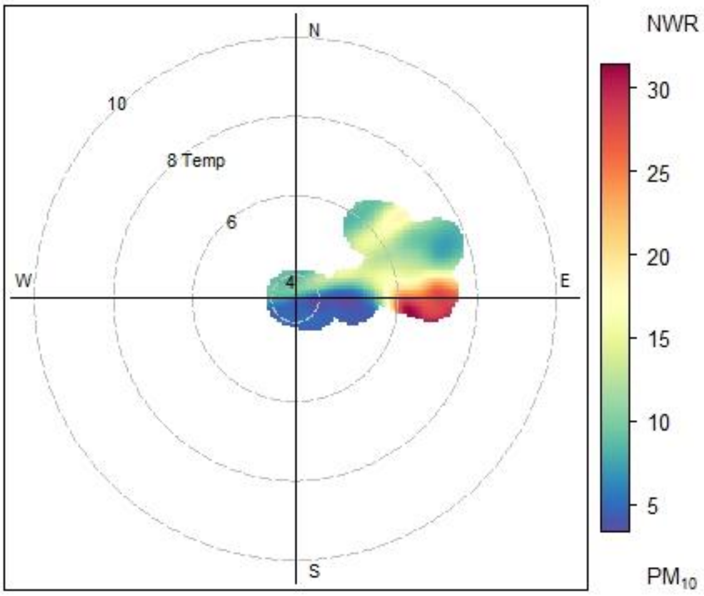

Figure 45: Polar plot function for the mean PM$_{10}$ concentration plotted against temperature at the Eskom Ezamokuhle air quality s**tation for** 14th August 2021

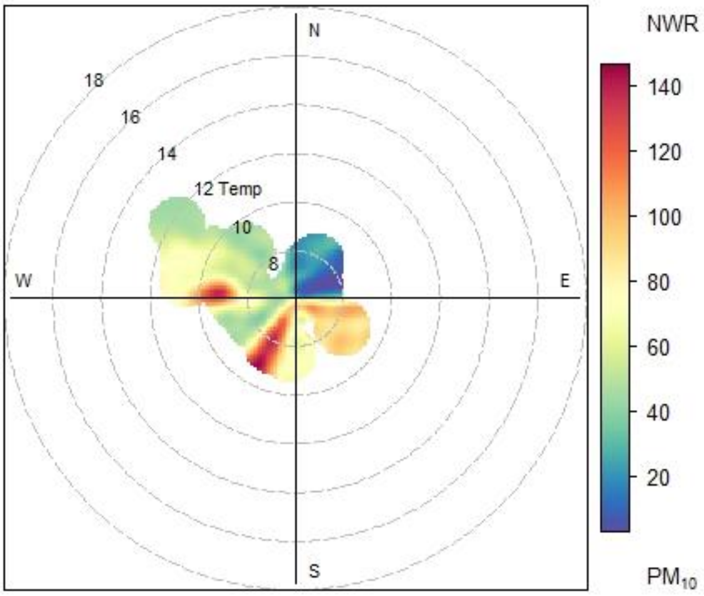

Figure 46: Polar plot function for the mean PM$_{10}$ concentration plotted against temperature at the Eskom Ezamokuhle air quality s**tation for** 15th August 2021

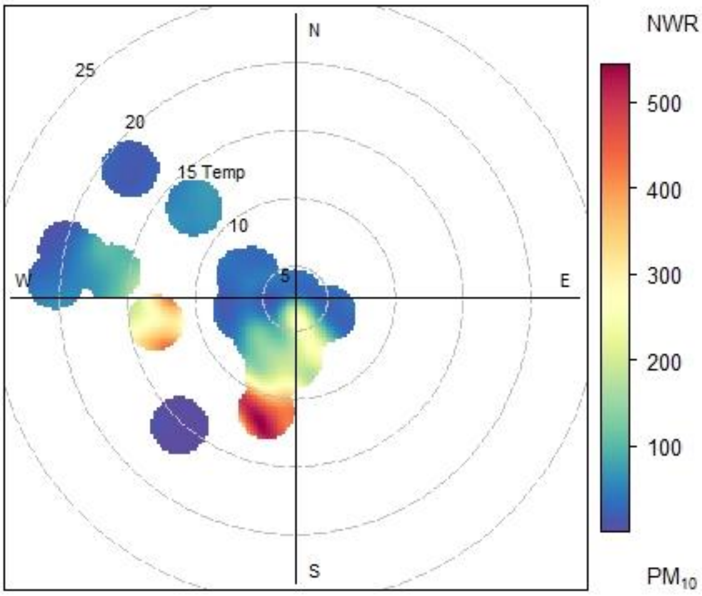

Figure 47: Polar plot function for the mean PM10 concentration plotted against temperature at the Eskom Ezamokuhle air quality s**tation for** 16th August 2021

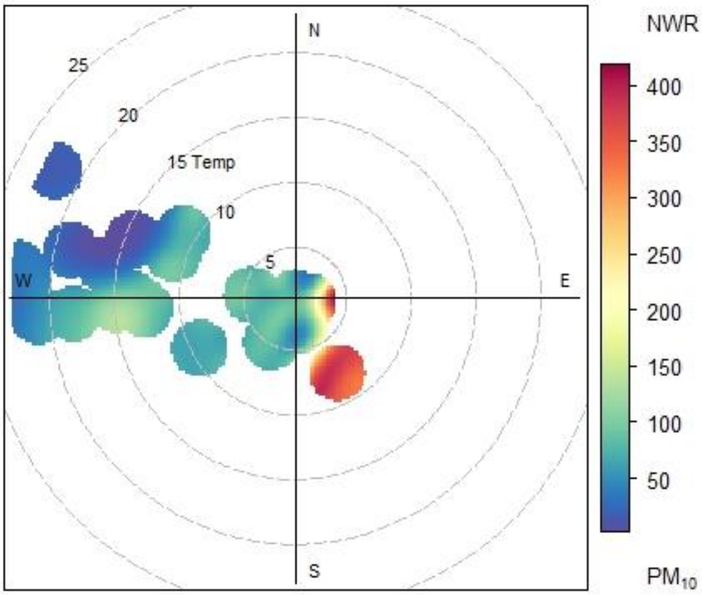

Figure 48: Polar plot function for the mean PM10 concentration plotted against temperature at the Eskom Ezamokuhle air quality s**tation for** 17th August 2021

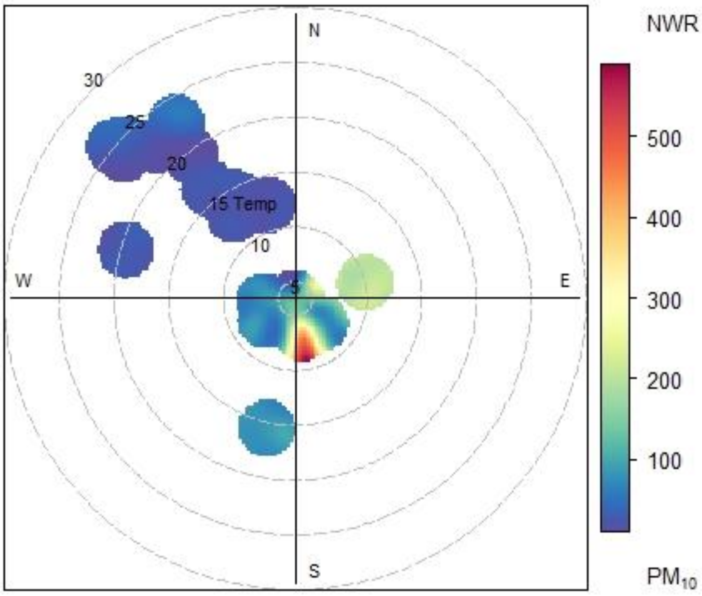

Figure 49: Polar plot function for the mean PM_{10} concentration plotted against temperature at the Eskom Ezamokuhle air quality s**tation for** 18th August 2021

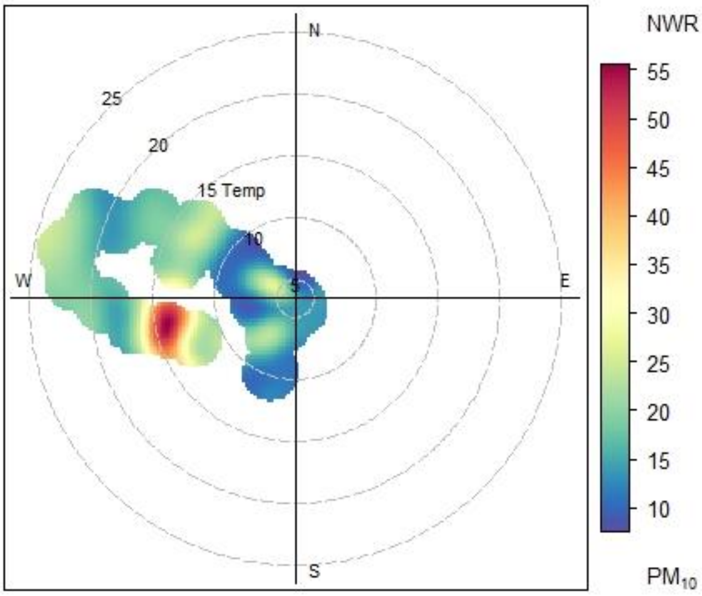

Figure 50: Polar plot function for the mean PM_{10} concentration plotted against temperature at the Eskom Ezamokuhle air quality s**tation for 1**9th August 2021

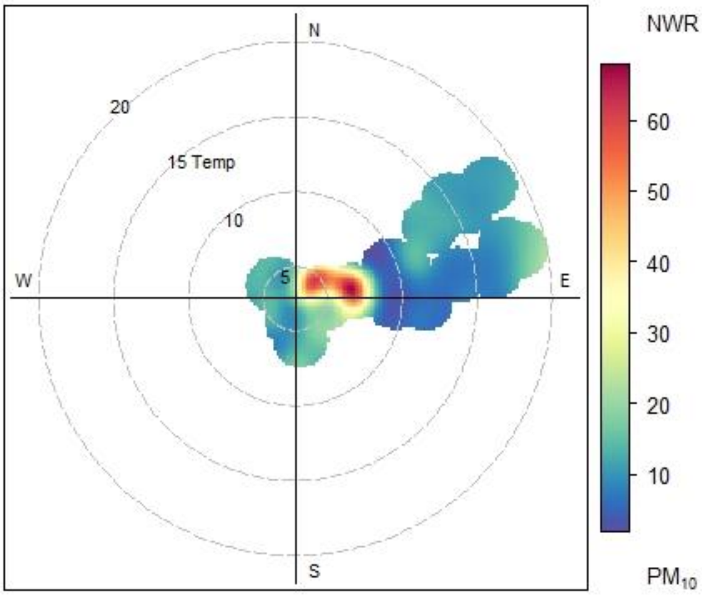

Figure 51: Polar plot function for the mean PM$_{10}$ **concentration plotted against temperature at the Eskom Ezamokuhle** air quality s**tation for** 20th August 2021

4.3.3 SUMMARY OF EMISSIONS SOURCE CONTRIBUTION

Table 4 presents a summary of the emission source contribution based on the results of the bivariate polar plot for mean concentration (section 4.3.1) and the bivariate polar plot for mean concentration & temperature (section 4.3.2). It's very interesting to note here that on the coldest days (Figure 12) over the entire sampling period of the Study, it's evident herein that the elevated PM$_{10}$ concentrations in Ezamokuhle are due primarily to residential fuel burning. This was clearly visible as ARM noticed numerous: mbaula's burning (Figure 52) , residential chimney stack emissions of both formal (Figure 53) and backyard informal homes (Figure 54) , coal merchants (Figure 56, Figure 57) and wood merchants (Figure 56) in Ezamokuhle during the sampling campaign (9 August to 20 August 2021).

Additionally, ARM noticed that the residential fuel burning emissions emitted from the household chimneys have a very low plume momentum and buoyancy (Figure 58)thus result in localised high ground level concentrations. It was interesting to note that due to the poor dispersion of the chimneys, very often it was the adjacent neighbouring household that was directly impacted from this plume. The impact of this localised impact is seen in Figure 59, where the non-buoyant residential fuel burning poorly diluted looping plume impacts directly on the MiniVOL located at the neighbouring household. Based on the field observations it was very clear to the team that although Ezamokuhle is a relatively small area (~2.5km by 1.3km) the PM$_{10}$ pollutant concentration profile for the township is not homogenous but rather heterogenous. This was also confirmed by the spatial distribution of the MiniVOL PM_{10} pollutant concentration results (Figure 14 to Figure 25).

Table 4: Summary of PM_{10} emission source contribution for the Study

Date	Emission Source Contribution		Maximum Daily Temperature
	Bivariate Polar Plot for Mean Concentration	Bivariate Polar Plot for Mean Concentration & Temperature	
09-Aug	Both RFB & Tall Stack Emissions	Both RFB & Tall Stack Emissions	24
10-Aug	RFB*	RFB	**12**
11-Aug	Both RFB & Tall Stack Emissions	Both RFB & Tall Stack Emissions	20
12-Aug	Both RFB & Tall Stack Emissions	Both RFB & Tall Stack Emissions	24
13-Aug	RFB	RFB	**10**
14-Aug	RFB	RFB	**7**
15-Aug	RFB	RFB	**12**
16-Aug	RFB	Both RFB & Tall Stack Emissions	20
17-Aug	RFB	Both RFB & Tall Stack Emissions	22
18-Aug	Both RFB & Tall Stack Emissions	Both RFB & Tall Stack Emissions	25
19-Aug	Both RFB & Tall Stack Emissions	Both RFB & Tall Stack Emissions	22
20-Aug	Both RFB & Tall Stack Emissions	Both RFB & Tall Stack Emissions	18

*RFB = Residential Fuel Burning

Figure 52: Mbaulas been burnt during the sampling campaign

Figure 53: Residential fuel burning emissions from formal households

Figure 54: Residential fuel burning emissions from informal households

Figure 55: Wood merchants in Ezamokuhle during the sampling campaign

Figure 56: Coal merchants in Ezamokuhle during the sampling campaign

Figure 57: Mobile coal merchants in Ezamokuhle during the sampling campaign

Figure 58: Poor dispersion from residential chimneys (low plume centerline)

Figure 59: Residential chimney emissions impacting adjacent neighbouring household and MiniVOL

4.4 Comparison of The MiniVOL & Eskom Ezamokuhle Air Quality Station Measured Results

A comparison was conducted between the closest MiniVOL sampling site and the Eskom Ezamokuhle air quality station. Thus, MiniVOL site 1 was selected herein as it is the closest (~450m) located site to the Eskom Ezamokuhle air quality station Figure 60. Figure 61 illustrates that there is in general agreement and a very good comparison between the MiniVOL, and the Eskom Ezamokuhle air quality station measured ambient PM_{10} pollutant concentrations. For the 14th, 15th and 19th August 2021, the measured MiniVOL concentrations are significantly higher than the Eskom Ezamokuhle air quality station however this is mostly likely attributable to the additional impact of localised residential fuel burning emission sources (Table 4) increased loading on Site 1 for these days.

Figure 60: Proximity of Eskom Ezamokuhle air quality station to MiniVOL sites

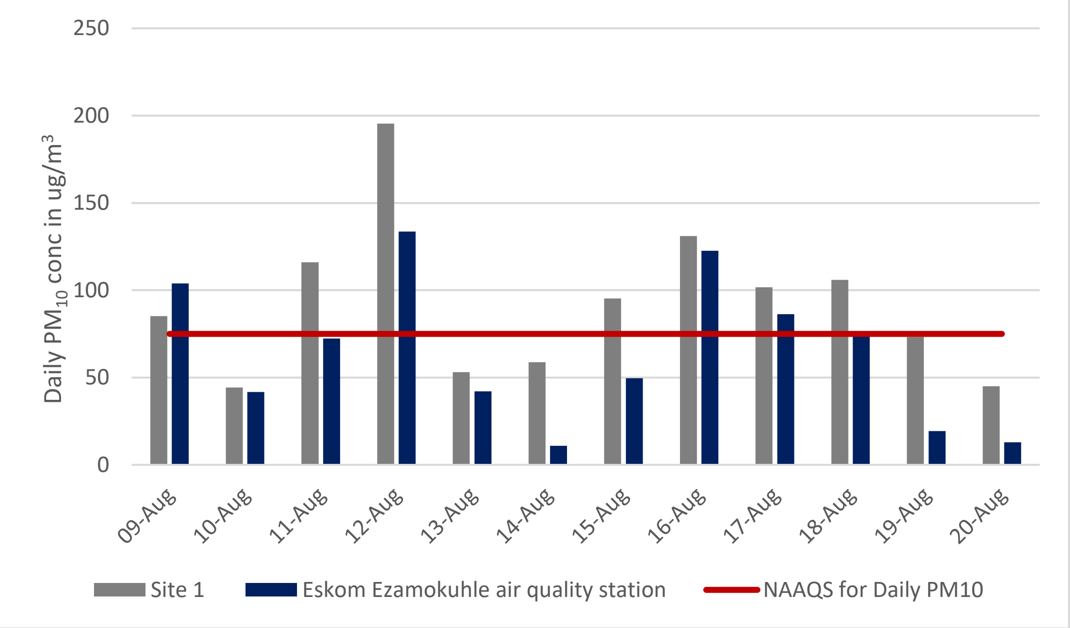

Figure 61: Comparison of the MiniVOL & Eskom Ezamokuhle air quality station PM_{10} measured results for the sampling campaign

5. CONCLUSION

This study used MiniVOL samplers that were developed by the Lane Regional Air Pollution Authority and the US Environmental Protection Agency (USEPA) to characterize the spatial and temporal distributions of ambient PM_{10}. The sampling was conducted for the period 9th August 2021 to 20th August 2021. An accredited World Meteorological Organisation (WMO) atmospheric chemistry laboratory prepared and analysed the Whatman Teflon filter papers. In summary the active measurement campaign has demonstrated that the ambient PM_{10} pollutant concentrations varied both spatially and magnitude in Ezamokuhle. Measured PM_{10} ambient concentrations were generally in non-compliance with the daily NAAQS for $PM_{10.}$ The study results have indicated that residential fuel burning has a significant impact in terms of ambient PM_{10} loading for Ezamokuhle. This coupled with the colder temperatures & poor air pollution dispersion potential of Ezamokuhle in winter, results in elevated localised ambient PM_{10} concentrations. Hence there is an opportunity herein to reduce human exposure to harmful levels of air pollution by reducing emissions from residential burning. Thus, supporting the roll-out of Eskom's PMV air quality offset intervention project in Ezamokuhle

6. ACKNOWLEDGEMENTS

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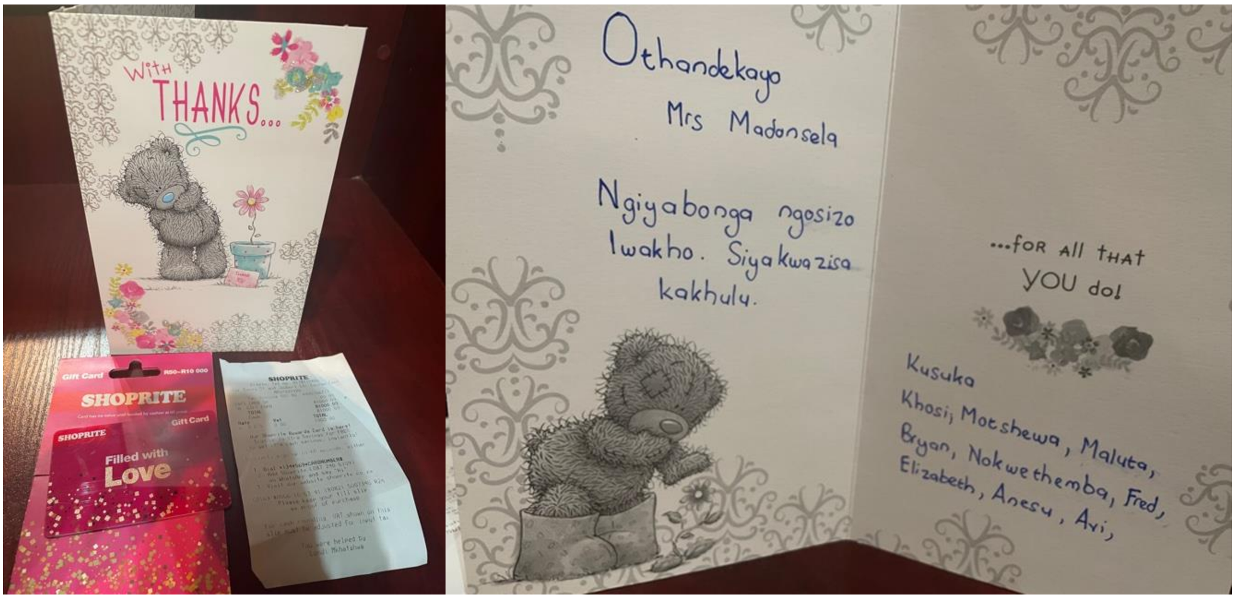
- Ms. Nokwethemba Khumalo & Ms. Makhosazana Mkongi for enabling ARM to engage with the Pixley Ka Seme Municipality &
- Ms. Mandisa Kunene from the Pixley Ka Seme Municipality for providing ARM with approval to engage with the households to place the active samplers in Ezamokuhle.
- Ms. N. Madonsela for kindly allowing us to place the MiniVOL sampler at her home in Ezamokuhle.
- Ms. E. Dladla for kindly allowing us to place the MiniVOL sampler at her home in Ezamokuhle.
- Councilor H. Twala for kindly allowing us to place the MiniVOL sampler at his home in Ezamokuhle.
- Mr. Zakhele for kindly allowing us to place the MiniVOL sampler at his home in Ezamokuhle.
- Ms. S.P Ndhlovu for kindly allowing us to place the MiniVOL sampler at his home in Ezamokuhle.
- Ms. Bontle Moiloa and Mr. Maluta Mbedzi for providing the team with the ambient air quality monitoring data for the Eskom Ezamokuhle station.



With THANKS...

Othandekayo
Mrs Madonsela

Ngiyabonga ngosizo lwakho. Siyakwazisa kakhulu.

...for all that YOU do!

Kusuka
Khosi, Motshewa, Maluta,
Bryan, Nokwethemba, Fred,
Elizabeth, Anesu, Avi,

Figure 62: Ngiyabonga

Figure 63: Ngiyabonga Ms. N. Madonsela

Figure 64: Ngiyabonga Ms. E. Dladla

Figure 65: Ngiyabonga Councilor H. Twala

Figure 66: Ngiyabonga Mr. Zakhele

Figure 67: Ngiyabonga Ms. S.P Ndhlovu

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ANNEXURE 1

Table 5: Measured daily PM_{10} concentrations in µg/m^3 at each site for the sampling campaign

Date	Day	Site 1	Site 2	Site 3	Site 4	Site 5
09-Aug	Monday	**85***	**215**	**116**	**136**	**101**
10-Aug	Tuesday	44	**148**	42	50	27
11-Aug	Wednesday	**116**	**161**	**100**	**99**	**97**
12-Aug	Thursday	**195**	**337**	**184**	**209**	**241**
13-Aug	Friday	53	**91**	42	**98**	**101**
14-Aug	Saturday	59	**223**	60	**99**	68
15-Aug	Sunday	**95**	**277**	**200**	**139**	**189**
16-Aug	Monday	**131**	**105**	**101**	**102**	**102**
17-Aug	Tuesday	**102**	**82**	**89**	59	**96**
18-Aug	Wednesday	**106**	**130**	**133**	**113**	**125**
19-Aug	Thursday	**73**	**99**	**97**	70	11
20-Aug	Friday	45	49	63	**105**	59

* Exceedances of the daily NAAQS PM_{10} standard appear in red bold text.

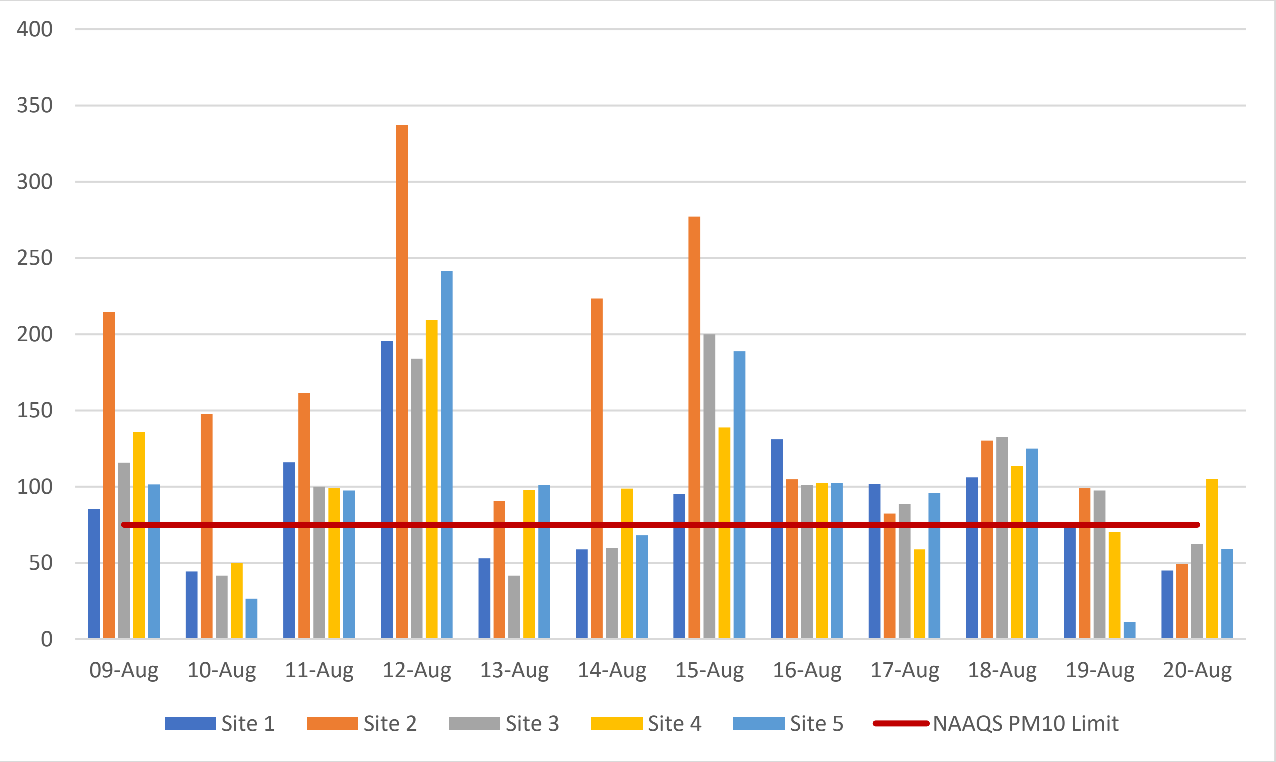

Figure 68: Measured daily PM_{10} concentrations in µg/m^3 at each site for the sampling campaign

ANNEXURE 2

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