PASSIVE MEASUREMENT CAMPAIGN REPORT FOR EZAMOKUHLE



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ARM
AIR RESOURCE MANAGEMENT

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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. In order 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* in order to evaluate compliance of the NAAQS at Ezamokuhle. This focus of this report is only on the *Passive Measurement Campaign* for Ezamokuhle. The objective of this study is to determine the ambient air quality concentrations of SO_2 and NO_2, their spatial distributions and assess possible exceedance of the NAAQS at Ezamokuhle

Passive sampling methods have been widely used for monitoring ambient air quality pollutants in different environments due to their inherent advantages including no electricity requirements and time-integrated sampling. Passive samplers are capable of taking gas samples from the atmosphere at a rate controlled by molecular diffusion, and which does not require the active movement of air through the sampler.

This study used a set of SO_2 and NO_2 passive samplers that were developed at the "Laboratoire d'Aérologie" in Toulouse, France. The passive samplers have been tested and validated extensively in Southern Africa as part of the Deposition of Biogeochemically Important Trace Species (DEBITS) programme. For passive measurement campaign, 8 sampling stations were installed in Ezamokuhle. The samplers were distributed across the entire area in order to capture the spatial distribution of pollutants over Ezamokuhle.

All 36 SO_2 and NO_2 passive samplers were affixed to light-poles at these 8 sites. The passive samplers were exposed in pairs to ensure reproducibility of the results and to reduce data loss if a sampler suffered interference. In support of the quality assurance and control (QA/QC) of the passive measurements, ARM undertook a rigorous QA/QC process. Additionally an accredited WMO atmospheric chemistry laboratory prepared and analysed the passive samplers. After the SO_2 and NO_2 passive samplers were exposed in Ezamokuhle for the 2 week period, the impregnated filters were removed and analysed for pollutant concentration in the laboratory using ion chromatography for SO_2 and spectrophotometry for NO_2.

The spatial distribution of the measured SO_2 and NO_2 concentrations showed that the highest concentrations occurred in China 2 with the lowest concentrations been measured at Jabavu. ARM's previous *Baseline modelling assessment* study results also demonstrated that the highest predicted model concentrations occurred in China 2. Thus this passive measurement campaign results echoes the same sentiment herein showing that the peak measured ambient concentrations for both pollutants occur in China 2 of Ezamokuhle.

The time series analysis of ambient SO_2 & NO_2 concentrations indicated that both pollutants are conditioned by non-buoyant low level localised sources in Ezamokuhle. For SO_2 there is a distinct second peak that occurs at 18:00 consistently throughout the week indicating the impact of residential fuel burning emission. As a consequence of China 2 having a higher density and spatial conglomeration of residential fuel burning emission sources in comparison to the other areas of Ezamokuhle, this contributes to the peak SO_2 concentration been measured herein.

For the passive measurement campaign, the SO_2 and NO_2 passive samplers were exposed for a 15 day window. Unfortunately there is not a 15-day NAAQS for either SO_2 or NO_2. Thus extrapolation was applied in order to compare the individual passive sampler's (15-day exposure period) SO_2 and NO_2 results to the applicable NAAQS. The extrapolated SO_2 and NO_2 concentrations were well below the applicable NAAQS limits. However in winter (June, July and August) there are elevated levels of SO_2 and NO_2 measured in Ezamokuhle due to the impact of residential fuel burning. Thus as this study was conducted in March, the extrapolated SO_2 and NO_2 concentrations must be considered on

the lower end of the spectrum as an extrapolation conducted for a winter set of measurement results will yield higher daily and annual values.

In summary the passive measurement campaign has demonstrated that the spatial distribution of the measured SO_2 and NO_2 concentrations showed that the highest concentrations occurred in China 2 with the lowest concentrations been measured at Jabavu. Thus it's recommended, Eskom considers prioritising China 2 in Ezamokuhle for the rollout of air quality offset interventions in order to reduce household emissions arising from residential fuel burning. Whilst the extrapolated SO_2 and NO_2 concentrations were well below the applicable NAAQS limits for March, it must noted that there will be higher elevated levels of these pollutants in winter due to the impact of residential fuel burning. The compliance to the applicable NAAQS limits in winter will be re-evaluated by ARM as part of Activity 10 of the Eskom PMV project.

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 & Manufactured.

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 (Figure 1), 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.

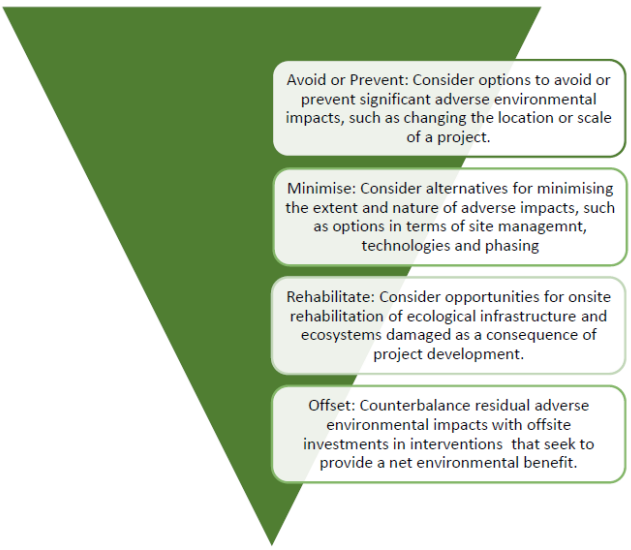

Figure 1: The mitigation hierarchy

1.2 Air Quality Offsets Guideline

(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

The DEFF 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 implementation of Eskom's air quality offsets. The air quality offsets programme are 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.

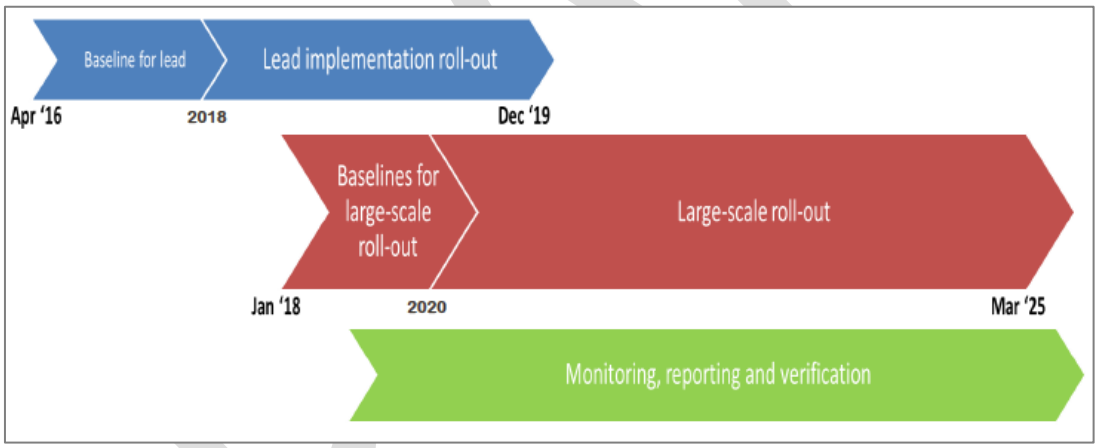

Figure 2: Concept Schedule for the implementation of Eskom's air quality offsets

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. In order to achieve this, Eskom has included sixteen targeted work package Activities (Table 1) for these respective communities.

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
Ozone (O_3)	8 hour	120 µg/m^3	11	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* in order to evaluate compliance of the NAAQS at Ezamokuhle (Figure 3). This focus of this report is only on the *passive measurement campaign* for Ezamokuhle.

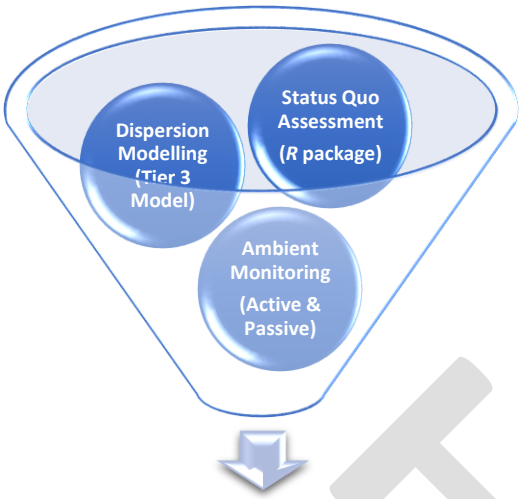

Figure 3: Phased approach to evaluate NAAQS non-compliance for Ezamokuhle

2.2 Study Objective

The objective of this study is to determine the ambient air quality concentrations of SO_2 and NO_2, their spatial distributions and assess possible exceedance of the NAAQS (Table 1) at Ezamokuhle (Figure 4).

Figure 4: Map illustrating the different area within Ezamokuhle

3. METHODOLOGY

3.1 PASSIVE SAMPLING

A passive sampler is a device capable of determining pollutant concentrations in the atmosphere without using pumps (Rosario, 2016). Passive sampling methods have been widely used for monitoring ambient air quality pollutants in different environments due to their inherent advantages including no electricity requirements and time-integrated sampling (Lai, 2018).

Passive sampling makes use of the laws of diffusion. Diffusion is the molecular transport of a substance and is observed in gaseous, liquid and solid media. The forces behind this substance transport are differences in concentration, partial pressure and temperature. Characteristic of diffusion processes is that transport of the substance takes place without any apparent flow, i.e. without movement of the whole medium. In general, diffusion is understood to be the process whereby molecules migrate within a system as a result of differences in potential.

During passive sampling the only force behind the transport of the substance is the difference in the concentration of the substance in the ambient air and that on the surface of the collection phase. To calculate the amount of substance which has diffused within a certain period of time, geometric parameters, such as the length of the diffusion path over which the concentration differs, and the cross-section through which a certain amount of substance diffuses within a defined period of time, must be taken into account. The diffusion process can be described mathematically by Fick's first law of diffusion (Giese, 2002).

3.2 PASSIVE SAMPLERS USED IN STUDY

This study used a set of SO_2 and NO_2 passive samplers that were developed at the "Laboratoire d'Aérologie" in Toulouse, France. The passive samplers have been tested and validated extensively in Southern Africa as part of the Deposition of Biogeochemically Important Trace Species (DEBITS) programme (Pienaar, 2003; Josipovic, 2011). The design of the passive sampler is presented in Figure 5.

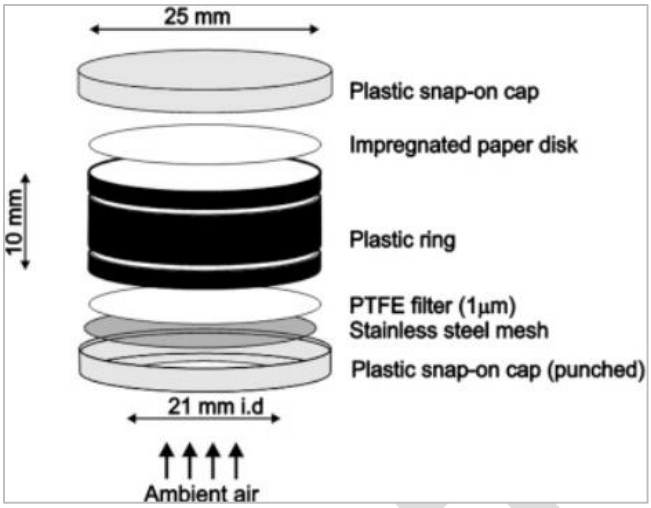

Figure 5: Laboratoire d'Aérologie passive sampler utilised

3.3 Passive Sampling Grid in Ezamokuhle

For passive measurement campaign, 8 sampling stations were installed in Ezamokuhle (Figure 6). The samplers were distributed across the entire area in order to capture the spatial distribution of pollutants over Ezamokuhle.

Figure 6: Location of Passive Sampling Locations in Ezamokuhle

All 36 SO_2 and NO_2 passive samplers were exposed in pairs to ensure reproducibility of the results and to reduce data loss if a sampler suffered interference. At the 8 monitoring sites, samplers were installed mesh- side down in the underside of a metal rain shelter, which was affixed to the top of a light pole (Figure 7 & 8) and left in position for ~ two weeks (1/03/21 to 15/03/21).

Figure 7: Passive sampler with rain shelter affixed to light-pole

Figure 8: Passive sampling location in Ezamokuhle

3.4 Quality Assurance & Quality Control (QA/QC) of The Measurements

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

1. duplicate passive samplers for both SO_2 and NO_2 were present sites in order to assess the reproducibility of the measurements;
2. some of the sites had samplers in place to be used as blanks which would serve as a zero check, such that blank concentration would be subtracted from measured pollutant concentrations as to ensure monitors contamination is adjusted for;

3. an accredited World Meteorological Organization (WMO) atmospheric chemistry laboratory with its own quality assurance and control measures was used;
4. for internal ARM quality control purposes, data analysis included checking for extreme concentrations that prompted the scientific flagging of outliers;
5. a 2 week campaign was undertaken in order to obtain a representative dataset and
6. a minimum data capture of 90% of the time for the campaign, allowing for a failure (leakage, theft, vandalism, presence of insects) of the diffusive samplers during 10% of the time.

3.5 Analysis of Passive Samplers

An accredited WMO atmospheric chemistry laboratory prepared and analysed the passive samplers. The passive sampler was supplied ready for use in a sealed container loaded with a filter treated for a nominated pollutant gas. After the SO_2 and NO_2 passive samplers had been exposed in Ezamokuhle for the 2 week period, the impregnated filters were removed and analysed for pollutant concentration in the laboratory using ion chromatography for SO_2 and spectrophotometry for NO_2.

4. RESULTS & DISCUSSION

4.1 Spatial Distribution of Pollutants in Ezamokuhle

For the purpose of mapping a pollutant, of which the SO_2 and NO_2 concentration were measured at the 8 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 SO_2 & NO_2 Concentrations in Ezamokuhle

The spatial distribution of both the SO_2 concentrations and NO_2 for the period of monitoring are presented in Figures 9 to 12. The measured concentrations for both of these pollutants were highest at the centre of China 2, dominated by the influence of site 2. The passive sites positioned further away from China 2 measured lower concentrations with the lowest concentrations been measured at Jabavu.

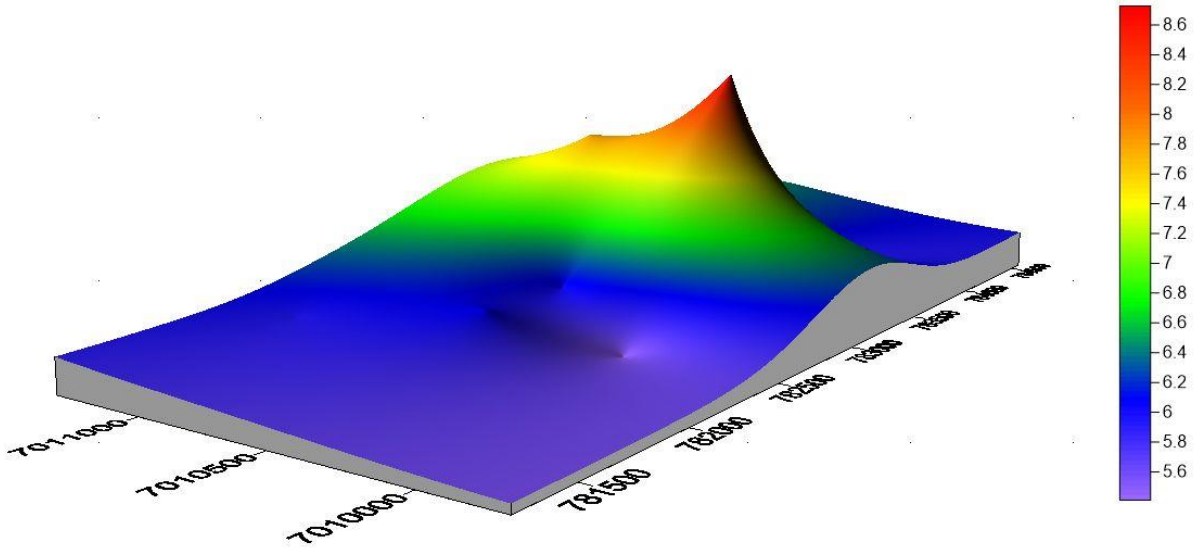

Figure 9: 3-D Surface map showing the spatial distribution of SO_2 in µg/m^3

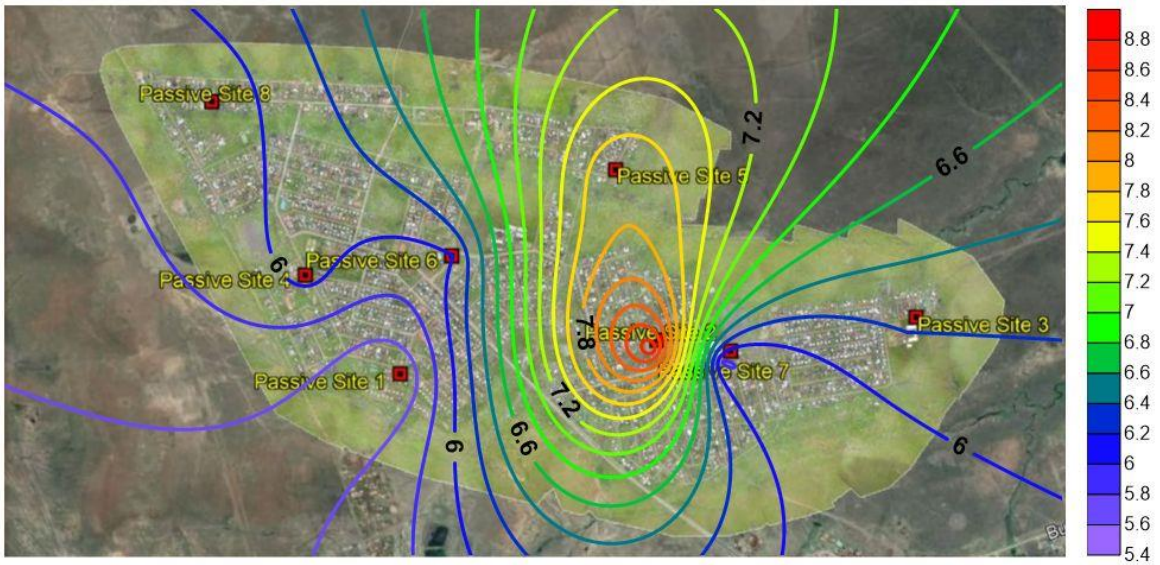

Figure 10: Isopleth map showing the spatial distribution of measured SO_2 concentrations in µg/m^3

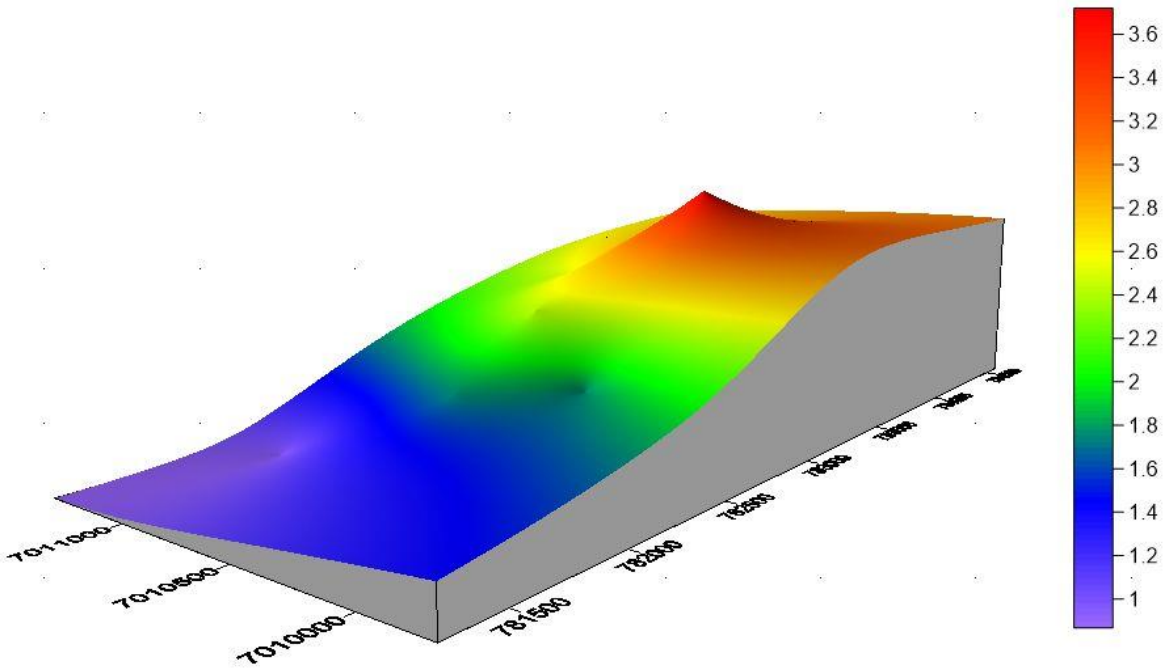

Figure 11: Surface map showing the spatial distribution of NO_2 in µg/m^3

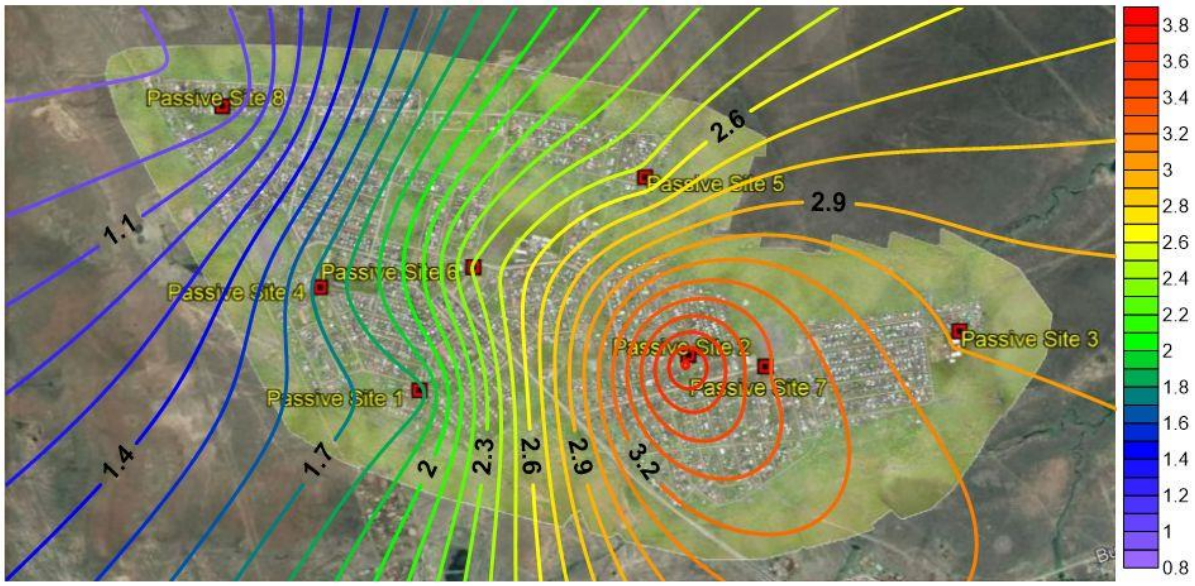

Figure 12: Isopleth map showing spatial distribution of measured NO_2 concentrations in µg/m^3

As highlighted previously, 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* in order to evaluate compliance of the NAAQS at Ezamokuhle (Figure 3).

ARM has already completed the *Baseline modelling assessment* (ARM, 2021a). The objective of this study was to firstly assess the modelled ambient concentrations against the NAAQS compliance limits (including both SO_2 & NO_2) & secondly to utilise the study results to inform the representative placement of active ambient air quality analysers at Ezamokuhle. The prioritisation of air quality hotspots for Ezamokuhe was ranked on the basis of impacts. This ensured that the areas that potentially pose the greatest risk to human health and the environment are identified for optimum placement of the active ambient air quality analysers.

It's noteworthy that *Baseline modelling assessment* study results demonstrated that the highest predicted model concentrations occurred in China 2. Thus China 2 was identified as the highest priority air quality hotspot in Ezamokuhle. Similarly this passive measurement campaign results echoes this same sentiment herein showing that the peak measured ambient concentrations for both pollutants occur in China 2 of Ezamokuhle.

Figure 13 presents an overview of the density of the various emission source categories for the different areas (Figure 4) in Ezamokuhle (ARM, 2021b). It clear from Figure 13 that China 2 has a higher density and spatial conglomeration of residential fuel burning emission sources in comparison

to the other areas of Ezamokuhle. Thus China 2 is anticipated to have a higher emissions loading of both SO_2 & NO_2 with regards to residential fuel burning.

Figure 13: Emission source categories identified in Ezamokuhle based on a ground and aerial based assessment (ARM, 2021b)

Figure 14 shows time series (mean with 95% confidence interval) of ambient SO_2 & NO_2 concentrations measured at the Eskom Ezamokuhle ambient air quality station for the period 2018 to 2020 (ARM, 2021c). Whilst SO_2 show a typically industrial signature with increased ambient air quality concentrations at just around midday due to the break-up of an elevated inversion layer it's evident that both SO_2 & NO_2 are conditioned by non-buoyant low level localised sources in Ezamokuhle. For SO_2 there is a second peak that occurs at 18:00 consistently throughout the week indicating the impact of residential fuel burning emission. Thus due to China 2 having a higher density and spatial conglomeration of residential fuel burning emission sources in comparison to the other areas of Ezamokuhle, this contributes to the peak SO_2 concentration been measured herein.

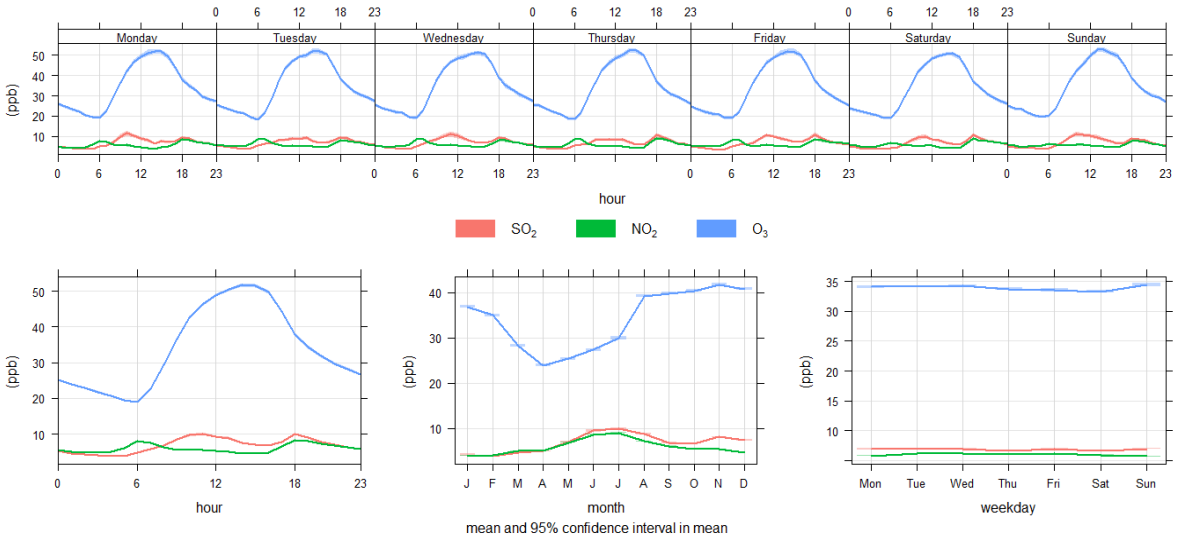

Figure 14: Mean pollutant concentrations for 2018 to 2020 in ppb for the Eskom Ezamokuhle air quality station calculated for hourly mean during weekdays and a single day, monthly, and daily mean (ARM, 2021c)

4.2 Comparision of Passive measurements at Ezamokuhle to NAAQS

For the passive measurement campaign, 8 sampling stations were installed in Ezamokuhle and the 36 SO_2 and NO_2 passive samplers were exposed for a 15 day window. Unfortunately there is not a 15-day NAAQS for either SO_2 or NO_2. Thus extrapolation was required to compare the individual passive sampler's (15-day exposure period) SO_2 and NO_2 results to the applicable NAAQS (Table 2).

This is achieved by applying the extrapolation formula after Beychok (2005):

$$C2 = C1\left(\frac{T1}{T2}\right)^{n}$$

Where:

Variable	Description
C1	Concentration, known or given
C2	Concentration, unknow
T1	Averaging time for C1
T2	Desired time for C2
N	Exponent based on the atmospheric stability

The “n” exponent is based on atmospheric stability which is typically categorised into five (5) classes as a function of the hourly standard deviation of wind direction, wind speed and solar radiation. These presented in Table 3 below.

Table 3: Categories of Atmospheric Stability Classes.

Class	A	B	C	D	E
Description	Highly turbulent	Moderately turbulent	Slightly turbulent	Neutral	Stable
“n” (exponent)	0.7	0.52	0.52	0.2	0.2

In instances where the atmospheric stability is not known or cannot be estimated, moderate to slightly turbulent (0.52) is assumed as is the case for the purpose of this report.

4.2.1 Extrapolated SO_2 & NO_2 Concentrations for Ezamokuhle

The extrapolated SO_2 and NO_2 concentrations are presented in Table’s 4. The extrapolated SO_2 and NO_2 concentrations (Figures 15 to 16) are well below to the applicable NAAQS limits. However in winter (June, July and August) there are elevated levels of SO_2 and NO_2 measured in Ezamokuhle due to the impact of residential fuel burning (ARM, 2021c). Thus as this study was conducted in March, the extrapolated SO_2 and NO_2 concentrations (Table 4) must be considered on the lower end of the spectrum as an extrapolation conducted for a winter set of measurement results will yield higher daily and annual values.

Table 4: Extrapolated SO_2 and NO_2 concentrations for Ezamokuhle in in µg/m3

Passive Site	SO_2 Daily Concentration in µg/m^3	SO_2 Annual Concentration in µg/m^3	NO_2 Annual Concentration in µg/m^3
1	22.1	1.0	0.32
2	35.6	1.6	0.67
3	25.3	1.1	0.54
4	24.8	1.1	0.32
5	31.7	1.4	0.46
6	24.4	1.1	0.44
7	23.6	1.0	0.60
8	23.7	1.0	0.17

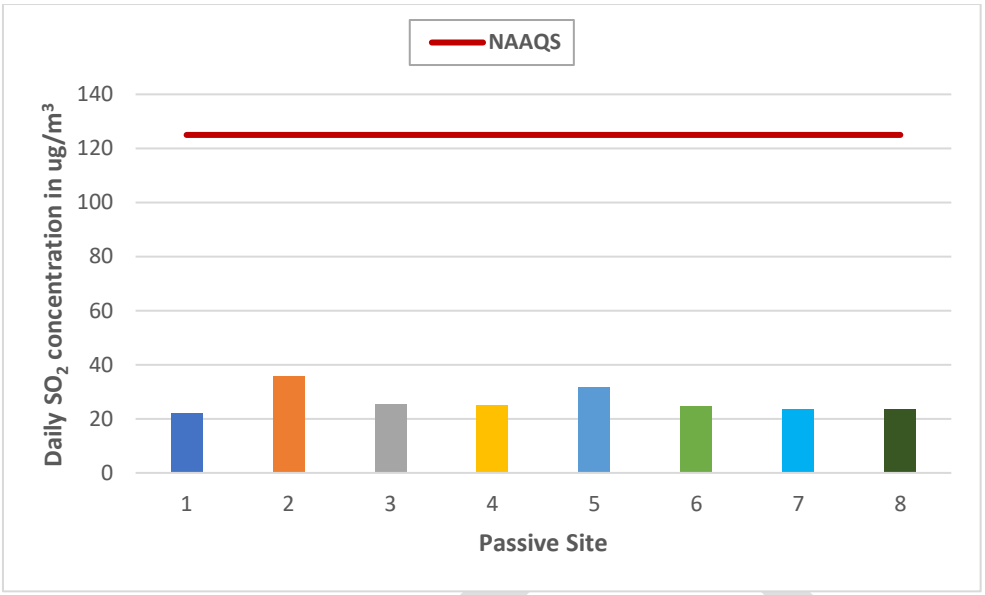

Figure 15: Extrapolated daily SO_2 concentration in µg/m³ compared to the applicable NAAQS

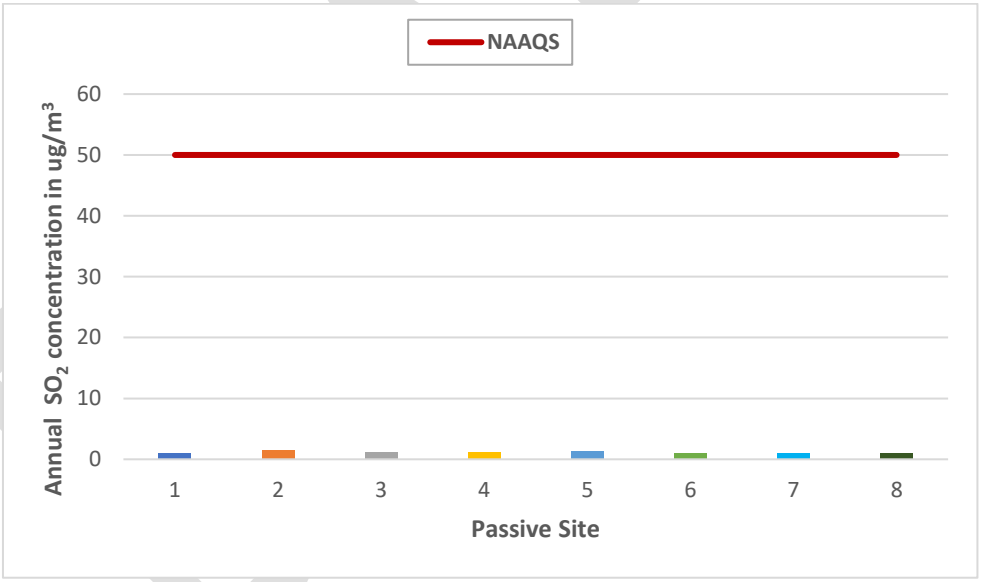

Figure 16: Extrapolated annual SO_2 concentration in µg/m³ compared to the applicable NAAQS

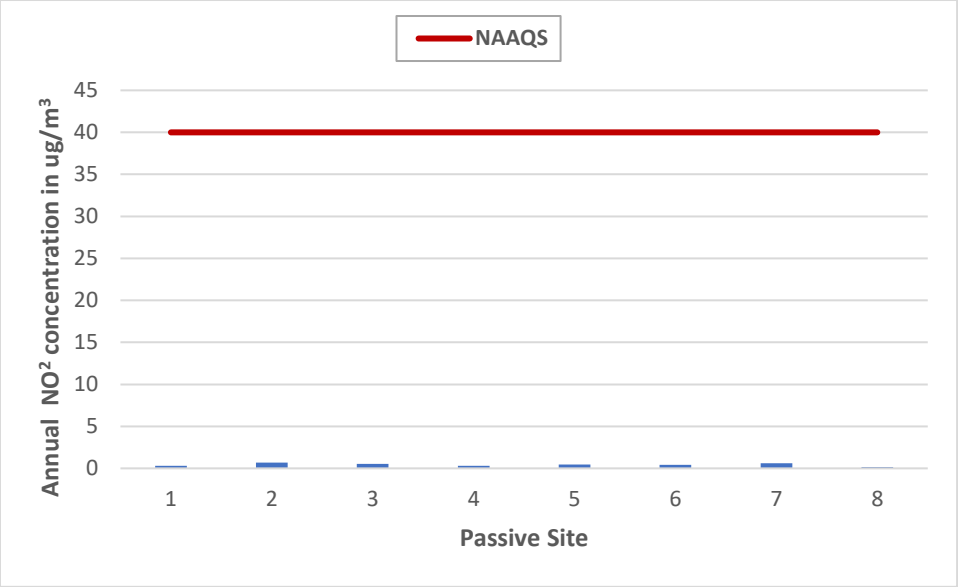

Figure 17: Extrapolated annual NO_2 concentration in µg/m^3 compared to the applicable NAAQS

5. CONCLUSION

The objective of this study was to determine the ambient air quality concentrations of SO_2 and NO_2, their spatial distributions and assess possible exceedance of the NAAQS at Ezamokuhle. For passive measurement campaign, 8 sampling stations were installed in Ezamokuhle. The samplers were distributed across the entire area in order to capture the spatial distribution of pollutants over Ezamokuhle. After the SO_2 and NO_2 passive samplers were exposed in Ezamokuhle for the 2 week period, the impregnated filters were removed and analysed for pollutant concentration in the laboratory using ion chromatography for SO_2 and spectrophotometry for NO_2.

The results of passive measurement campaign has demonstrated that the spatial distribution of the measured SO_2 and NO_2 concentrations were highest at the centre of China 2 with the lowest concentrations been measured at Jabavu. Thus it's recommended, Eskom considers prioritising China 2 in Ezamokuhle for the rollout of air quality offset interventions in order to reduce household emissions arising from residential fuel burning. Whilst the extrapolated SO_2 and NO_2 concentrations were well below the applicable NAAQS limits for March, it must noted that there will be higher elevated levels of these pollutants in winter due to the impact of residential fuel burning. The compliance to the applicable NAAQS limits in winter will be re-evaluated by ARM as part of Activity 10 of the Eskom PMV project.

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ANNEXURE 1

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