Activity 10: Ambient air quality monitoring

Activity 10.1: E-bam deployment and air quality assessment (baseline) for eZamokuhle

Document by:

ARM
AIR RESOURCE MANAGEMENT

Final Report

3rd November 2023

Document Title

Client		**Eskom**
Title		**E-bam deployment and air quality (AQ) assessment (baseline) for eZamokuhle**
Our Reference		**ESKPMV-2023- ACT-10.1-00**
Issued to Client		**3rd November 2023**
Classification		**Company Confidential**

Document Change Record

Revision Number	Date	Description of Revision
00A	21st July 2023	Creation of Document
00B	20th August 2023	Peer Review of Document
00	6th September 2023	Draft Document issued to Eskom
01	3rd November 2023	Final Document issued to Eskom

Document Approval

	Name	Date
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Reviewed by	Fred Goede	20th August 2023
Approved by	Fred Goede	3rd November 2023

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EXECUTIVE SUMMARY

This study performed an analysis of the baseline trends, correlations and general relations which were based on collected ambient air quality measurement data obtained from the: Eskom eZamokuhle Station (the in-situ station), the Eskom Majuba Station (the industrial station), as well as three sampling locations in the eZamokuhle residential region. Its noted that these measurements at eZamokuhle were conducted prior to the rollout of the Eskom AQO Project interventions in the eZamokuhle community and thus serves as the status quo air quality baseline herein. The Openair model was utilised to statistically analyse the semi-empirical mathematical relationships between air pollutant concentrations and meteorological parameters for these three stations.

Three E-BAM Environmental Beta Attenuation Mass Monitors were commissioned at three residential sampling sites in the eZamokuhle region. The E-BAMs were placed outdoors in the yard of each of the residential sampling sites. The E-BAM instrument is a portable, real-time beta gauge comparable to U.S.-EPA methods for $PM_{2.5}$ and PM_{10} particulate measurements. The E-BAM automates particulate measurement by continuously sampling and reporting concentration data. The sampling assessment was conducted from mid-August to mid-October 2022 at the three residential sampling sites.

The hourly diurnal PM cycle at House 4 is indicative of residential fuel burning. Maximum hourly ambient PM_{10} concentrations of 400 ug/m^3 were recorded at House 4 during the survey. Maximum daily ambient concentrations of 120 ug/m^3 were recorded, with exceedances of the daily NAAQS for PM_{10}. These exceedances were prominent during the colder months during the sampling period. No exceedances of the daily NAAQS for PM_{10} were recorded for the second half of September, as well as the October at House 4. A daily mean ambient PM_{10} concentration of 57.1 ug/m^3 were recorded for House 4 during the sampling period.

The hourly diurnal cycle at House 1 and House 5 are indicative of residential fuel burning. Maximum hourly ambient PM_{10} concentrations of 500ug/m^3 were recorded at House 1 and House 5 during the survey. Maximum daily ambient concentrations of 80ug/m^3 were recorded at both Houses, with exceedances of the daily NAAQS for $PM_{2.5}$. These exceedances were more prominent during the colder months during the sampling period, but exceedances were also reported during October for both Houses. A daily mean ambient $PM_{2.5}$ concentration of 40.0 ug/m^3 and 43.7 ug/m^3 were recorded for House 1 and House 5 respectively during the sampling period.

An analysis of the Eskom eZamokuhle and Eskom Majuba air quality monitoring stations (AQMS) data for PM_{10}, $PM_{2.5}$, SO_2 and NO_2 are also given for the same period as the particulate sampling survey in eZamokuhle for reference purposes. The Eskom eZamokuhle and Majuba ambient monitoring stations as well as the three residential E-BAM sampling sites in the eZamokuhle recorded multiple exceedances of the daily NAAQS for both PM_{10} and $PM_{2.5}$. Due to the bi-modal particulate matter peaks and localised contribution evident in the study analysis, these elevated concentrations show a typical profile for residential fuel burning. These elevated concentrations were more pronounced in the winter months with the increased space heating requirements of the eZamokuhle households in winter.

There were no exceedances of the SO_2 or NO_2 NAAQS recorded at the Eskom eZamokuhle and Eskom Majuba AQMS. The SO_2 concentrations were generally associated with a typically industrial signature whereas the analysis indicated that the variability of NO_2 concentration was associated with vehicle emissions.

In summary the results of this study has demonstrated 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.

The analysis provided indicated serves as a baseline for the impact of the Eskom air quality offset programme with the monitoring being repeated once the interventaion is eZamokuhle is completed.

1. BACKGROUND

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 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).

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

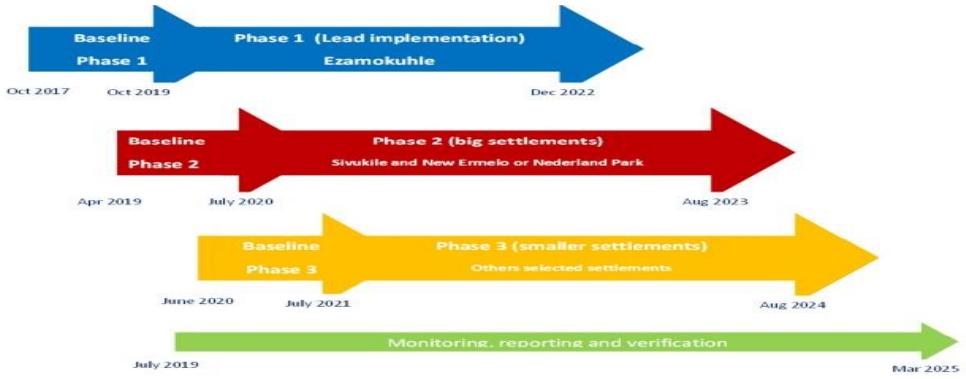

Figure 1: Concept Schedule for the implementation of Eskom's air quality offsets (Matimolane, 2020)

Eskom has adopted the phased approach (Figure 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 2: 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).

1.3 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. 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 10.1 The E-bam deployment and AQ assessment (baseline) for eZamokuhle.*

Table 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 Scope of Work

In accordance with the scope of work, for Activity 10: *Conduct Ambient Air Quality Monitoring*, ARM is to conduct ambient air quality monitoring utilising the Environmental beta Attenuation Monitors to monitor baseline PM concentrations in eZamokuhle before the implementation and rollout of the intended Eskom household interventions.

2. METHODOLOGY

2.1 SAMPLING METHODOLOGY

Three E-BAM Environmental Beta Attenuation Mass Monitors were commissioned at three residential sampling sites in the eZamokuhle region. The E-BAM instrument is a portable, real-time beta gauge comparable to U.S.-EPA methods for $PM_{2.5}$ and PM_{10} particulate measurements. The E-BAM automates particulate measurement by continuously sampling and reporting concentration data. Data records are updated every minute. Figure 3 is a graphical representation of the E-BAM instrument.

Figure 3: E-Bam Instrument

2.2 SAMPLING LOCATIONS

Table 2 is a summary of the E-BAM site locations as well as the sampling duration. Figure 4 is a picture of the E-BAM instrument commissioned at House 5 whereas Figure 5 is a close-up of these sampling locations in the eZamokuhle residential region. Figure 6 is

locality map of the E-BAM samplers in relation to the Eskom eZamokuhle and Eskom Majuma AQMS, whilst Figure 7 is indicative of the eZamokuhle residential region in the Highveld.

Table 2: Summary of E-BAM sampling locations

Site	Pollutant Measured	Latitude (°S)	Longitude (°E)	Sampling Duration
House 1	$PM_{2.5}$	27.000325°	29.853501°	6 August 2023 to 21 October 2023
House 4	PM_{10}	27.001456°	29.856803°	14 August 2023 to 21 October 2023
House 5	$PM_{2.5}$	27.000133°	29.855321°	8 August 2023 to 19 October 2023

Figure 4: E-Bam instrument commissioned at House 5

Figure 5: Close-up of the sampling sites in eZamokuhle community

Figure 6: Map indicating the sampling sites in relation to the Majuba Power Station.

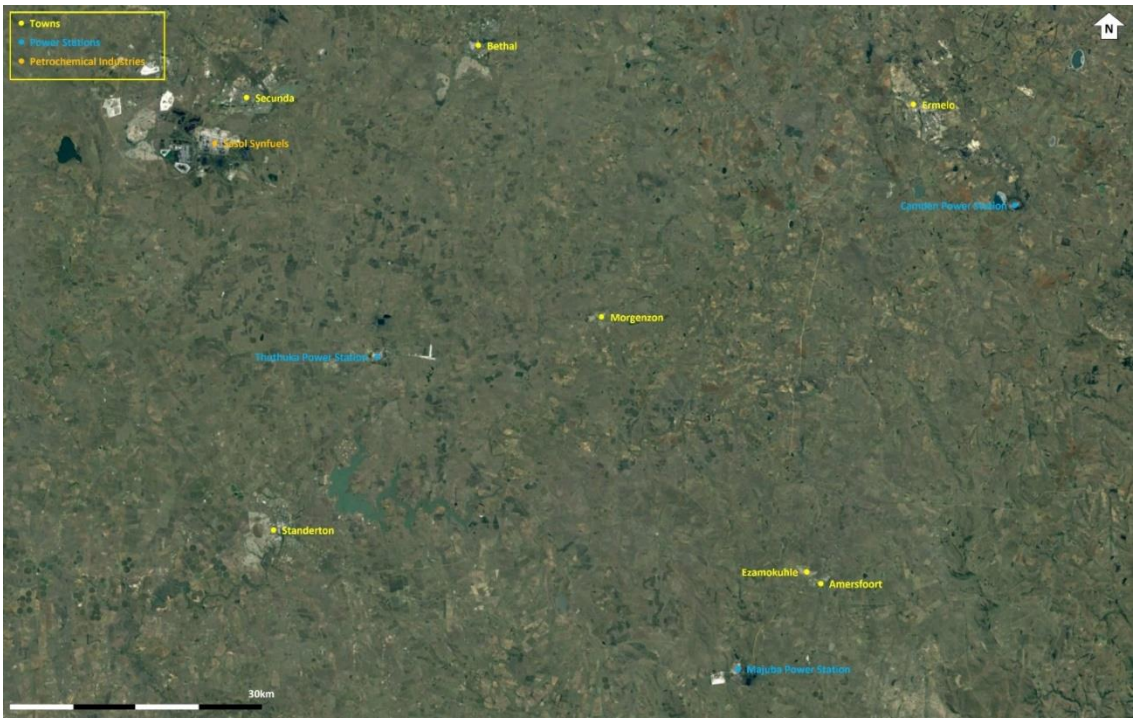

Figure 7: Layout of eZamokuhle in the Highveld.

3. RESULTS AND DISCUSSION

3.1 METEOROLOGICAL RESULTS

Air quality is strongly influenced by meteorology. Meteorological mechanisms govern the dispersion 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 the rate of dilution of pollutants. The wind rose is a very useful way for showing how wind speed and wind direction conditions vary by year. Meteorological data for the sampling period were obtained from the Eskom eZamokuhle and Eskom Majuba AQMS.

3.1.1 WIND SPEED AND WIND DIRECTION

Wind drives the atmospheric transport and strongly affects vertical air mixing and thus the ventilation of the urban air (Grundstrom et al., 2015). The understanding of how wind speed affects ground–level air pollution concentrations is relatively well established.

Stagnant atmospheric conditions with calm, clear weather often led to stable atmospheric stratification which can transform into strong nocturnal temperature inversions due to rapid surface cooling. The resulting restriction in vertical air mixing near the surface consequently leads to poor air quality (Delaney and Dowding, 1998; Janhall et. al., 2006; Olofson et al., 2009). Low wind speeds deteriorate air quality with respect to pollutants emitted near the ground due to restricted air ventilation (Jones et al., 2010). In contrast higher wind speeds are associated with increased dispersion and mixing of atmospheric pollutants which may result in low ambient pollution concentrations. Figure 4 illustrates

the predominant wind directions for the sampling period for the Eskom eZamokuhle and Eskom Majuba AQMS.

For the Eskom eZamokuhle AQMS station the average wind speed for the sampling period (Figure 8) was recorded at 3.04m/s with calm condition 0%. Calm condition means that wind speed is recorded at zero meter/second (Carlaw, 2015). The predominant wind direction was westerly (≈17% frequency of occurrence) followed by north westerly and easterly winds (≈13% frequency of occurrence) with maximum wind speed of 8 – 11m/s.

For the Eskom Majuba AQMS station the average wind speed for the sampling period (Figure 8) was recorded at 4.31m/s with calm condition 0.3%. Calm condition means that wind speed is recorded at zero meter/second (Carlaw, 2015). The predominant wind direction was south westerly (≈16% frequency of occurrence) followed by westerly and north easterly winds (≈13% frequency of occurrence) with maximum wind speed of 8 – 11m/s.

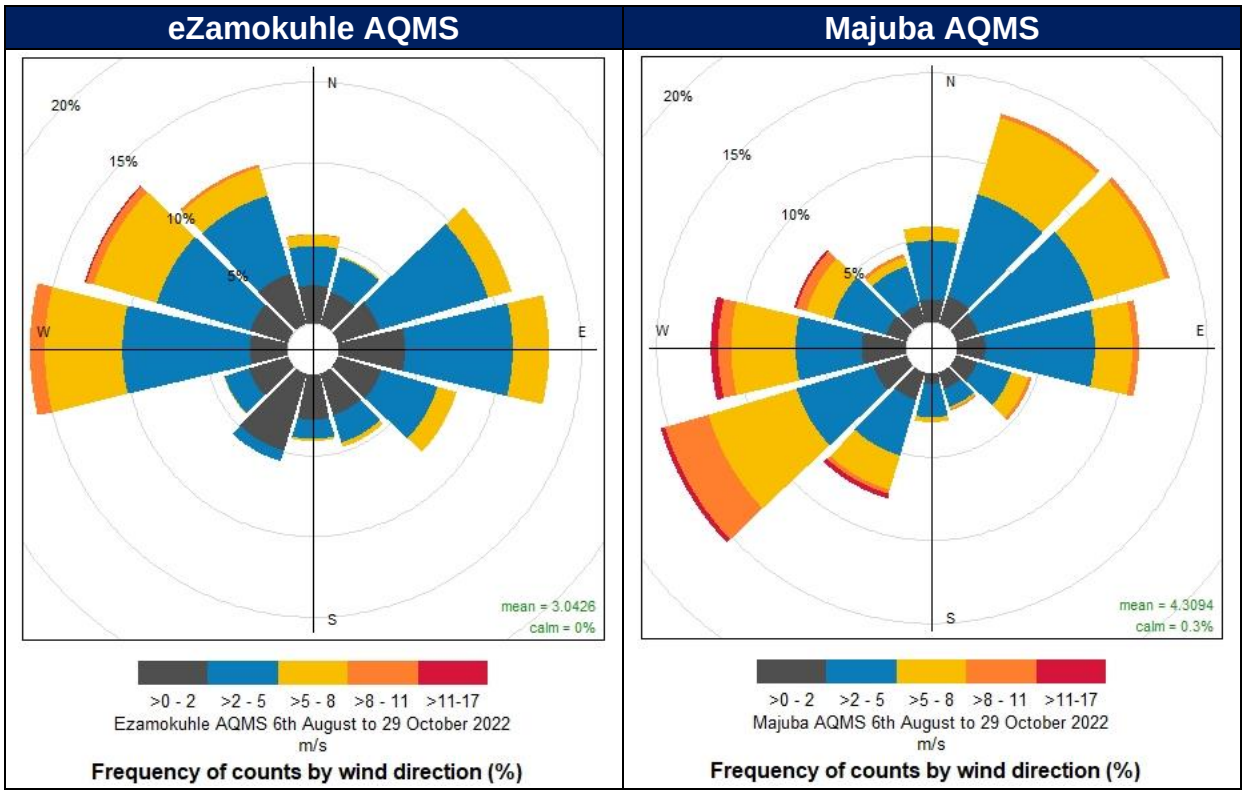

Figure 8: Wind roses for the Eskom eZamokuhle and Eskom Majuba AQMS for the sampling period

Figure 9 provides the diurnal wind speed, whilst Figure 10 is indicative of the monthly mean ambient wind speeds recorded at the Eskom eZamokuhle and Eskom Majuba AQMS respectively.

It is evident from Figure 9 that the wind speed for both stations increase at 08:00 with a decrease at around 17:00. Maximum wind speeds are recorded for both stations at 15:00. Figure 10 illustrates slightly higher monthly mean wind speeds for the Majuba AQMS in comparison to the eZamokuhle AQMS.

As a norm, wind speeds in excess of 5.4m/s potentially have sufficient energy to pick-up and transport loose and/or disturbed particulate matter, which gives rise to visible nuisance dust and clouds of dust at ground level. The extent, to which this occurs / can

occur, depends on several parameters, such as the properties and characteristics of the particulate matter, moisture content, etc.

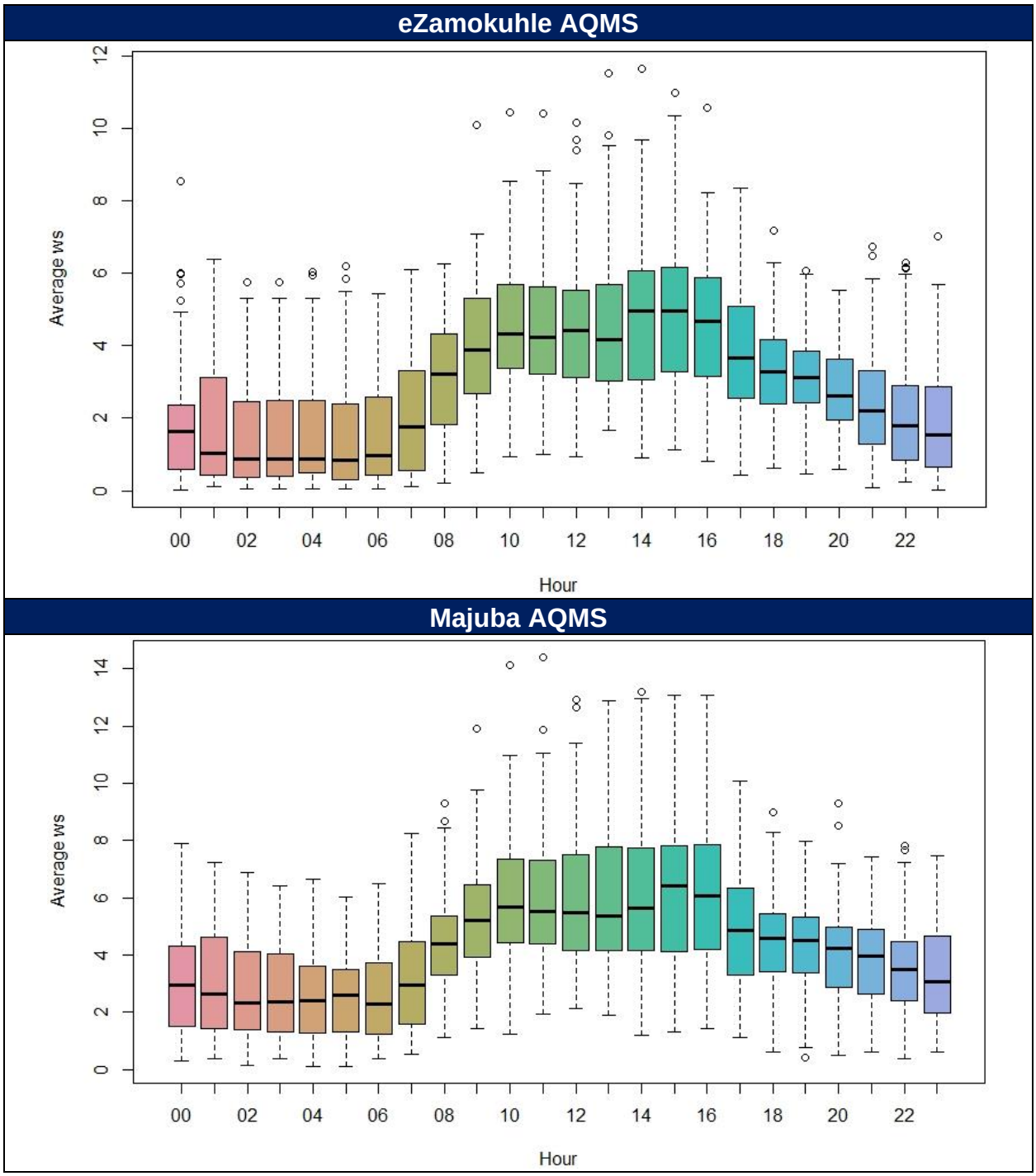

Figure 9: Diurnal wind speeds recorded at the eZamokuhle and Majuba AQMS (m/s).

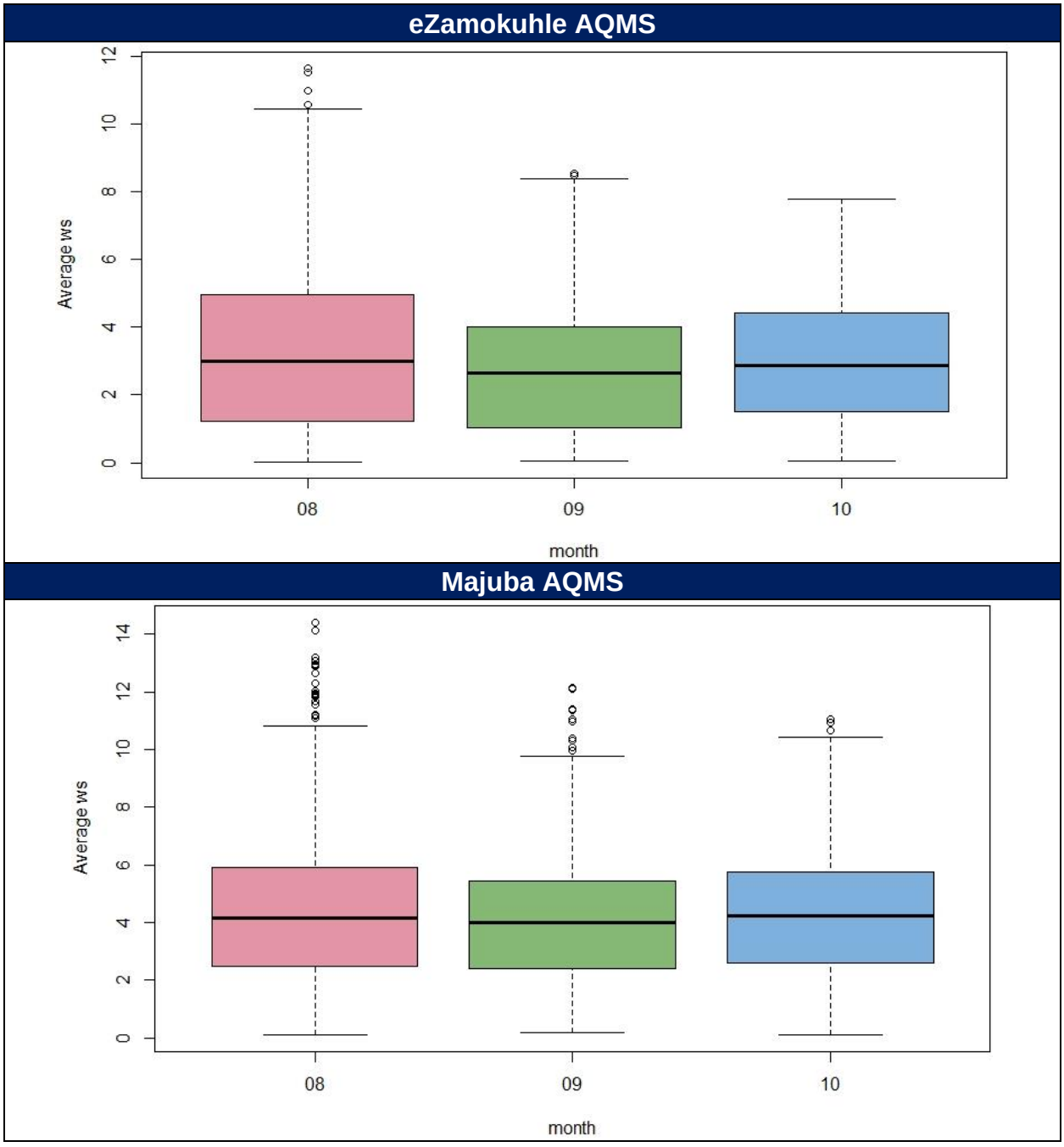

Figure 10: Monthly mean wind speeds recorded at the eZamokuhle and Majuba AQMS (m/s).

3.1.2 TEMPERATURE

Air temperature is important, both for determining the effect of plume buoyancy (the larger the temperature difference between the plume and the ambient air, the higher the plume can rise), and determines the development of the mixing and inversion layers. Figure 11 provides daily mean ambient temperatures for the Eskom eZamokuhle and Eskom Majuba AQMS respectively. From Figure 11, it is evident how the average ambient air temperatures are between 5 and 15°C for August, and slowly increasing to 15 and 22°C for the month of October. An increase in wind speed and ambient temperature improves the dispersion of air pollutants in the air.

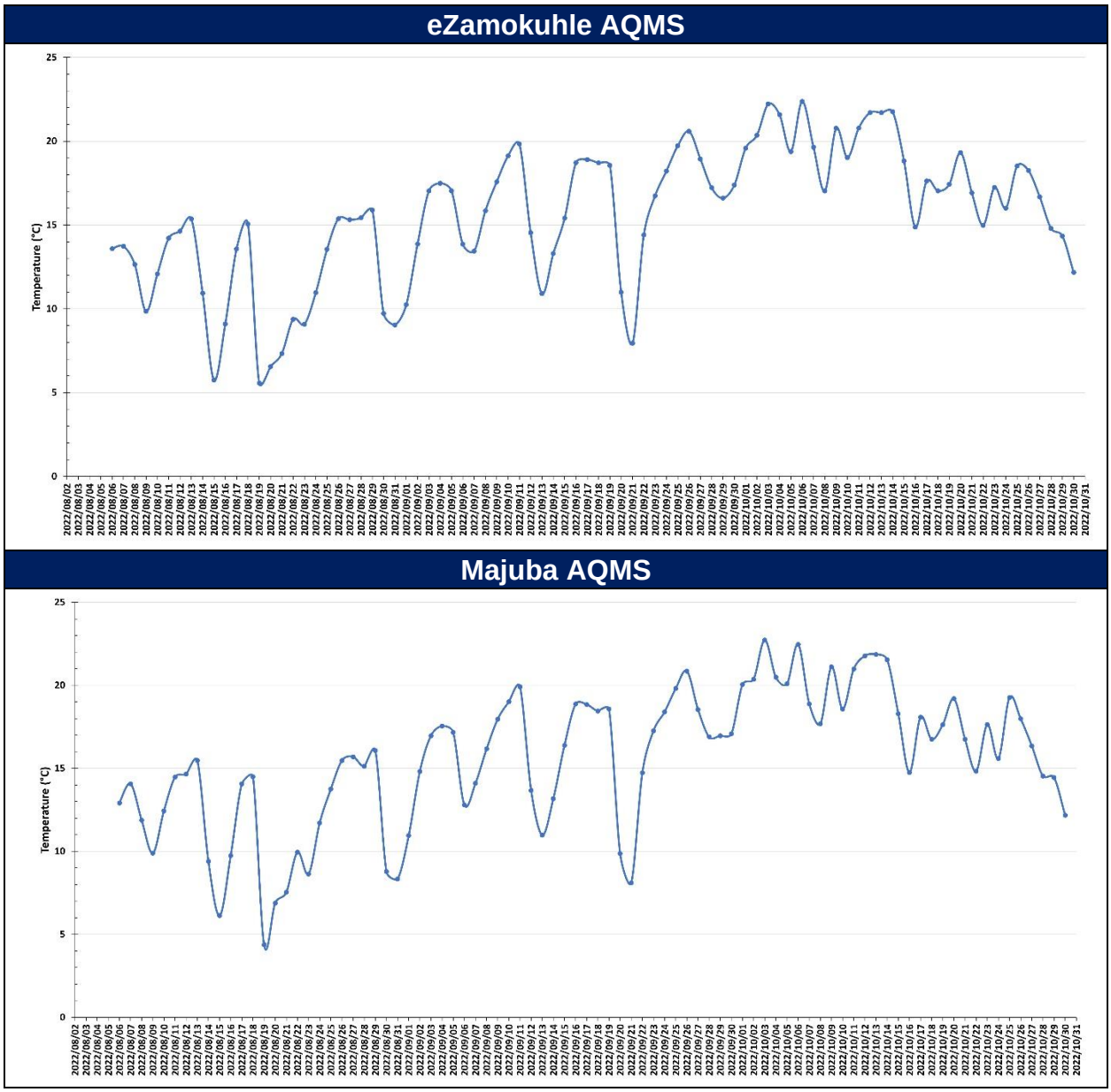

Figure 11: Daily average temperature at the eZamokuhle and Majuba AQMS (°C).

3.1.3 TEMPERATURERAINFALL ?

Figure 12 provides daily total rainfall/precipitation recorded for the Eskom eZamokuhle and Eskom Majuba AQMS respectively. From Figure 12, it is evident both stations recorded a maximum rainfall of 17mm on 20 August 2022. Frequent rainfall events were recorded for both stations from 18 to 28 October 2022.

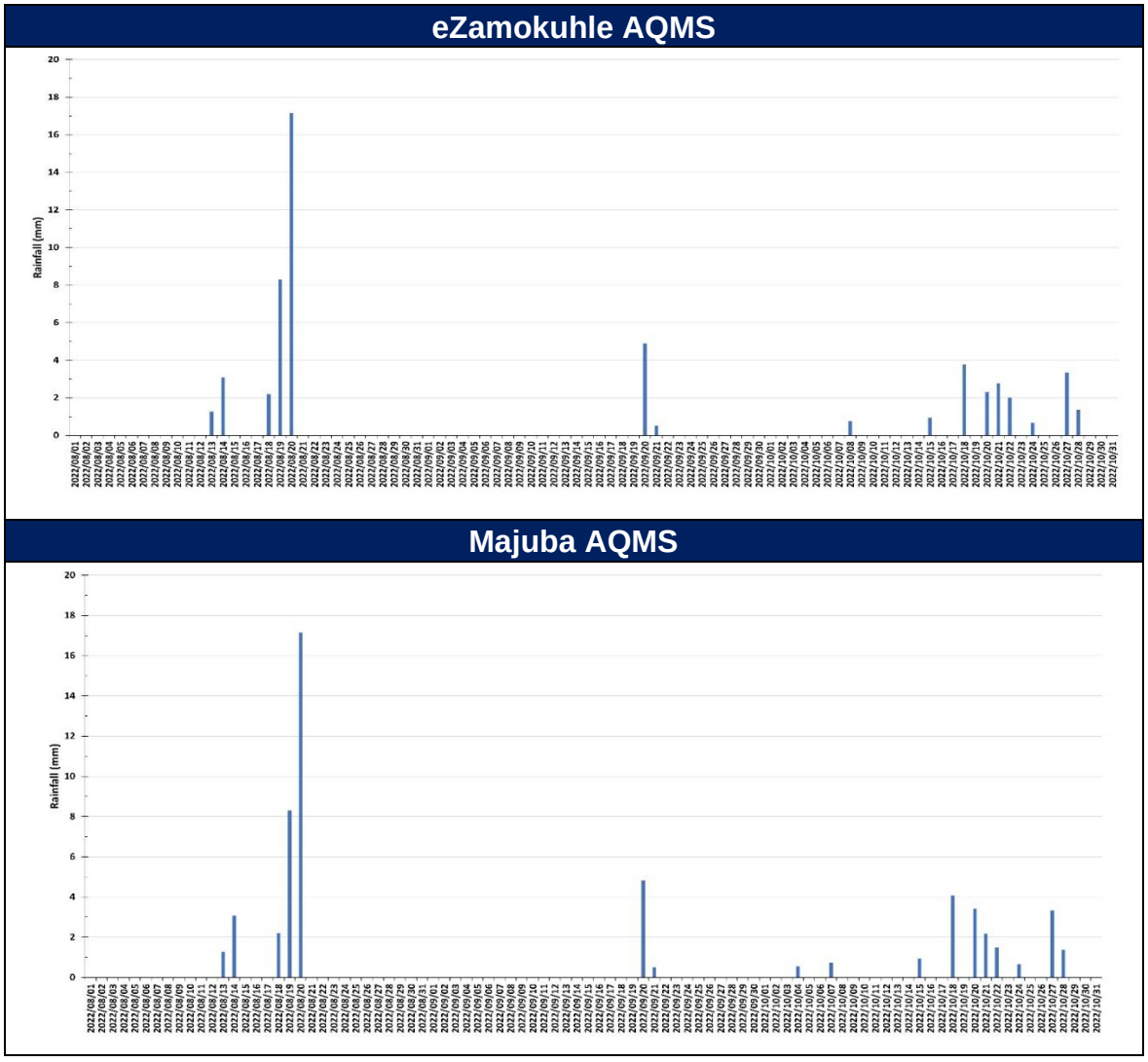

Figure 12: Daily total precipitation (rainfall) at the eZamokuhle and Majuba AQMS (mm).

3.2 POLLUTANT TREND & ANALYSIS

Openair is an air quality model for statistically analysing semi-empirical mathematical relationships between air pollutant concentration and other factors that may affect it (Tiwary, 2010). The Openair model can analyse emissions of pollutant sources, pollutant characteristics, trend estimates and model evaluations. Additionally, Openair model has the advantage of data manipulation or interpolation, statistical data analysis, creation, and visualization of high-quality graphics (Carslaw, 2015).

The Openair model has been successfully applied to determine the potential emission sources based on urban air quality measurements (Munir et al., 2016, Czernecki et al., 2016) as well as for air quality research campaigns (Crilley et al. 2017), studies concerning pollution exposure (Pattinson et al. 2016), and natural events (Salvador et al. 2014; Schweizer, Cisneros 2014). Often multiple functions provided in Openair are combined to provide comprehensive information & insight for the analysed data (Crilley et al., 2015 and Jang et al., 2016).

The relationship and trends of concentrations, including PM_{10}, $PM_{2.5}$, SO_2, NO_2 and meteorological parameters such as wind speed and direction, temperature for the five sampling sites were examined using the Openair model.

3.2.1 PARTICULATE MATTER (PM_{10})

Figure 13 indicate the ambient hourly PM_{10} concentrations recorded at the Eskom, Eskom Majuba and House 4 sampling sites. Although no NAAQS exists for hourly PM_{10} concentrations, Figure 13 highlight that for both the eZamokuhle and Majuba sites maximum hourly concentrations of 500ug/m3 were recorded, whilst House 4 indicate maximum concentrations of 400ug/m^3. Figure 14 is a graphical representation of the average hourly PM_{10} concentrations for the sampling period. It is evident from Figure 14

that the highest average values are recorded during hours 06:00 to 08:00 for both the eZamokuhle and House 4 sites, but all three sites indicate elevated hourly values from 17:00 to 19:00. These diurnal profiles are also illustrated in Figure 15. The bi-modal particulate matter peak for both the Eskom eZamokuhle, Majuba and House 4 sites (Figure 4-8) is a typical profile for residential fuel burning. A morning peak occurs at 07:00 whilst the evening peak occurs at 18:00. The morning peaks reduces towards midday as the inversion layer rises & improves the mixing height of the planetary boundary layer. The morning peak is not that prevalent at the Majuba AQMS.

Figure 16 indicate the daily ambient PM_{10} concentrations recorded at the Eskom eZamokuhle, Eskom Majuba and House 4 sampling sites. The daily NAAQS for PM_{10} of 75 ug/m3 is exceeded at all three stations, especially during the colder months of August and September, which indicate higher daily ambient concentrations (Figure 16). Daily maximum PM_{10} concentrations of 200 ug/m^3 were recorded for both the Eskom eZamokuhle and Eskom Majuba sampling sites, whilst House 4 recorded maximum concentrations of approximately 120 ug/m^3. Few exceedances were recorded for October. These elevated daily concentrations during the colder months are indicated in the calendar plots (Figure 17). These elevated concentrations could be attributed to colder ambient temperatures leading to an increase in residential fuel burning. Figure 18 highlights the average weekday PM_{10} concentrations. The Eskom eZamokuhle and House 4 sampling sites indicate elevated concentrations on Thursdays, whilst the Eskom Majuba AQMS recorded elevated concentrations for Sundays and Mondays. All three stations recorded lower concentrations for Tuesdays compared to the other days in the week.

Figure 19 illustrates the monthly mean ambient PM_{10} concentrations recorded at the Eskom eZamokuhle, Eskom Majuba and House 4 sampling sites. Both the Eskom eZamokuhle and Eskom Majuba illustrates a decrease in monthly concentrations from

August to October, whilst House 4 indicate an increase from August to September, and a significant decrease to October.

As mentioned previously, the bi-modal particulate matter peak for both the Eskom eZamokuhle, Majuba and House 4 sites (Figure 15) is a typical profile for residential fuel burning. These peaks are evident in Figure 20 illustrating the weekly diurnal ambient PM_{10} concentrations. A morning peak occurs at 07:00 whilst the evening peak occurs at 18:00. The morning peaks are less prominent at the Eskom Majuba sampling site.

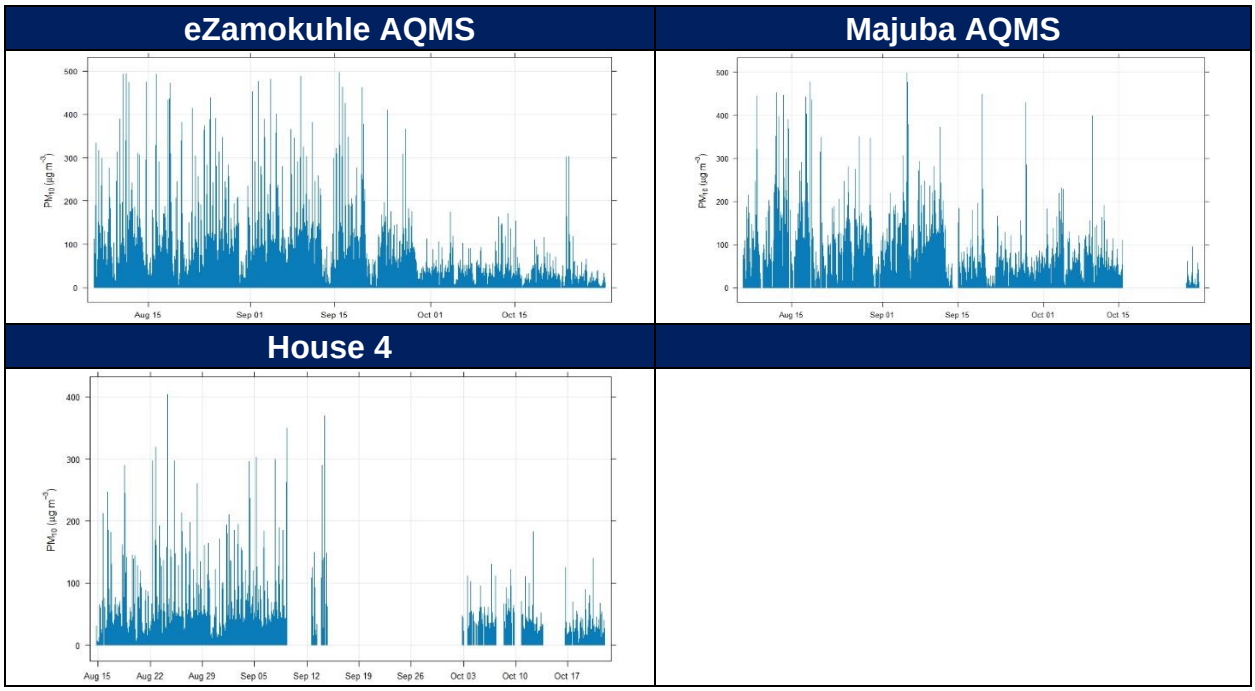

Figure 13: Hourly ambient PM_{10} concentrations (ug/m^3) measured at the sampling locations during the sampling survey.

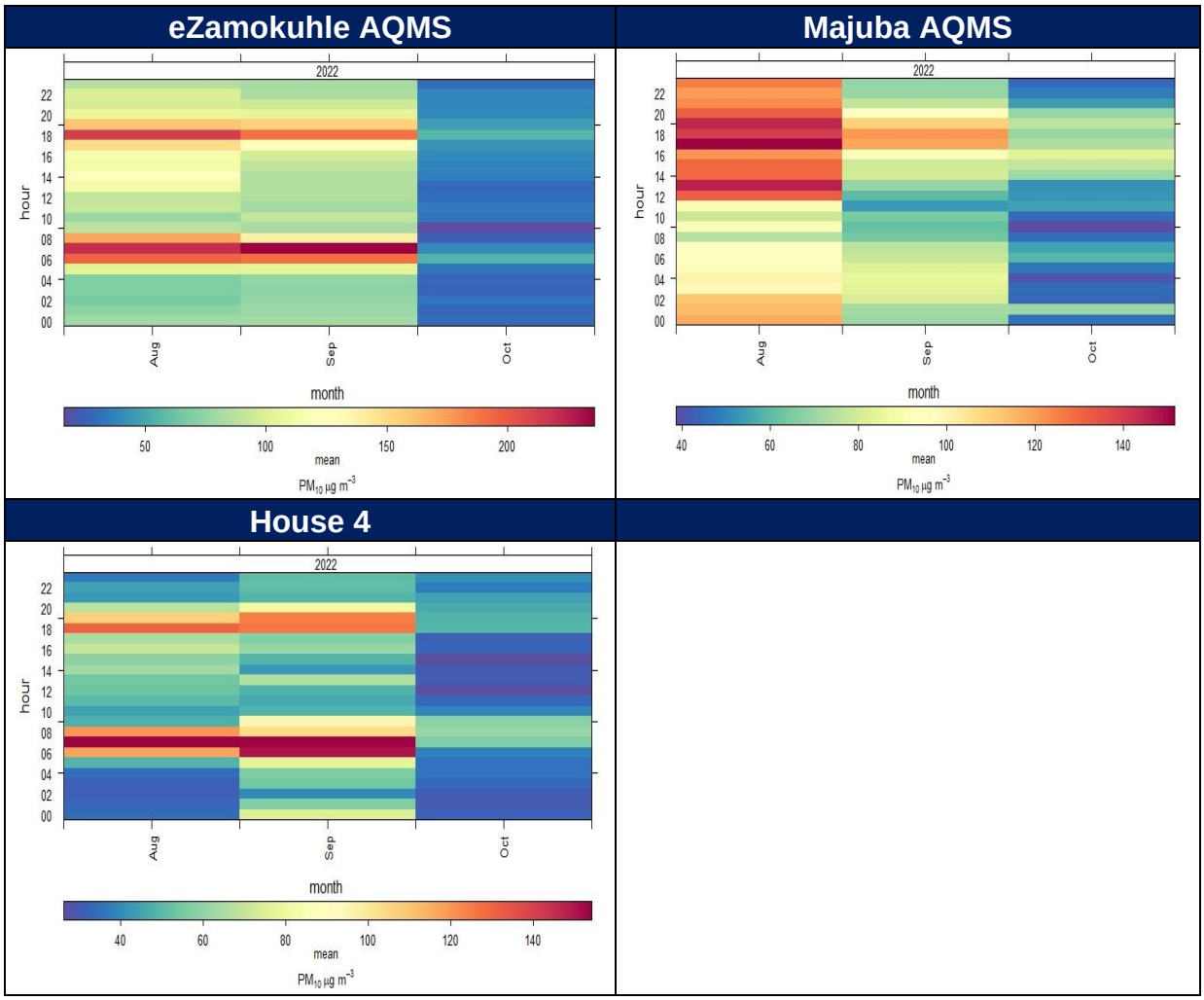

Figure 14: Mean hourly ambient PM_{10} concentrations (ug/m3) measured at the sampling locations during the sampling survey.

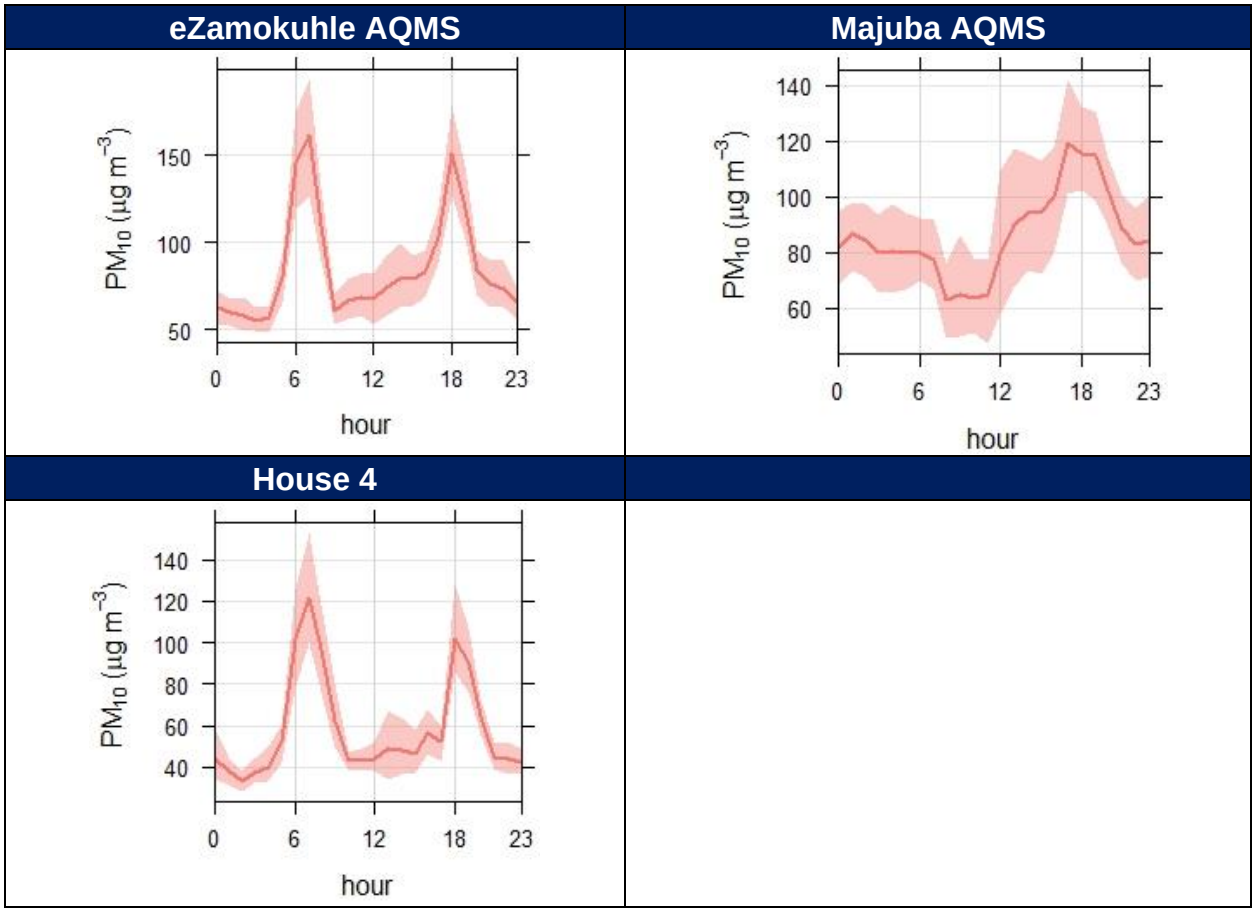

Figure 15: Mean hourly diurnal PM_{10} concentrations (ug/m3) measured at the sampling sites during the sampling survey

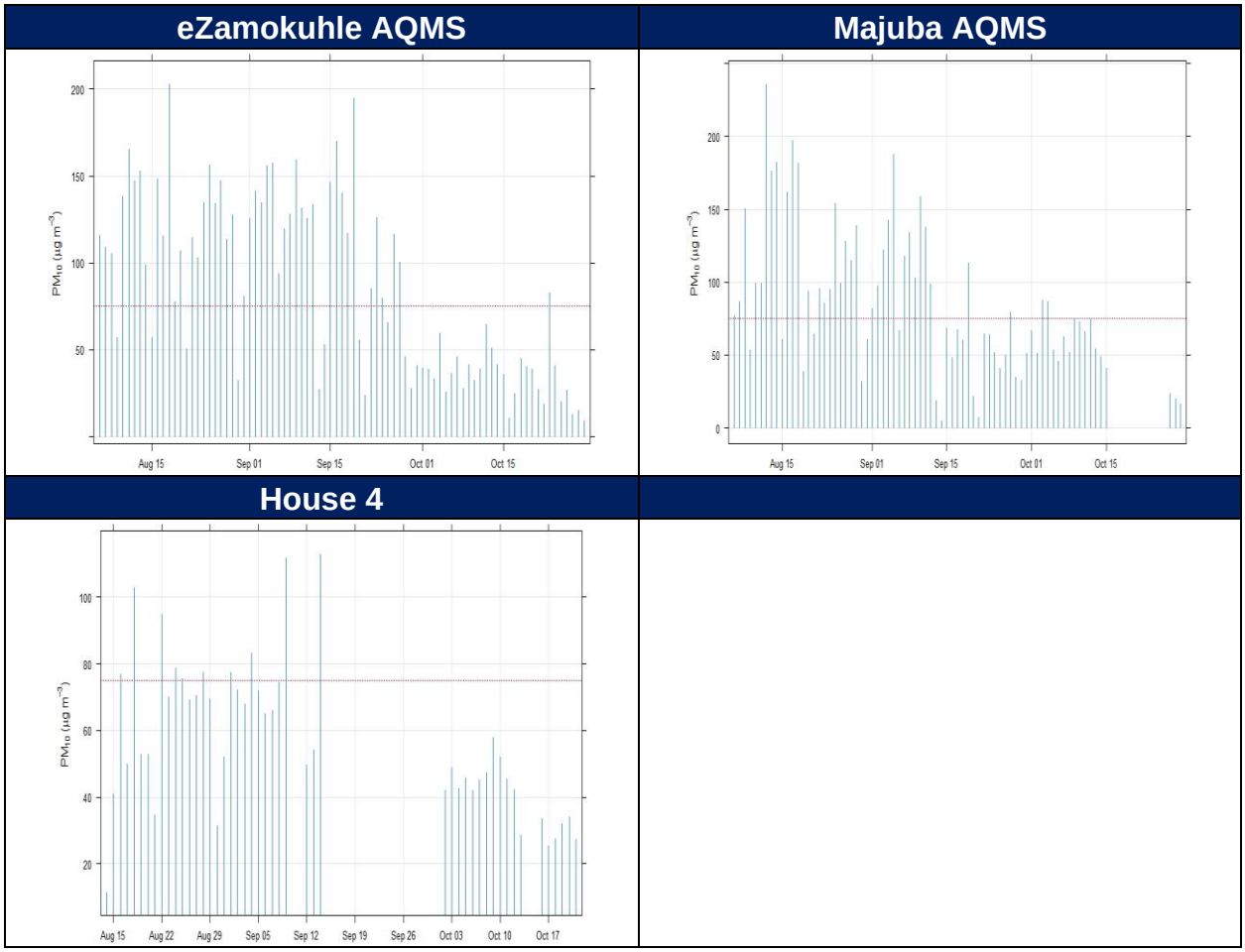

Figure 16: Daily ambient PM_{10} concentrations (ug/m3) measured at the sampling sites during the sampling survey

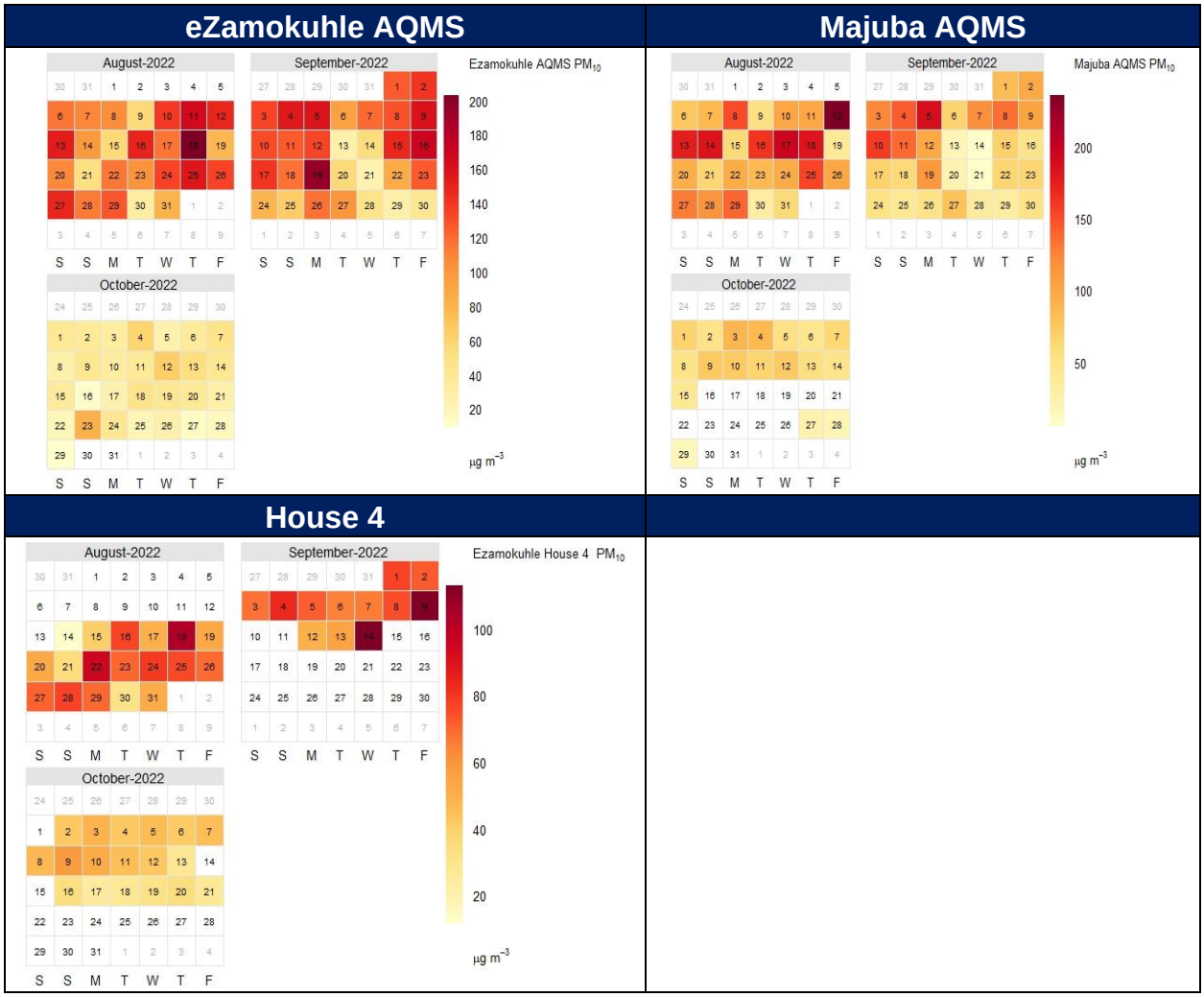

Figure 17: Daily ambient PM_{10} concentrations (ug/m3) measured at the sampling sites during the sampling survey

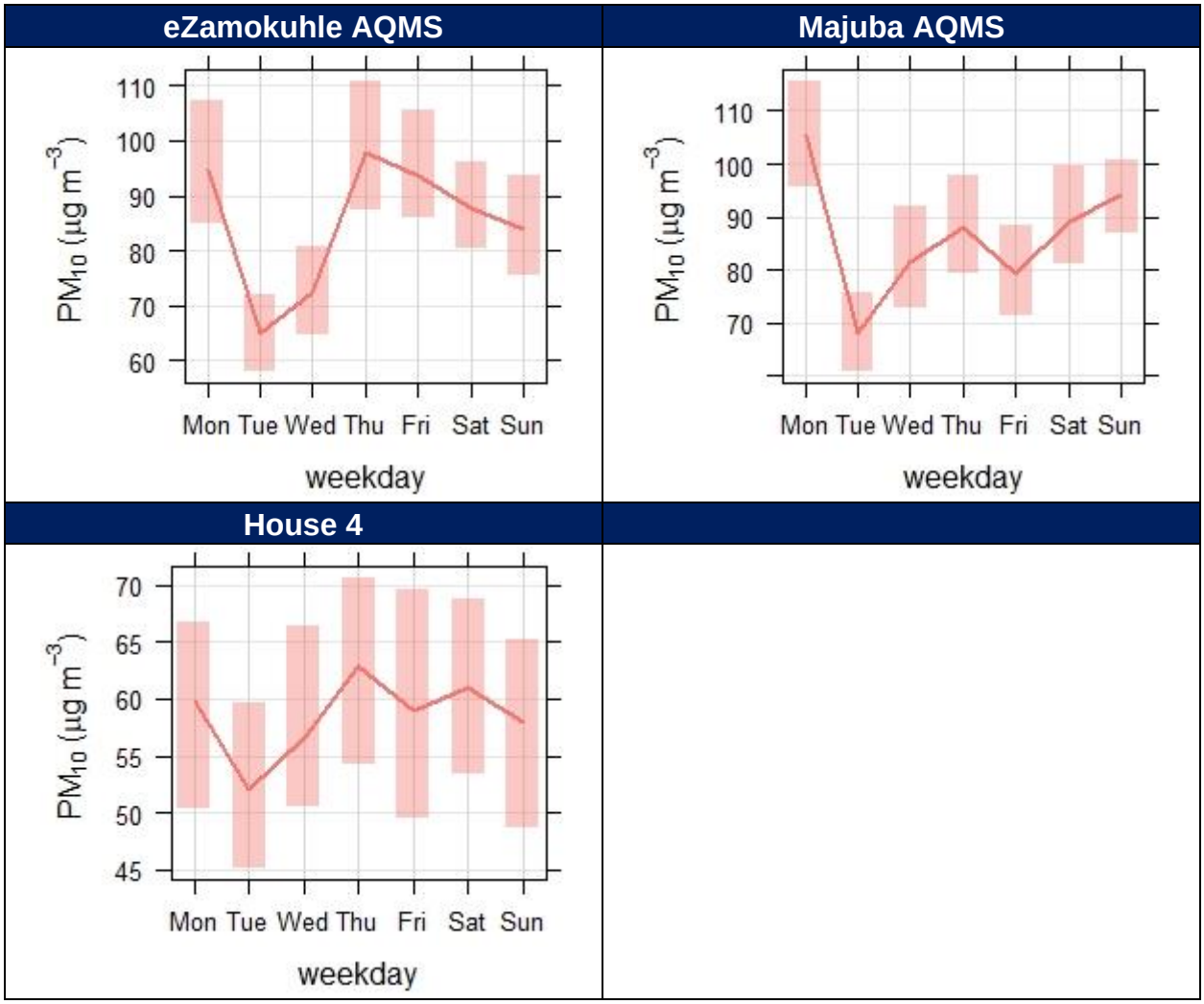

Figure 18: Average weekday ambient PM_{10} concentrations (ug/m3) measured at sampling sites during the sampling survey

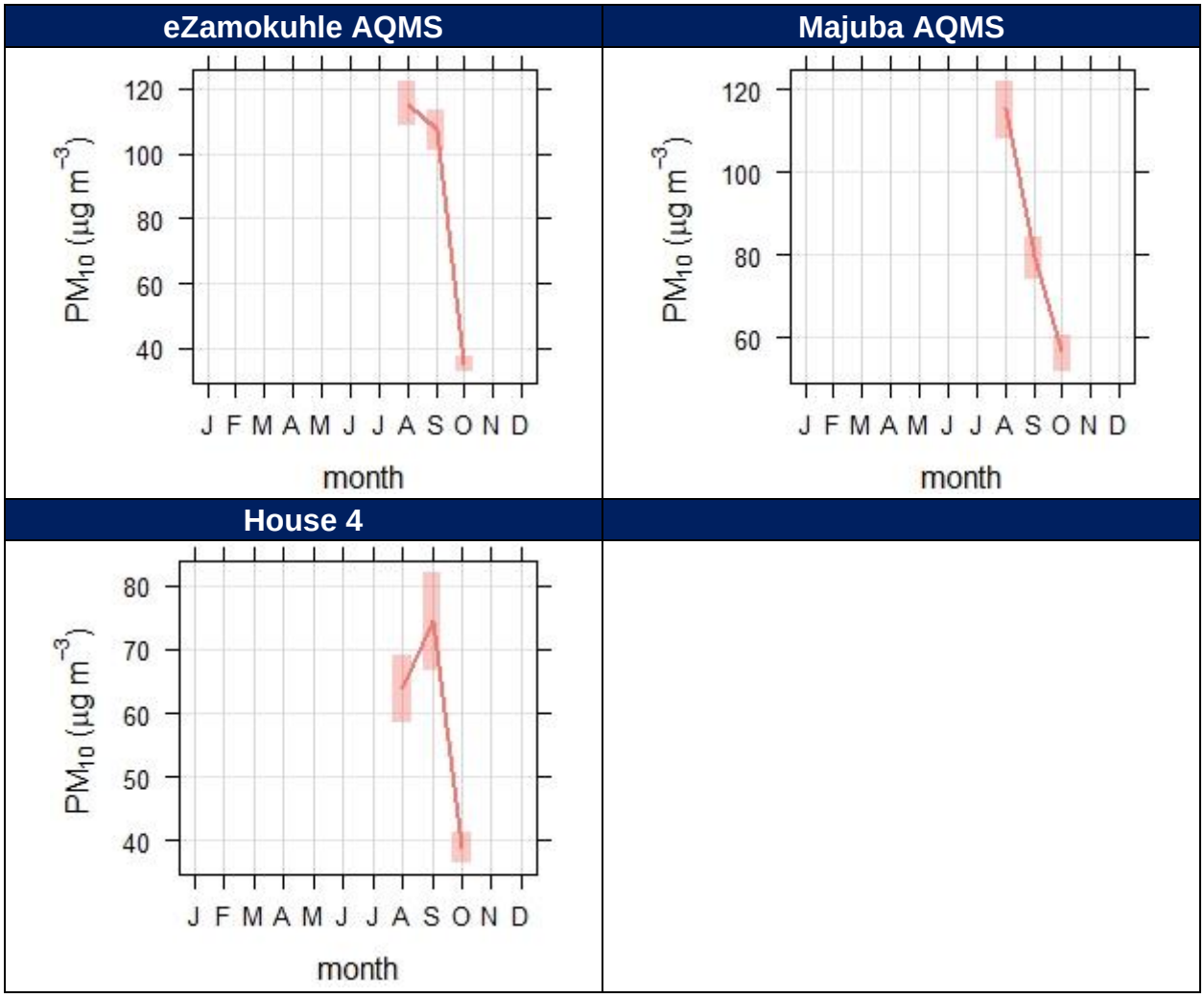

Figure 19: Monthly mean ambient PM_{10} concentrations (ug/m3) measured at sampling sites during the sampling survey.

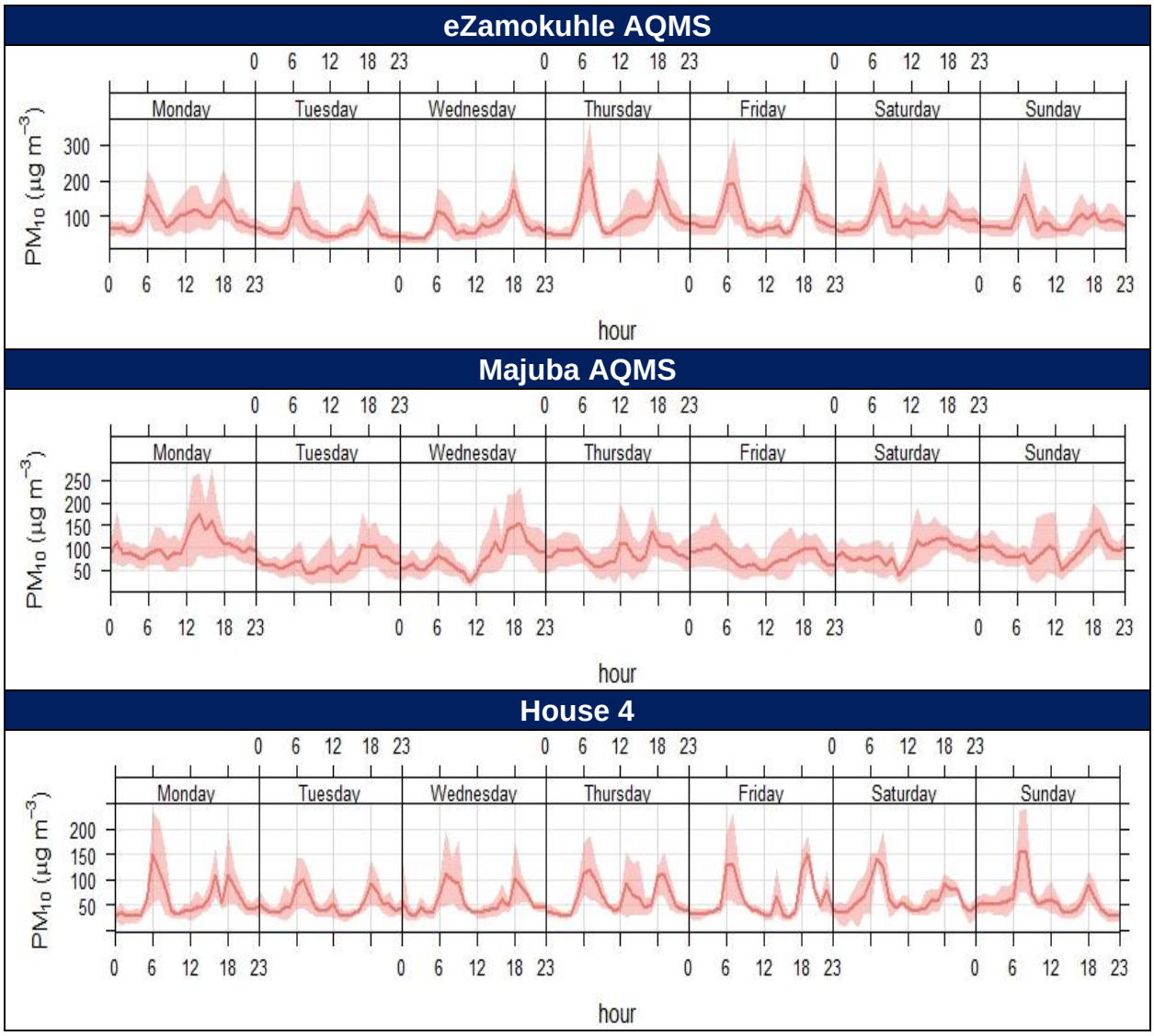

Figure 20: Weekly diurnal PM_{10} concentrations (ug/m3) measured at the sampling sites during the sampling survey

3.2.2 PARTICULATE MATTER ($PM_{2.5}$)

Figure 21 indicate the ambient hourly $PM_{2.5}$ concentrations recorded at the Eskom eZamokuhle, Eskom Majuba, House 1, and House 5 sampling sites. Although no NAAQS exist for hourly $PM_{2.5}$ concentrations, Figure 21 highlight that for both the eZamokuhle and Majuba sites maximum hourly concentrations of 250 ug/m^3 were recorded, whilst House 1 and House 5 indicate maximum concentrations of 500ug/m^3. Figure 22 is a graphical representation of the mean hourly $PM_{2.5}$ concentrations for the sampling period. It is evident from Figure 22 that the highest average values are recorded during hours 06:00 to 08:00 for both the eZamokuhle, House 1 and House 5 sites, but all four sites indicate elevated hourly values from 17:00 to 19:00. These diurnal profiles are also illustrated in Figure 23. The bi-modal particulate matter peak for both the Eskom eZamokuhle, Majuba, House 1 and House 5 sites (Figure 23) is a typical profile for residential fuel burning. A morning peak occurs at 07:00 whilst the evening peak occurs at 18:00. The morning peaks reduces towards midday as the inversion layer rises & improves the mixing height of the planetary boundary layer. As with the PM_{10} concentrations, the morning peak is less prevalent at the Eskom Majuba station.

Figure 24 indicate the daily ambient $PM_{2.5}$ concentrations recorded at the Eskom eZamokuhle, Eskom Majuba, House 1, and House 5 sampling sites respectively. The daily NAAQS for $PM_{2.5}$ of 40 ug/m^3 is exceeded at all four stations, although only once at the Eskom eZamokuhle site. The Eskom Majuba, House 1, and House 5 sampling sites recorded multiple exceedances of the daily NAAQS for $PM_{2.5}$ for the sampling period. These elevated daily concentrations are indicated in the calendar plots (Figure 25). These elevated concentrations could be attributed to colder ambient temperatures leading to an increase in residential fuel burning.

Figure 26 highlights the mean weekday ambient $PM_{2.5}$ concentrations. The Eskom eZamokuhle, House 1 and House 4 sampling sites indicate elevated concentrations on

Thursdays, whilst the Eskom Majuba AQMS recoded elevated concentrations for Sundays and Mondays.

Figure 27 illustrates the mean monthly ambient $PM_{2.5}$ concentrations recorded at the Eskom eZamokuhle, Eskom Majuba, House 1, and House 5 sampling sites. The Eskom Majuba, House 1, and House 5 illustrates a decrease in monthly concentrations from August to October, whilst the Eskom eZamokuhle station indicate an increase from August to September, and a significant decrease to October.

As mentioned previously, the bi-modal particulate matter peak for both the Eskom eZamokuhle, Majuba and House 4 sites (Figure 23) is a typical profile for residential fuel burning. These peaks are evident in Figure 28 illustrating the weekly diurnal ambient $PM_{2.5}$ concentrations. A morning peak occurs at 07:00 whilst the evening peak occurs at 18:00. These peaks are less prominent at the Eskom Majuba sampling site.

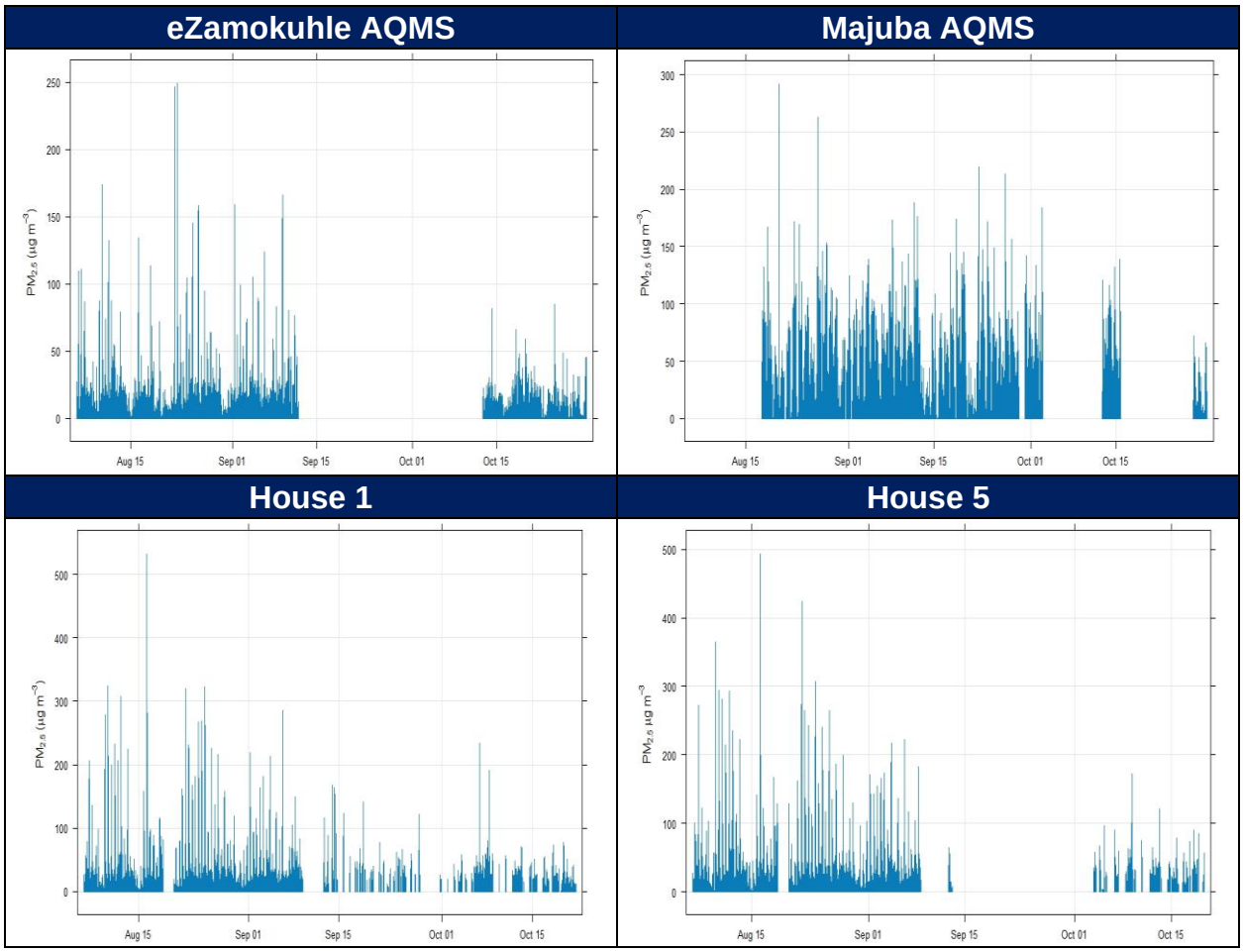

Figure 21: Hourly ambient $PM_{2.5}$ concentrations (ug/m^3) measured at the sampling sites during the sampling survey

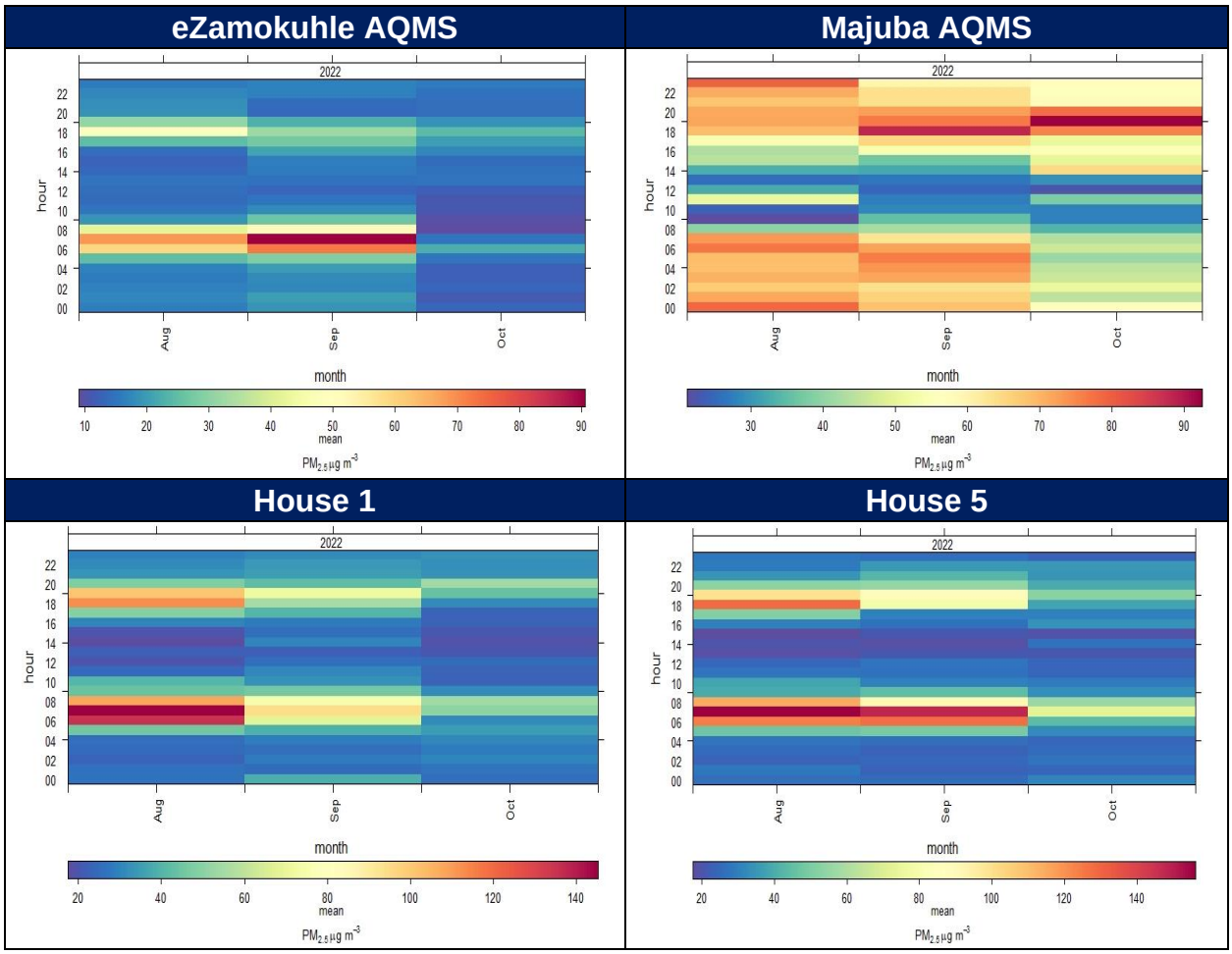

Figure 22: Mean hourly ambient $PM_{2.5}$ concentrations (ug/m^3) measured at the sampling sites during the sampling survey.

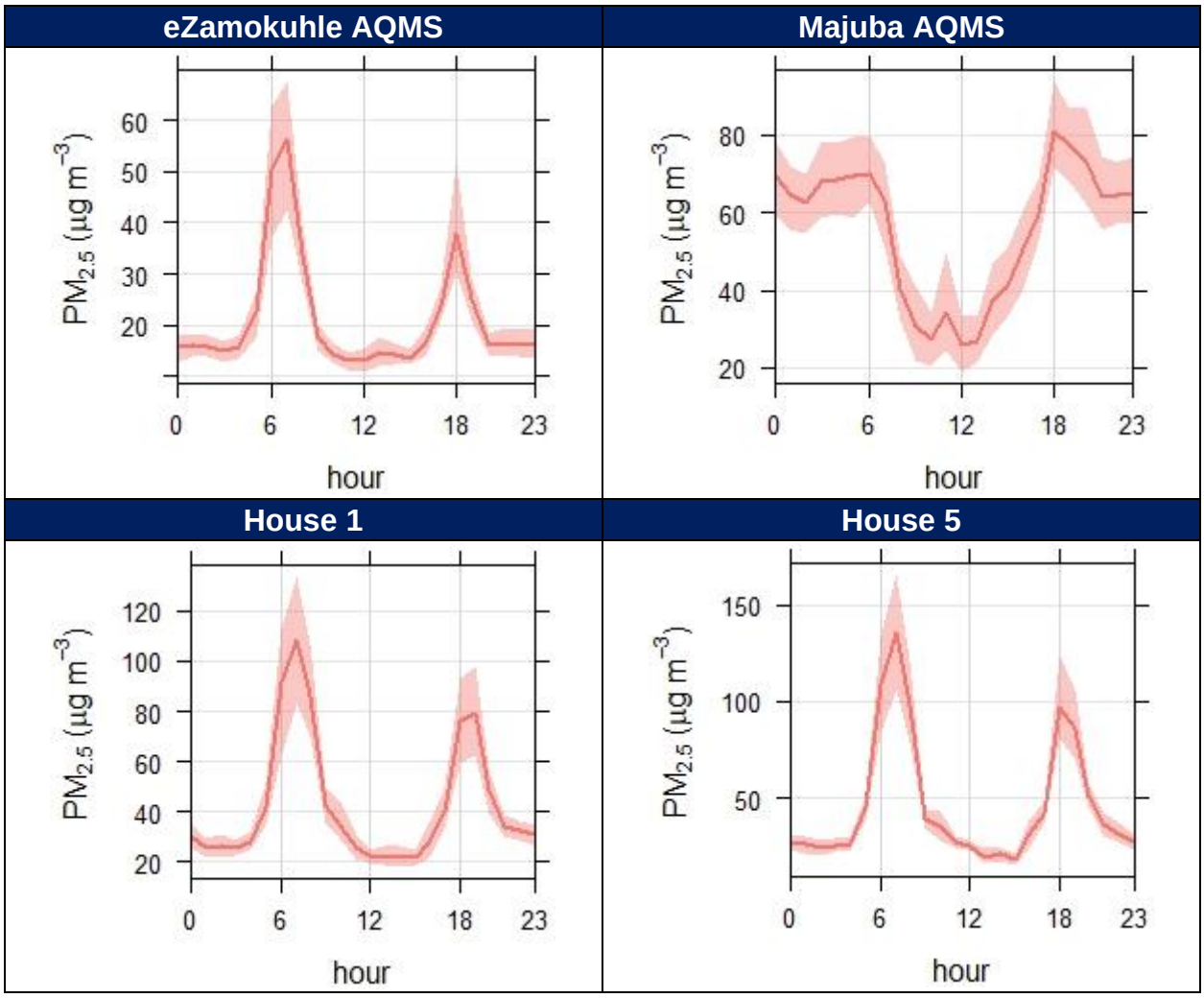

Figure 23: Hourly diurnal $PM_{2.5}$ concentrations (ug/m^3) measured at the sampling sites during the sampling survey.

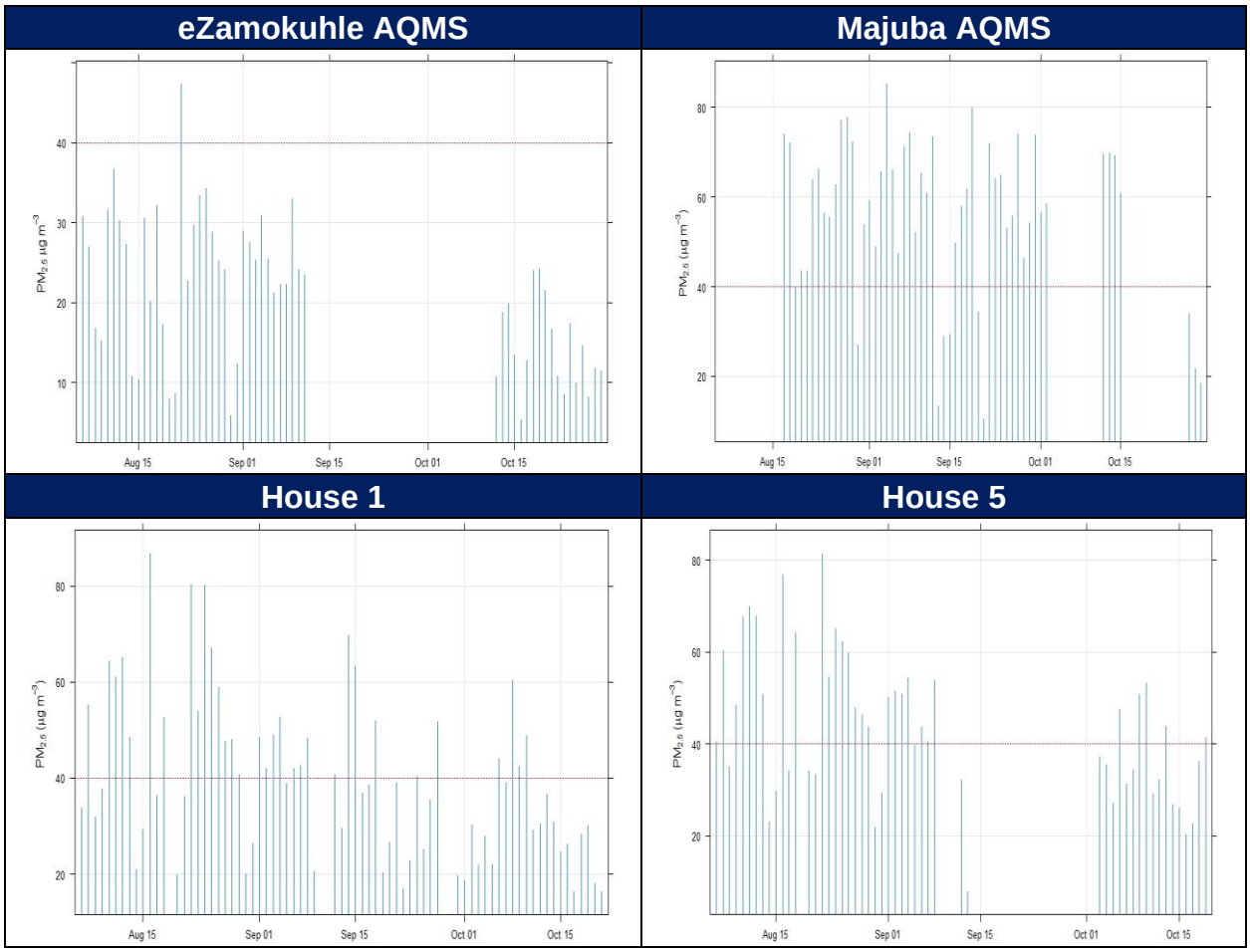

Figure 24: Daily ambient $PM_{2.5}$ concentrations (ug/m^3) measured at the sampling sites during the sampling survey

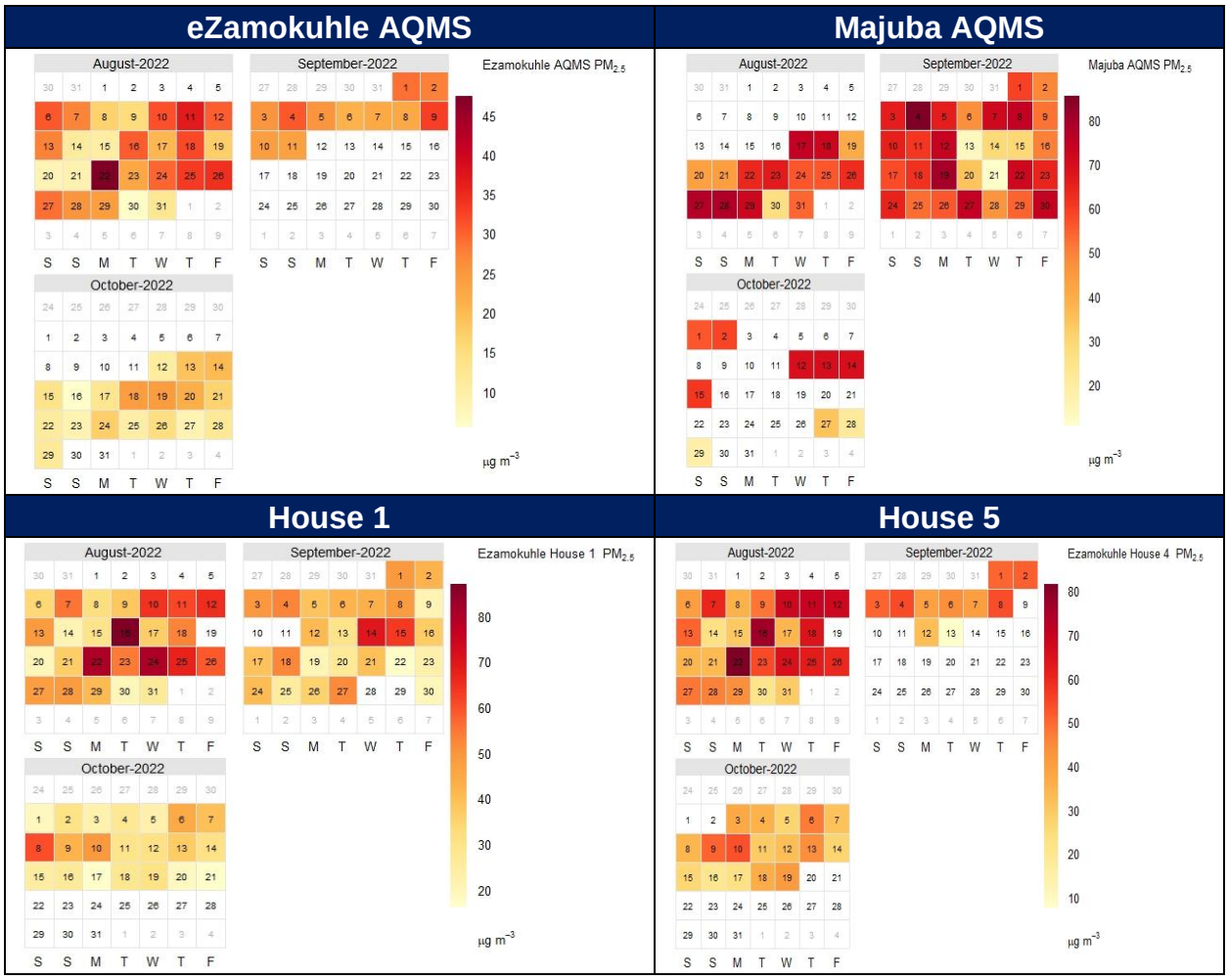

Figure 25: Daily ambient $PM_{2.5}$ concentrations (ug/m^3) measured at the sampling sites during the sampling survey

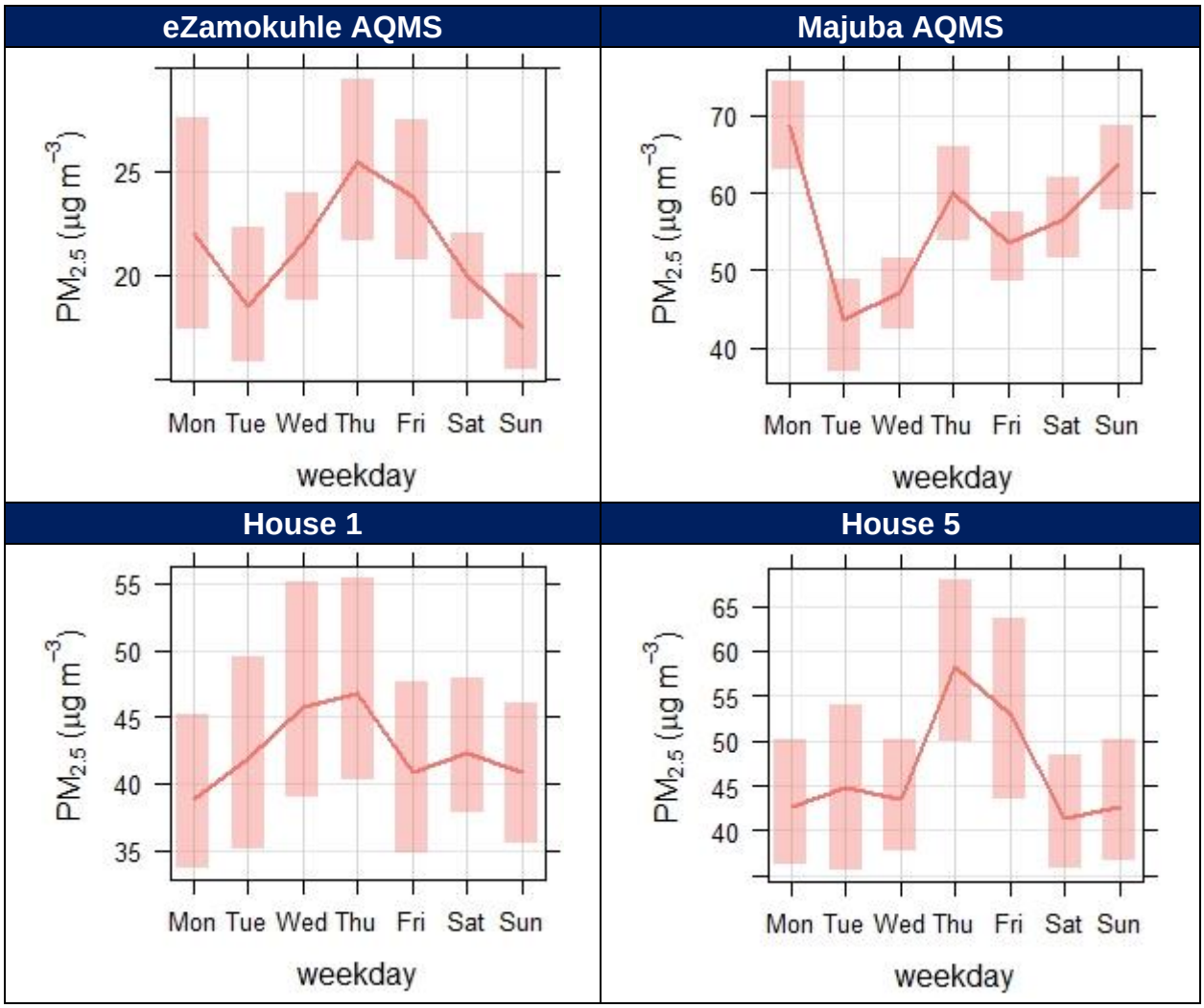

Figure 26: Weekday ambient $PM_{2.5}$ concentrations (ug/m^3) measured at the sampling sites during the sampling survey

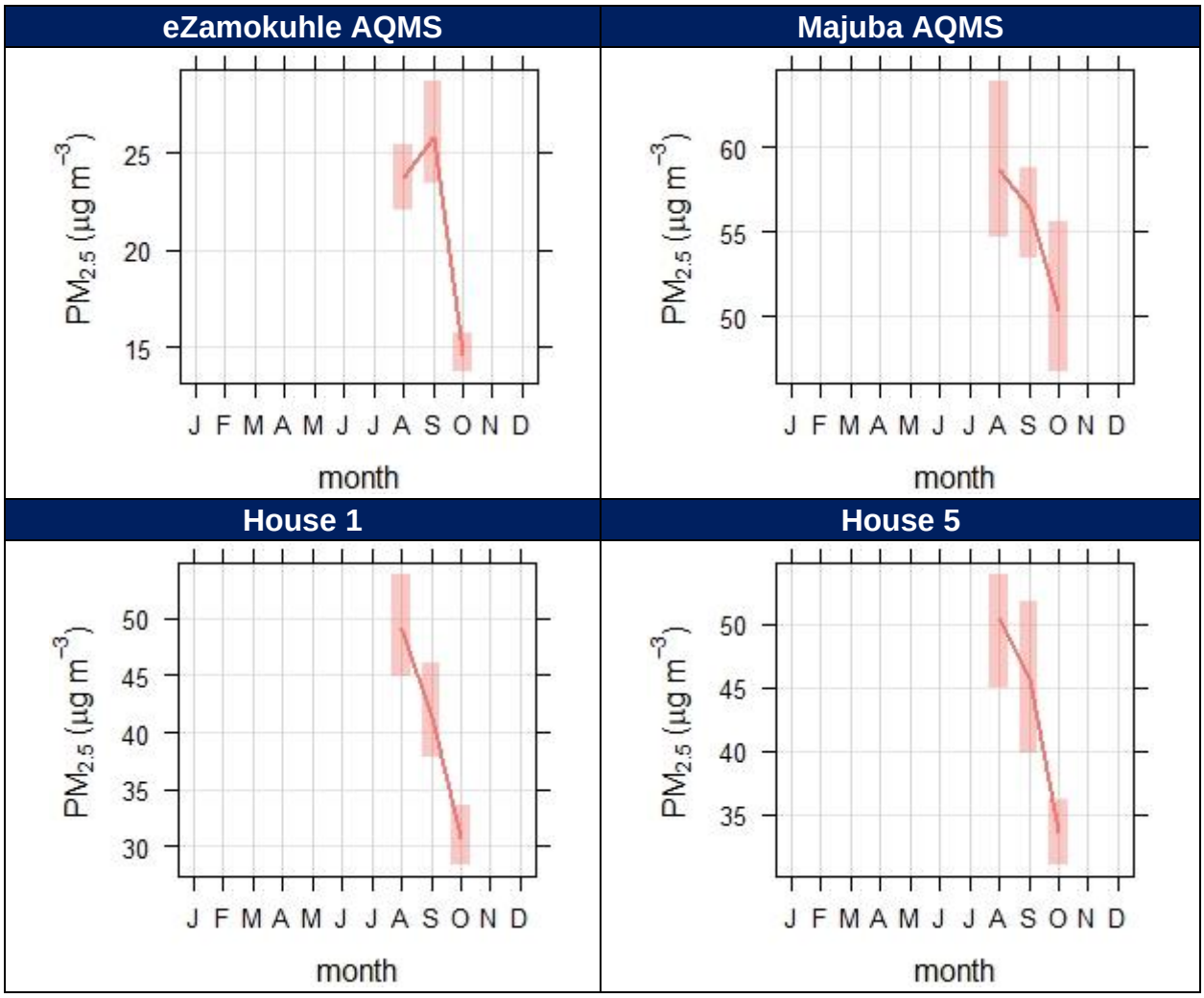

Figure 27: Mean monthly ambient $PM_{2.5}$ concentrations (ug/m^3) measured at sampling sites during the sampling survey.

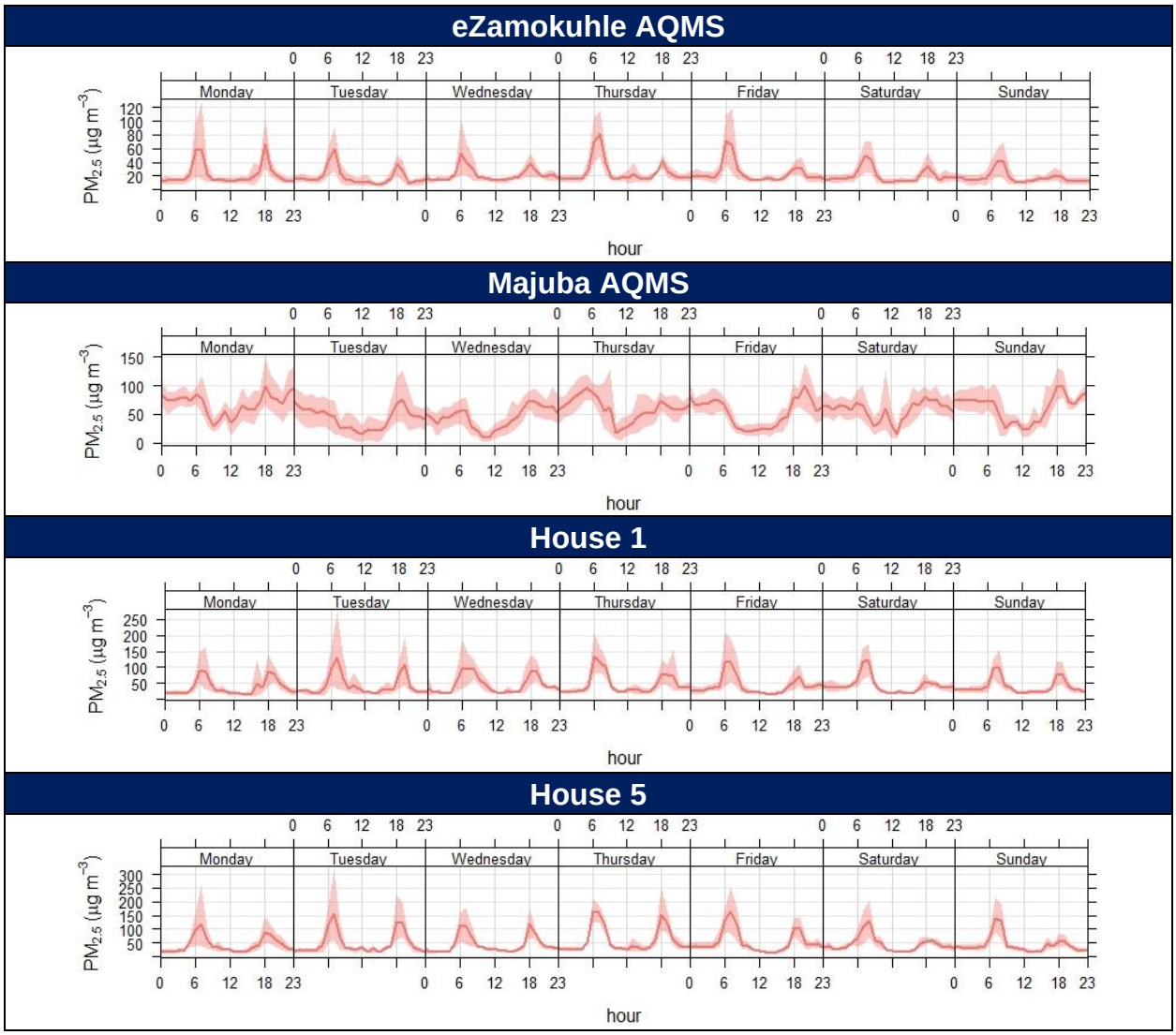

Figure 28: Weekly diurnal $PM_{2.5}$ concentrations (ug/m^3) measured at sampling sites during the sampling survey.

3.2.3 SULPHUR DIOXIDE (SO_2)

Figure 29 indicate the hourly ambient SO_2 concentrations recorded at the Eskom eZamokuhle and Eskom Majuba AQMS. The NAAQS for hourly SO_2 concentrations is 134ppb. No exceedances of the hourly NAAQS were recorded for an hourly time average for both stations. Figure 29 highlight maximum hourly SO_2 concentrations of 80ppb at the Eskom eZamokuhle station, whilst maximum concentrations of above 150ppb were recorded for the Eskom Majuba AQMS.

Figure 30 is a graphical representation of the mean hourly SO_2 concentrations for the sampling period. It is evident from Figure 3 that the highest mean concentrations were recorded during hours 10:00 to 14:00 and 18:00 for both stations, although the 18:00 peak is less prevalent at the Eskom Majuba station. These diurnal profiles are also illustrated in Figure 31. Figure 31 indicates a typically industrial signature with increased SO_2 concentrations as just before midday due to the break-up of an elevated inversion layer, in addition to the development of daytime convective conditions causing the plume to be brought down to ground level relatively close to the point of release from tall stacks. The 18:00 peak recorded for the Eskom eZamokuhle station is indicative of the impact of residential fuel burning emissions.

Figure 32 indicate the daily ambient SO_2 concentrations recorded at the Eskom eZamokuhle and Eskom Majuba AQMS. No exceedances of the daily NAAQS for SO_2 were recorded for both stations during the sampling period. Daily maximum SO_2 concentrations of above 20ppb were recorded for both stations. Figure 32 also indicate lower daily SO_2 concentrations during October for the Eskom eZamokuhle station compared to the Eskom Majuba station. These lower daily concentration in October could be related to lower domestic fuel burning practices that have a direct impact on the Eskom eZamokuhle station. These daily concentrations are indicated in calendar plots (Figure 33). Both stations indicate lower concentrations for October, compared to August and

September, and could be attributed to colder ambient temperatures leading to an increase in residential fuel burning.

Figure 34 highlights the mean weekday and mean monthly ambient SO_2 concentrations. The Eskom eZamokuhle station as well as the Eskom Majuba station indicate higher recorded ambient concentrations on a Thursday. Both stations also illustrate a decrease in monthly concentrations from August to September, but a slight elevation in October were recorded for the Eskom Majuba station.

Figure 35 is indicative of the mean weekly SO_2 concentrations. It is evident for the Eskom eZamokuhle station (Figure 28) a second less pronounced peak compared to midday, that occurs consistently throughout the entire week at 18:00. A comparison of the trend level plot for eZamokuhle (Figure 30) clearly indicates that the 18:00 peak occurs in winter (August) thus indicating the impact of residential fuel burning emissions. The evening (18:00) peak is less prominent at the Eskom Majuba sampling site.

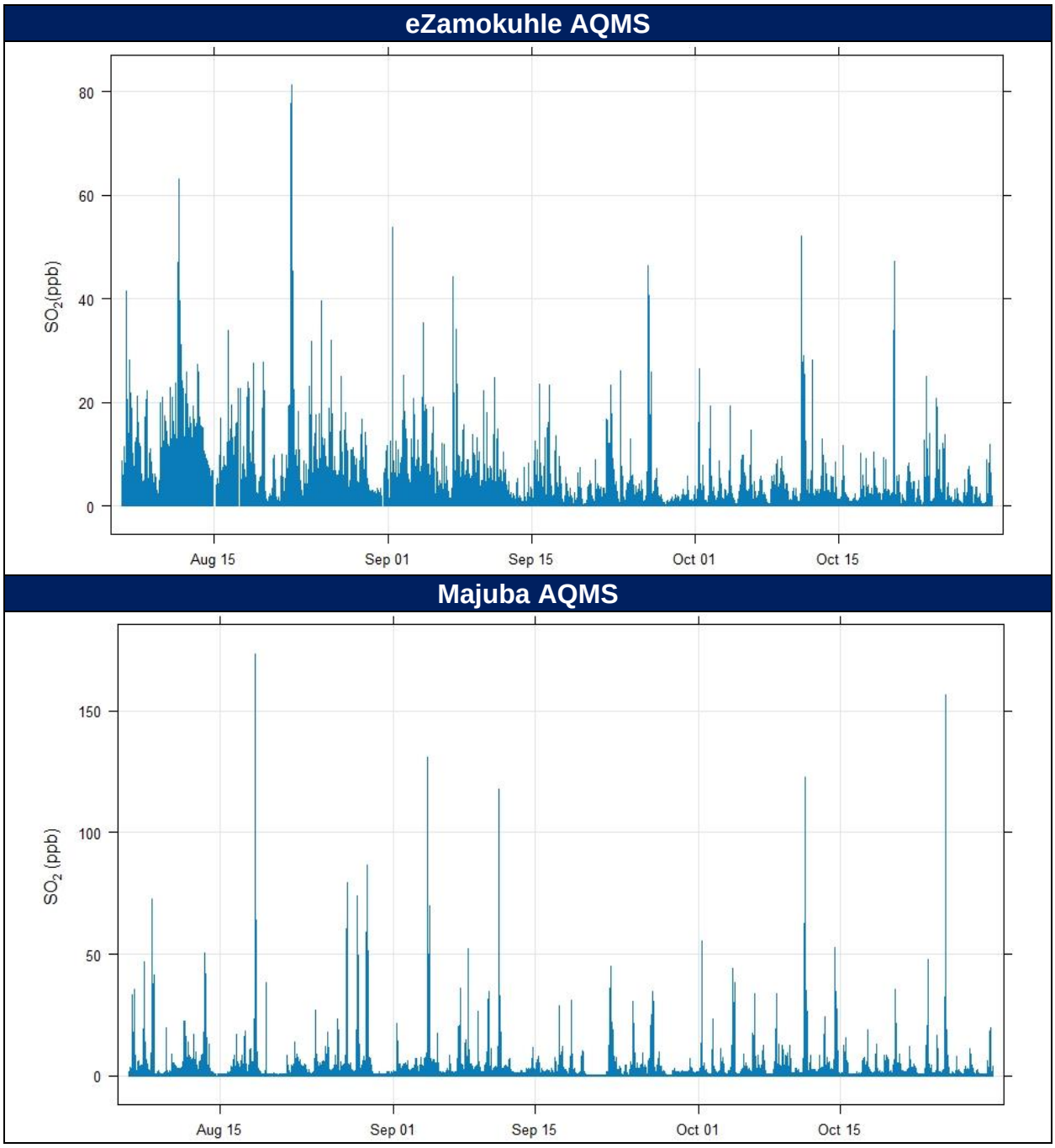

Figure 29: Hourly ambient SO_2 concentrations (ppb) measured at the Eskom eZamokuhle and Eskom Majuba AQMS during the sampling survey (Hourly SO_2 NAAQS = 134ppb)

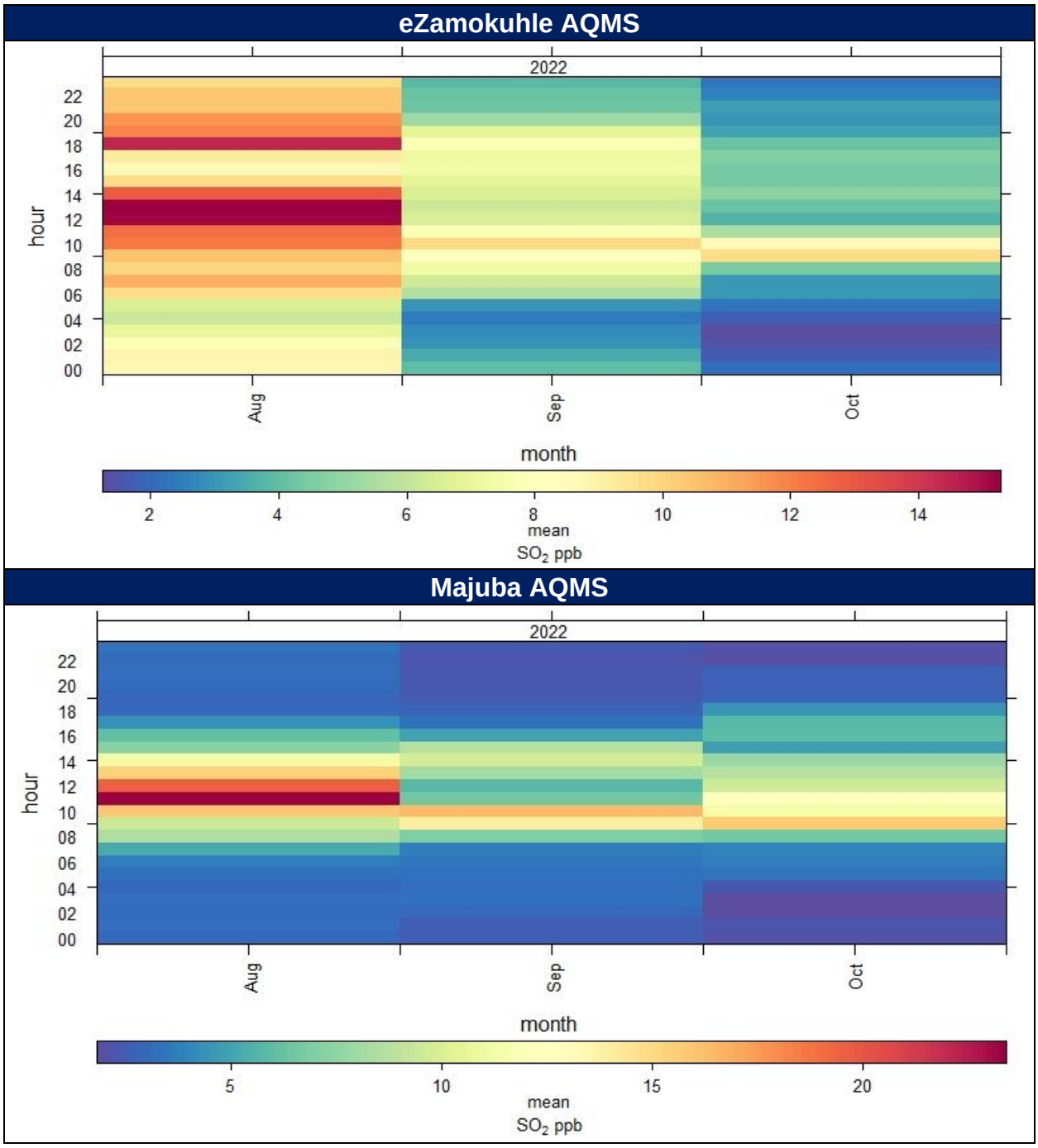

Figure 30: Hourly mean ambient SO_2 concentrations (ppb) measured at the Eskom eZamokuhle and Eskom Majuba AQMS during the sampling survey (Hourly SO_2 NAAQS = 134ppb)

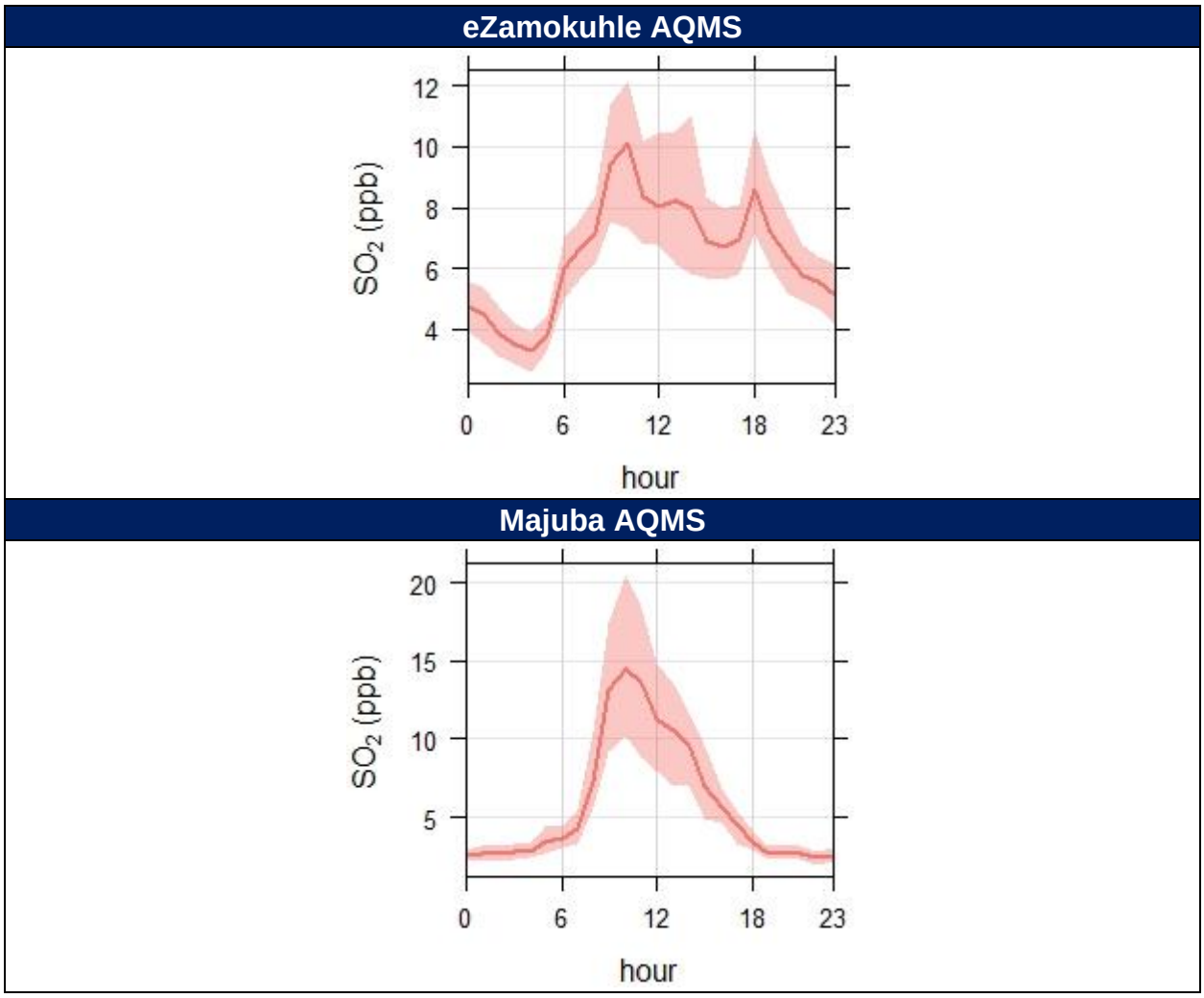

Figure 31: Mean hourly diurnal ambient SO_2 concentrations (ppb) measured at sampling sites during the sampling survey

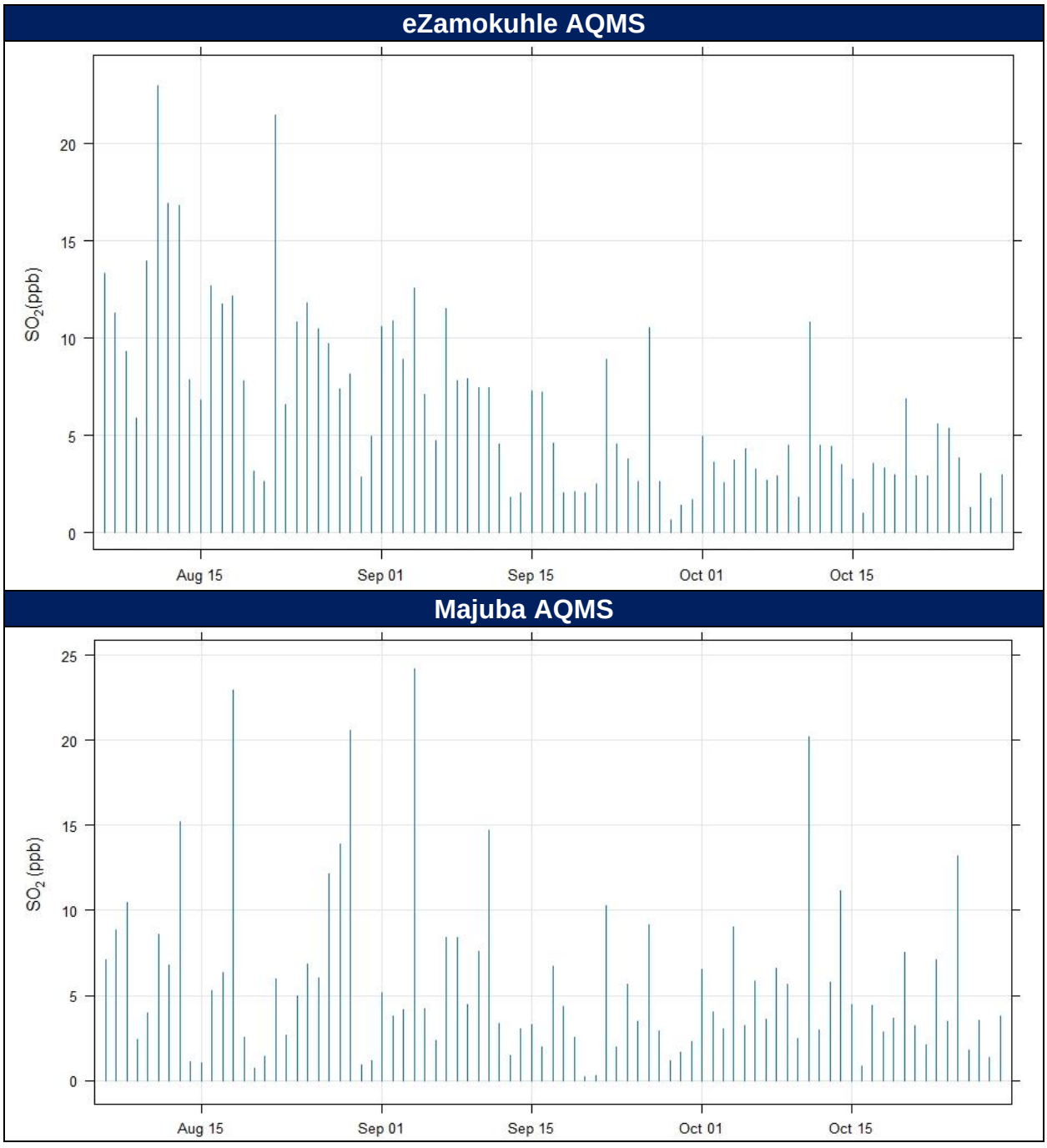

Figure 32: Daily ambient SO_2 concentrations (ppb) measured at the Eskom eZamokuhle and Eskom Majuba AQMS during the sampling survey (Hourly SO_2 NAAQS = 48ppb)

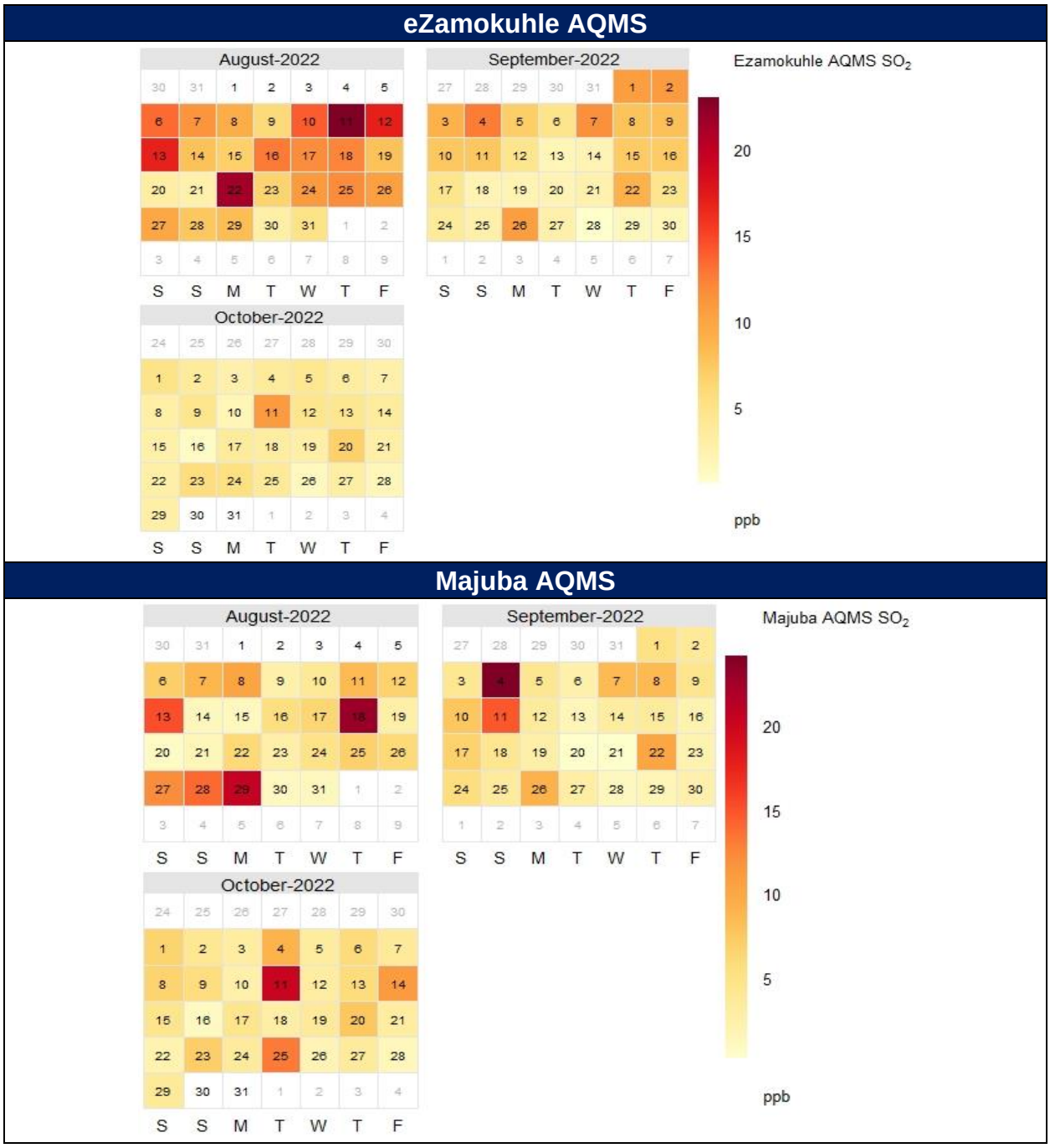

Figure 33: Daily ambient SO_2 concentrations (ppb) measured at the Eskom eZamokuhle and Eskom Majuba AQMS during the sampling survey (Hourly SO_2 NAAQS = 48ppb).

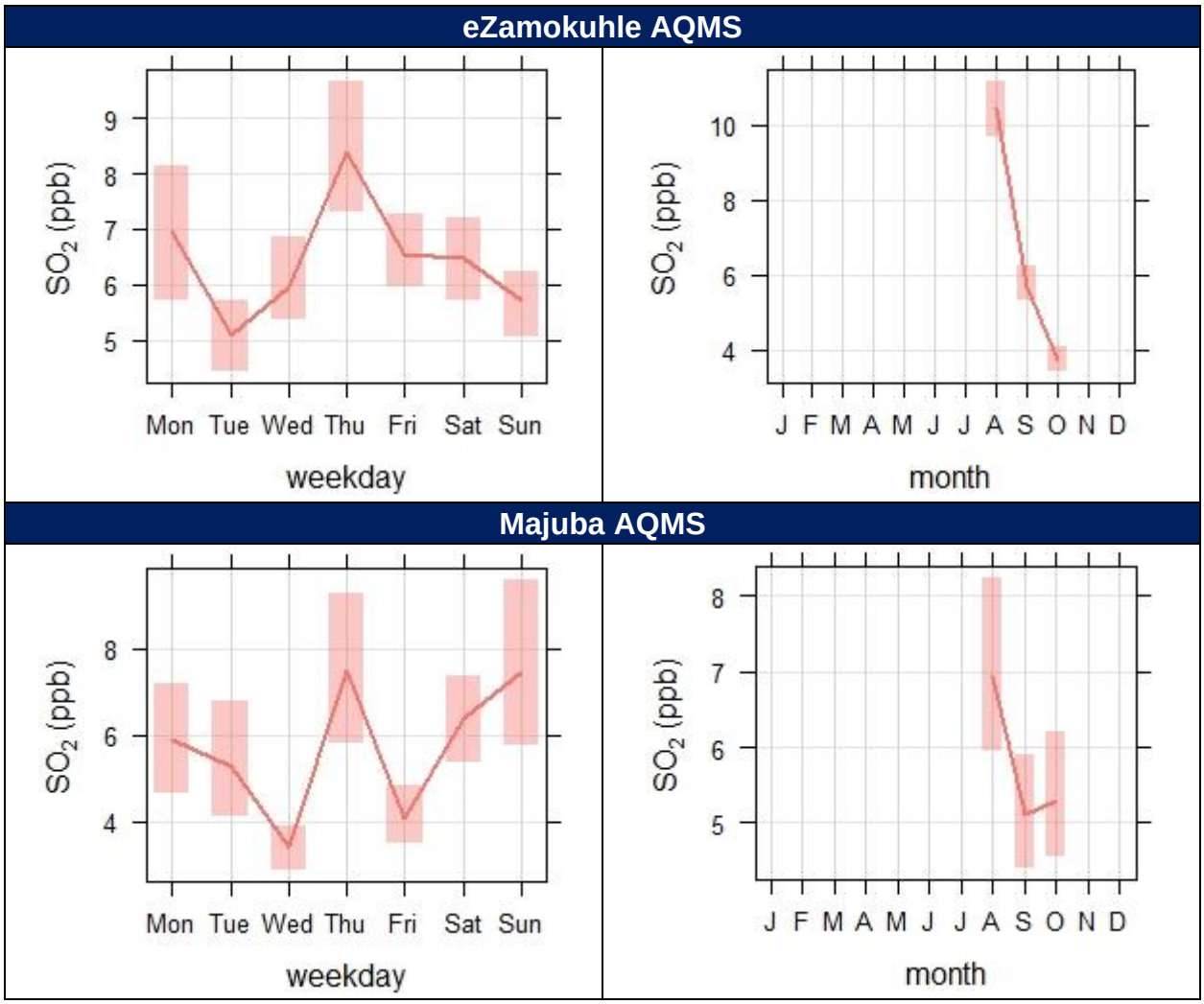

Figure 34: Mean weekday and mean monthly ambient SO_2 concentrations (ppb) measured at sampling sites during the sampling survey

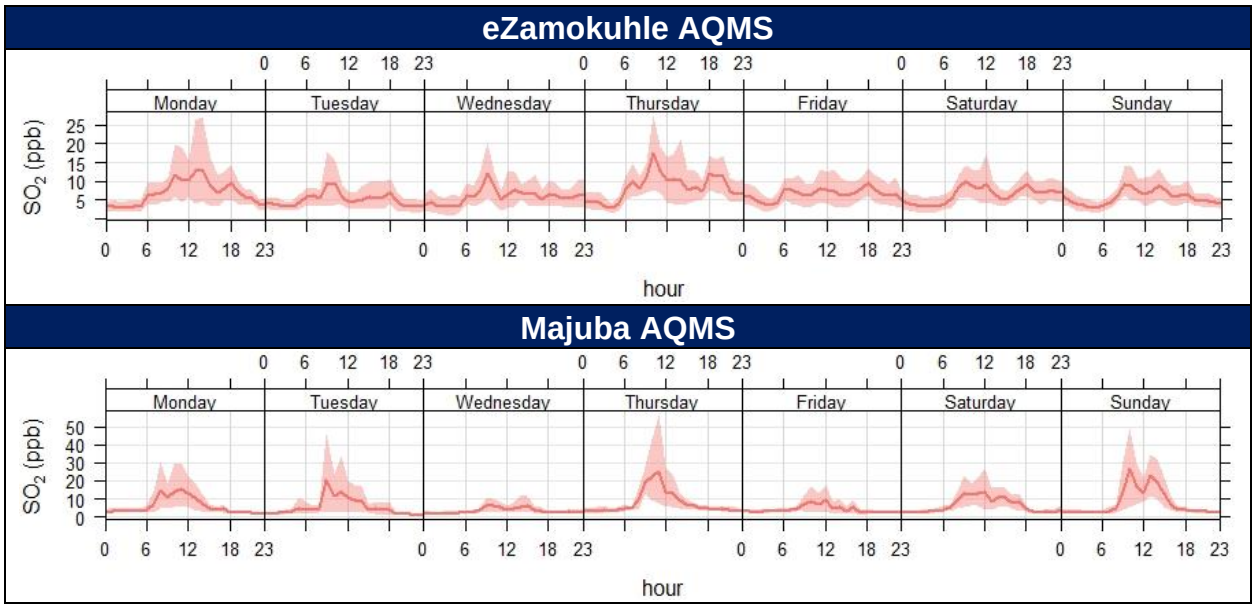

Figure 35: Weekly diurnal SO_2 concentrations (ppb) measured at sampling sites during the sampling survey

3.2.4 NITROGEN DIOXIDE (NO_2)

Figure 36 indicate the hourly ambient NO_2 concentrations recorded at the Eskom eZamokuhle and Eskom Majuba AQMS. The NAAQS for hourly NO_2 concentrations is 106ppb. No exceedances of the hourly NAAQS were recorded for an hourly time average for both stations. Figure 36 highlight maximum hourly NO_2 concentrations of approximately 25ppb at the Eskom eZamokuhle station, whilst maximum concentrations of 40ppb were recorded for the Eskom Majuba AQMS.

Figure 37 is a graphical representation of the mean hourly NO_2 concentrations for the sampling period. It is evident from Figure 30 that the highest mean concentrations were recorded during hours 06:00 to 08:00 and 16:00 to 18:00 for the Eskom eZamokuhle station, whilst elevated concentrations were recorded at 10:00 to 12:00 for the Eskom Majuba station. These diurnal profiles are also illustrated in Figure 38. The Eskom eZamokuhle signature in Figure 38 explicitly reveal that the variability of this pollutant concentration is conditioned by vehicle emissions. The diurnal cycle corresponds to the cyclical nature of traffic volume with marked peaks in concentration on weekdays around the early-morning and late-afternoon rush-hours. For the Eskom Majuba station (Figure 38), there is an increased NO_2 concentrations at just before midday due to the break-up of an elevated inversion layer, in addition to the development of daytime convective conditions causing the plume to be brought down to ground level relatively close to the point of release from tall stacks.

Figure 39 indicate the daily ambient NO_2 concentrations recorded at the Eskom eZamokuhle and Eskom Majuba AQMS. No daily NAAQS for NO_2 exists. Daily maximum NO_2 concentrations of approximately 10ppb were recorded for both stations. These daily mean NO_2 concentrations are graphically presented in Figure 40.

Figure 40 highlights the mean weekday and mean monthly ambient NO_2 concentrations. Both stations indicate higher recorded ambient concentrations on a Thursday, as well as a decrease in monthly concentrations from August to October.

Figure 41 is indicative of the mean weekly NO_2 concentrations. It is evident for the Eskom eZamokuhle station that the weekly diurnal cycle corresponds to the cyclical nature of traffic volume with marked peaks in concentration on weekdays around the early-morning and late-afternoon rush-hours. For the Eskom Majuba station (Figure 41), there is an increased NO_2 concentrations at just before midday due to the break-up of an elevated inversion layer, in addition to the development of daytime convective conditions causing the plume to be brought down to ground level relatively close to the point of release from tall stacks.

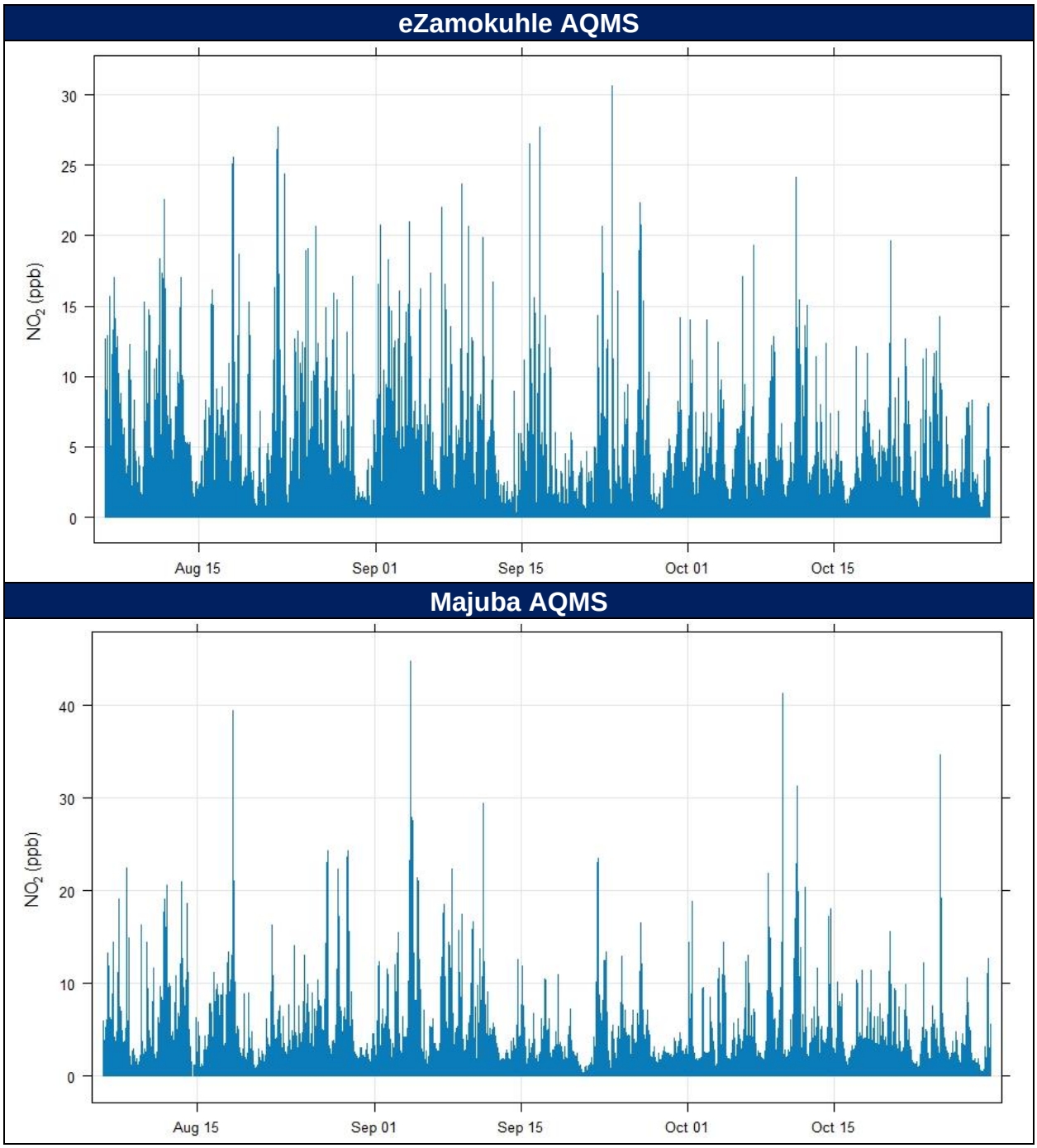

Figure 36: Hourly ambient NO_2 concentrations (ppb) measured at Eskom eZamokuhle AQMS during the sampling survey (Hourly NO_2 NAAQS = 106ppb).

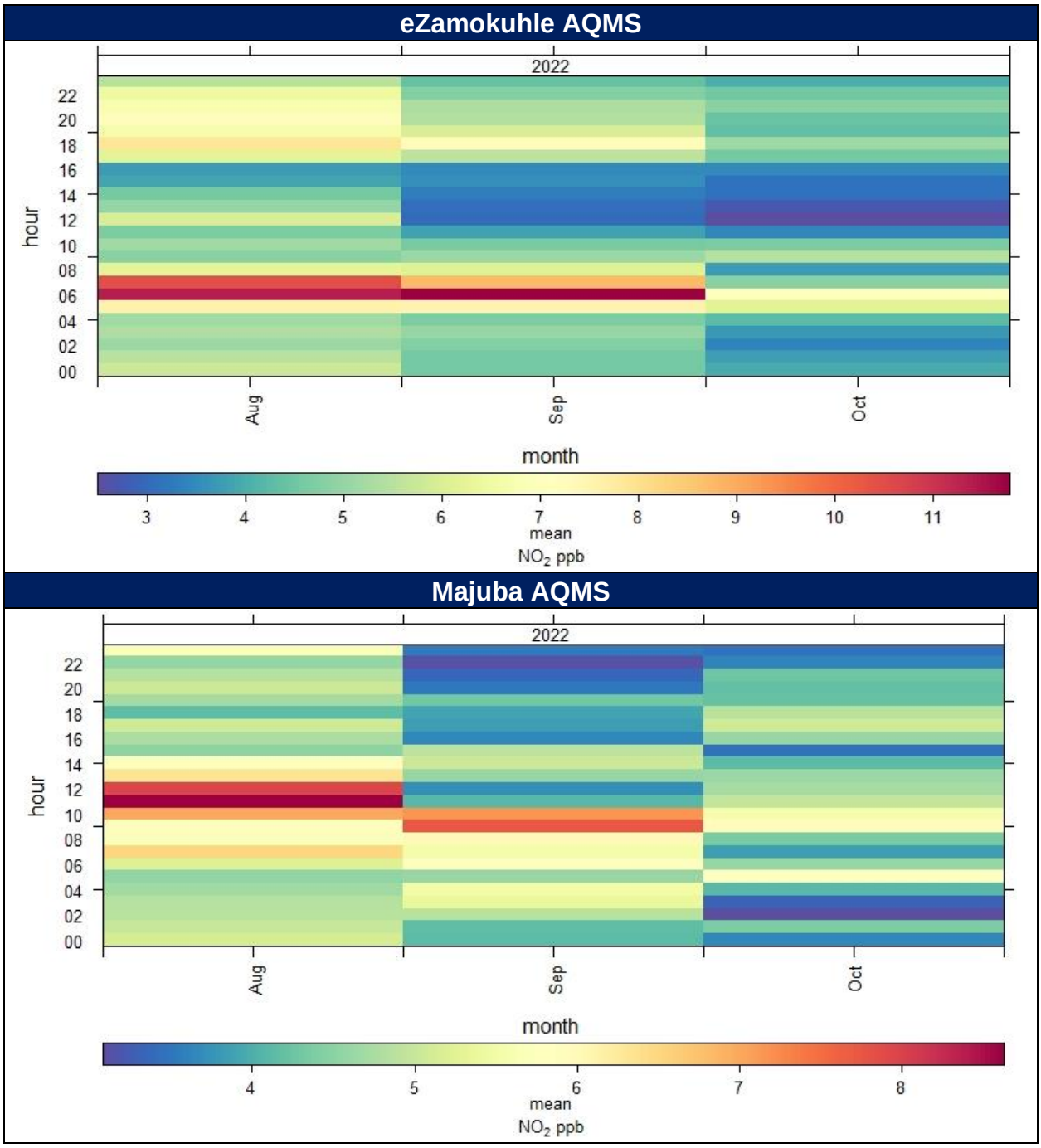

Figure 37: Hourly mean ambient NO_2 concentrations (ppb) measured at Eskom eZamokuhle AQMS during the sampling survey (Hourly NO_2 NAAQS = 106ppb).

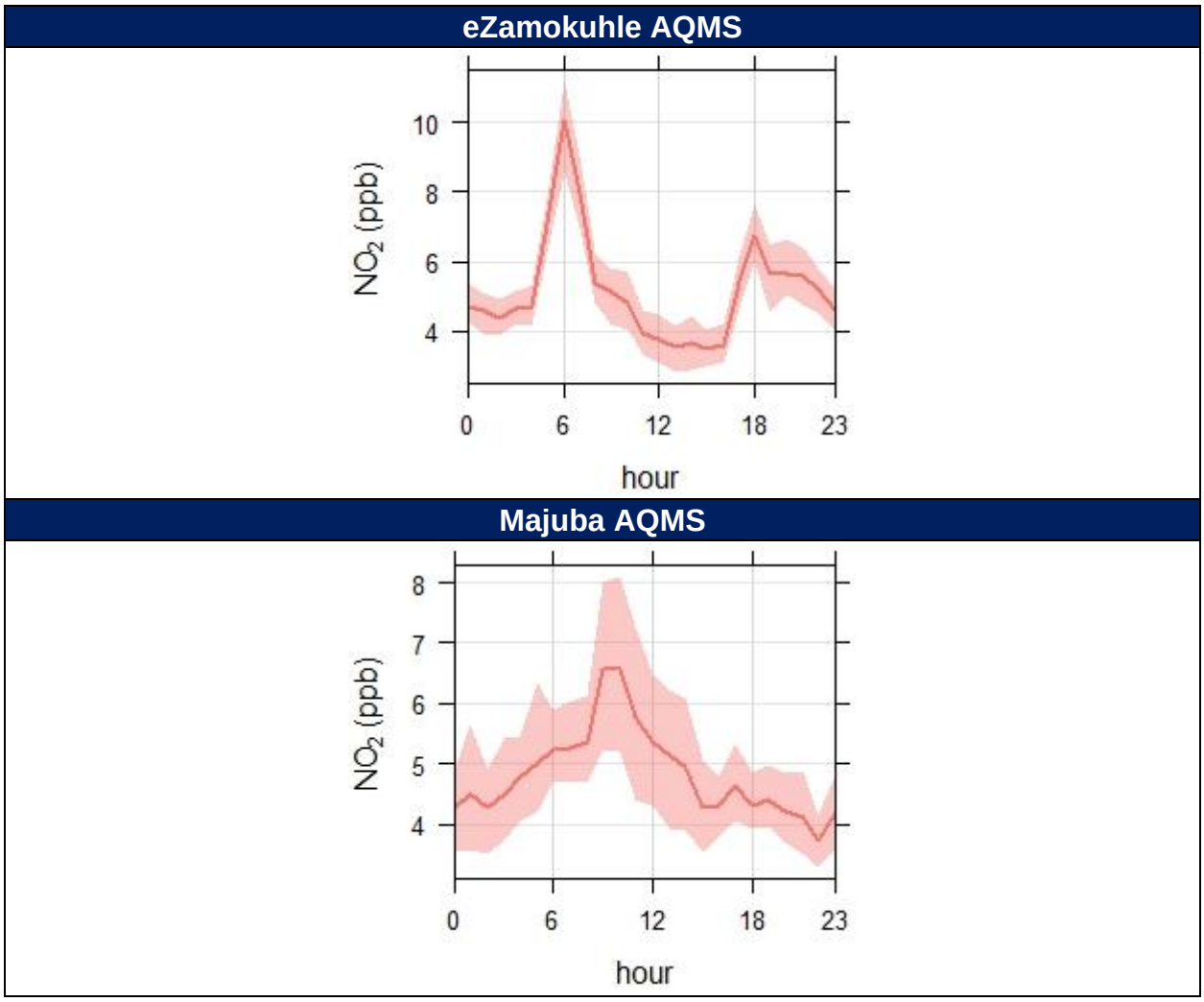

Figure 38: Mean hourly diurnal NO_2 concentrations (□g/m3) measured at sampling sites during the sampling survey

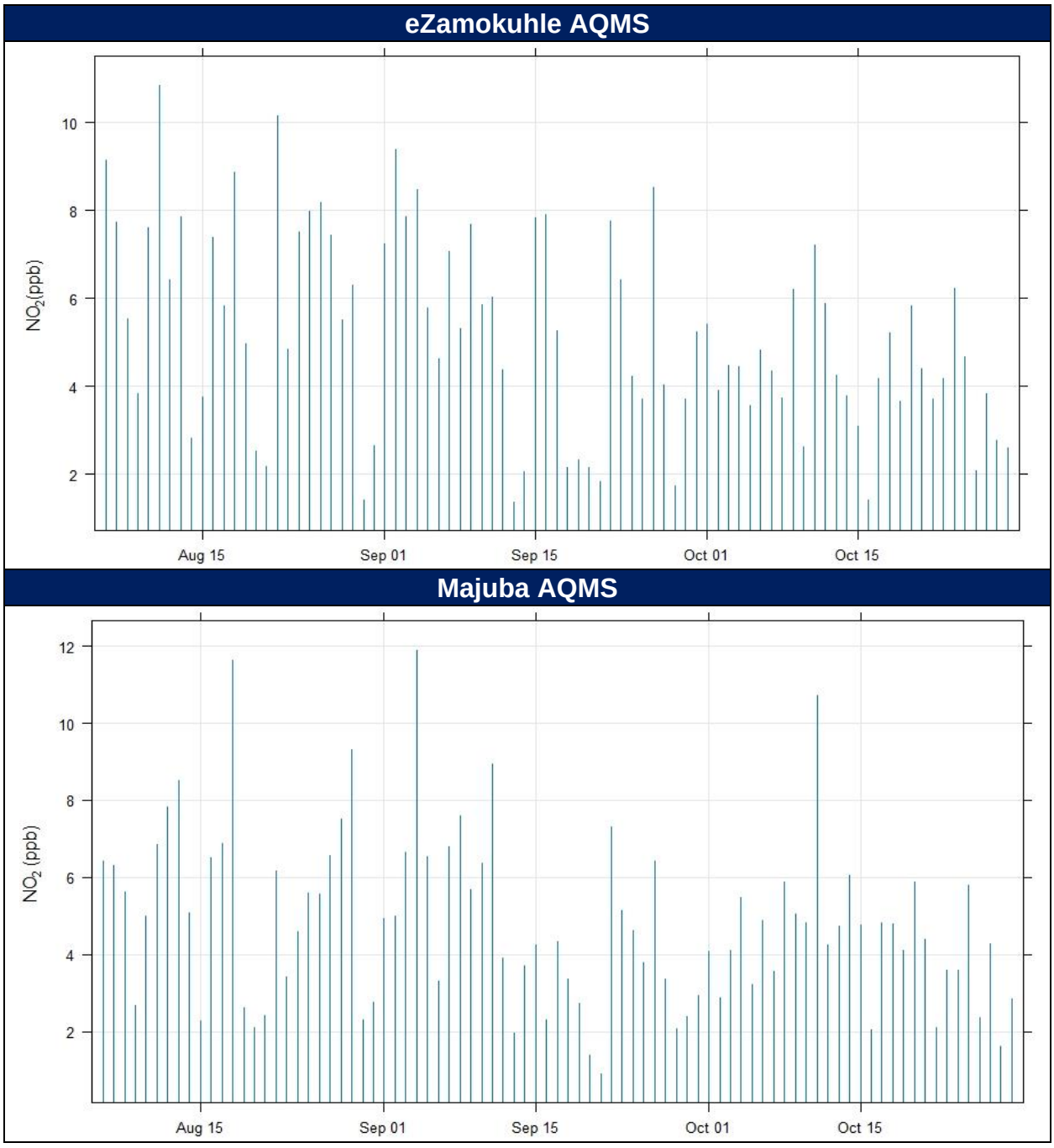

Figure 39: Daily ambient NO_2 concentrations (ppb) measured at Eskom eZamokuhle AQMS during the sampling survey

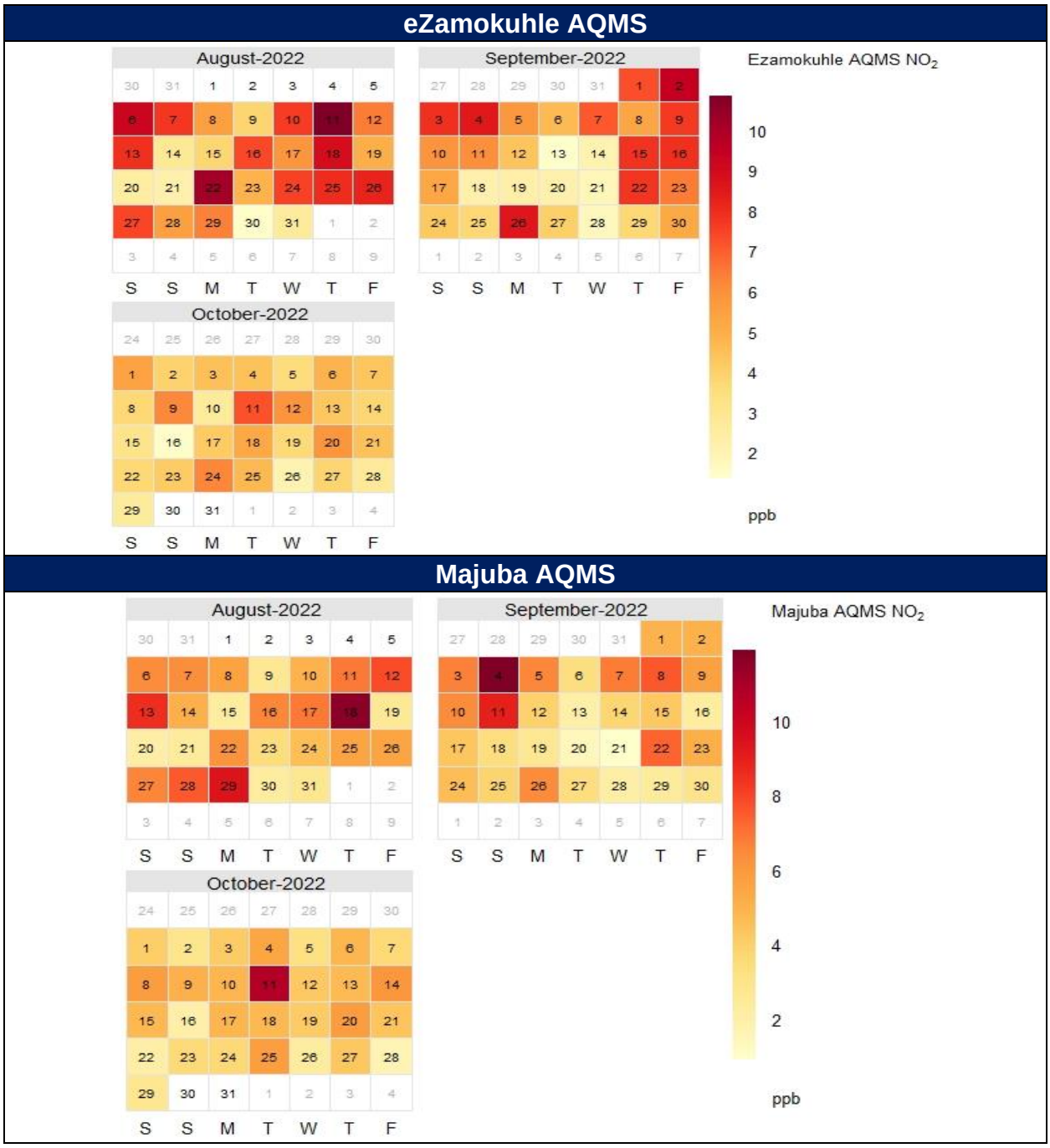

Figure 40: Daily ambient NO_2 concentrations (ppb) measured at Eskom eZamokuhle AQMS during the sampling survey

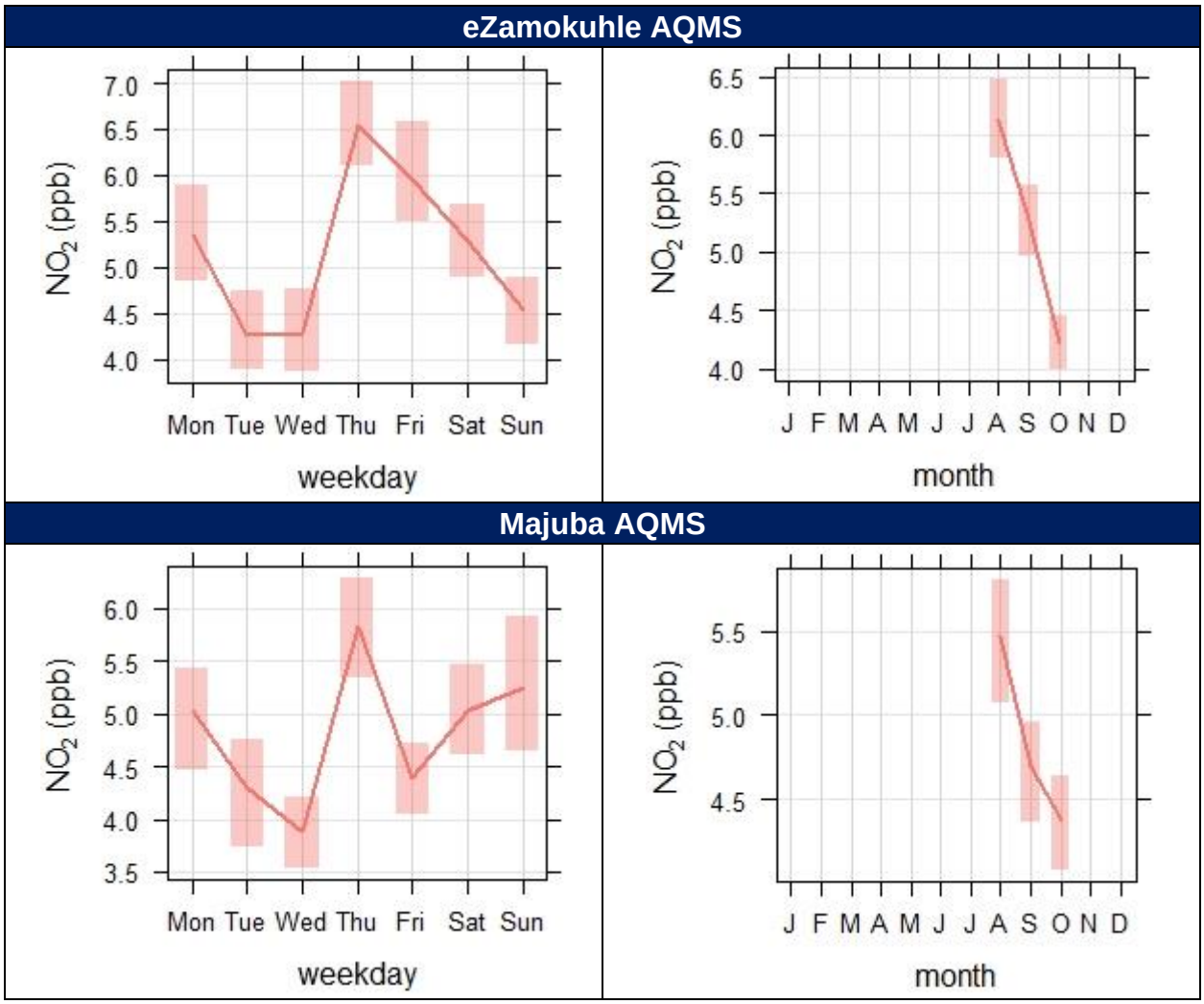

Figure 41: Mean weekday and mean monthly ambient NO_2 concentrations (ppb) measured at sampling sites during the sampling survey

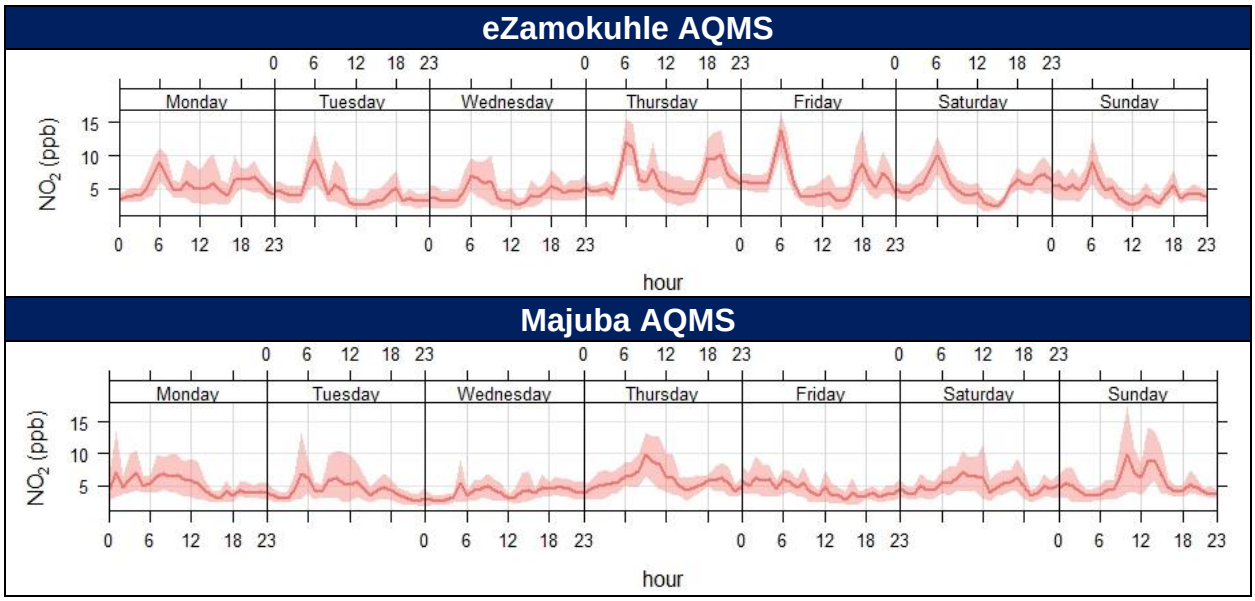

Figure 42: Weekly diurnal NO_2 concentrations (□g/m3) measured at sampling sites during the sampling survey

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. However, ambient data are not conventionally used for such purposes because individual signals tend to be modified, obscured, or complicated by confounding factors (Szulecka et al., 2017). However, more detailed and source-specific information can be extracted if analyses are performed using a subset of the data that has been "conditionally-selected" to exclude superimposed impacts from non-relevant sources (Malby et al., 2013). 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 pollution roses and 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 POLLUTION ROSES

The pollution rose is useful for considering pollutant concentrations by wind direction, or more specifically the percentage time the concentration is in a particular range. This type of approach can be very informative for air pollutant species (Henry et al. 2009).

4.3.1.1 Particulate Matter (PM_{10})

Figure 43 illustrates the pollution roses for PM_{10} measured at the Eskom eZamokuhle & Majuba stations. These plots are very useful for understanding which wind directions control the overall mean concentrations. The pollution rose clearly indicates that high episodes of pollutant levels are primarily related to winds from the: west-, north-westerly direction; east-, north easterly direction, as well a south westerly direction. A comparison of the annual wind rose for the Eskom eZamokuhle station and the Eskom Majuba station (Figure 8) to the pollution roses (Figure 43) shows higher pollutant concentrations occur at higher wind speeds. Conversely lower wind speeds (Figure 8) are associated with lower concentrations (Figure 43). It should be noted that higher wind speeds are typically associated with elevated emissions from tall stack sources whilst low-level emissions behave differently, and higher concentrations would normally be observed during weak-wind conditions.

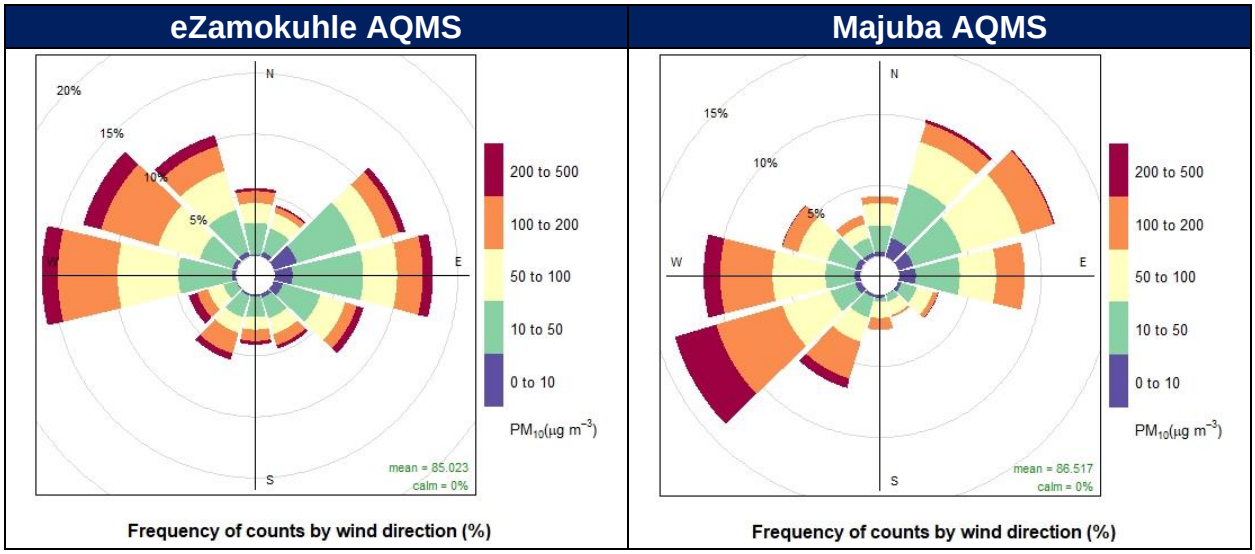

Figure 43: Pollution roses indicating which wind directions contribute most to overall mean concentrations for PM_{10}

4.3.1.2 Particulate Matter ($PM_{2.5}$)

Figure 44illustrates the pollution roses for $PM_{2.5}$ measured at the Eskom eZamokuhle & Majuba stations. The pollution rose clearly indicates that high episodes of pollutant levels are primarily related to winds from the: west-, north-westerly direction; east-, north easterly direction, as well a south westerly direction.

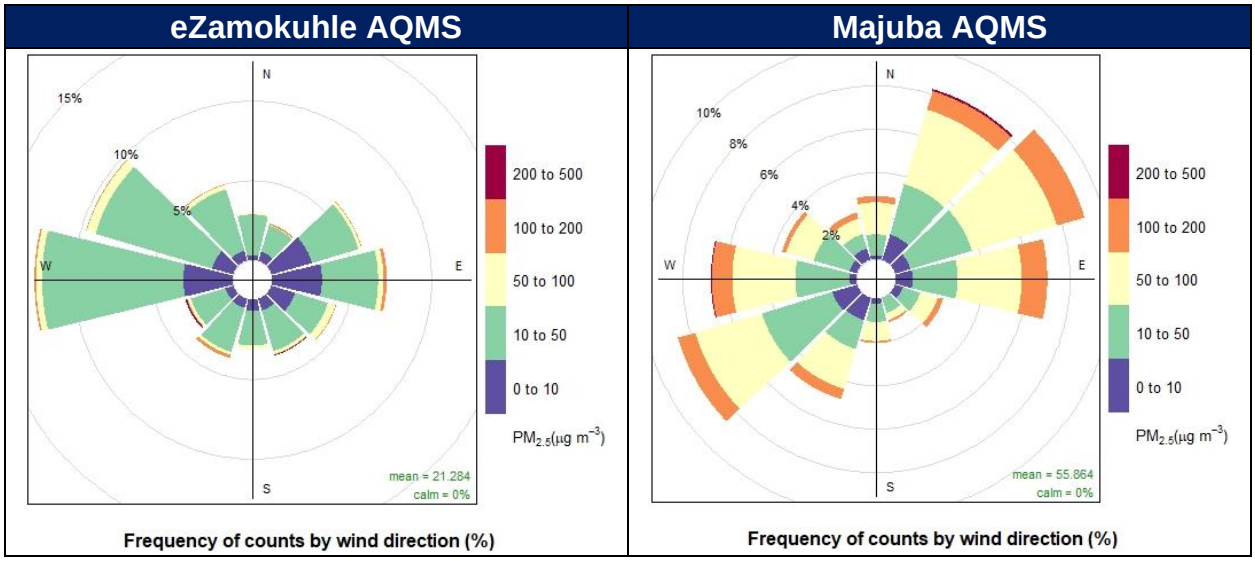

Figure 44:Pollution roses indicating which wind directions contribute most to overall mean concentrations for $PM_{2.5}$

4.3.1.3 Sulphur Dioxide (SO_2)

Figure 45 illustrates the pollution roses for SO_2 measured at the Eskom eZamokuhle & Majuba stations. The pollution rose clearly indicates that high episodes of pollutant levels are primarily related to winds from the: west-, north-westerly direction; east-, north easterly direction, as well a south westerly direction. Figure 45 illustrates that hourly mean concentrations of 10 to 50ppb SO_2, recorded at the Eskom eZamokuhle station are predominantly associated with sources emanating from a westerly/west north-westerly direction.

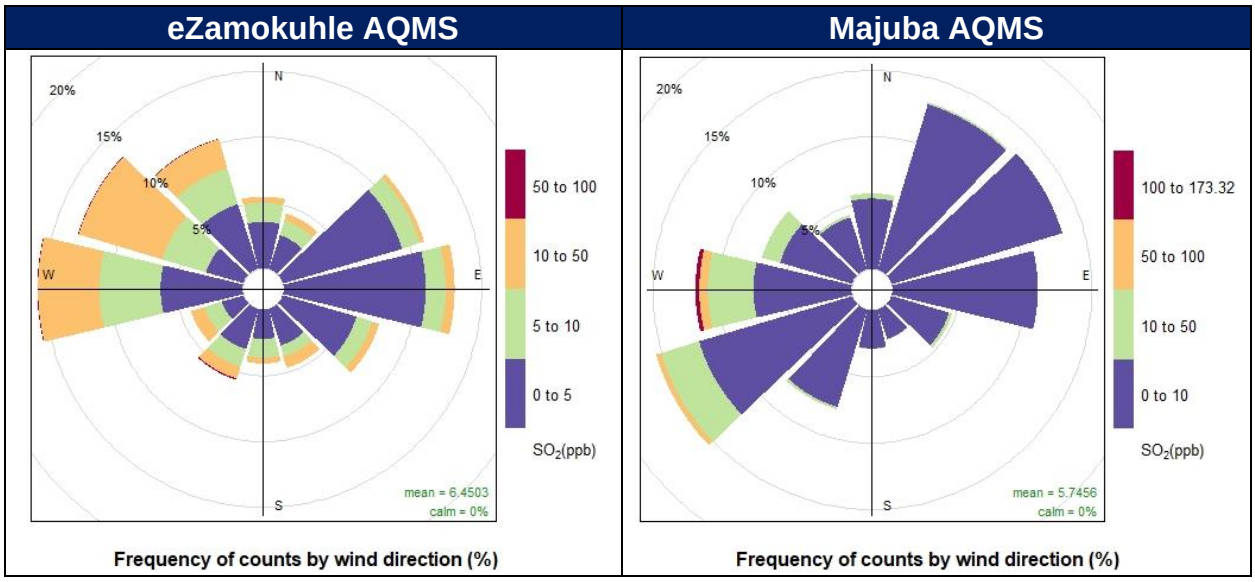

Figure 45: Pollution roses indicating which wind directions contribute most to overall mean concentrations for SO_2

4.3.1.4 Nitrogen Oxide (NO_2)

Figure 46 illustrates the pollution roses for NO_2 measured at the Eskom eZamokuhle & Majuba stations. The pollution rose clearly indicates that high episodes of pollutant levels are primarily related to winds from the: west-, north-westerly direction; east-, north easterly direction, as well a south westerly direction. Figure 46 illustrates those hourly mean concentrations of 10 to 50 ppb NO_2, recorded at the Eskom eZamokuhle station are predominantly associated with sources emanating from a westerly/south-westerly direction.

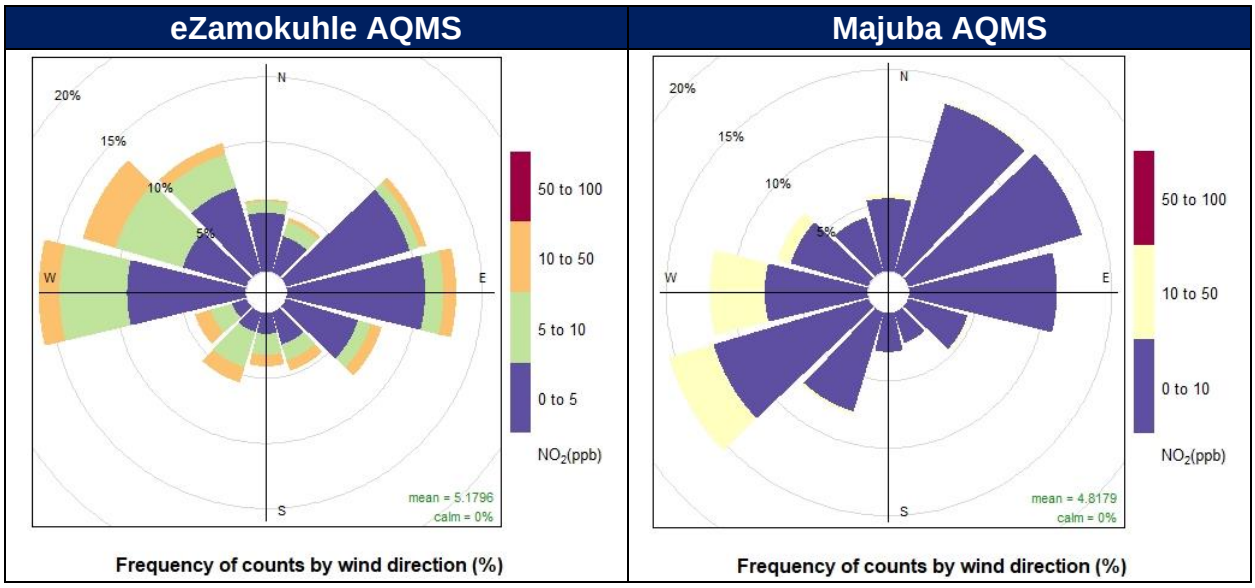

Figure 46: Pollution roses indicating which wind directions contribute most to overall mean concentrations for NO_2

4.3.2 Bivariate Polar Plots for Mean Concentration & Wind Speed

Bivariate plots indicate 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.

4.3.2.1 Particulate Matter (PM_{10})

Elevated particulate (PM_{10}) concentrations at Eskom eZamokuhle show source contributions from the north-west and the south-east at higher (between 8 and 12 m/s) wind speeds (Figure 47). At low wind speeds the symmetrical plot shows a localised contribution, most likely the result of residential fuel burning (Figure 47). The Eskom Majuba station indicate source contributions from a westerly, south-westerly as well as a north-easterly direction. The higher concentrations (400 to 450 ug/m^3) is associated with sources from a south-westerly direction (10 to 14m/s).

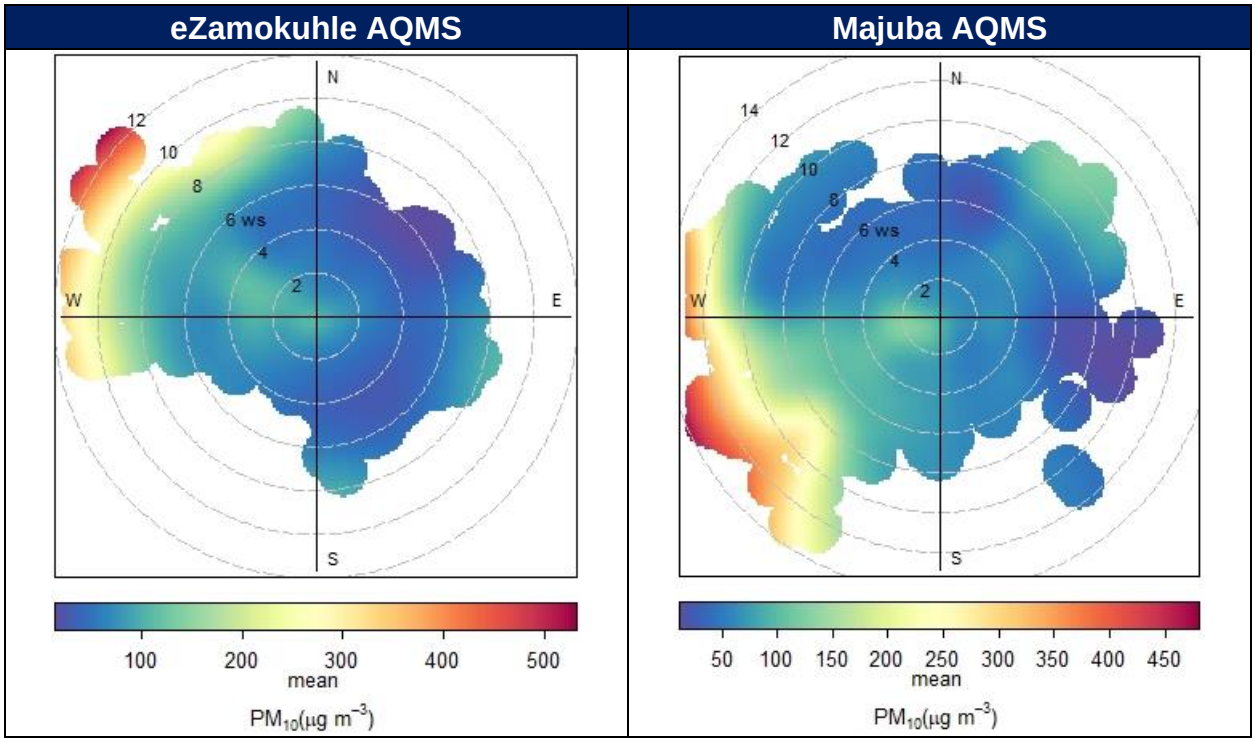

Figure 47: Polar plot of hourly mean PM_{10} concentration at the Eskom AQMS for the sampling period

4.3.2.2 Particulate Matter ($PM_{2.5}$)

Elevated particulate ($PM_{2.5}$) concentrations at Eskom eZamokuhle show source contributions from the north-west and the south-east at higher (between 8 and 12 m/s) wind speeds (Figure 48). At low wind speeds the symmetrical plot shows a localised contribution, most likely the result of residential fuel burning (Figure 48). The Eskom Majuba station indicate the highest source contribution from a westerly direction. These high concentrations (>120 ug/m^3) is associated with sources from a westerly direction and wind speeds of 12 to 14 m/s.

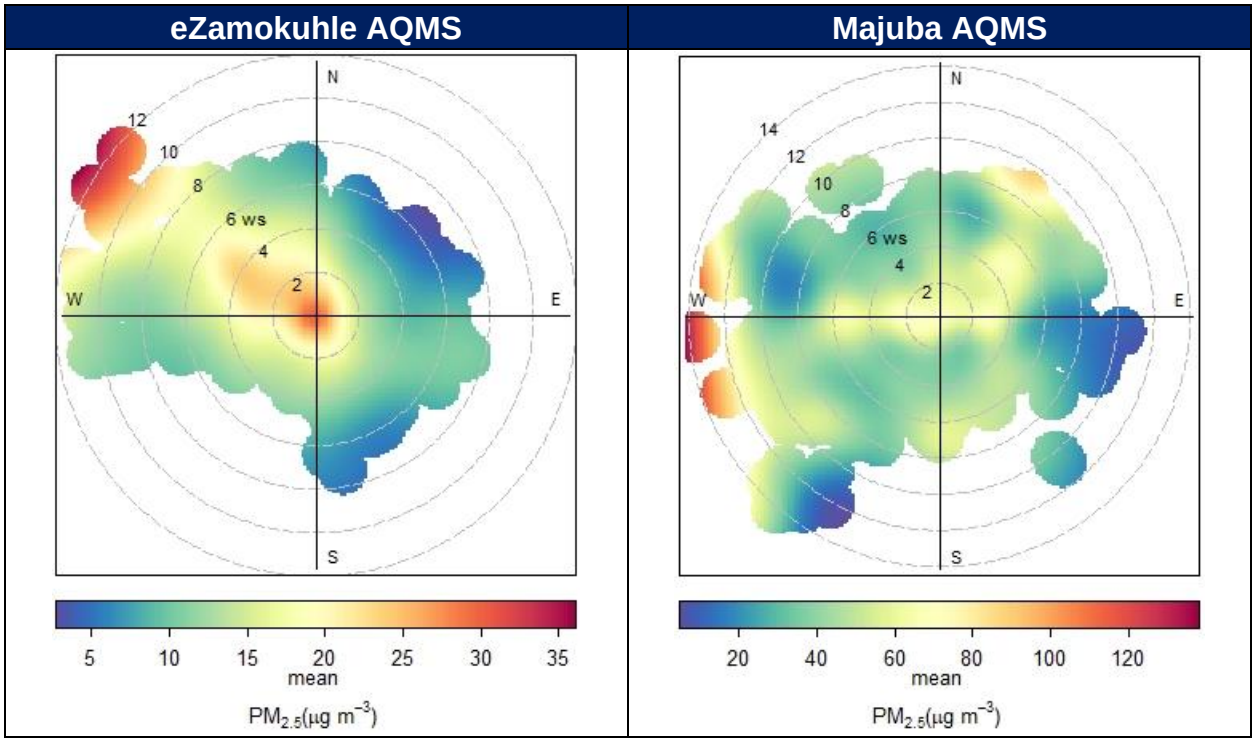

Figure 48: Polar plot of hourly mean $PM_{2.5}$ concentration at the Eskom AQMS for the sampling period

4.3.2.3 Sulphur Dioxide (SO_2)

The SO_2 concentrations observed at the Eskom eZamokuhle station (Figure 49) show two distinct wind directions, namely from the south-west and the north-west. High concentrations present at high wind speeds are indicative of emissions from stacks rather than non-buoyant ground-level sources. Hence the higher SO_2 concentrations associated with the south-westerly winds are most likely due to emissions from the Eskom Majuba power station. Similarly, the SO_2 concentrations from the north-west indicates a distinct tall stack emission source and this corresponds to the exact direction of a significant petrochemical facility located in Secunda which may be the likely emission source.

SO_2 concentrations (Figure 49) observed at the Eskom Majuba AQMS clearly show that the highest SO_2 concentrations occur when the wind is blowing from the west/north-west. These high concentrations occur under very high wind speeds conditions (between 10 to 15 m/s) from the south-west which is most likely due to emissions from the Eskom Majuba power station. At low wind speeds the symmetrical plot shows a localised contribution, most likely the result of residential fuel burning (Figure 49).

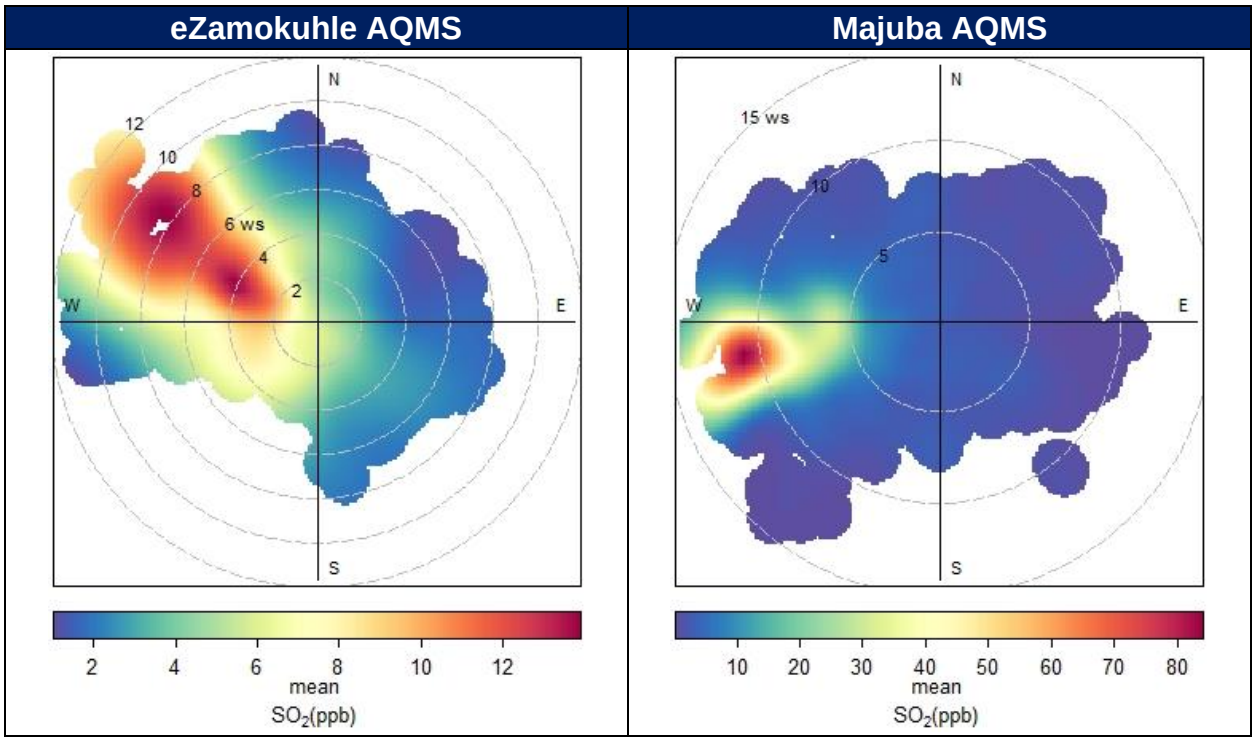

Figure 49: Polar plot of hourly mean SO_2 concentration at the Eskom AQMS for the sampling period

4.3.2.3 Nitrogen Dioxide (NO_2)

Figure 50 indicate the bivariate NO_2 polar plots for the Eskom eZamokuhle and Majuba AQMS. The highest concentrations occur under very low wind speed conditions (0 to 2m/s) from the south-west. These high concentrations occur under stable atmospheric conditions when non-buoyant ground-level sources are important such as road transport emissions. Figure 48 confirms that these NO_2 concentrations are the likely impact of vehicle emissions. The bivariate polar plot also indicates an area of high concentration to the north-west that occur at high wind speeds (8 to 12m/s), possibly corresponding to the activities of a petrochemical facility located in Secunda.

NO_2 concentrations (Figure 50) observed at the Eskom Majuba station clearly show that the highest NO_2 concentrations occur when the wind is blowing from the south-west. The high concentrations occur under very high wind speeds conditions (between 10 to 15 m/s) from the north-west which is most likely due to emissions from the Eskom Majuba power station. At low wind speeds the symmetrical plot shows a localised contribution, most likely the result of residential fuel burning in the region.

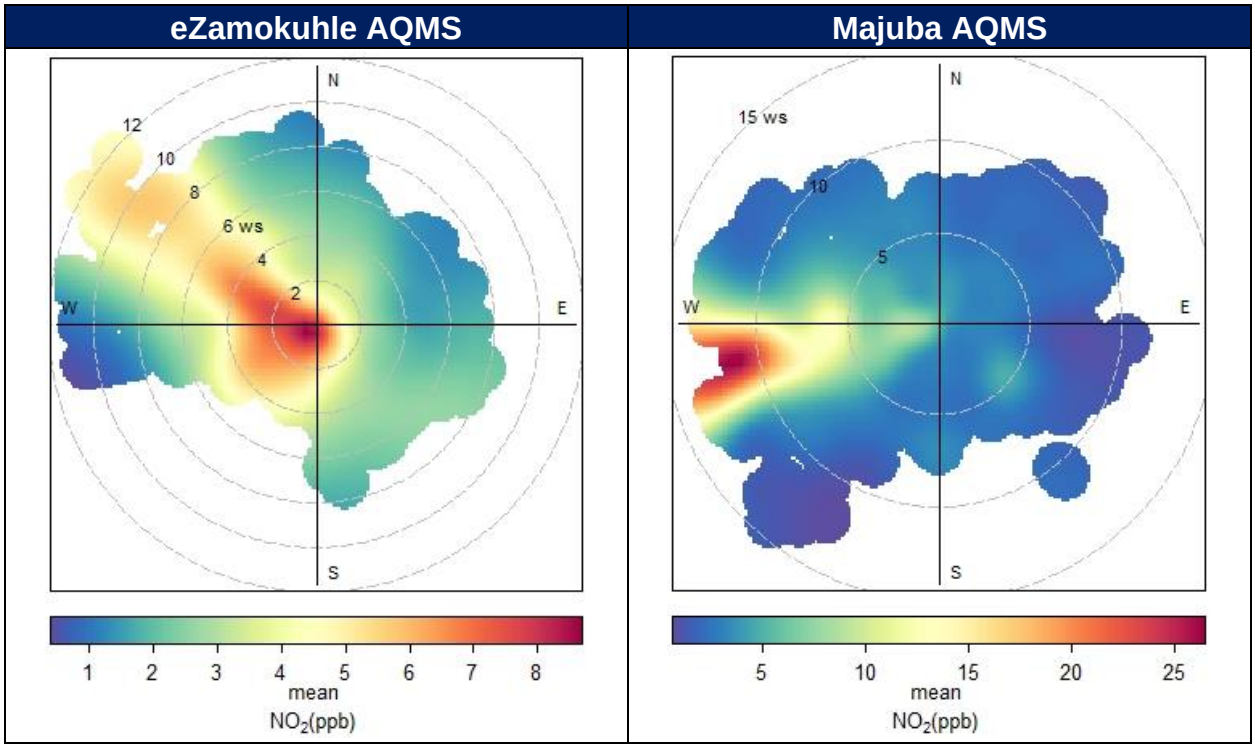

Figure 50: Polar plot of hourly mean NO_2 concentration at the Eskom AQMS for the sampling period

4.3.3 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.

4.3.3.1 Particulate Matter (PM_{10})

Figure 51 indicates the bivariate polar plots for PM_{10} concentrations as a function of wind direction and surface temperature for both the Eskom eZamokuhle and Eskom Majuba AQMS. The highest concentrations occur during low temperatures, which results mostly from residential fuel burning.

4.3.3.2 Particulate Matter ($PM_{2.5}$)

Figure 52 indicates the bivariate polar plots for $PM_{2.5}$ concentrations as a function of wind direction and surface temperature for both the Eskom eZamokuhle and Eskom Majuba AQMS. Lower localised concentrations occur during low temperatures, which results mostly from residential fuel burning.

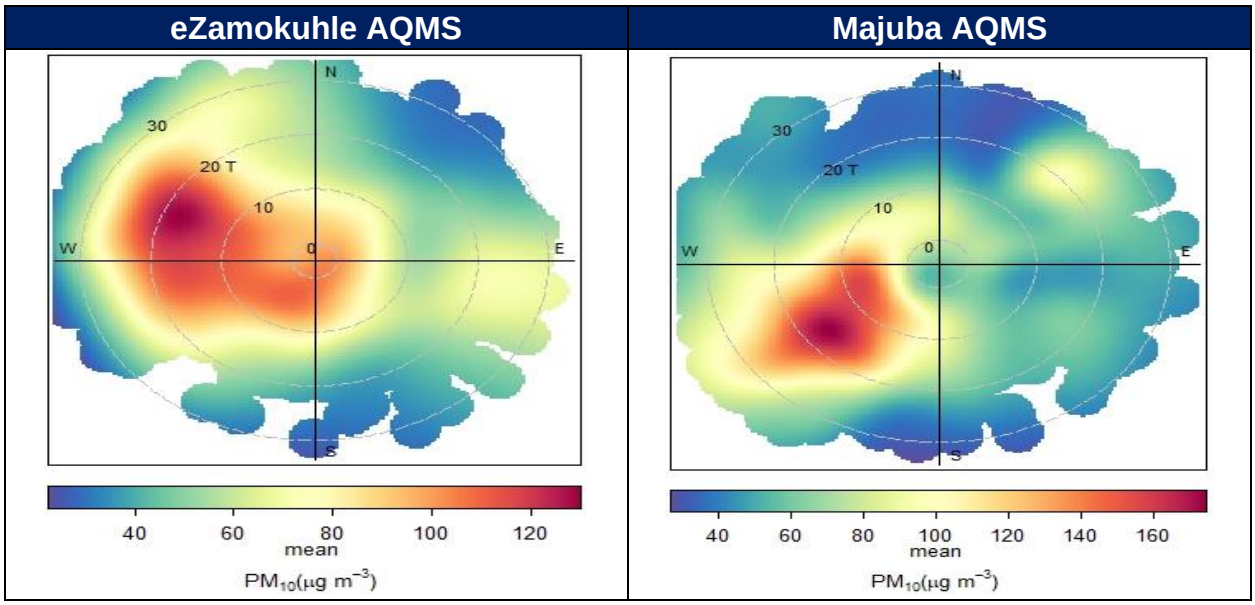

Figure 51: Polar plot of hourly mean PM_{10} concentration at the Eskom AQMS for the sampling period

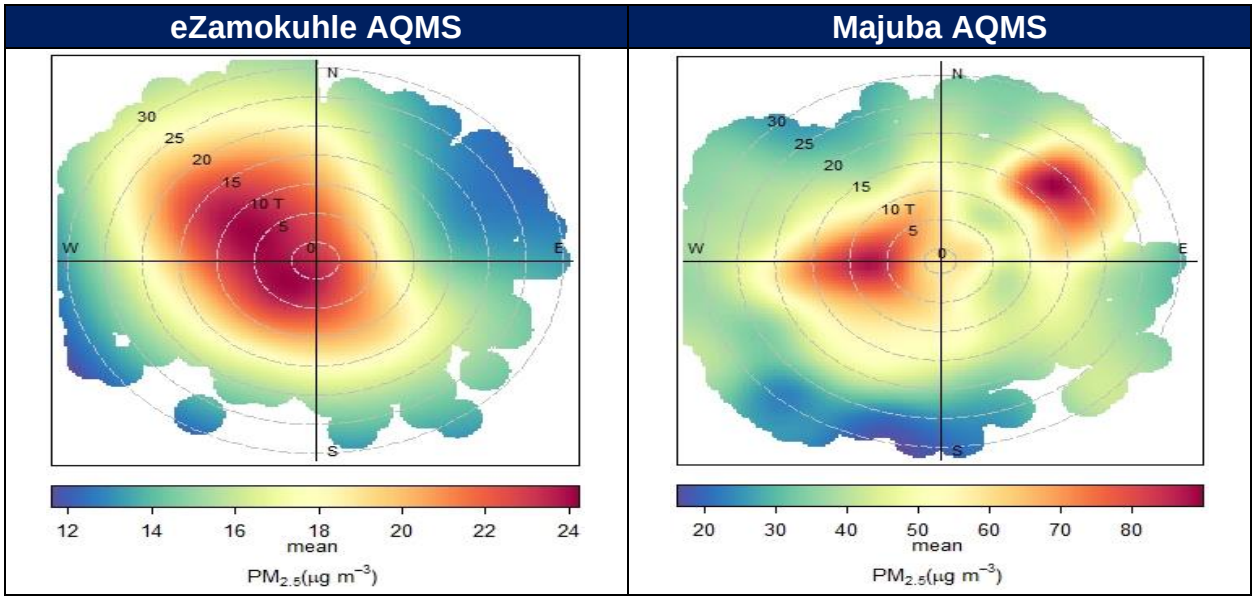

Figure 52: Polar plot of hourly mean $PM_{2.5}$ concentration at the Eskom AQMS for the sampling period

4.3.3.3 Sulphur Dioxide (SO_2)

Figure 53 indicate the bivariate polar plot for hourly SO_2 concentrations as a function of wind direction and surface temperature. It is apparent that there is a clear dependence of SO_2 concentrations with increasing ambient temperature for both the Eskom eZamokuhle and Eskom Majuba AQMS. These concentrations increase with increasing temperature can be attributed to dispersing plumes from tall stacks that are brought down to ground level under unstable atmospheric conditions when thermal turbulence is increased. The bivariate polar plot (Figure 53) also indicates an area of high concentration to the north-west that occur at higher temperatures (20 to 30°C), possibly corresponding to the activities of a petrochemical facility located in Secunda.

The area of high concentration for the Eskom Majuba station toward the west could possibly correspond to the Eskom Majuba power station, located towards the west of the Eskom Majuba AQMS.

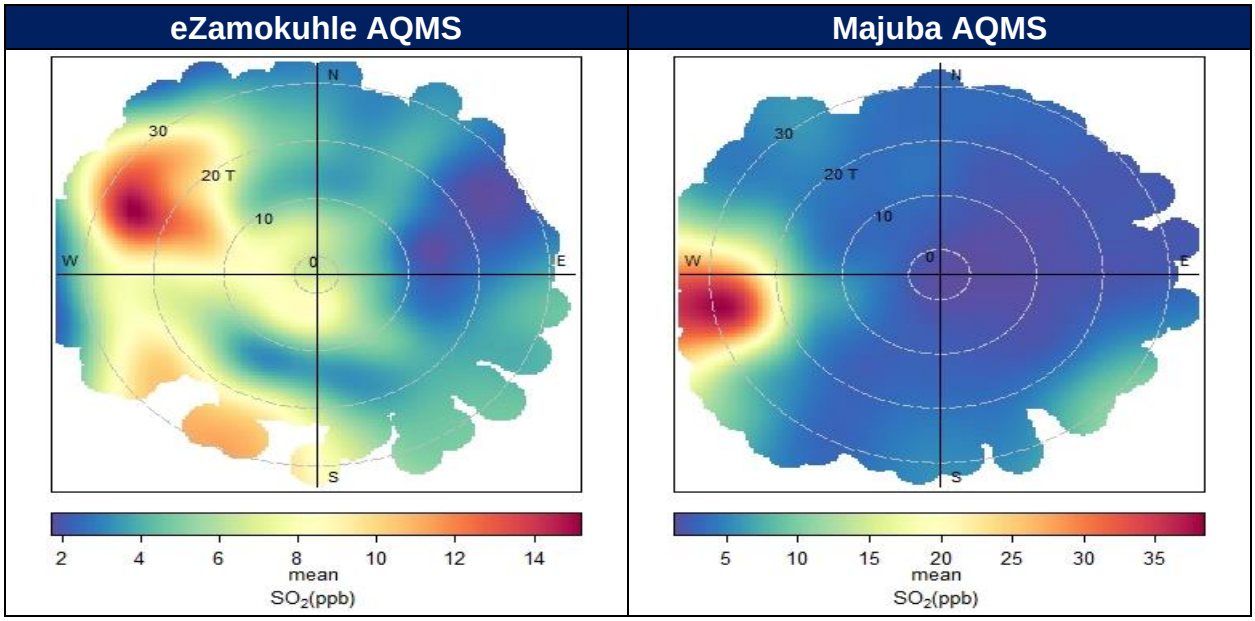

Figure 53: Polar plot of hourly mean SO_2 concentration at the Eskom AQMS for the sampling period

4.3.3.4 Nitrogen Dioxide (NO_2)

Figure 54 indicate the bivariate polar plot for hourly NO_2 concentrations as a function of wind direction and surface temperature. It is apparent that there is a clear dependence of NO_2 concentrations with increasing ambient temperature for both the Eskom eZamokuhle and Eskom Majuba AQMS. These concentrations increase with increasing temperature can be attributed to dispersing plumes from tall stacks that are brought down to ground level under unstable atmospheric conditions when thermal turbulence is increased. The bivariate polar plot (Figure 54) also indicates an area of high concentration to the north-west that occur at higher temperatures (20°C), possibly corresponding to the activities of a petrochemical facility located in Secunda. The area of high concentration in the south-westerly direction ate temperatures from 0 to 30°C could correspond to vehicle emissions.

The area of high concentration for the Eskom Majuba station (Figure 54) toward the west could possibly correspond to the Eskom Majuba power station, located towards the west of the Eskom Majuba AQMS.

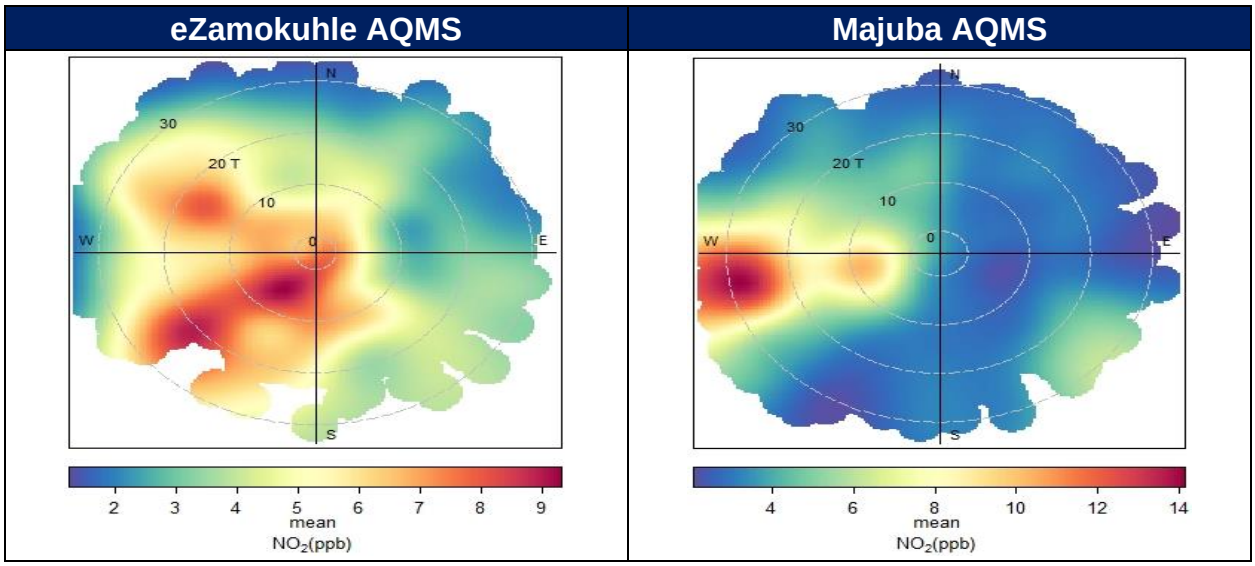

Figure 54: Polar plot of hourly mean NO_2 concentration at the Eskom AQMS for the sampling period

5. CONCLUSIONS

5.1 PARTICULATE MATTER (PM_{10})

The bi-modal hourly diurnal cycle at House 4 is indicative of residential fuel burning. Maximum hourly ambient PM_{10} concentrations of 400 ug/m^3 were recorded at House 4 during the survey. Maximum daily ambient concentrations of 120 ug/m^3 were recorded, with exceedances of the daily NAAQS for PM_{10}. These exceedances were prominent during the colder months during the sampling period. No exceedances of the daily NAAQS for PM_{10} were recorded for the second half of September, as well as the October at House 4. A daily mean ambient PM_{10} concentration of 57.1ug/m^3 was recorded for House 4 during the sampling period. The results are conclusive that residential fuel burning is the major contributing emission source to these measured PM_{10} concentrations.

5.2 PARTICULATE MATTER ($PM_{2.5}$)

The bi-modal hourly diurnal cycle at House 1 and House 5 are indicative of residential fuel burning. Maximum hourly ambient PM_{10} concentrations of 500 ug/m^3 were recorded at House 1 and House 5 during the survey. Maximum daily ambient concentrations of 80ug/m^3 were recorded at both Houses, with exceedances of the daily NAAQS for $PM_{2.5}$. These exceedances were prominent during the colder months during the sampling period, but exceedances were also reported during October for both Houses respectively. A daily mean ambient $PM_{2.5}$ concentration of 40.0 ug/m^3 and 43.7 ug/m^3 were recorded for House 1 and House 5 respectively during the sampling period.

For both PM_{10} and $PM_{2.5}$ the results are conclusive that residential fuel burning is the major contributing emission source to the elevated concentrations measured in eZamokuhle. These elevated concentrations were more pronounced in the winter months with the increased space heating requirements of the eZamokuhle households in winter. 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

Air Resource Management would like to thank the following individuals for their assistance in this study:

- Ms Bontle Moiloa for timeously providing the team with the ambient air quality monitoring data for the Eskom Majuba and eZamokuhle stations;
- Mr Motshewa Matimolane and Mr Bryan McCourt for their technical comments and support.

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