SUMMARY
ATMOSPHERIC IMPACT REPORT (AIR)

In support of

Eskom's application for postponement of the Minimum Emission Standards for its Coal-Fired Power Stations

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ABBREVIATIONS

AIRs	Atmospheric Impact Reports
DEA	Department of Environmental Affairs

FGD	Flue-gas Desulphurisation
NAAQS	National Ambient Air Quality Standards
NO_2	Nitrogen dioxide
NO	Nitrogen oxide
NO_x	Nitrogen oxides
PM	Particulate Matter
SO_2	Sulphur dioxide

1 INTRODUCTION

The Atmospheric Impact Reports (AIRs) reflected in this summary report have been compiled in support of Eskom's application to postpone the Minimum Emissions Standards (MES) compliance timeframes for their coal-fired power stations. Eskom contends that for various resource, financial and time constraints, it is not possible to comply with the MES and so has submitted a suite of postponement applications to have compliance deferred either indefinitely (in the case of power stations that will be decommissioned within the next decade) or until such time as it will be possible to retrofit the power station with the necessary pollution abatement equipment. For each application Eskom has also proposed alternative emission limits that could apply in the interim period until compliance can be achieved or the power station decommissioned.

For a decision to be made on the acceptability of proposed alternative emissions limits the implications for ambient air quality have to be understood. Ambient air quality in the areas where the power stations operate has therefore been analysed to ascertain the current status and as a basis for assessing the likely changes in air quality as a result of the proposed emission limits. Atmospheric dispersion modelling has also been used to predict ambient air quality concentrations for two emissions scenarios namely:

- Current emissions; and,
- MES Compliance emissions.

Such assessments have been conducted for each of the individual power stations and have been presented in the Atmospheric Impact Reports (AIRs) that accompany the various applications. The collective findings of these various AIRs are presented in this report.

2 PREVAILING AMBIENT AIR QUALITY

Some fourteen ambient air quality monitoring stations have been identified as representative of the air quality that prevails in the areas in which the Eskom power stations operate. The positions of the stations are shown relative to the power stations in Figures 1. These stations were established, in many instances, by Eskom themselves but also by the Department of Environmental Affairs (DEA). The monitoring stations all include monitoring of at least the four key pollutants associated with coal-fired power station emissions, together with associated meteorological parameters such as wind velocity, temperature, solar radiation and others. The pollutants for which MES have been set for coal-fired power generation are sulphur dioxide (SO_2), nitrogen oxides (NO_x) (measured at ground level as nitrogen dioxide (NO_2)) and particulate matter (measured at ground level as PM_{10} and $PM_{2.5}$).

From the data available it is possible to ascertain the respective pollutant concentrations for the different averaging periods for which National Ambient Air Quality Standards (NAAQS) have been set. The only exception has been for the ten-minute averaging period for SO_2 where such ten-minute averages are available only for the Eskom monitoring stations (Camden, Elandsfontein, Kendal, Komati, Kriel, KwaZamokuhle and Phola). The NAAQS are shown in Table 1.

Table 1: National ambient air quality standards (NAAQS) for South Africa.

Pollutant	Averaging Period	Concentration	Frequency of Exceedence
Sulphur dioxide (SO_2)	10 minutes	500 µg/m^3 (191 ppb)	526
	1 hour	350 µg/m^3 (134	88

Pollutant	Averaging Period	Concentration	Frequency of Exceedence
		ppb)	
	24 hours	125 µg/m^3 (48 ppb)	4
	1 year	50 µg/m^3 (19 ppb)	0
	The reference method for the analysis of Sulphur dioxide shall be ISO 6767		
Nitrogen oxides (NO_2)	1 hour	200 µg/m^3 (106 ppb)	88
	1 year	40 µg/m^3 (21 ppb)	0
	The reference method for the analysis of Nitrogen dioxide shall be ISO 7996		
Particulate matter (PM_{10})	24 hours	75 µg/m^3	4
	1 year	40 µg/m^3	0
	The reference method for the determination of the Particulate Matter fraction of suspended Particulate Matter shall be EN 12341		
Particulate matter ($PM_{2.5}$)	24 hours	40 µg/m^3	4
	1 year	20 µg/m^3	0
	The reference method for the determination of the Particulate Matter fraction of suspended Particulate Matter shall be EN 12341		

As can be seen from the table, it is only the annual average limits that apply 100% of the time. The remaining standards all apply for 99% of the time so for 10-minute averages 556 exceedances are allowed, 1 hour averages, 88 exceedances and daily averages, 4 exceedances of the prescribed limit value. This 99% of the time is also referred to as the '99th percentile' and serves to exclude 'outliers' (i.e. not easily explained given the pattern in the rest of the data).

Unfortunately the data from the monitoring stations varies considerably as a result of power fluctuations, theft and vandalism with NO_2 analyzers proving to be particularly sensitive. As such the percentage data recovery differs for different monitoring years and for different monitoring stations. In general terms data recovery of 80% or better is considered representative. Unless the data was obviously deficient, all of the data has been reflected in this report even where data recovery was less than 80%, for the sake of completeness. It should be noted though that where data recovery is less than 80% compliance cannot be assured even if it is implied in the monitoring data.

2.1 Sulphur dioxide (SO_2)

2.1.1 10-minute average

Exceedances of the 10-minute average SO_2 NAAQS limit value for the monitoring stations where such averages are recorded are shown in Figure 2. It can be seen from the figure that there are no circumstances where the allowable number of NAAQS limit value exceedances is surpassed indicating compliance with the NAAQS at all the stations. The Kendal monitoring station which is immediately downwind of the power station shows the highest number of exceedances of the NAAQS limit value, with more than 300 in 2015, even with a data recovery of less than 50%.

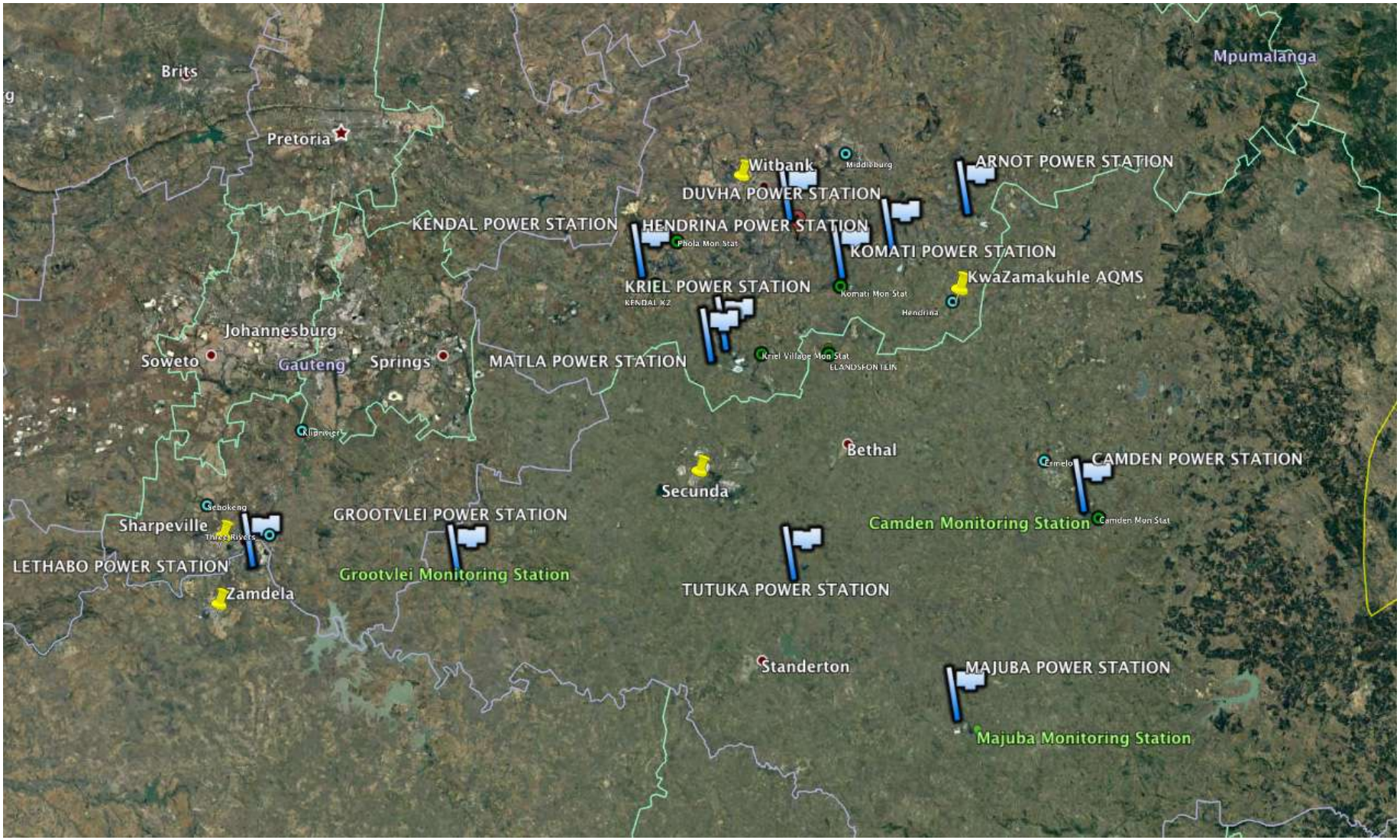

Figure 1: Positions of the ambient air quality monitoring stations relative to the power stations.

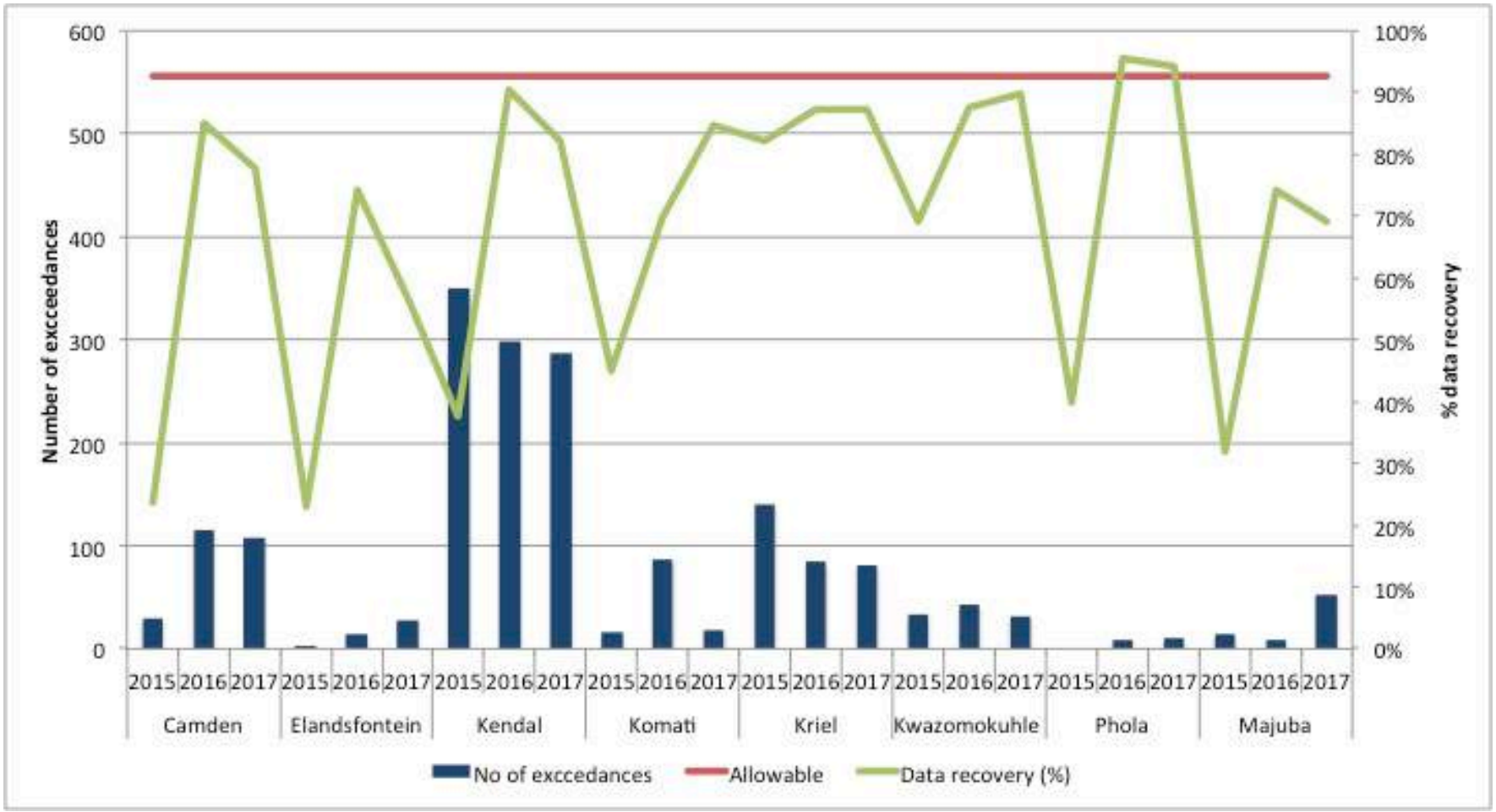

Figure 2: Frequency of exceedances of the sulphur dioxide (SO_2) 10-minute average NAAQS limit value. If the allowable number of exceedances is surpassed then there is non-compliance with the standard. Note that the percentage data recovery is plotted relative to a secondary y axis (on the right hand side of the graph).

2.1.2 Hourly average

Exceedances of the hourly average SO_2 NAAQS limit value shown for all the monitoring stations used in this analysis in Figure 3. It can be seen from the figure that there was compliance at all the monitoring stations for all the years with the Kendal monitoring station again exhibiting the greatest number of exceedances, followed by Komati, Witbank and Kriel. The year-to-year reduction in SO_2 concentrations at the Witbank monitoring station is noteworthy due to the closure of Highveld Steel and Vanadium in July 2015 and the possible role that closure played in the reduction in ambient SO_2 concentrations.

2.1.3 Daily average

Exceedances of the daily average SO_2 NAAQS limit value are shown for all the monitoring stations in Figure 4. The same patterning is evident as for the shorter averaging periods with non-compliance with the NAAQS evident at Kendal, Komati, Kriel, Witbank and KwaZamokuhle.

2.1.4 Annual average

Annual average SO_2 concentrations are shown in Figure 5 relative to the NAAQS. It can be seen from the graph that the annual average NAAQS is exceeded at Komati, but large concentrations are evident at many of the Highveld monitoring stations. It is interesting to note that the Vaal Triangle stations have generally smaller concentrations than the Highveld stations.

2.2 Nitrogen dioxide (NO_2)

2.2.1 Hourly average

Exceedances of the hourly average NO_2 NAAQS limit value shown for all the monitoring stations used in this analysis in Figure 6. It can be seen from the figure that there was compliance at all the monitoring stations for all the stations and years other than for Sebokeng in 2015, which is deemed to be spurious given the general patterning of the other years at Sebokeng and the other monitoring stations. Monitoring of NO_2 is known to be difficult given the sensitivity of the monitoring instruments and data inconsistencies are evident at a number of the monitoring stations where data has not been used because it is obviously incorrect (an order of magnitude higher than data from the other monitoring stations).

2.2.2 Annual average

Annual average NO_2 concentrations are shown in Figure 7 relative to the NAAQS. It can be seen from the graph that there is non-compliance for Secunda, Sharpville and Sebokeng and that the Vaal Triangle monitoring stations have a generally larger NO_2 concentrations than the Highveld stations.

2.3 Particulate matter (PM_{10})

2.3.1 Daily average

Exceedances of the daily average PM_{10} NAAQS limit value are shown for all the monitoring stations used in this analysis in Figure 8. It can be seen from the figure that there is ubiquitous non-compliance with the NAAQS to the extent that a logarithmic scale has to be used to show the number of exceedances. There are 8 monitoring years where there were more than 100 days of exceedances of the NAAQS limit value (where no more than 4 are allowed). A generally larger $PM_{2.5}$ loading is evident where the monitoring stations are in dense residential settlements suggesting an important contribution to the measured concentrations from domestic fuel use.

2.3.2 Annual average

Annual average PM_{10} concentrations are shown in Figure 9 relative to the NAAQS. It can be seen from the graph that there is again almost ubiquitous non-compliance for the various stations and monitoring years and where for Phola, Sharpeville and Kliprivier the measured annual average concentrations in some years are more than double the NAAQS.

2.4 Particulate matter ($PM_{2.5}$)

2.4.1 Daily average

Exceedances of the daily average $PM_{2.5}$ NAAQS limit value are shown for all the monitoring stations used in this analysis in Figure 10. It can be seen from the figure that there is again ubiquitous non-compliance with the NAAQS to the extent that a logarithmic scale has to be used to show the number of exceedances. There are 10 monitoring years where there were more than 100 days of exceedances of the NAAQS limit value (where no more than 4 are allowed). A generally larger $PM_{2.5}$ loading is evident where the monitoring stations are in dense residential settlements suggesting an important contribution to the measured concentrations from domestic fuel use.

2.4.2 Annual average

Annual average $PM_{2.5}$ concentrations are shown in Figure 11 relative to the NAAQS. It can be seen from the graph that there is again almost ubiquitous non-compliance for the various stations and monitoring years and where for Phola, Sharpeville and Kliprivier the measured annual average concentrations in some years are more than four times the NAAQS.

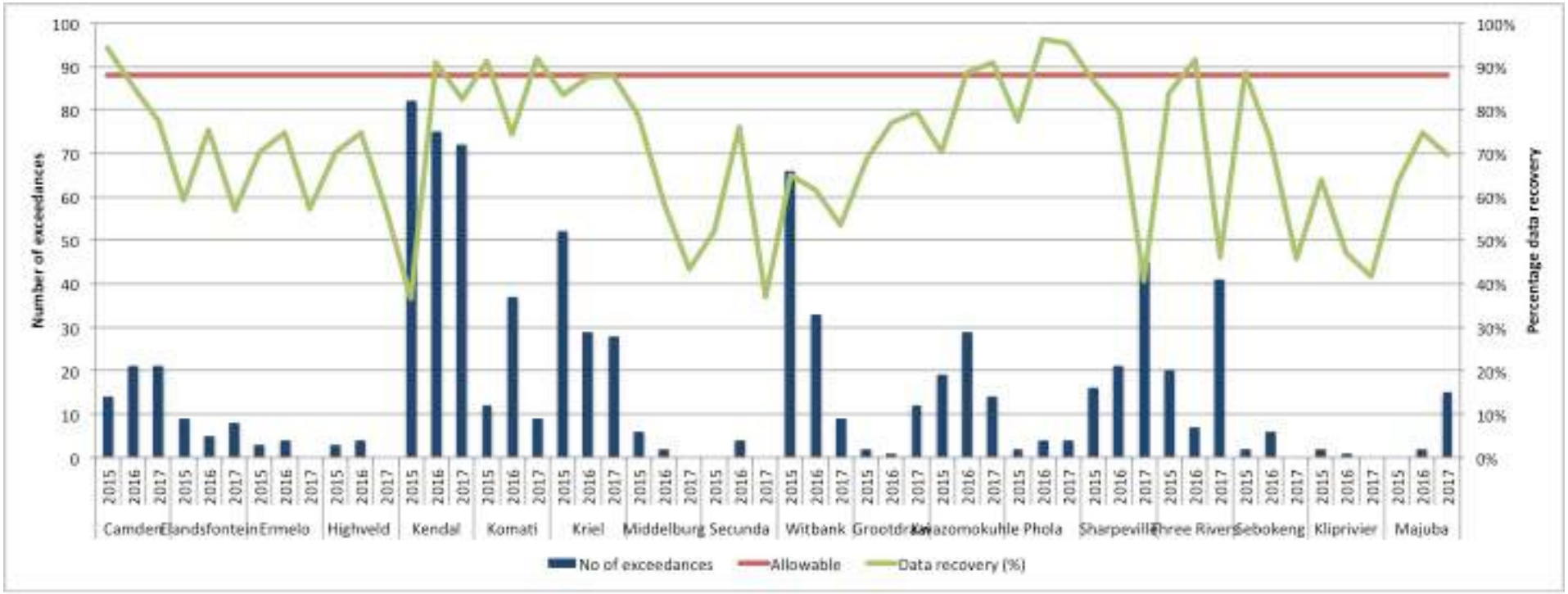

Figure 3: Frequency of exceedances of the sulphur dioxide (SO_2) hourly average NAAQS limit value. If the allowable number of exceedances is surpassed then there is non-compliance with the standard. Note that the percentage data recovery is plotted relative to a secondary y axis (on the right hand side of the graph).

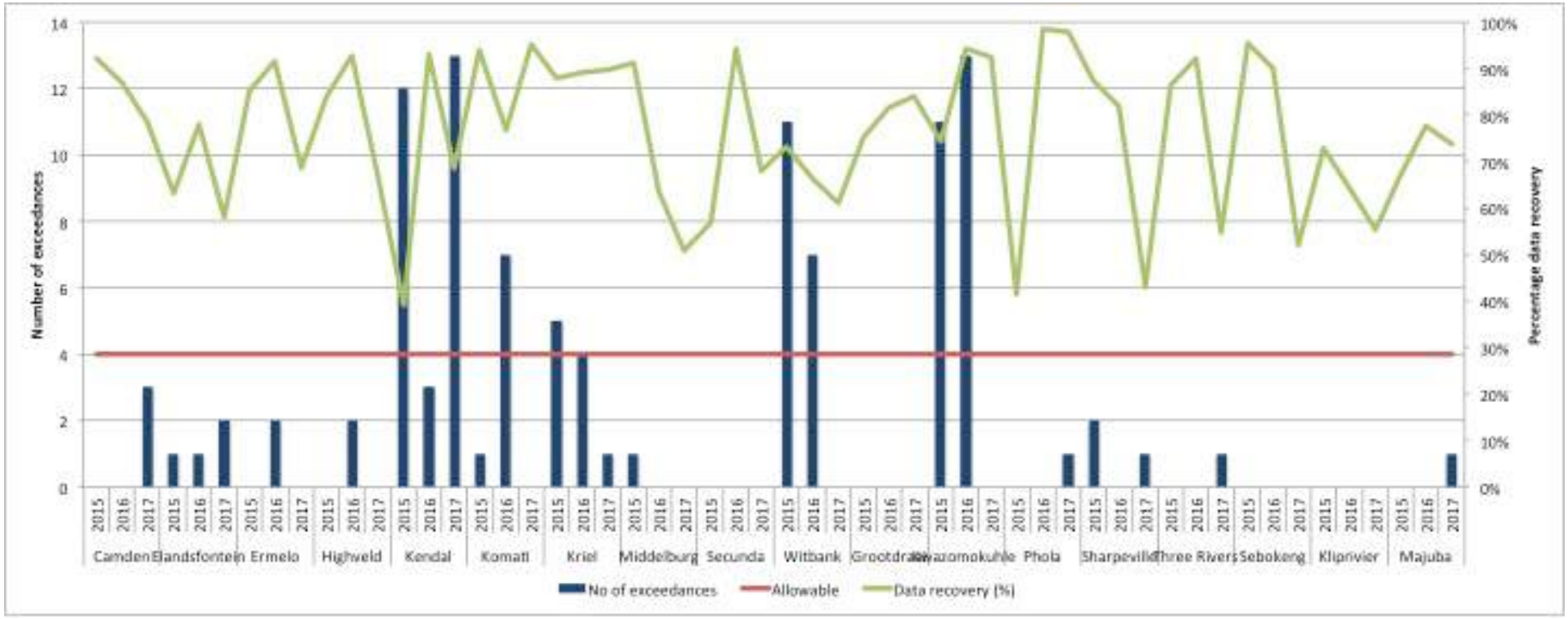

Figure 4: Frequency of exceedances of the sulphur dioxide (SO_2) daily average NAAQS limit value. If the allowable number of exceedances is surpassed then there is non-compliance with the standard. Note that the percentage data recovery is plotted relative to a secondary y axis (on the right hand side of the graph).

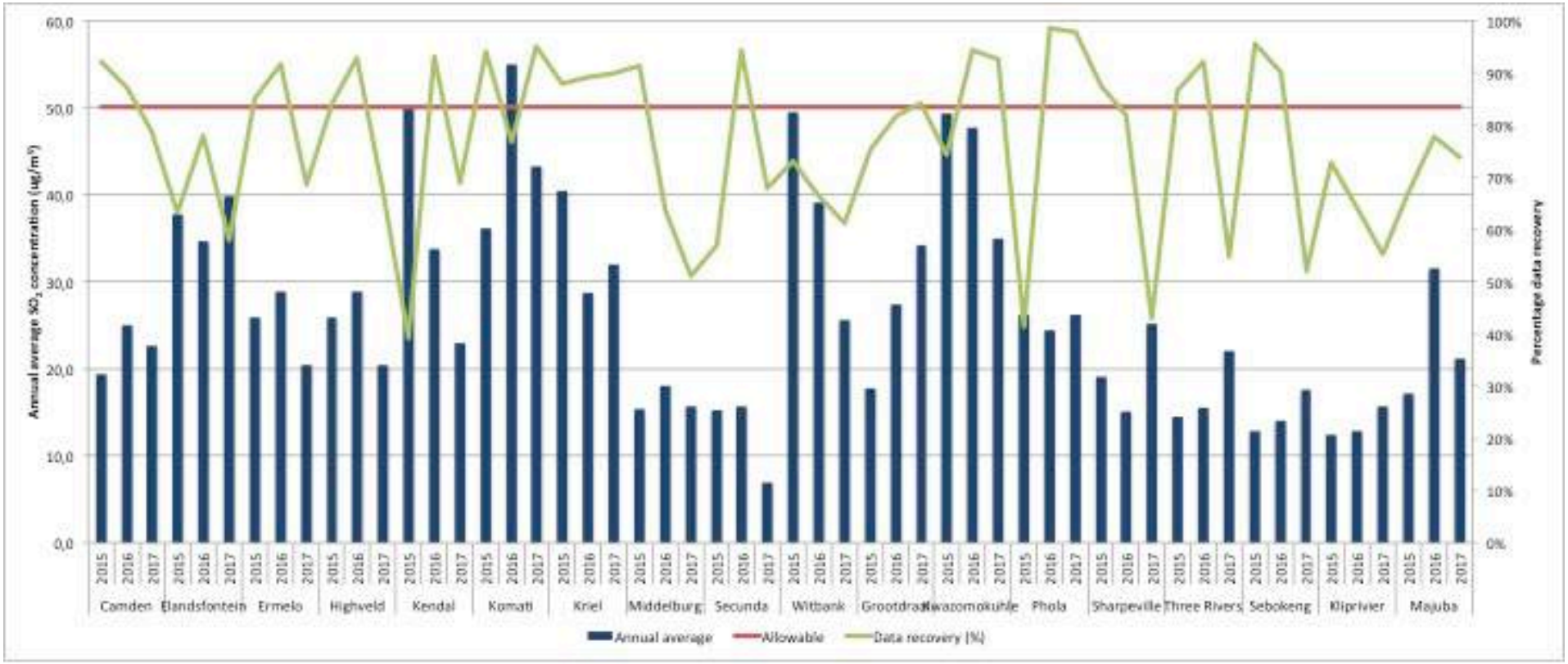

Figure 5: Annual average concentrations of sulphur dioxide (SO_2) relative to the NAAQS. Note that the percentage data recovery is plotted relative to a secondary y axis (on the right hand side of the graph).

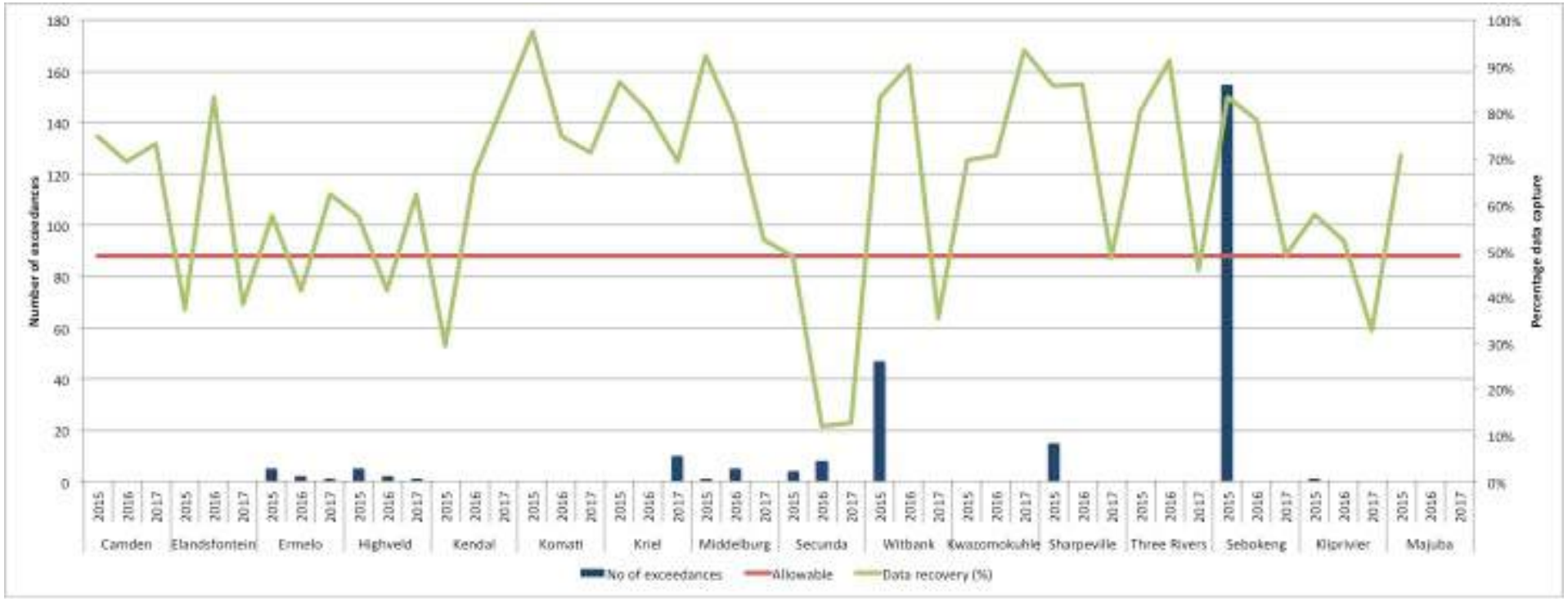

Figure 6: Frequency of exceedances of the nitrogen dioxide (NO_2) hourly average NAAQS limit value. If the allowable number of exceedances is surpassed then there is non-compliance with the standard. Note that the percentage data recovery is plotted relative to a secondary y axis (on the right hand side of the graph).

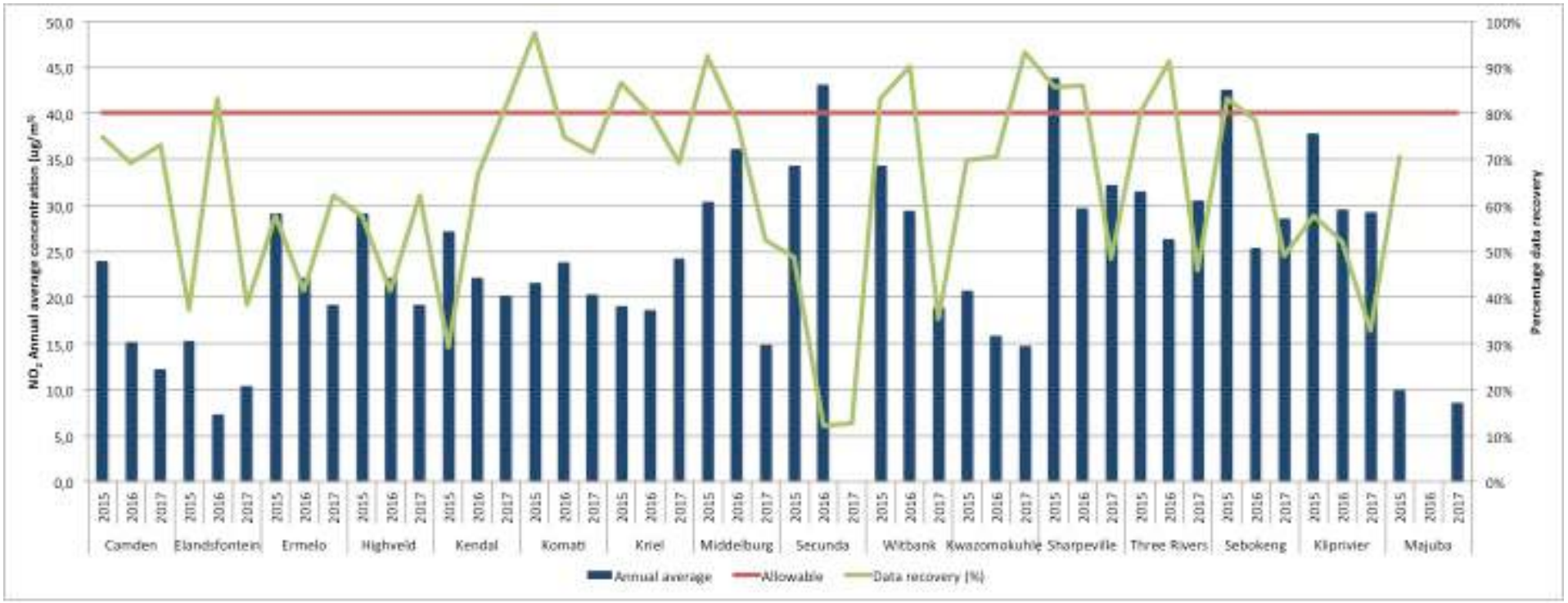

Figure 7: Annual average concentrations of nitrogen dioxide (NO_2) relative to the NAAQS. Note that the percentage data recovery is plotted relative to a secondary y axis (on the right hand side of the graph).

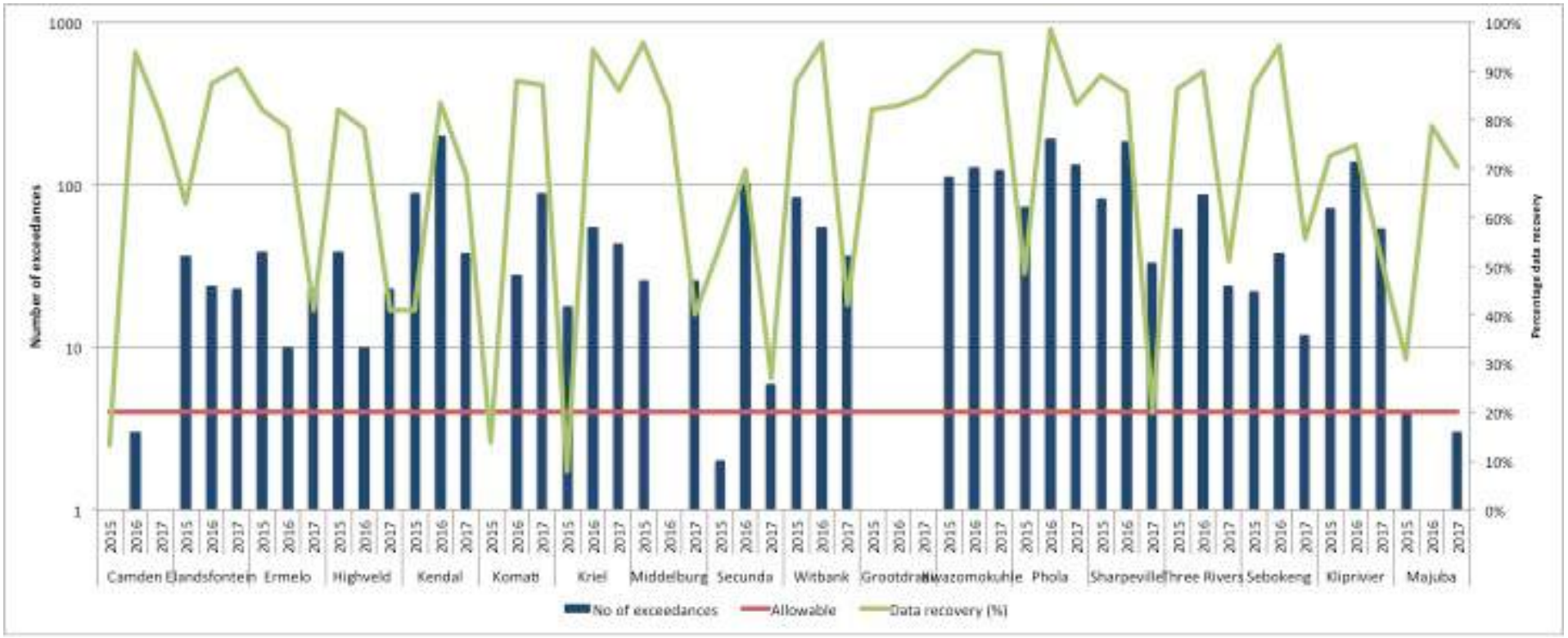

Figure 8: Frequency of exceedances of the particulate matter (PM_{10}) daily average NAAQS limit value. If the allowable number of exceedances is surpassed then there is non-compliance with the standard. Note that a logarithmic scale has been used for the number of exceedances and the percentage data recovery is plotted relative to a secondary y axis (on the right hand side of the graph).

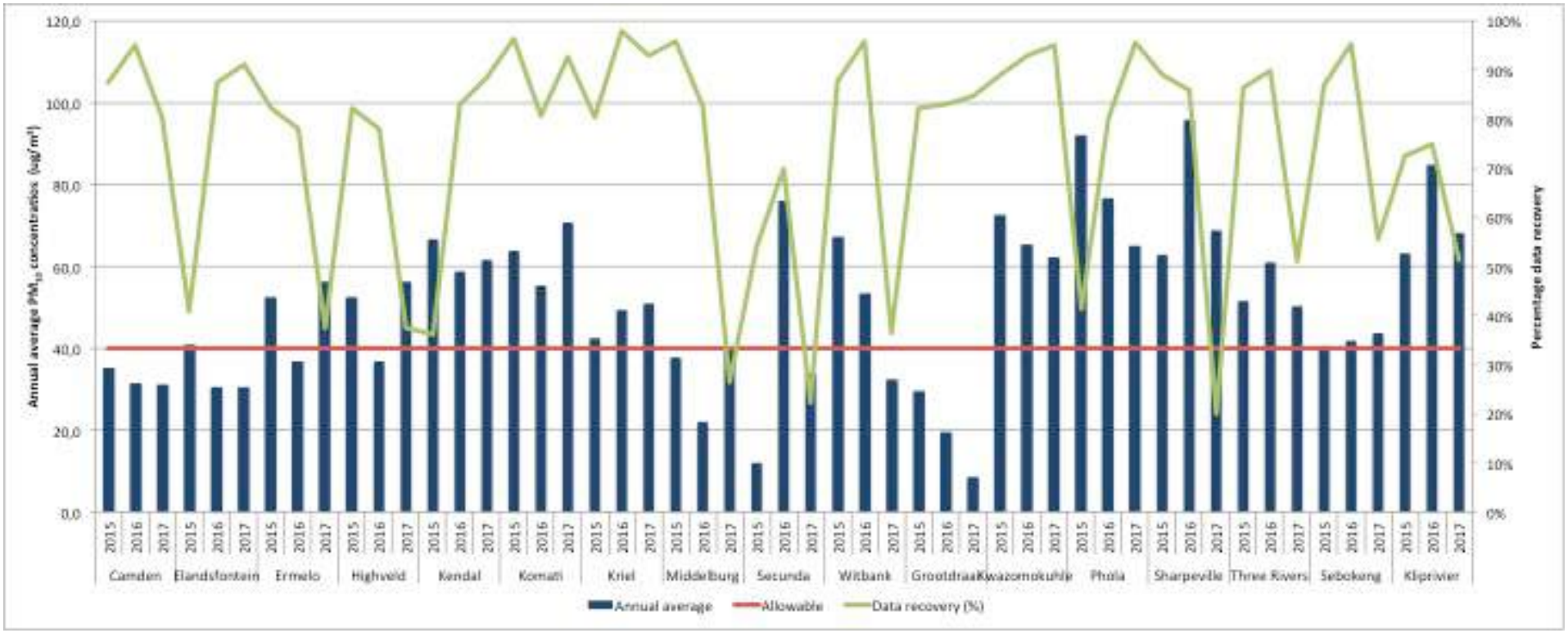

Figure 9: Annual average concentrations of particulate matter (PM_{10}) relative to the NAAQS. Note that the percentage data recovery is plotted relative to a secondary y axis (on the right hand side of the graph).

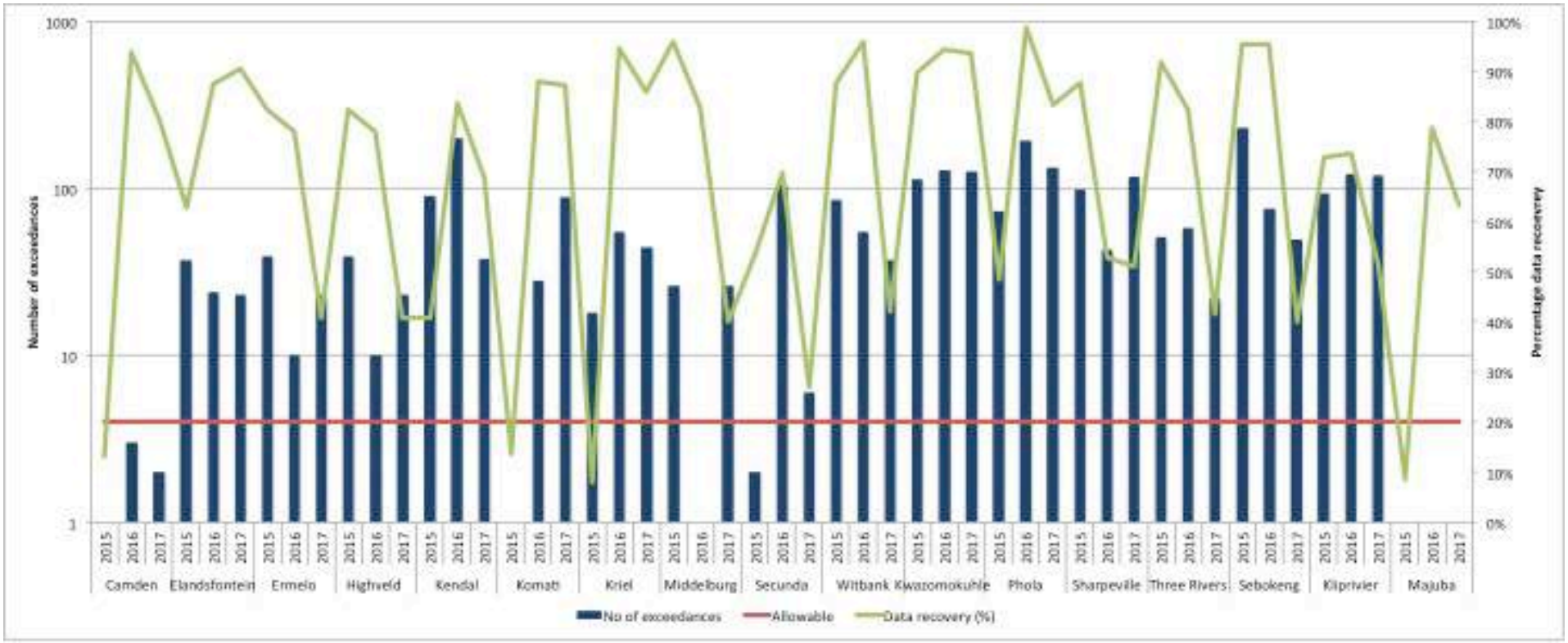

Figure 10: Frequency of exceedances of the particulate matter ($PM_{2.5}$) daily average NAAQS limit value. If the allowable number of exceedances is surpassed then there is non-compliance with the standard. Note that a logarithmic scale has been used for the number of exceedances and the percentage data recovery is plotted relative to a secondary y axis (on the right hand side of the graph).

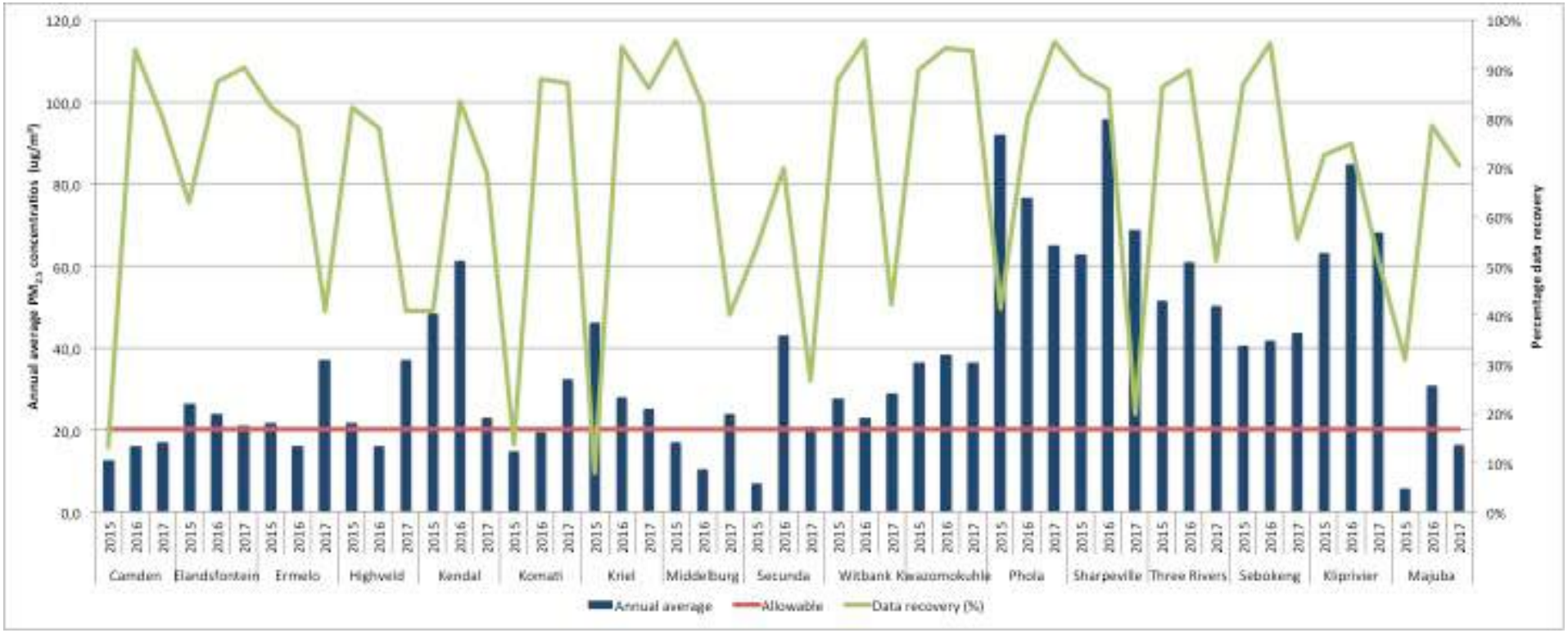

Figure 11: Annual average concentrations of particulate matter ($PM_{2.5}$) relative to the NAAQS. Note that the percentage data recovery is plotted relative to a secondary y axis (on the right hand side of the graph).

2.5 Source apportionment

Source apportionment is notoriously difficult, but essential to the analysis presented here. Perhaps the most instructive way of considering source apportionment on the basis of the ambient air quality data, without conducting physical pollutant speciation studies, is through presenting the diurnal variation in pollutant concentrations. This is because the creation of air pollution follows trends in space and time that make it possible to distinguish, by means of insinuation/ implication, between air pollution sources. For example, air pollution stemming from low-level burning practices associated with low-income community activities for heating and cooking, tends to arise in the early mornings and the early evenings, and so it is to be expected that measured peaks in pollutant concentrations during these times could be attributed to sources at a community level. Conversely, it can be assumed that power station emissions are most likely to reach the ground during the middle of the day when the atmosphere is unstable due to increased mixing activities, and so pollution peaks in the daytime can be attributed to industrial sources. As such, diurnal variability in pollutant concentrations is illustrated in Figures 7-11, as area plots of average hourly concentrations for each of the stations for each of the years (2015-2017).

For SO_2 (**Figure 12**) a clear midday peak is evident of some 120 ug/m^3 with generally lower concentrations of at or below 50 ug/m^3 from 17:00 through to 06:00, whereafter concentrations are seen to increase again to the midday peaks. For NO_2, two peaks are evident, the first at 06:00 and the second at 18:00-19:00 (**Figure 13**). The lowest concentrations occur between 10:00 and 11:00. A similar pattern is seen for PM_{10} and $PM_{2.5}$ where, for both pollutants, a morning peak is evident at between 06:00 and 07:00 and an evening peak at 18:00 (**Figure 14** and **Figure 15**). When overlaid, the patterning of the pollutant peaks suggests that the primary sources of SO_2 are different from the primary sources of NO_2, PM_{10}, and $PM_{2.5}$ (**Figure 16**). What is postulated is that the SO_2 sources are high altitude emissions while the NO_2, PM_{10}, and $PM_{2.5}$ are sourced at ground level.

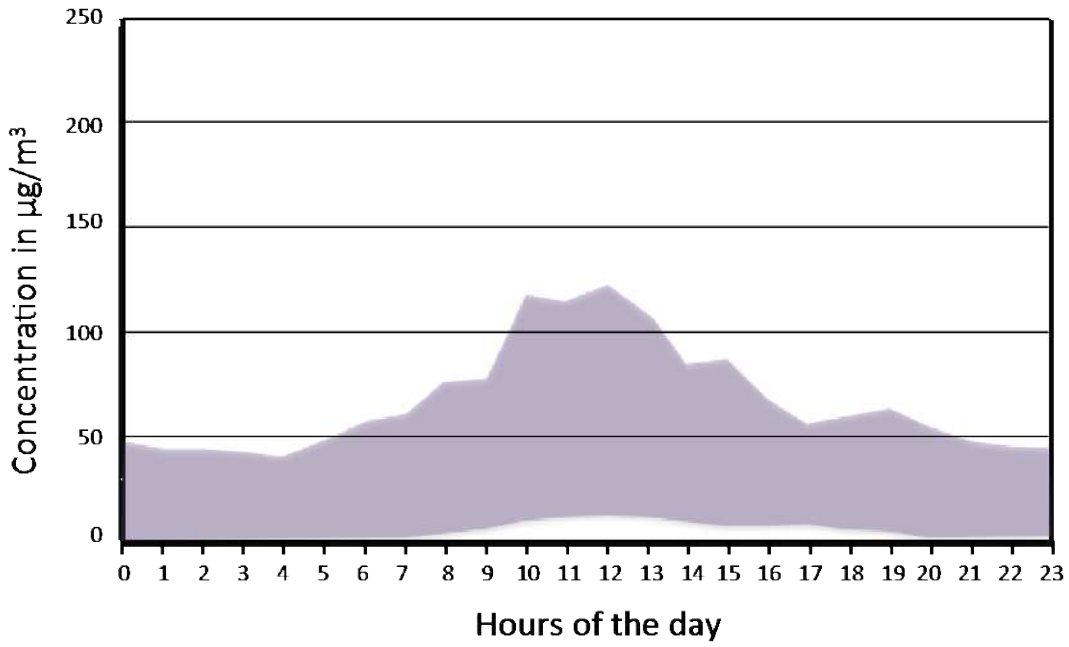

Figure 12: Area plot of the range of average diurnal SO_2 concentrations for all monitoring stations across the Mpumalanga Highveld (2015-2017).

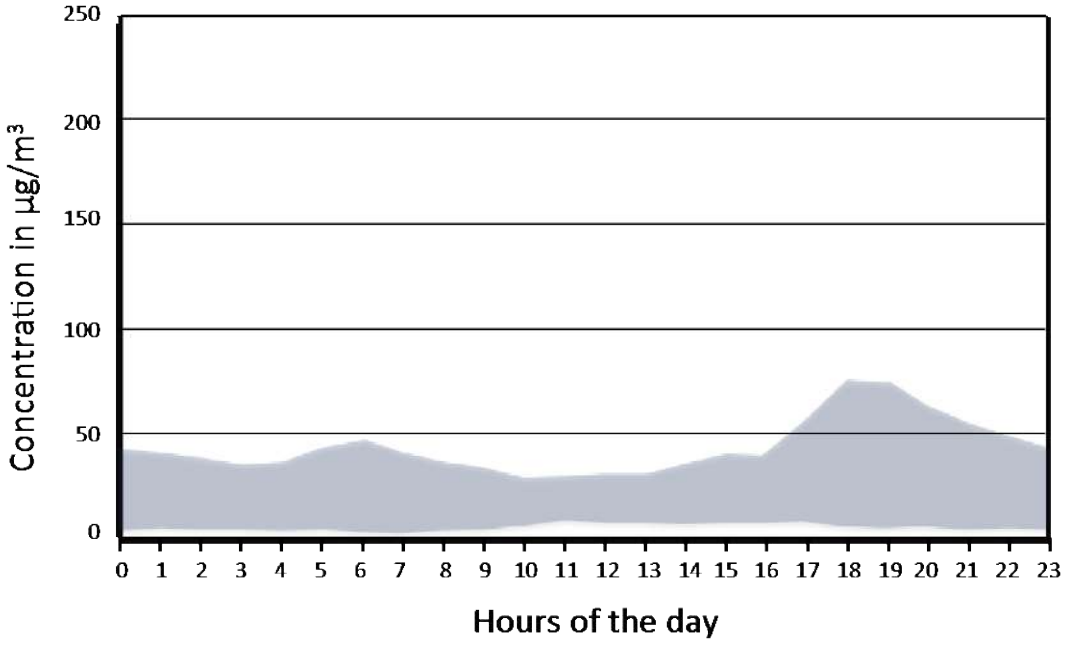

Figure 13: **Area plot of the range of average diurnal NO_2 concentrations for all monitoring stations across the Mpumalanga Highveld (2015-2017).**

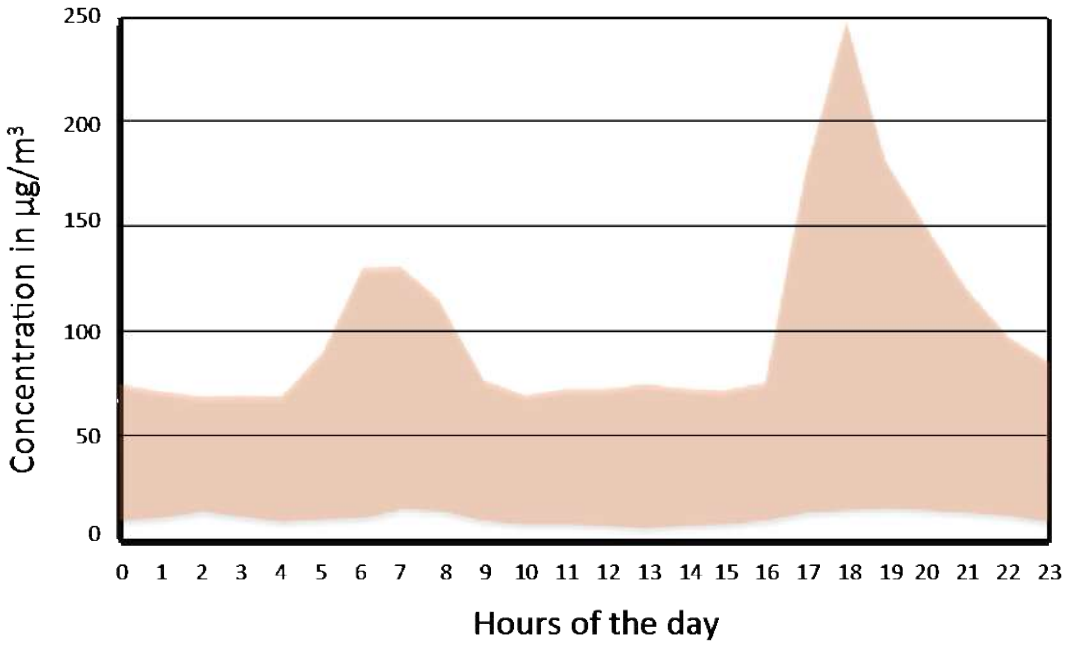

Figure 14: **Area plot of the range of average diurnal PM_{10} concentrations for all monitoring stations across the Mpumalanga Highveld (2015-2017).**

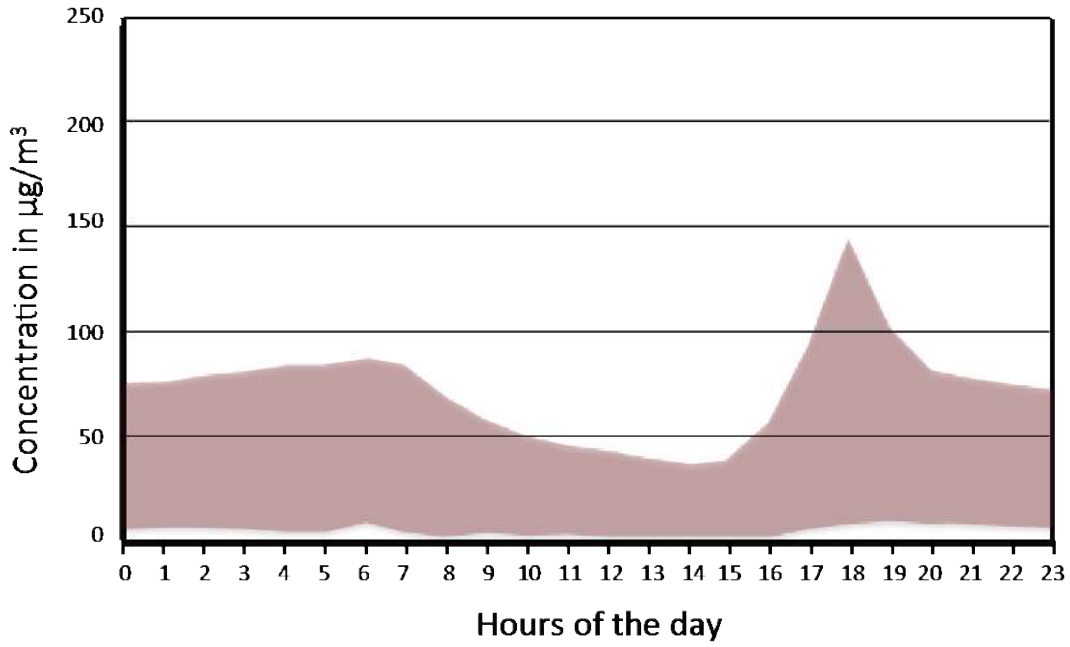

Figure 15: Area plot of the range of average diurnal $PM_{2.5}$ concentrations for all monitoring stations across the Mpumalanga Highveld (2015-2017).

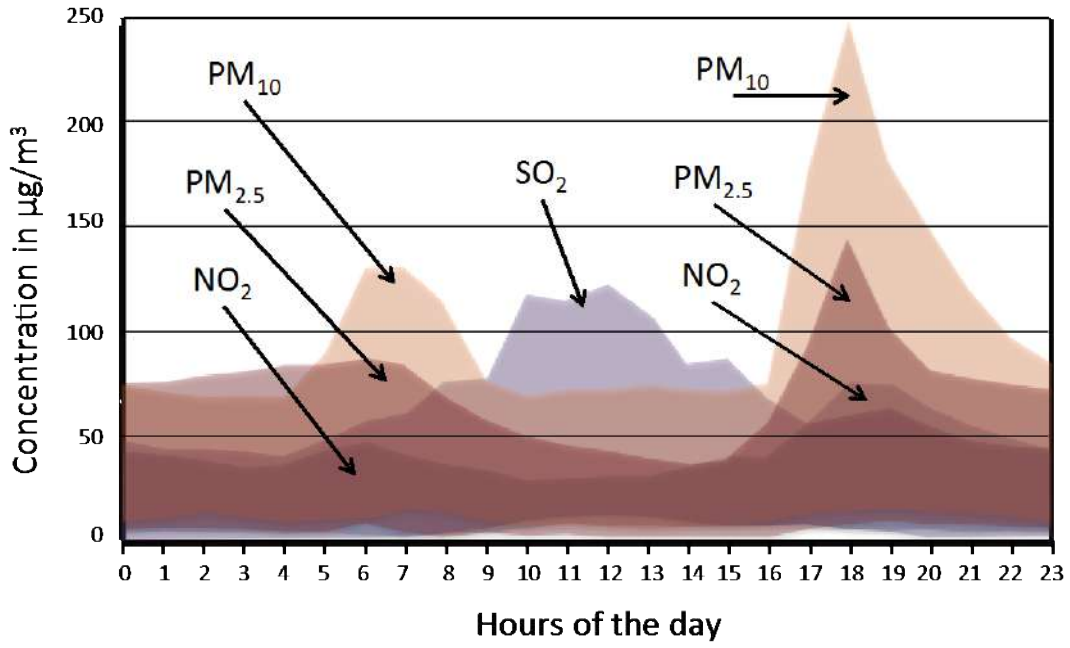

Figure 16: Area plot of the range of average diurnal SO_2, NO_2, PM_{10} and $PM_{2.}$ concentrations for all monitoring stations across the Mpumalanga Highveld (2015-2017).

The use of domestic fuels for cooking and space heating is a well-known phenomenon in South Africa, most notable in low-income dense settlements, even where electricity may be available. These sources result in

emissions of SO_2, NO_2 and PM_{10} at ground level, particularly so during the early hours of the morning and the late hours of the afternoon/ early hours of the evening. The diurnal patterns described above can be explained as follows: During the night the atmosphere becomes stable with inversions often occurring. When the atmosphere is stable, emissions from elevated sources (e.g. stacks) do not come to ground-level as they are released into a stable atmosphere and simply cannot penetrate down towards the ground. Emissions that occur at ground-level, such as domestic fuel burning and motor vehicle emissions are similarly trapped closer to the ground by the stable atmosphere and cannot disperse.

When the sun rises the heating of the earth's surface sees the start of turbulence and mixing in the atmosphere and the dissolution of the surface inversion. The mixing gets deeper and deeper as the day progresses until at some point in the day the elevated source's plume is brought to ground-level. As the elevated source's plume comes to ground, there is a significant increase in the ambient SO_2 concentration. As the afternoon wears on, the earth's surface cools and the atmosphere becomes more stable with reduced atmospheric mixing. The stable atmosphere results in the ambient SO_2 concentration reducing significantly as, once again, the elevated source's plume is prevented from reaching the ground. The ambient SO_2 concentration, as well as the time of day during which peak SO_2 concentrations are measured, therefore provide a powerful indicator of the contribution of the elevated sources to ambient air quality.

The morning and night-time PM_{10} peaks would then derive from ground level sources, whereas the SO_2 peak would imply elevated sources. Secondary aerosol formation, which constitutes the formation of particulates in the form of nitrates and sulphates , does not appear to contribute significantly to episodes of high $PM_{2.5}$ concentrations as the PM_{10} and $PM_{2.5}$ peaks mirror one another but cannot be discounted on the basis of the available data. The diurnal patterning described above is well documented in Venter *et al*, (2012) and seen to be exhibited in the North West Province too.

3 DISPERSION MODELLING

3.1 Overview

Direct physical measurements are without a doubt the best indication of the state of the air quality. Not only is the air quality time resolved, but whatever is in the air at the monitoring station (regardless of its source) will be reflected in the measurements. Unfortunately, air quality monitoring stations are very expensive to establish and to operate and are resource intensive, requiring regular maintenance and calibration. It is simply impractical to try and cover all possible areas with air quality monitoring stations. Atmospheric dispersion models have been developed to predict the likely ambient air pollution concentrations in areas where direct monitoring does not take place and for future emissions sources. In the individual AIRs, detailed technical descriptions are included of the modelling and the modelling approach used. Suffice it to say, for the purposes of this summary document, that the dispersion model operates broadly as follows:

- A three dimensional grid is created around the emission source. The grid provides a series of receptor points at every intersection on the grid;
- Measured atmospheric data is entered into the model, which is combined with modelled atmospheric data to predict the atmospheric dispersion potential at each of the receptor points;
- The atmospheric emission source is then entered into the model including the emission load, the temperature and the height above the ground that the emission enters the atmosphere;
- The model then 'moves' the emission plume through the grid as a function of the atmospheric dispersion characteristics that were previously determined;
- The predicted concentrations are then extracted from the model from each of the grid points that occur at ground level;
- Points of equal air pollution concentration are then connected by lines that are called 'isopleths' (in the same way that 'contours' connect points of equal height on maps); and,
- The isopleth maps are then interpreted to determine areas of possible non-compliance with the NAAQS.

3.2 Model accuracy

An obvious question is how well the model predicts the concentrations that are measured at the various monitoring stations. Comparing measured and modelled concentrations is not straight forward because the measured concentrations reflect all sources of pollution whereas the model can obviously only predict the ambient concentrations that occur as a function of the emissions included in the model. Past experience has shown that in general terms most of the SO_2 derives from the power stations whereas NO_2 and especially PM derive from multiple other sources, notwithstanding the contribution of the power stations to secondary aerosol formation. In this section the issue of how well the model outputs replicate what is measured, is presented.

In the first instance, only SO_2 concentrations are compared as these are deemed to be the only pollutant where the modelled and measured concentrations can be expected to approximate one another. Also, only hourly average concentrations are compared as the findings of the comparison can be extended to the longer averaging periods. Earlier in the report the monitored data were presented as probability distributions (viz. the probability of a given concentration as a function of the measured data). It is not helpful to simply compare a single modelled value with a single measured value because that presents only one part of a more complex relationship. As such the approach that has been used here is to compare the data distributions of the measured values with the data distributions of the modelled values.

This comparison can be done statistically using for example the Kolmogorov-Smirnov statistic but there is a specific patterning in the comparisons that needs to be illustrated here namely that in general terms the model does not predict the multiple smaller concentrations that are evident in the measured data. What has

been done therefore, is to compare the two data sets by comparing the respective 10th, 25th, 50th, 75th and 99th percentile concentrations in the two data sets (viz. the measured and the modelled) as illustrated conceptually in Figure 17. This was done for each of the 15 monitoring stations that were included in this analysis (and presented individually in the AIRs) and averaged for the purpose of this summary report as shown in **Figure 18**.

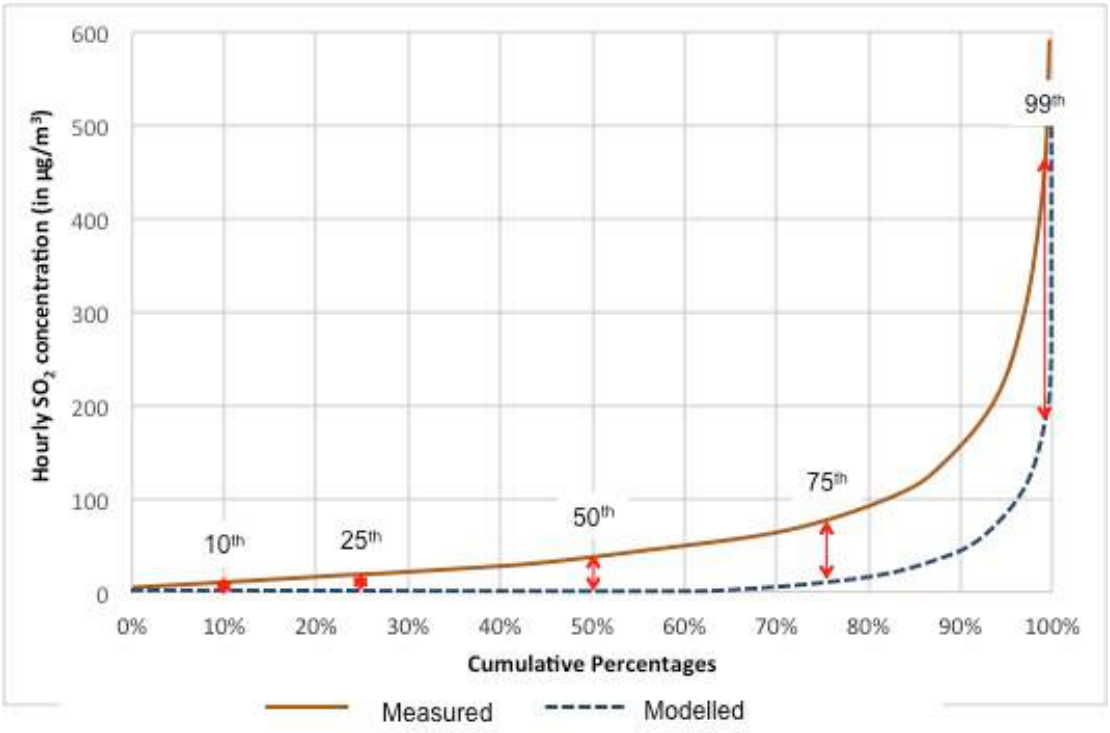

Figure 17: Conceptual illustration of the method used to compare modelled and measured ambient hourly SO_2 concentrations.

The modelled concentrations derive from the combined emissions sources (viz. all coal fired power stations in the domain). There will always be an inherent degree of error in the modelling predictions, which plays some role in the differences seen. At the same time other SO_2 emission sources (as described above) will play a role in the differences seen between modelled and measured, the quantum of which will vary from place to place across the modelling domain. It is simply not possible to determine the relative role of each source of error but for the purposes of this report it is assumed that the dispersion modelling itself is acceptably accurate and that it is the presence of SO_2 from other sources not included in the dispersion modelling that is the dominant source of error. On average the model may not account for as much as 103.9 µg/m^3 for hourly average concentrations and 18,2 µg/m^3 for annual average concentrations with the daily concentrations somewhere between the two.

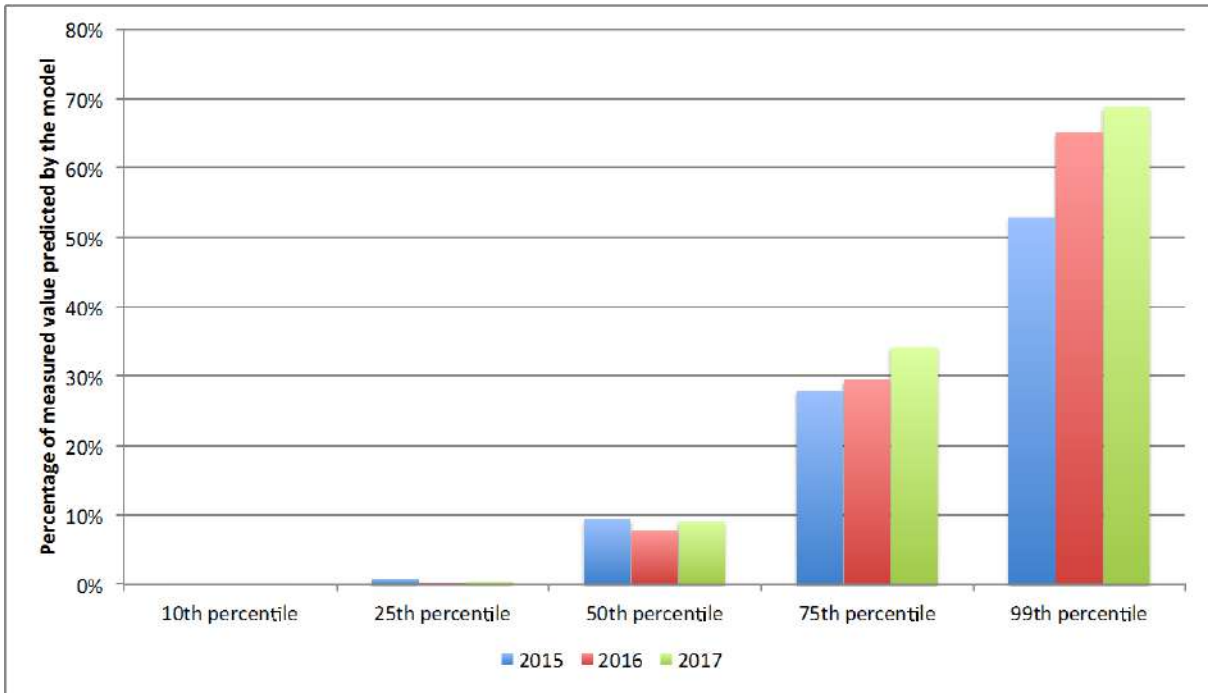

Figure 18: Average difference between the measured and modelled 10th, 25th, 50th, 75th and 99th percentiles for all the monitoring stations used in this assessment. A perfect correlation would be expressed as 100%.

3.3 Modelled ambient concentrations for the combined emissions from Eskom's Highveld power stations

In the individual AIRs, emissions from the individual power stations were modelled so as to present the impact of the power stations alone. It is however common cause that the impact of the power stations cannot be assessed in *isolation* but must rather be assessed in *combination* in order to assess the cumulative impact of the power stations on the ambient air quality of the Highveld. In this section the results are presented of such an assessment again in the form of predicted (modelled) ambient concentrations of SO_2, NO_2, PM_{10} and $PM_{2.5}$ and again in the form of isopleth representations of the spatial extent of different concentrations. The same two emissions scenarios have been modelled namely for current actual emissions and for compliance with the Minimum Emission Standards for new plants with the results presented in the sections that follow. In addition a third collective emissions scenario has been modelled which is the expected circumstance in 2030 when at least 5 of the power stations will have ceased operations.

Thirteen Eskom-owned and operated coal-fired power stations are included in this dispersion modelling assessment. The power stations included in the assessment have a combined installed capacity of 38 510 MW and may collectively consume more than 155 million tons of coal per annum at peak load, although normal operating conditions result in generally less coal being consumed (e.g. In 2017 Eskom's coal fired power stations, including Medupi and Matimba consumed 113 million tonnes). The power stations are listed in Table 2. Of these, twelve are in Mpumalanga Province and one is in the Free State Province. Their relative locations are shown in Figure 19. The individual power stations are generally located in rural areas where the surrounding land use is primarily agriculture and includes coal mining. On a larger scale, the surrounding land-use includes amongst others, urban areas with residential, commercial and recreational areas, industrial areas, agriculture, mining, forestry, undeveloped areas and conservation areas. Land use is shown in Figure 20. The monthly average emissions for the 13 power stations are available in the respective AIRs but summarized here in Table 3 average emission rates (t/a). The process units and the corresponding stacks at each of the 13 power stations are listed in Table 4 with the physical stack data and emission parameters.

Table 2: Eskom coal-fired power stations and their installed capacity

Power Station	Province	Installed capacity (MW)
Arnot	Mpumalanga	2 352
Camden	Mpumalanga	1 561
Duvha	Mpumalanga	3 600
Grootvlei	Mpumalanga	1 180
Hendrina	Mpumalanga	1 893
Kendal	Mpumalanga	4 116
Komati	Mpumalanga	950
Kriel	Mpumalanga	3 000
Kusile	Mpumalanga	4 800
Lethabo	Free State	3 708
Majuba	Mpumalanga	4 110
Matla	Mpumalanga	3 600
Tutuka	Mpumalanga	3 600

Table 3: Emission rates in tonnes per annum for the two modelled scenarios for the 13 power stations. Please note that monthly average emissions were used in the modelling.

Power station	Pollutant	Actual emissions	MES Compliance
Arnot	**NO_X**	45 728	96 514
	SO_2	64 812	64 342
	PM	1 536	6 434
Camden	**NO_X**	38 624	58 132
	SO_2	69 772	38 756
	PM	1 160	3 876
Duvha	**NO_X**	63 984	119 776
	SO_2	124 692	79 850
	PM	4 268	7 986
Grootvlei	**NO_X**	31 338	50 612
	SO_2	41 382	33 740
	PM	3 390	3 374
Hendrina	**NO_X**	37 982	76 852
	SO_2	88 708	51 236
	PM	938	5 124
Kendal	**NO_X**	75 934	126 220
	SO_2	207 034	84 146
	PM	9 182	8 414
Komati	**NO_X**	21 906	34 230
	SO_2	28 238	22 820
	PM	2 020	2 282

Power station	Pollutant	Actual emissions	MES Compliance
Kriel	**NO_X**	89 306	110 842
	SO_2	121 874	73 894
	PM	9 572	7 390
Kusile[2]	**NO_X**	7 034	151 946
	SO_2	22 372	101 298
	PM	6	10 130
Lethabo	**NO_X**	95 854	110 618
	SO_2	179 380	73 744
	PM	9 436	7 374
Majuba	**NO_X**	125 410	152 866
	SO_2	156 060	101 910
	PM	2 208	10 192
Matla	**NO_X**	108 358	135 612
	SO_2	153 820	90 408
	PM	6 652	9 040
Tutuka	**NO_X**	94 332	149 210
	SO_2	160 216	99 474
	PM	17 162	9 948

[2]: *Emissions for Kusile are averaged from June 2017 to December 2017*

Table 4: Physical stack parameters and emission parameters at the 13 power stations

	Point Source Code	Source name	UTM m East	UTM M South	Release height above ground (m)	Height above nearby building (m)	Diameter at Stack Tip Exit (m)	Actual Gas Exit Temp (^{0}C)	Actual stack gas volumetric flow (m^3/hr)	Actual Gas Exit Velocity (m/s)	Batch or continuous emissions
Arnot	Stack 1	Boiler unit 1,2 & 3	779 601	7 127 669	193	173	11	145	9 921 462	29	Continuous
	Stack 2	Boiler unit 4, 5 & 6	779 631	7 127 459	193	173	11	145	9 921 462	29	Continuous
Camden	Stack 1	Boiler unit 1 & 2	210 133	7 052 145	154.5	100	8.74	150	3 023 731	13.8	Continuous
	Stack 2	Boiler unit 3 & 4	210 222	7 052 165	154.5	100	8.74	150	3 023 731	13.8	Continuous
	Stack 3	Boiler unit 5 & 6	210 301	7 052 184	154.5	100	8.74	150	3 023 731	13.8	Continuous
	Stack 4	Boiler unit 7 & 8	210 301	7 052 184	154.5	100	8.74	150	3 023 731	13.8	Continuous
Duvha	Stack 1	Boiler unit 1,2 & 3	734 259	7 126 405	300	200	12.47	130	11 871 045	23.2	Continuous
	Stack 2	Boiler unit 4, 5 & 6	734 360	7 126 632	300	200	12.47	130	11 871 045	23.2	Continuous
Grootvlei	Stack 1	Boiler unit 1,2 & 3	648 888	7 038 364	152	85.5	8.99	140	5 141 552	19.57	Continuous
	Stack 2	Boiler unit 4, 5 & 6	648 924	7 038 251	152	85.5	8.99	140	5 141 552	19.57	Continuous
Hendrina	Stack 1	Boiler unit 1,2 & 3	760 383	7 118 306	155.45	85.45	11.14	135	7 272 000	15.4	Continuous
	Stack 2	Boiler unit 4, 5 & 6	760 304	7 118 047	155.45	85.45	11.14	135	7 272 000	15.4	Continuous
Kendal	Stack 1	Boiler unit 1,2 & 3	696 850	7 112 881	275	177	13.51	126	12 385 520	24	Continuous
	Stack 2	Boiler unit 4, 5 & 6	697 052	7 112 799	275	177	13.51	126	12 385 520	24	Continuous
Kom ati	Stack 1	Boiler unit 1,2 & 3	747 225	7 112 052	220	165	8	150	4 867 708	24	Continuous
	Stack 2	Boiler unit 4, 5 &	747 348	7 111 997	220	165	8	145	4 867 708	24	Continuous

	Point Source Code	Source name	UTM m East	UTM M South	Release height above ground (m)	Height above nearby building (m)	Diameter at Stack Tip Exit (m)	Actual Gas Exit Temp (^{0}C)	Actual stack gas volumetric flow (m^3/hr)	Actual Gas Exit Velocity (m/s)	Batch or continuous emissions
		6									
Kriel	Stack 1	Boiler unit 1,2 & 3	717 541	7 094 474	213	79.2	14.3	130	10 985 453	17	Continuous
	Stack 2	Boiler unit 4, 5 & 6	717 645	7 094 275	213	79.2	14.3	130	10 985 453	17	Continuous
Kusile	Stack 1	Boiler unit 1,2 & 3	692 062	7 131 782	220	100	15.4	50	12 051 300	18	Continuous
	Stack 2	Boiler unit 4, 5 & 6	692 304	7 132 016	220	100	15.4	50	12 051 300	18	Continuous
Lethabo	Stack 1	Boiler unit 1,2 & 3	597 261	7 041 798	275	200	13.3	145	11 371 360	24.7	Continuous
	Stack 2	Boiler unit 4, 5 & 6	597 261	7 041 798	275	200	13.3	145	11 371 360	24.7	Continuous
Majuba	Stack 1	Boiler unit 1,2 & 3	774 816	6 999 525	250	120	12.3	125	15 142 786	22	Continuous
	Stack 2	Boiler unit 4, 5 & 6	774 683	6 999 307	250	120	12.3	125	15 142 786	22	Continuous
Matla	Stack 1	Boiler unit 1,2 & 3	713 902	7 091 326	213	125	14.3	124	13 240 362	23	Continuous
	Stack 2	Boiler unit 4, 5 & 6	713 902	7 091 326	213	125	12.5	124	13 243 017	30	Continuous
Tutuka	Stack 1	Boiler unit 1,2 & 3	733 778	7 036 119	275	125	12.3	135	14 971 681	35	Continuous
	Stack 2	Boiler unit 4, 5 & 6	734 012	7 036 123	275	125	12.3	135	14 971 681	35	Continuous

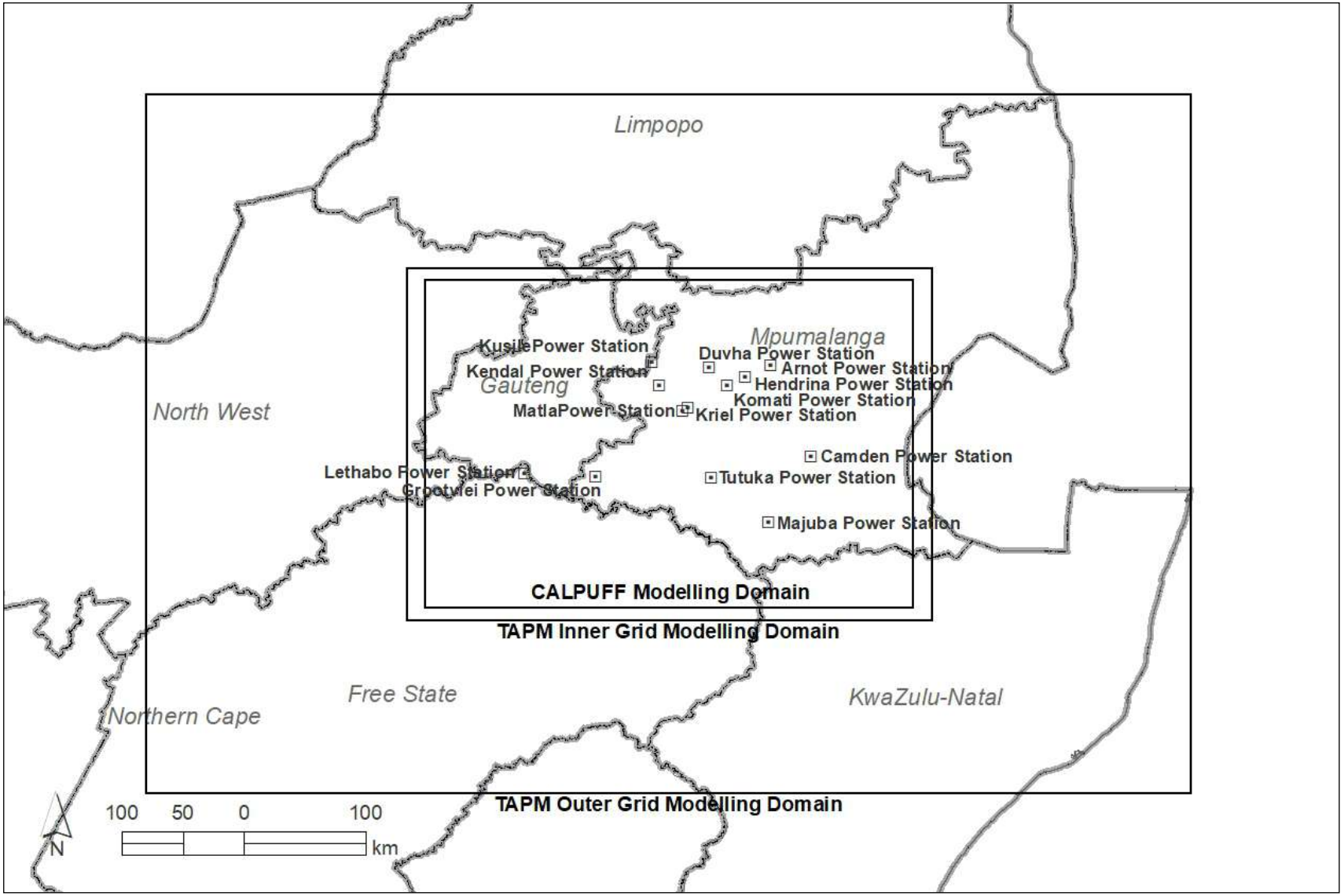

Figure 19: Relative location of the Eskom's coal-fired power stations in Mpumalanga and the Free State

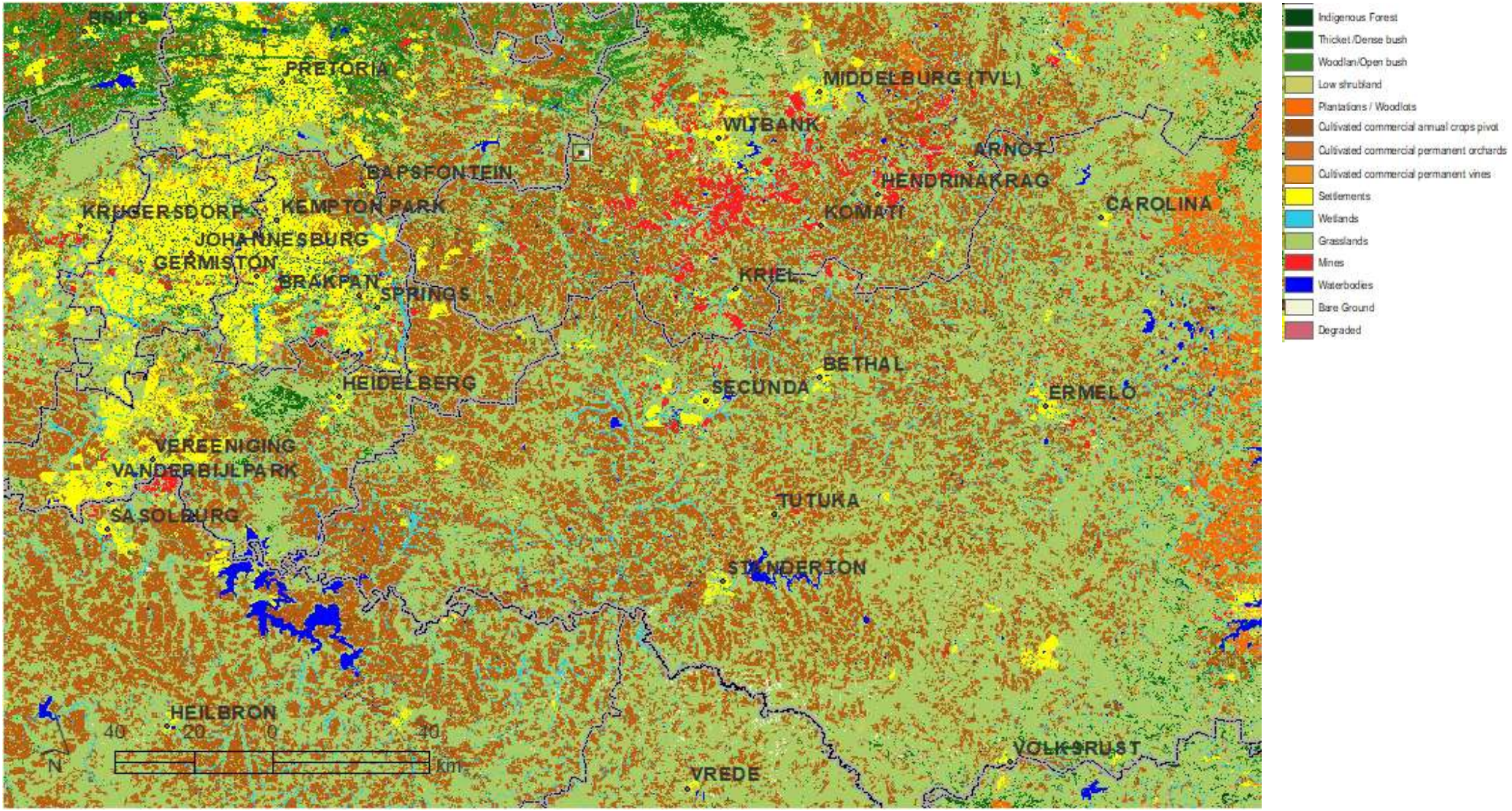

Figure 20: Land-use types in the assessment area

3.4 Modelled scenarios

The predicted annual average ambient concentrations for SO_2, NO_2, PM_{10}, $PM_{2.5}$ and secondary particulate concentrations resulting from emissions from Eskom's 13 coal-fired power stations for the two modelling scenarios are presented as isopleth maps over the modelling domain in Figure 21 to **Figure 38**. The isopleth maps include the relative positions of the 13 coal-fired power stations and the ambient air quality monitoring stations. The 99th percentile concentrations of the predicted maximum 24-hour and 1-hour ambient concentrations are used to determine the isopleths. The DEA (2014) recommend the 99th percentile concentrations for short-term assessment with the NAAQS since the highest predicted ground-level concentrations can be considered outliers due to complex variability of meteorological processes. Comparison is made in the modelling domain between the predicted annual average concentrations and the predicted 99th percentile concentrations with the respective NAAQS for the two scenarios. The predicted annual average concentration and the 99th percentile concentration at the points of maximum ground-level concentration for actual emissions (Scenario 1) and emissions that meet the MES for new plants (Scenario 2) are presented in Table 5.

Table 5: Maximum predicted annual average concentration and the highest 99th percentile concentration at the points of maximum ground-level concentration for the two emission scenarios. Please note that direct emissions of PM and secondary PM formation must be seen in combination. They are separated here only to differentiate the origin.

Averaging period	Scenario 1 - Actual Emissions	Scenario 2 - New plant MES compliance
	SO_2 (µg/m^3)	
1-hour	245	257
24-hour	123	98
Annual	22	15
Averaging period	**NO_2 (µg/m^3)**	
1-hour	121	303
Annual	7.0	14
Averaging period	**PM_{10} or $PM_{2.5}$ (µg/m^3)**	
24-hour	8.3	10.0
Annual	1.1	1.6
Averaging period	**Secondary particulates (µg/m^3)**	
24-hour	34	25
Annual	4.2	3.0

3.5 Scenario 1: Current emissions

3.5.1 Sulphur dioxide

For actual monthly emissions of SO_2 from the 13 coal-fired power stations the predicted annual average SO_2 concentration (which is 22 µg/m^3 at the point of highest impact in the domain) is less than the national ambient SO_2 standard of 50 µg/m^3 throughout the modelling domain (Figure 21 and Table 5). Similarly, the 99th percentile of the predicted 24-hour SO_2 concentrations with a maximum of 123 µg/m^3 (Figure 22 and Table 5) does not exceed the NAAQS of 125 µg/m^3 anywhere in the modelling domain. At the point of

maximum ground-level concentration, the 99th percentile 1-hour SO_2 concentration is 245 µg/m^3, which is below the limit value of the NAAQS of 350 µg/m^3 (

Figure **23** and Table 5). The areas of largest predicted SO_2 concentrations occur over the central Highveld southeast of Witbank where seven power stations are in relatively close proximity to one another, i.e. Arnot, Hendrina, Komati, Kendal, Kriel, Matla and Duvha. The area extends south-eastward beyond Ermelo because of the Camden and Majuba power stations. A westward extension of the relatively high concentrations results from the Grootvlei and Lethabo power stations.

3.5.2 Nitrogen dioxide

For actual monthly emissions of NO_X from the 13 coal-fired power stations the predicted annual average NO_2 concentration (which is 7.0 µg/m^3 at the point of highest impact in the domain) is significantly less than the national ambient NO_2 standard of 40 µg/m^3 (Figure 24 and Table 5). At the point of maximum ground-level impact, the predicted 99th percentile of the 1-hour NO_2 concentration is 121 µg/m^3, which is below the limit value of the NAAQS of 200 µg/m^3 (Figure 25 and Table 5). The areas of highest predicted NO_2 concentrations, albeit that these are relatively low, occur over the central Highveld southeast of Witbank where seven power stations are in relatively close proximity to one another, i.e. Arnot, Hendrina, Komati, Kendal, Kriel, Matla and Duvha. The area extends south-eastward beyond Ermelo because of the Camden and Majuba power stations. A westward extension of the relatively high concentrations results from the Grootvlei and Lethabo power stations.

3.5.3 PM_{10}

In this scenario the emissions of PM are assumed to consist entirely of PM_{10}. For actual emissions from the 13 coal-fired power stations the predicted annual average PM_{10} concentration (which is 1.1 µg/m^3 at the point of highest impact in the domain) is significantly less than the national ambient PM_{10} standard of 40 µg/m^3 (Figure 26 and Table 5). At the point of maximum ground-level impact, the predicted 99th percentile of the 24-hour PM_{10} concentration is 8.3 µg/m^3, which is well below the limit value of the NAAQS of 75 µg/m^3 (Figure 27 and Table 5). For both averaging periods the areas of highest predicted PM_{10} concentrations, although these are relatively low, occur over the central Highveld southeast of Witbank where seven power stations are in relatively close proximity to one another, i.e. Arnot, Hendrina, Komati, Kendal, Kriel, Matla and Duvha. The area extends south-eastward beyond Ermelo because of the Camden and Majuba power stations. A westward extension of the relatively high concentrations results from the Grootvlei and Lethabo power stations.

3.5.4 $PM_{2.5}$

In this scenario the emissions of PM are assumed to consist entirely of $PM_{2.5}$. For actual emissions from the 13 coal-fired power stations the predicted annual average $PM_{2.5}$ concentration (which is 8.3 µg/m^3 at the point of highest impact in the domain) is less than the national ambient $PM_{2.5}$ standard of 20 µg/m^3 (Figure 28 and Table 5). At the point of maximum ground-level impact, the predicted 99th percentile of the 24-hour $PM_{2.5}$ concentration is 8.3 µg/m^3, which is well below the limit value of the NAAQS of 40 µg/m^3 (Figure 29 and Table 5). For both averaging periods the areas of highest predicted $PM_{2.5}$ concentrations, although these are relatively low, occur over the central Highveld southeast of Witbank where seven power stations are in relatively close proximity to one another, i.e. Arnot, Hendrina, Komati, Kendal, Kriel, Matla and Duvha. The area extends south-eastward beyond Ermelo because of the Camden and Majuba power stations. A westward extension of the relatively high concentrations results from the Grootvlei and Lethabo power stations.

3.5.5 Secondary Particulates

For actual emissions of SO_2 and NO_X from the 13 coal-fired power stations the predicted annual average secondary particulate concentration (which is 4.2 µg/m^3 at the point of highest impact in the domain) is some 25% of the annual average $PM_{2.5}$ NAAQS of 20 µg/m^3 (Figure 30 and Table 5). At the point of maximum ground-level impact, the predicted 99th percentile of the 24-hour secondary particulate concentration is

34 µg/m^3, which is some 84% of the NAAQS of 40 µg/m^3 (Figure 31 and Table 5). In addition much of the modelling domain is seen to be in excess of 50% of the NAAQS with an area surrounding Emalahleni where the predicted secondary particulate concentrations exceed 75% of the NAAQS.

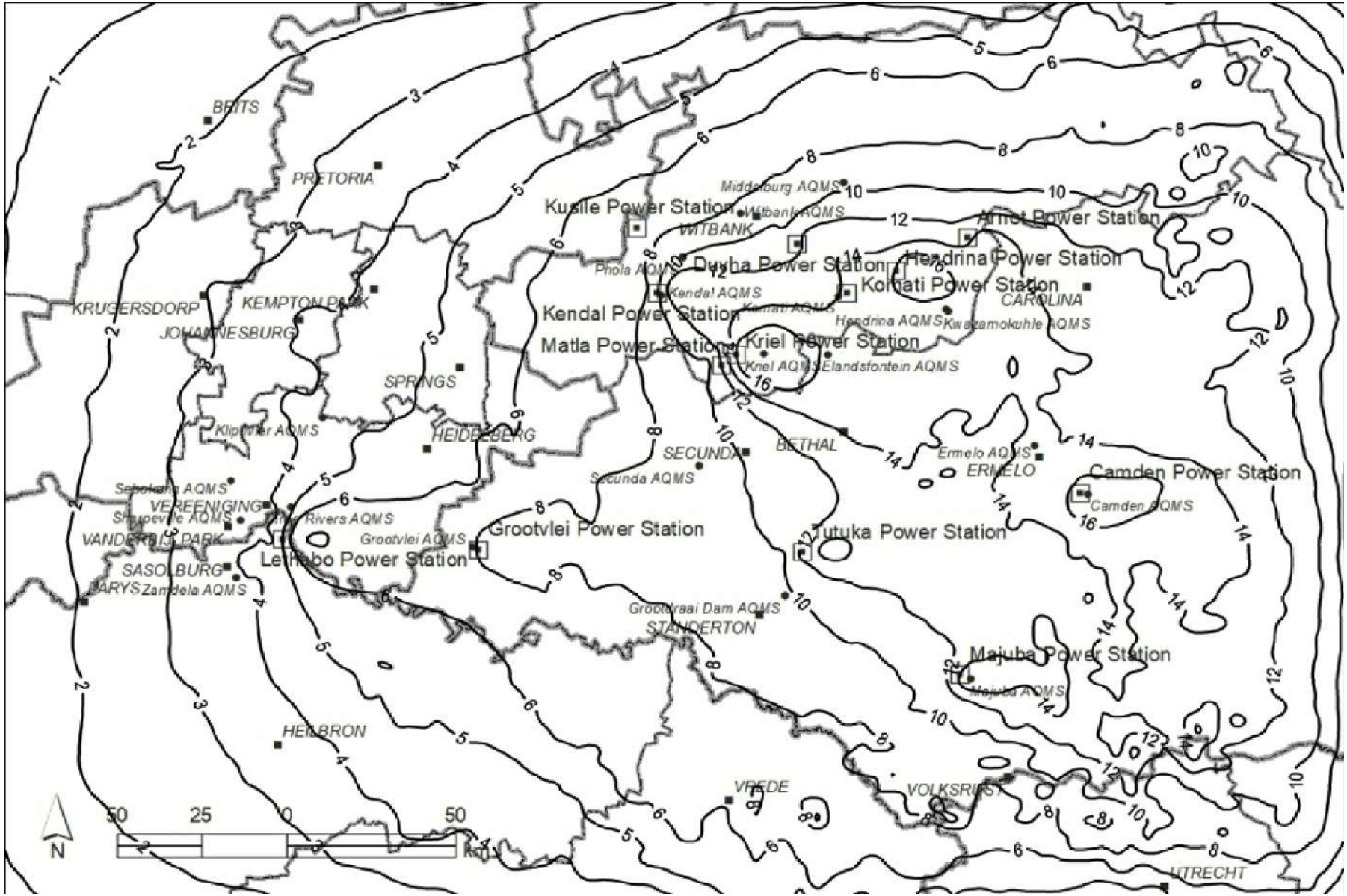

Figure 21: Predicted annual average SO_2 concentrations (µg/m^3) resulting from actual emissions from the 13 coal-fired power stations (Scenario 1)

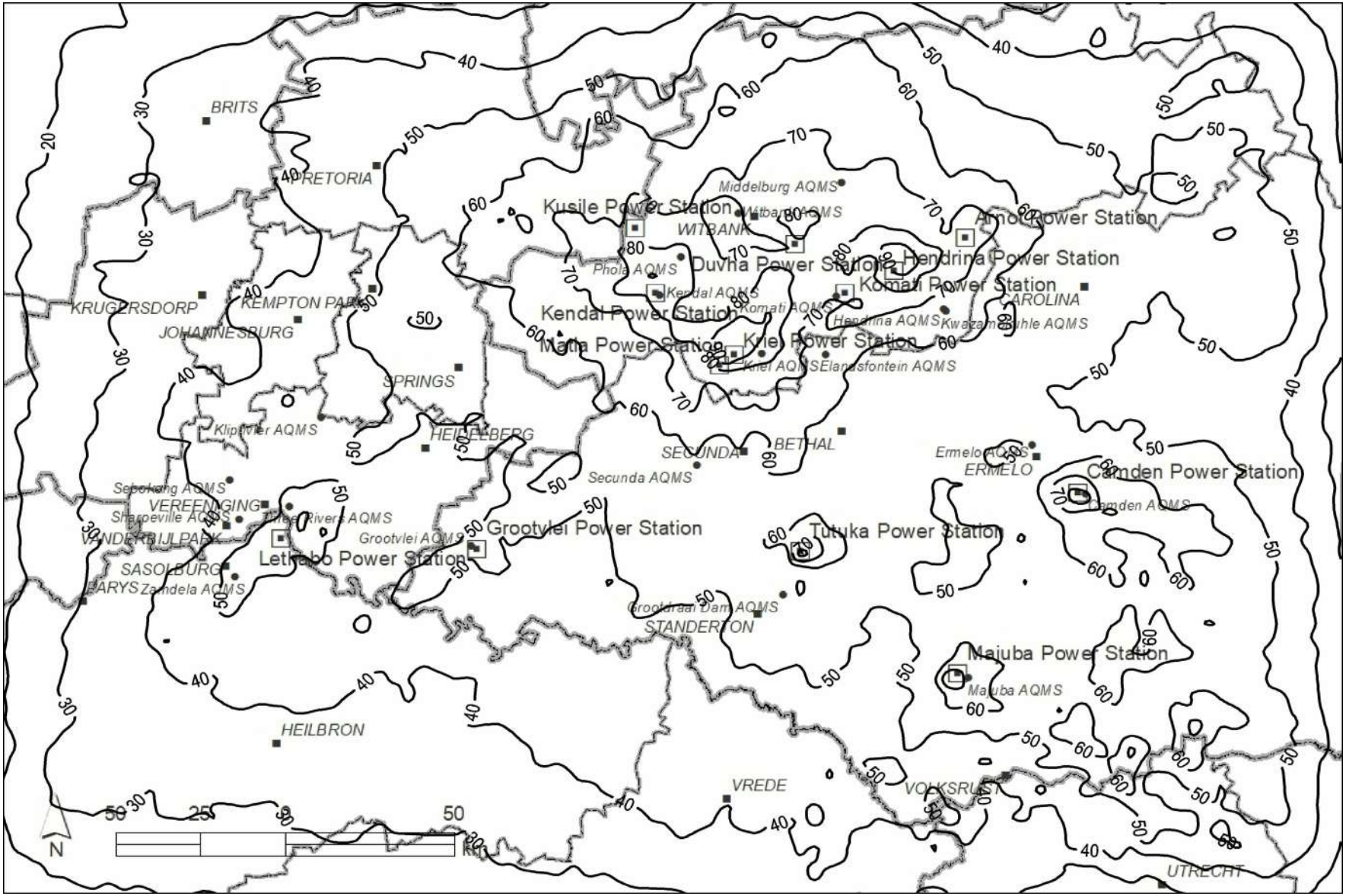

Figure 22: 99th percentile of the predicted 24-hour SO_2 concentrations for actual emissions from the 13 coal-fired power stations (Scenario 1).

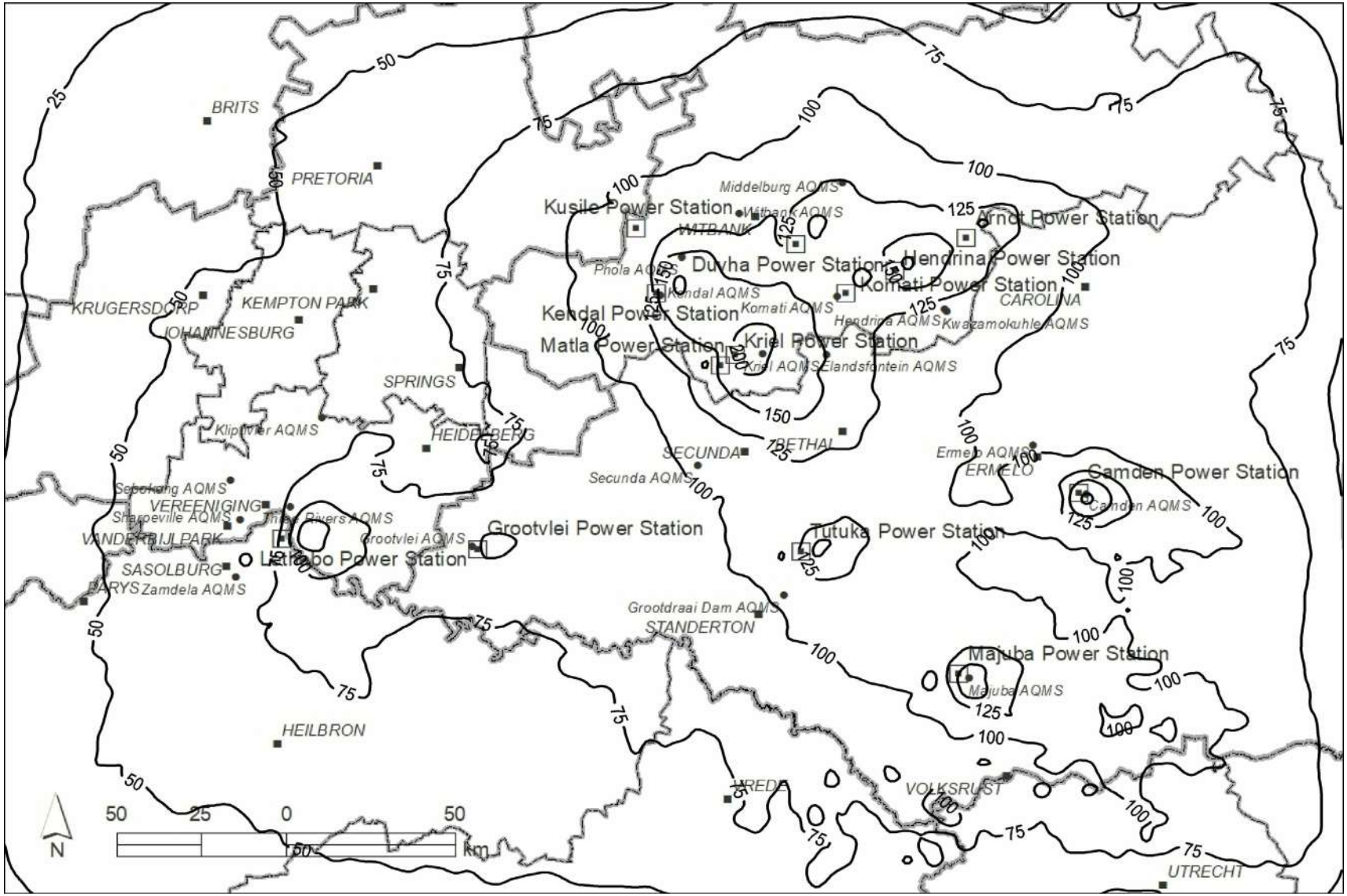

Figure 23: 99th percentile of the predicted 1-hour SO_2 concentrations resulting from actual emissions from the 13 coal-fired power stations (Scenario 1)

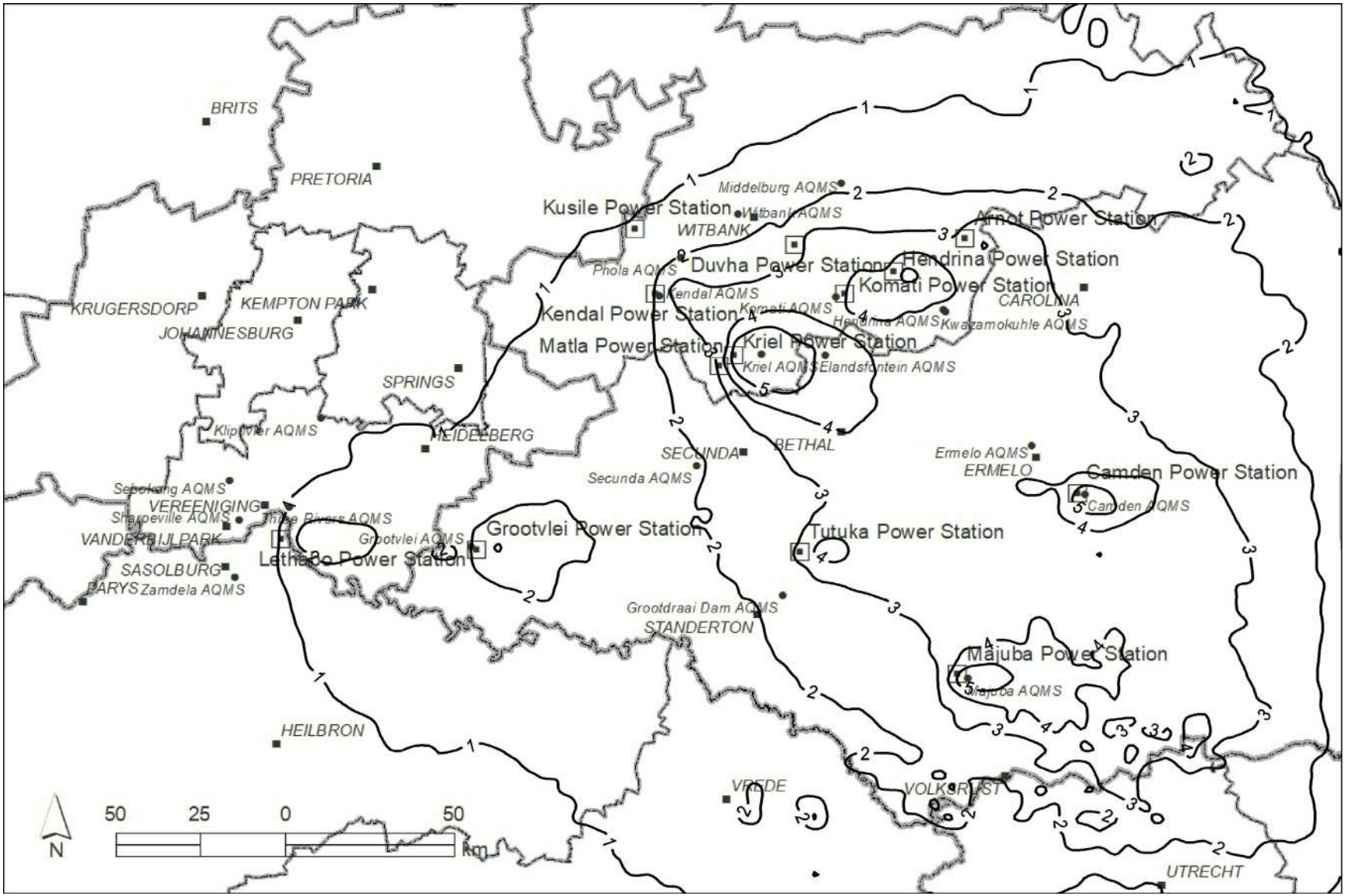

Figure 24: Predicted annual average NO_2 concentrations (µg/m^3) resulting from actual emissions from the 13 coal-fired power stations (Scenario 1).

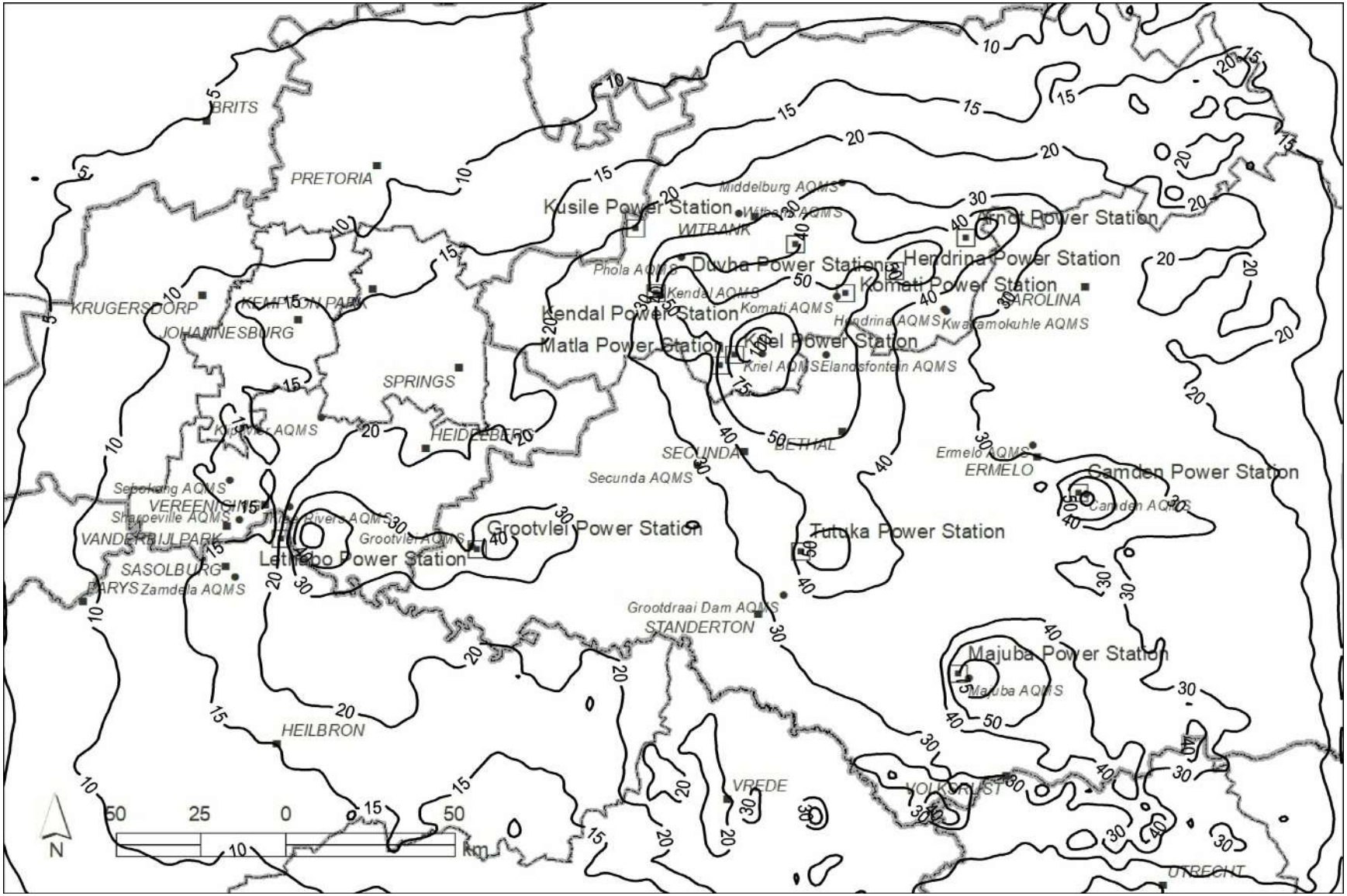

Figure 25: 99th percentile of the predicted 1-hour NO_2 concentrations resulting from actual emissions from the 13 coal-fired power stations (Scenario 1)

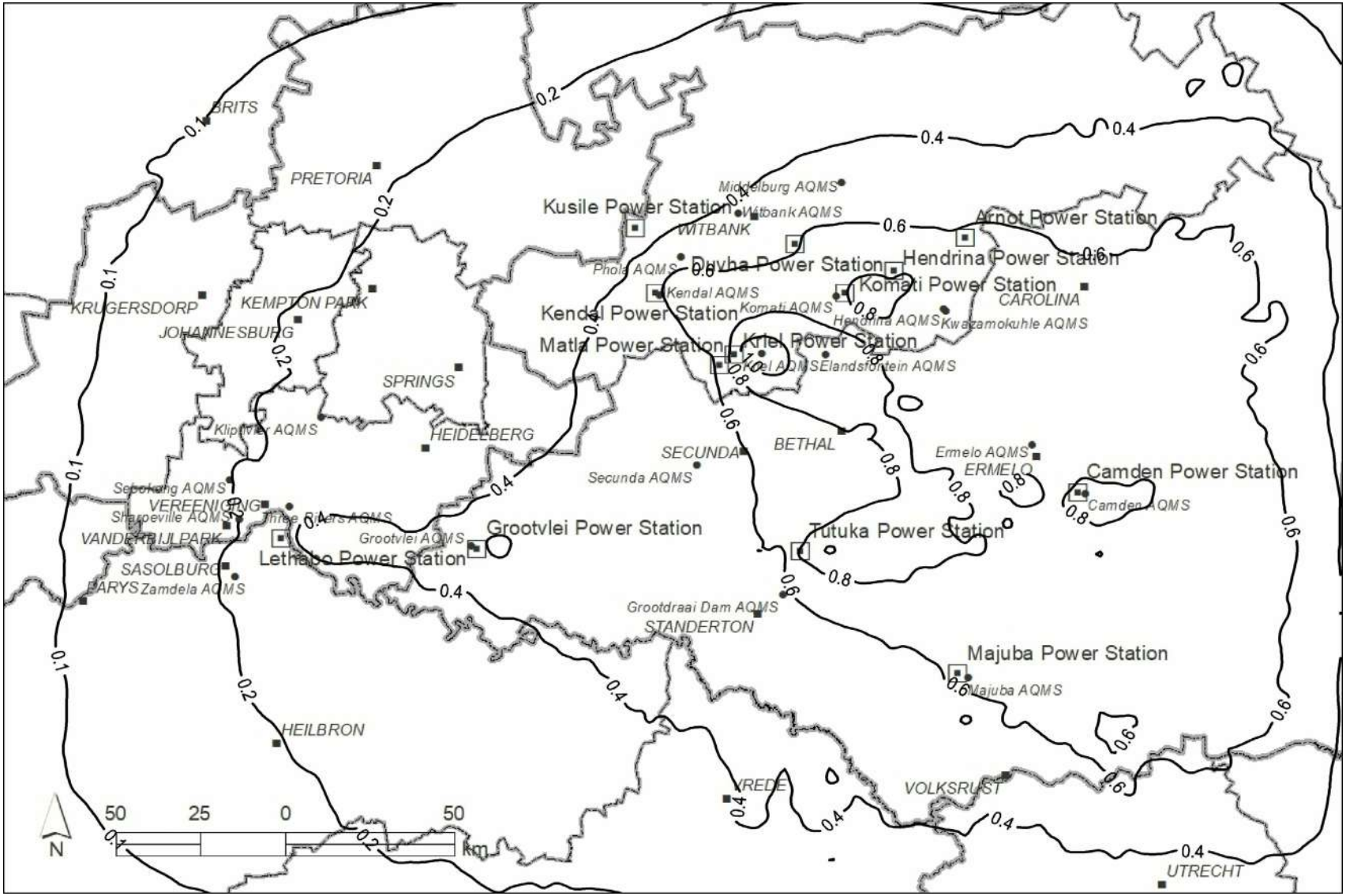

Figure 26: Predicted annual average PM_{10} concentrations (µg/m³) resulting from actual emissions from the 13 coal-fired power stations (Scenario 1)

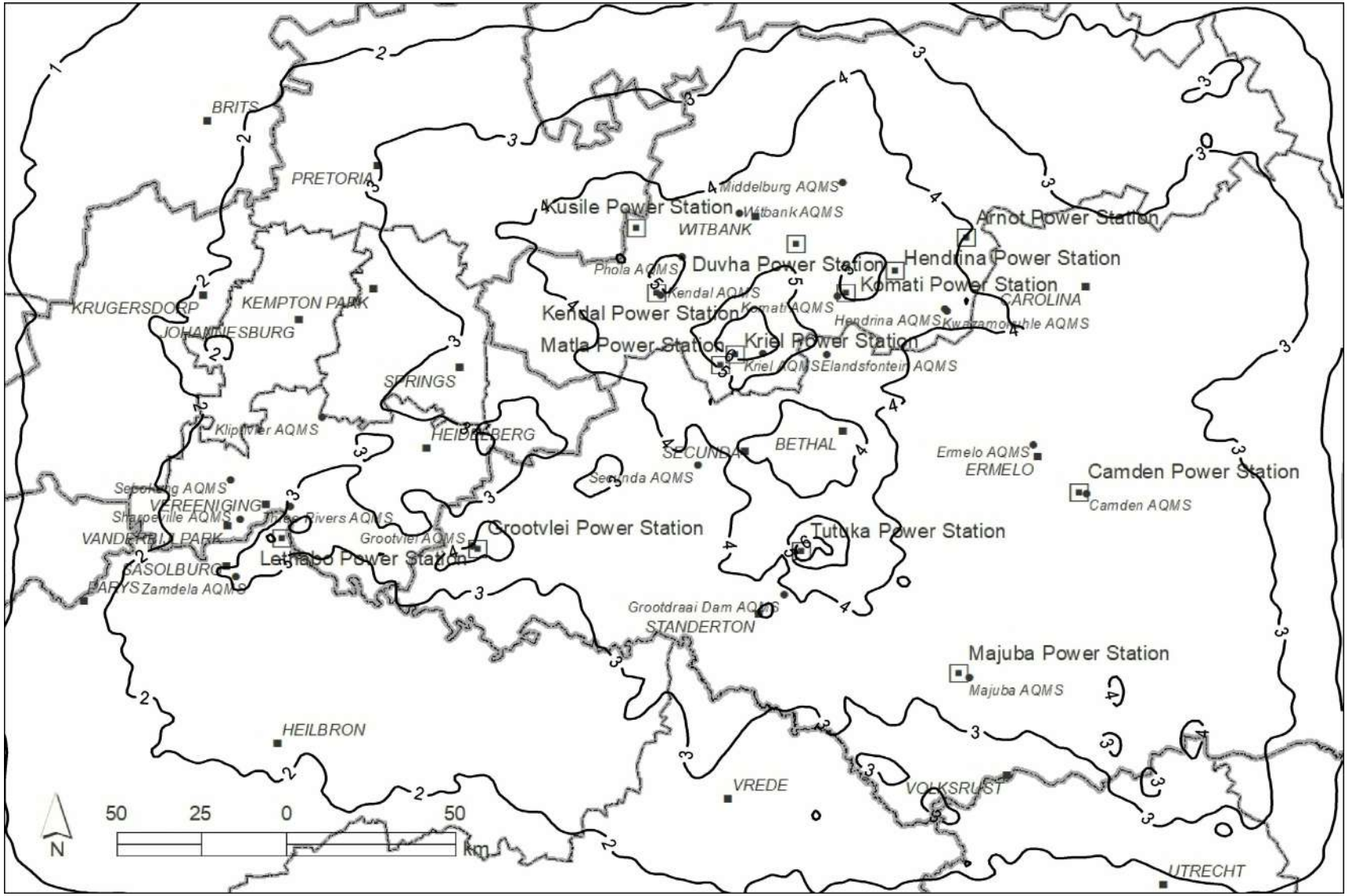

Figure 27: 99th percentile of the predicted 24-hour PM_{10} concentrations resulting from actual emissions from the 13 coal-fired power stations (Scenario 1)

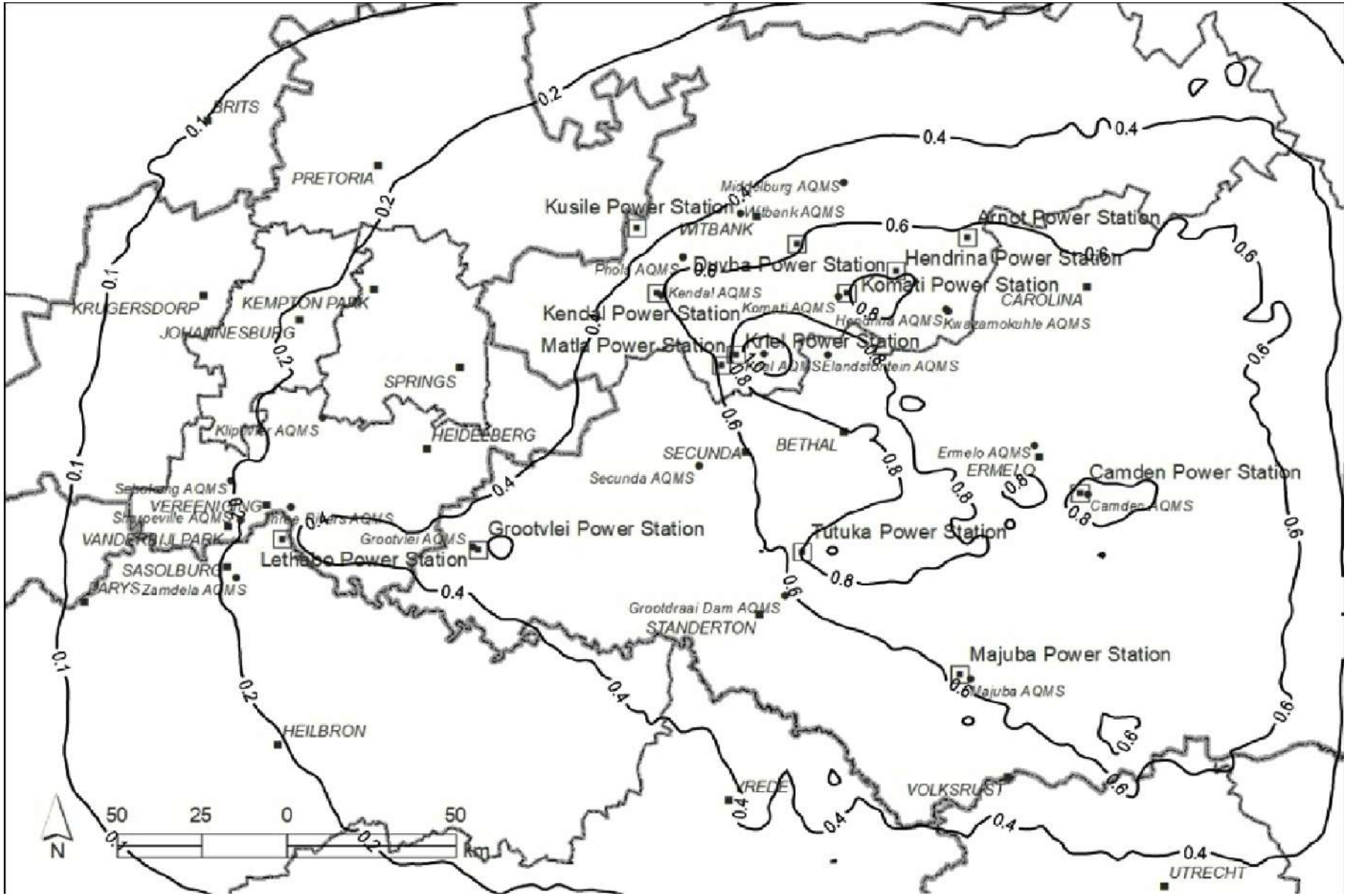

Figure 28: Predicted annual average $PM_{2.5}$ concentrations (µg/m^3) resulting from actual emissions from the 13 coal-fired power stations (Scenario 1)

Figure 29: 99th percentile of the predicted 24-hour $PM_{2.5}$ concentrations resulting from actual emissions from the 13 coal-fired power stations (Scenario 1)

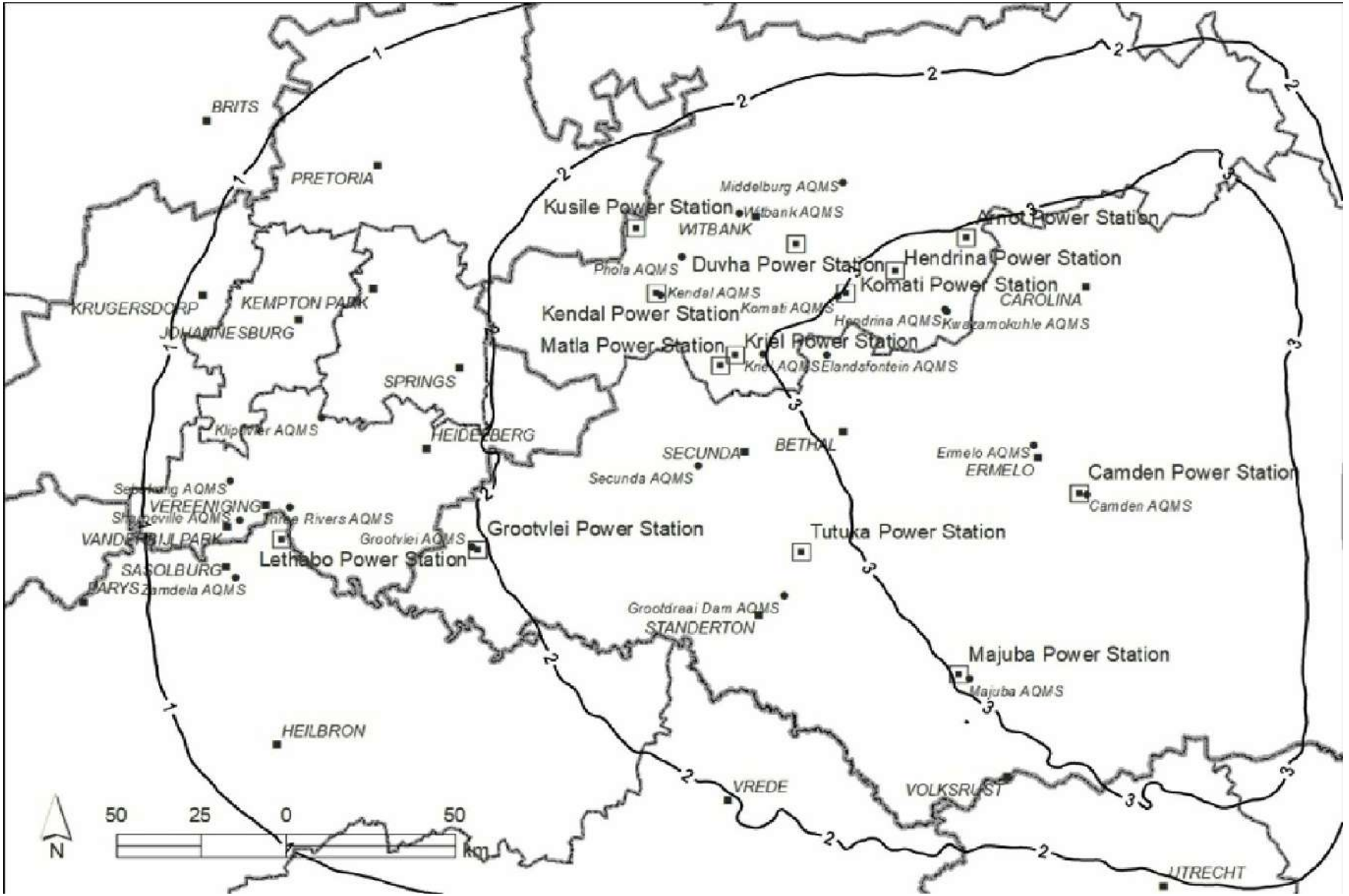

Figure 30: Predicted annual average secondary particulate concentrations (µg/m^3) resulting from actual emissions from the 13 coal-fired power stations (Scenario 1)

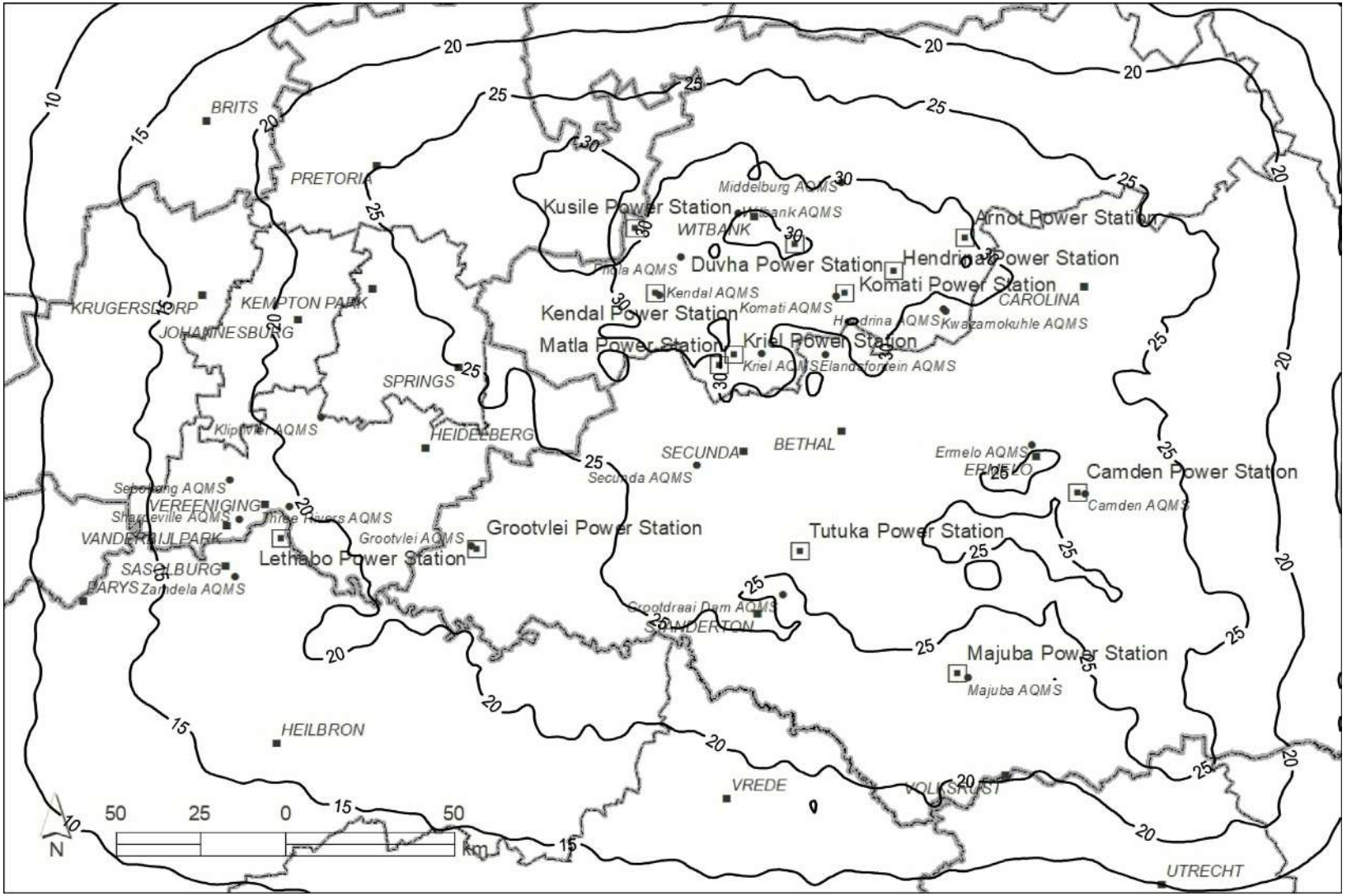

Figure 31: 99th percentile of the predicted 24-hour secondary particulate concentrations resulting from actual emissions from the 13 coal-fired power stations (Scenario 1)

3.6 Scenario 2 – New plant MES compliance

3.6.1 Sulphur dioxide

For the scenario that assumes that SO_2 emissions for the 13 coal-fired power stations are at the MES for new plants, the predicted annual average SO_2 concentrations (which is 15 µg/m^3 at the point of highest impact in the domain) are significantly less than the national ambient SO_2 standard of 50 µg/m^3 throughout the modelling domain (Figure 32 and Table 5). The 99th percentile of the predicted 24-hour SO_2 concentrations is 98 µg/m^3, which is below the limit value of the NAAQS of 125 µg/m^3 (Figure 33 and Table 5). This is also somewhat less than the concentration for actual emissions, and the predicted 24-hour concentrations comply with the NAAQS throughout the modelling domain. At the point of maximum ground-level impact, the 99th percentile 1-hour SO_2 concentration is 257 µg/m^3, which is lower than the limit value of the NAAQS 350 µg/m^3 (Figure 34 and Table 5). The predicted 24-hour concentrations comply with the NAAQS throughout the modelling domain. The areas of highest predicted SO_2 concentrations are somewhat lower than for actual emissions and occur over the central Highveld southeast of Witbank where seven power stations are in relatively close proximity to one another, i.e. Arnot, Hendrina, Komati, Kendal, Kriel, Matla and Duvha. The area extends south-eastward beyond Ermelo because of the Camden and Majuba power stations. A westward extension of the relatively high concentrations results from the Grootvlei and Lethabo power stations.

3.6.2 Nitrogen dioxide

For the scenario that assumes that NO_X emissions for the 13 coal-fired power stations are at the MES for new plants, the predicted annual average NO_2 concentration (which is 14.2 µg/m^3 at the point of highest impact in the domain) is less than the national ambient NO_2 standard of 40 µg/m^3 (Figure 35 and Table 5). The predicted ambient concentrations are notably higher than for the actual emission scenario. At the point of maximum ground-level impact, the predicted 99th percentile 1-hour concentration for NO_2 is 303 µg/m^3, which exceeds the limit value of the NAAQS of 200 µg/m^3 (Figure 36 and Table 5). An exceedance of the NAAQS requires that the tolerance of 4 exceedances per annum is exceeded, or 12 exceedances in the 3-year modelling period. This tolerance is exceeded in a relatively small area to the south of the Kusile Power Station (Figure 37). Elsewhere in the modelling domain the predicted 24-hour NO_2 concentrations comply with the NAAQS. The areas of highest predicted NO_2 concentrations occur over the central Highveld southeast of Witbank where seven power stations are in relatively close proximity to one another, i.e. Arnot, Hendrina, Komati, Kendal, Kriel, Matla and Duvha. The area extends south-eastward beyond Ermelo because of the Camden and Majuba power stations. A westward extension of the relatively high concentrations results from the Grootvlei and Lethabo power stations.

3.6.3 PM_{10}

For the scenario that assumes that PM emissions for the 13 coal-fired power stations are at the MES for new plants, the predicted annual average PM_{10} concentration (which is 1.6 µg/m^3 at the point of highest impact in the domain) is significantly less than the national ambient PM_{10} standard of 40 µg/m^3 (Figure 38 and Table 5) and similar to those resulting from actual emissions. At the point of maximum ground-level impact, the predicted 99th percentile 24-hour concentration for PM_{10} is 10.0 µg/m^3, which is well below the limit value of the NAAQS of 75 µg/m^3 (Figure 39 and Table 5).

For both averaging periods the areas of highest predicted PM_{10} concentrations, although these are relatively small, occur over the central Highveld southeast of Witbank where seven power stations are in relatively close proximity to one another, i.e. Arnot, Hendrina, Komati, Kendal, Kriel, Matla and Duvha. The area extends south-eastward beyond Ermelo because of the Camden and Majuba power stations. A westward extension of the relatively high concentrations results from the Grootvlei and Lethabo power stations.

3.6.4 $PM_{2.5}$

For the scenario that assumes that PM emissions for the 13 coal-fired power stations are at the MES for new plants, the predicted annual average $PM_{2.5}$ concentration (which is 1.6 µg/m^3 at the point of highest impact in the domain) is significantly less than the national ambient PM_{10} standard of 40 µg/m^3 (Figure 40 and Table 5). These are similar to Scenario 1 for actual emissions. At the point of maximum ground-level impact, the predicted 99th percentile 24-hour concentration for PM_{10} is 10.0 µg/m^3, which is well below the limit value of the NAAQS of 75 µg/m^3 (Figure 42 and Table 5). For both averaging periods the areas of highest predicted $PM_{2.5}$ concentrations, although these are relatively small, occur over the central Highveld southeast of Witbank where seven power stations are in relatively close proximity to one another, i.e. Arnot, Hendrina, Komati, Kendal, Kriel, Matla and Duvha. The area extends south-eastward beyond Ermelo because of the Camden and Majuba power stations. A westward extension of the relatively larger concentrations results from the Grootvlei and Lethabo power stations.

3.6.5 Secondary Particulates

For SO_2 and NO_X emissions for operations assumed at the MES for new plants at from the 13 coal-fired power stations the predicted annual average secondary particulate concentration (which is 4.3 µg/m^3 at the point of highest impact in the domain) is small and significantly less than the national ambient $PM_{2.5}$ standard of 20 µg/m^3 (Figure 41 and Table 5). At the point of maximum ground-level impact, the predicted 99th percentile of the 24-hour secondary particulate concentration is 30 µg/m^3. This concentration is below the limit value of the NAAQS of 40 µg/m^3 (Figure 43 and Table 5), but noteworthy is that it is 75% of the limit value. Secondary particulates are a function of SO_2 and NO_X emissions and atmospheric chemistry, and so the dispersion cannot be directly related to the emissions from individual power stations. Rather a regional effect is demonstrated, and the highest concentrations are predicted to occur over an area that extends south-eastward towards KwaZulu-Natal.

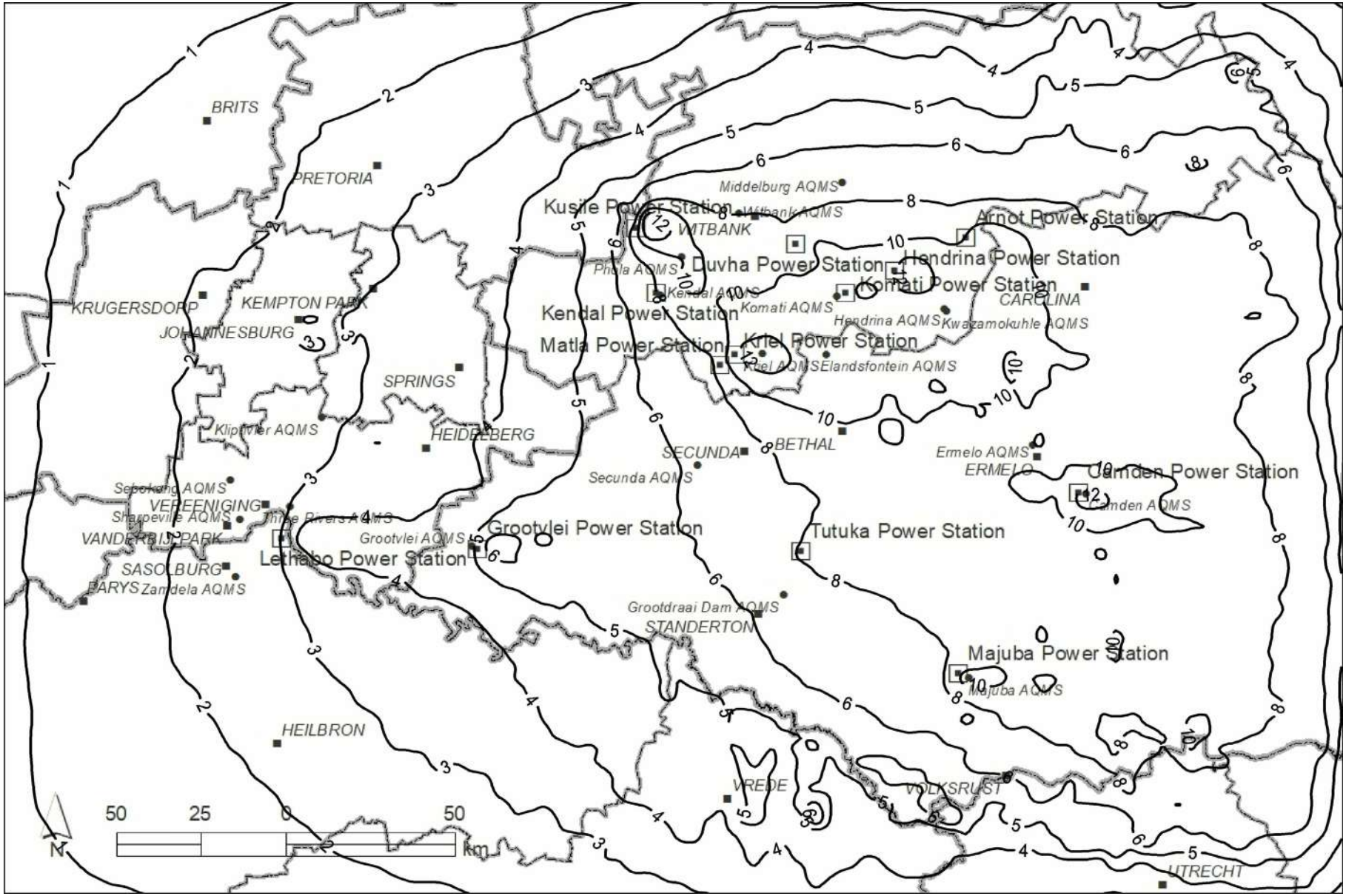

Figure 32: Predicted annual average SO_2 concentrations (µg/m^3) assuming new plant MES from the 13 coal-fired power stations (Scenario 2)

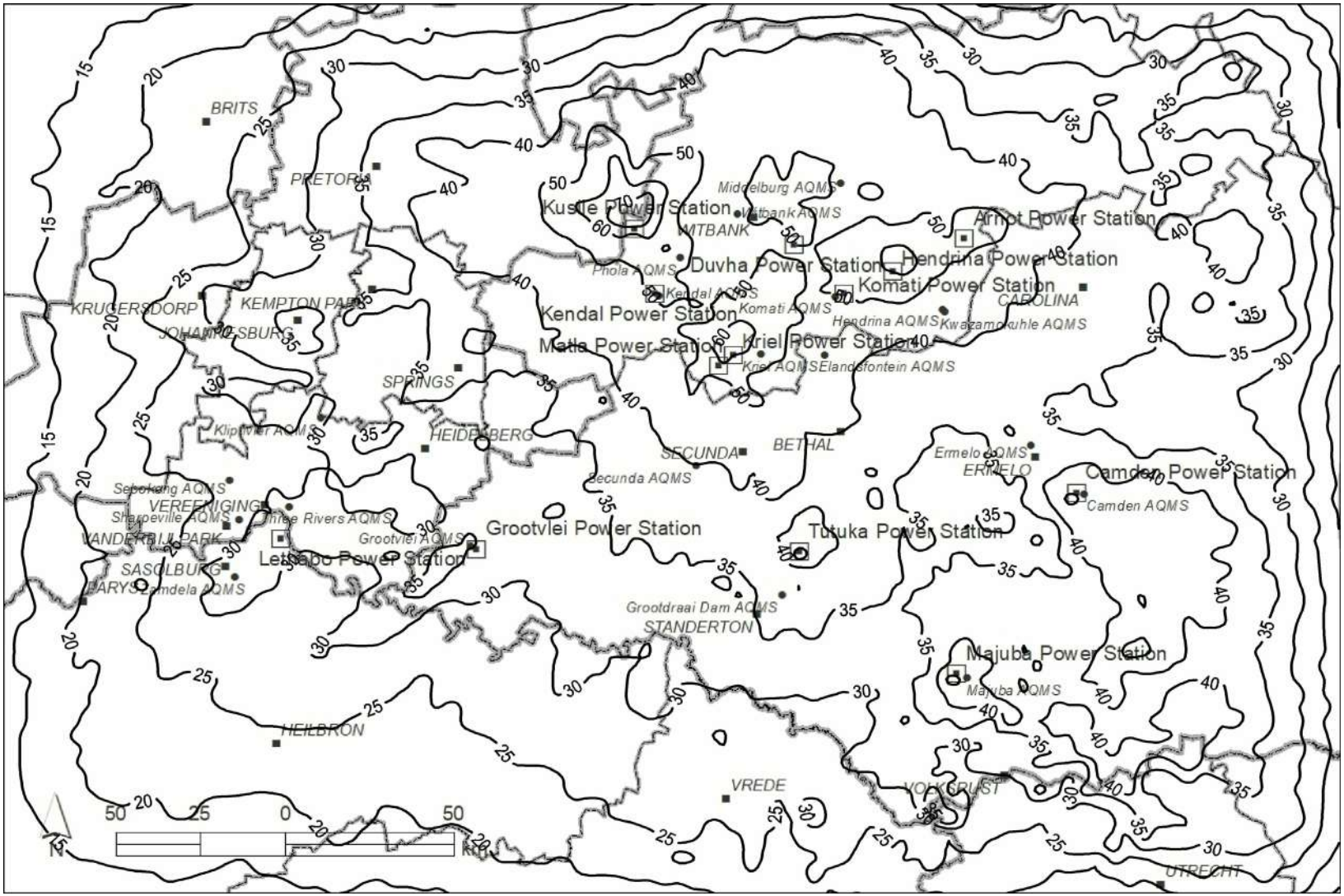

Figure 33: 99th percentile of the predicted 24-hour SO_2 concentrations assuming new plant MES from the 13 coal-fired power stations (Scenario 2)

Figure 34: 99th percentile of the predicted 1-hour SO_2 concentrations assuming new plant MES emission from the 13 coal-fired power stations (Scenario 2)

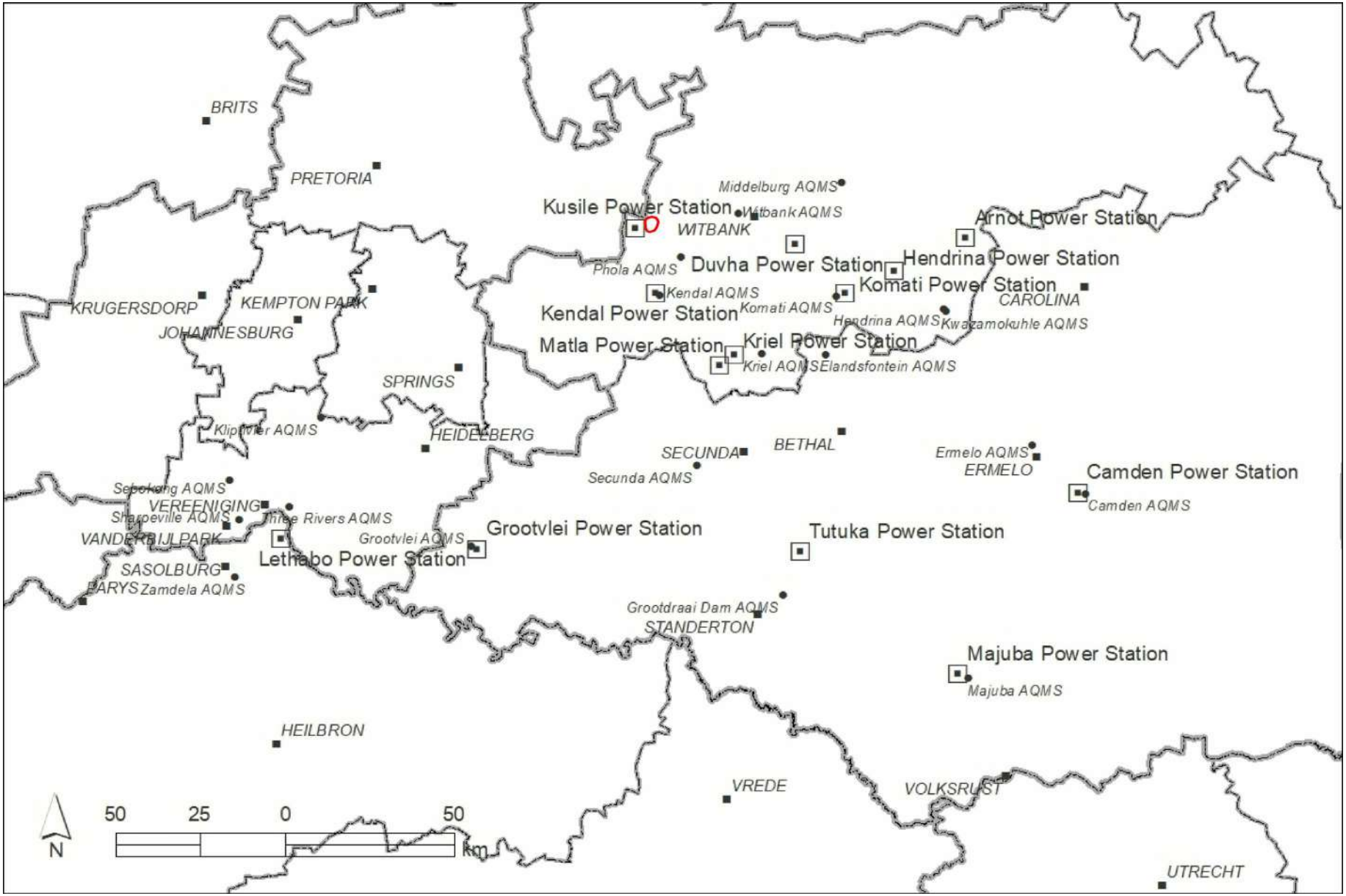

Figure 35: Predicted annual average NO_2 concentrations resulting assuming new plant MES from the 13 coal-fired power stations (Scenario 2)

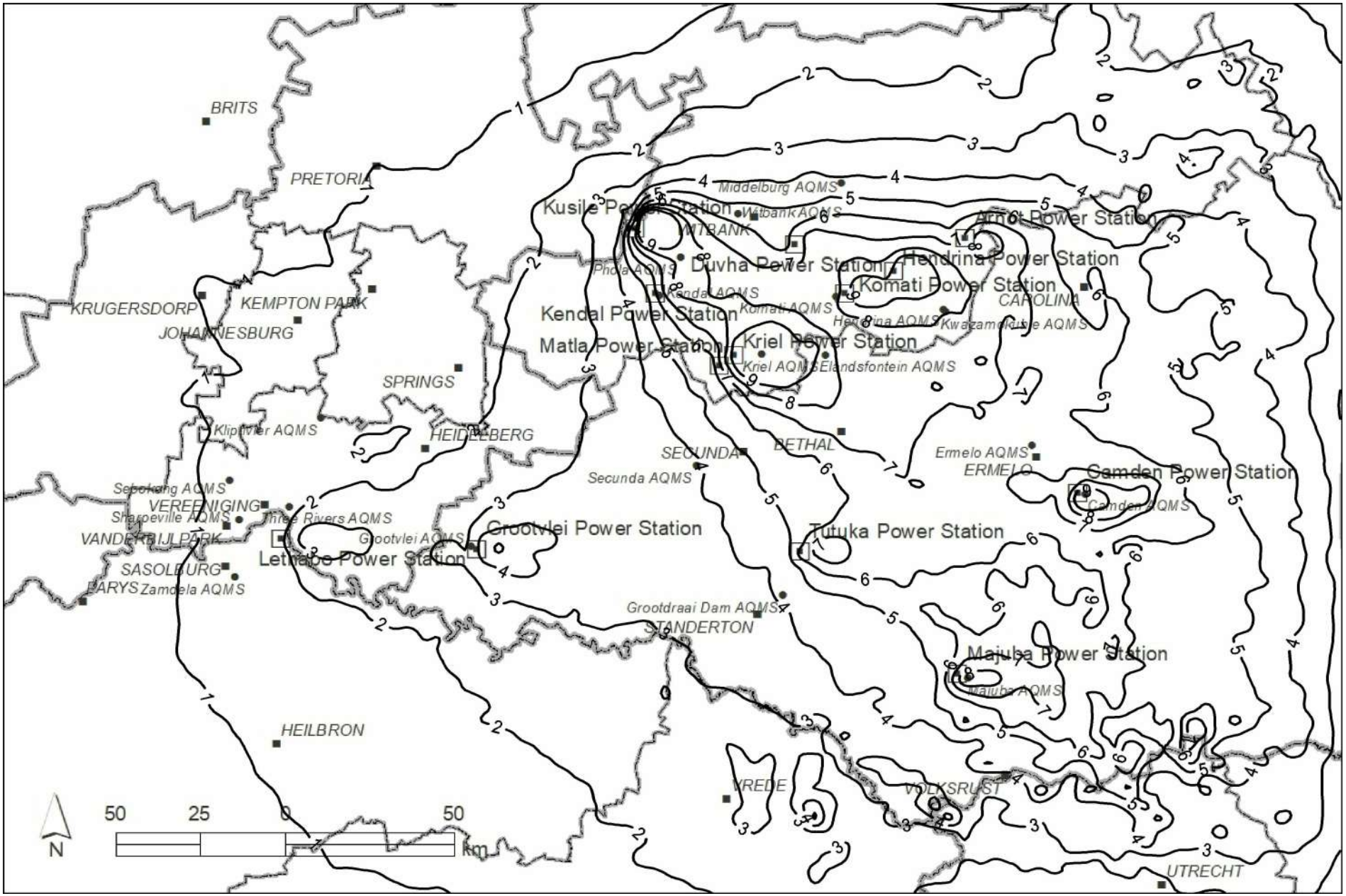

Figure 36: 99th percentile of the predicted 1-hour NO_2 concentrations assuming new plant MES from the 13 coal-fired power stations (Scenario 2)

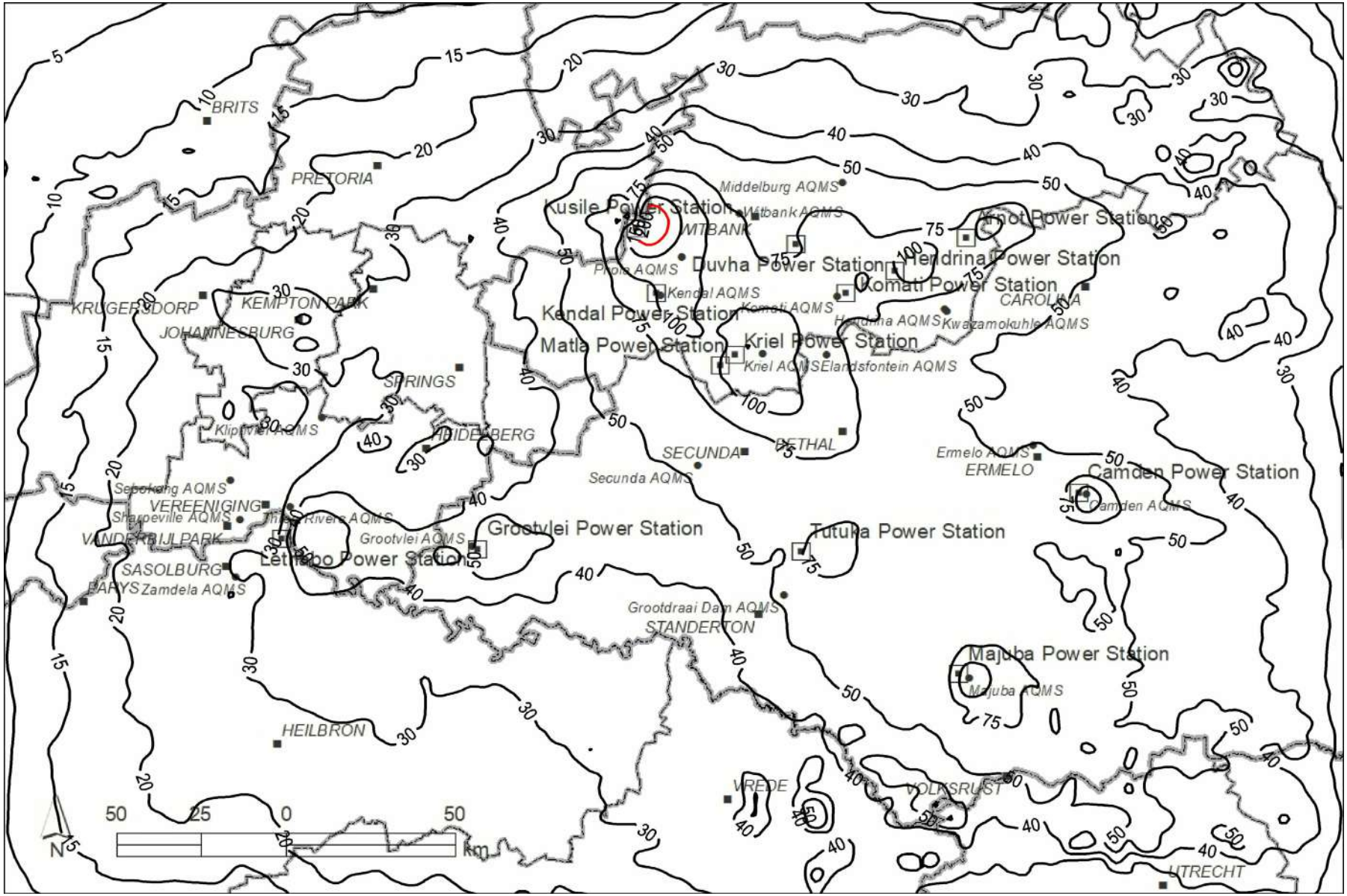

Figure 37: Predicted number of exceedances of the 1-hour NO_2 limit value indicated by the red line which indicates 264 exceedances

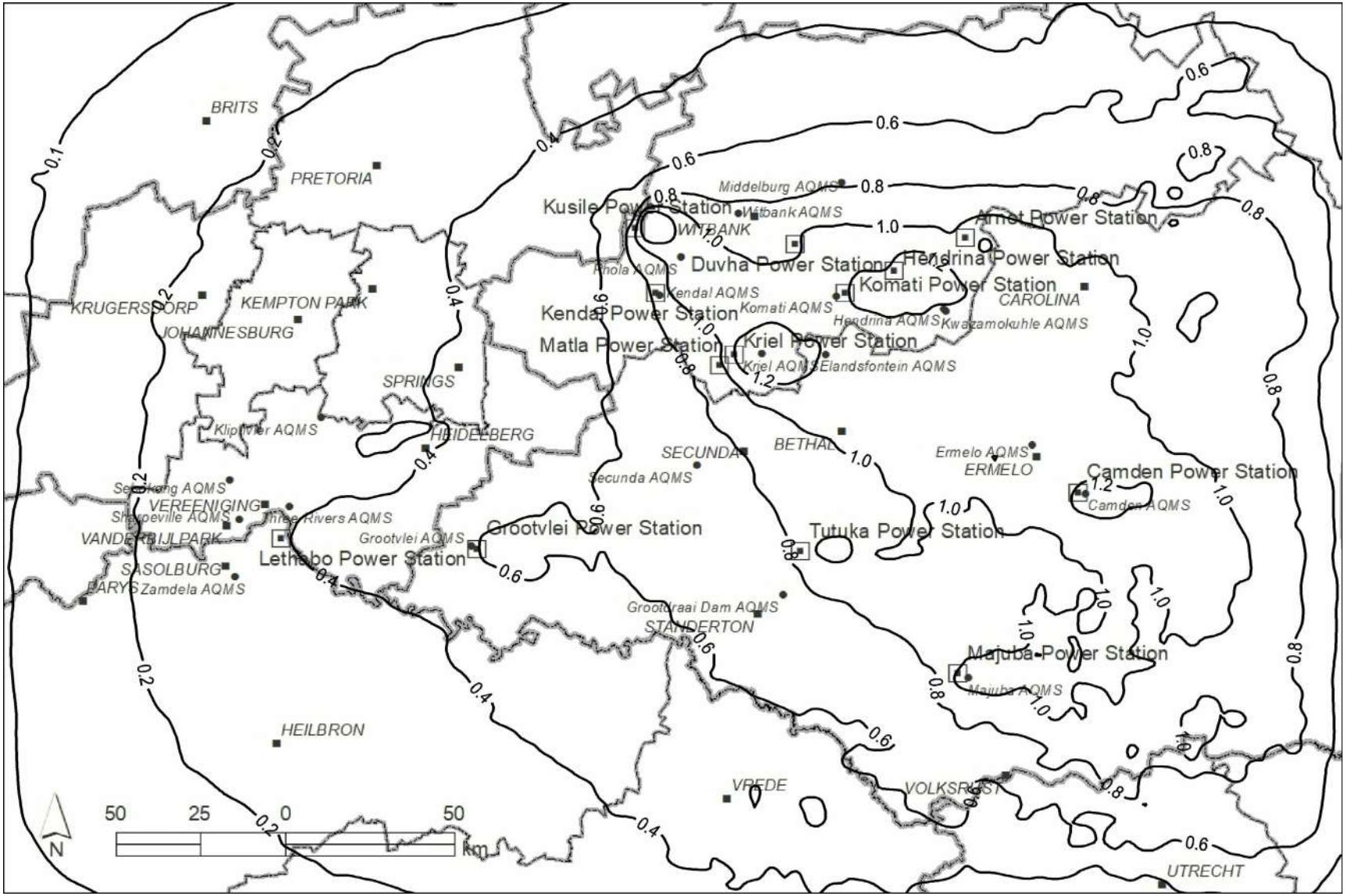

Figure 38: Predicted annual average PM_{10} concentrations resulting from new plant MES from the 13 coal-fired power stations (Scenario 2)

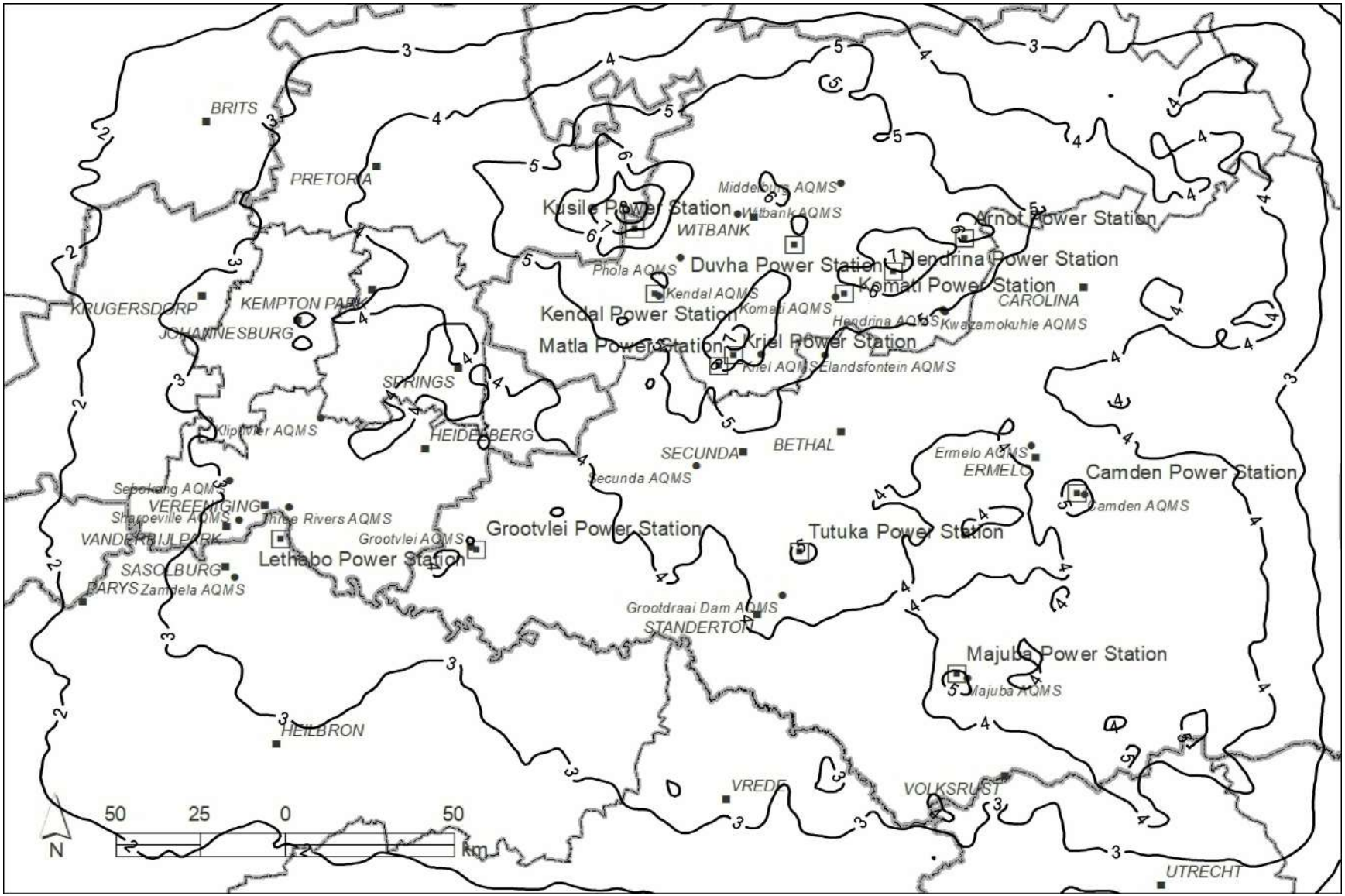

Figure 39: 99th percentile of the predicted 24-hour PM_{10} concentrations resulting from new plant MES from the 13 coal-fired power stations (Scenario 2)

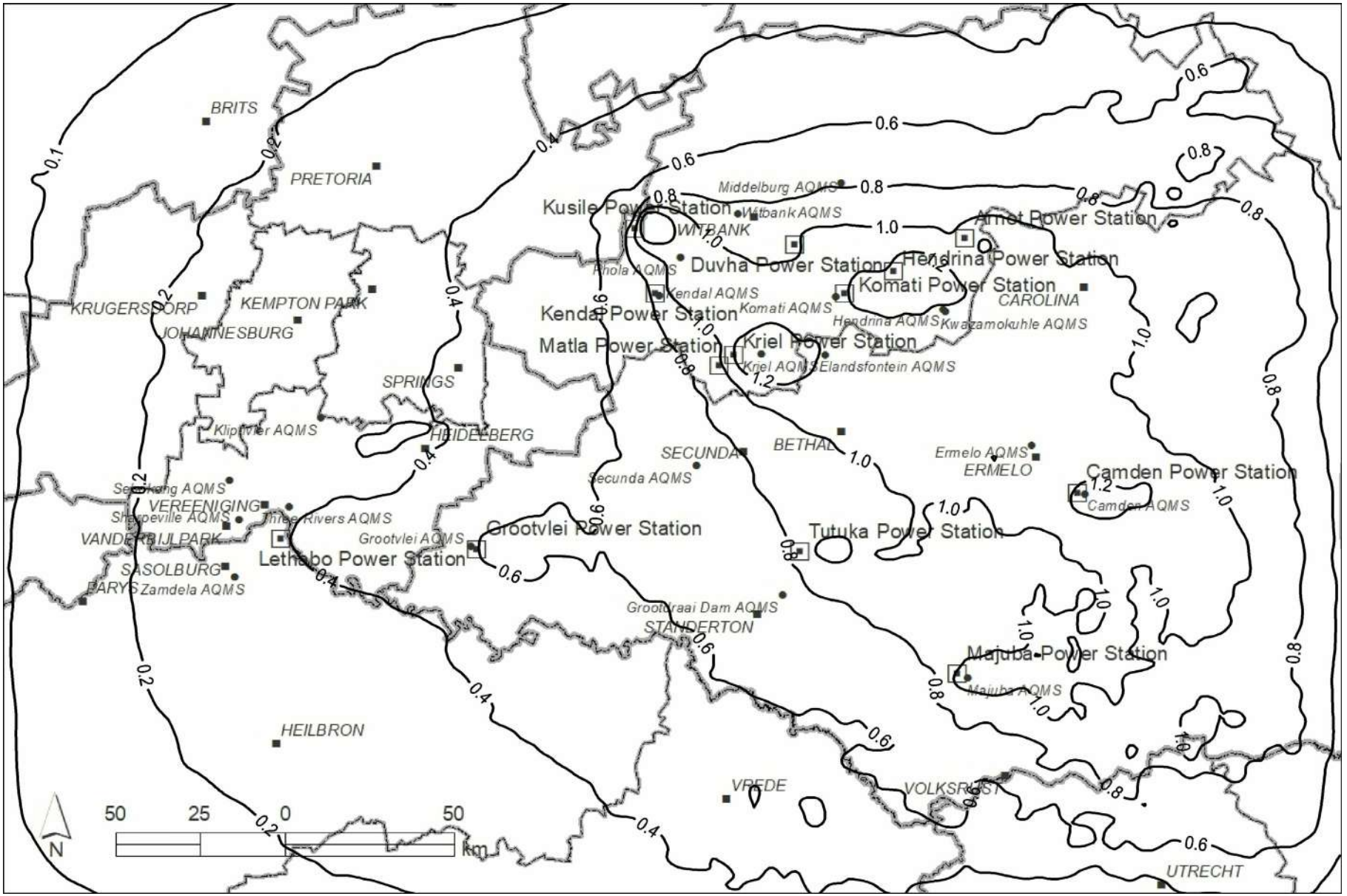

Figure 40: Predicted annual average $PM_{2.5}$ concentrations (µg/m^3) assuming new plant MES from the 13 coal-fired power stations (Scenario 2)

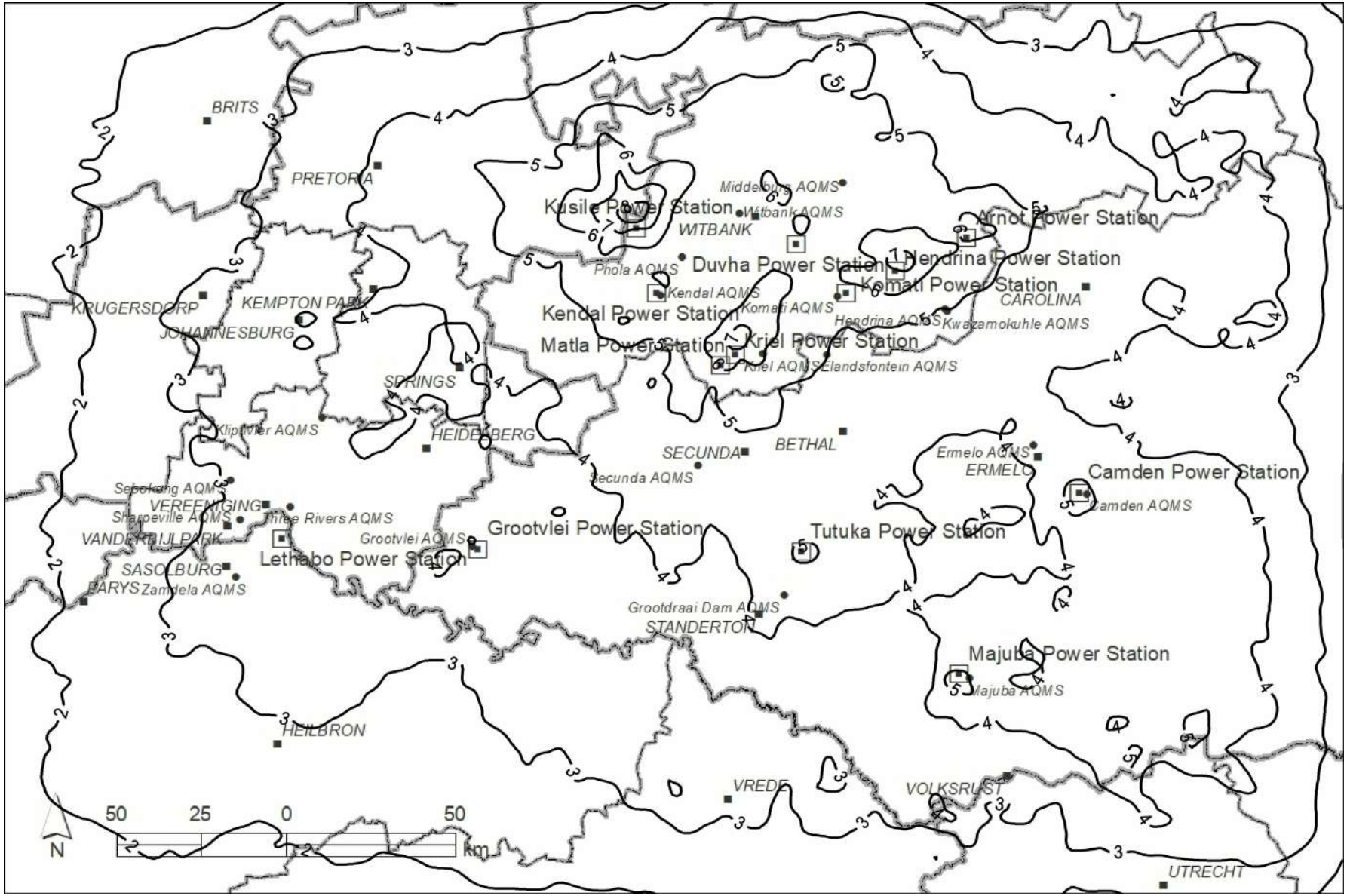

Figure 41: Predicted annual average secondary particulate concentrations (µg/m^3) assuming new plant MES from the 13 coal-fired power stations (Scenario 2)

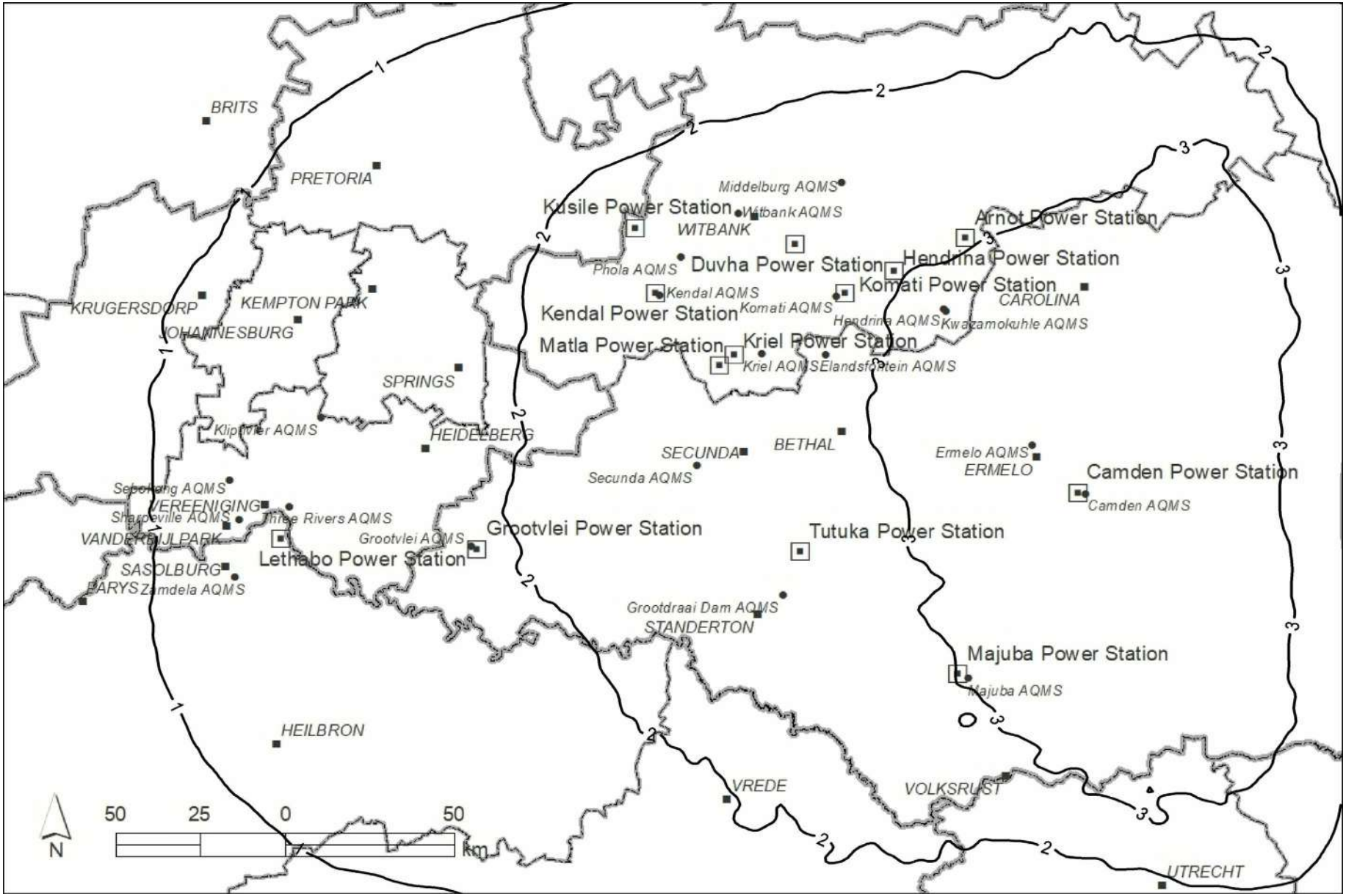

Figure 42: 99th percentile of the predicted 24-hour $PM_{2.5}$ concentrations assuming new plant MES from the 13 coal-fired power stations (Scenario 2)

Figure 43: 99th percentile of the predicted 24-hour secondary particulate concentrations assuming new plant MES from the 13 coal-fired power stations (Scenario 2).

3.7 Scenario 3: Combined emissions with 5 power stations non-operational

The predicted annual average ambient concentrations for SO_2, NO_2, PM_{10}, $PM_{2.5}$, secondary particulate and secondary particulate with $PM_{2.5}$ concentrations resulting from emissions from Eskom's 7 coal-fired power stations for the 2030 Emission Scenario are presented as isopleth maps over the modelling domain. The 7 coal-fired power stations include Duvha, Kendal, Lethabo, Majuba, Matla, Tutuka and Kusile. The 99th percentile concentrations of the predicted maximum 24-hour and 1-hour ambient concentrations are also presented as isopleths for these pollutants. Comparison is made between the predicted annual average concentrations and the predicted 99th percentile concentrations with the respective NAAQS. The predicted annual average concentration and the 99th percentile concentration at the points of maximum ground-level concentration for the 2030 Emission Scenario are presented in Table 6.

Table 6: Maximum predicted annual average concentration and the highest 99th percentile concentration at the points of maximum ground-level concentration for the 2030 Emission Scenario. Please note that direct emissions of PM and secondary PM formation must be seen in combination. They are separated here only to differentiate the origin.

Averaging periods	2030 Emission Scenario
	SO_2 (µg/m^3)
1-hour	191
24-hour	81.6
Annual	14.2
	NO_2 (µg/m^3)
1-hour	92.7
Annual	4.9
	PM_{10} or $PM_{2.5}$ (µg/m^3)
24-hour	7.2
Annual	0.8
	Secondary particulates with $PM_{2.5}$ (µg/m^3)
24-hour	26.5
Annual	3.6

3.7.1 Sulphur dioxide (SO_2)

For actual monthly emissions of SO_2 from the 7 coal-fired power stations the predicted annual average SO_2 concentration (which is 14.2 µg/m^3 at the point of highest impact in the domain) is less than the national ambient SO_2 standard of 50 µg/m^3 throughout the modelling domain (**Figure 44** and Table 6). Similarly, the 99th percentile of the predicted 24-hour SO_2 concentrations with a maximum of 81.6 µg/m^3 (**Figure 45** and Table 6) does not exceed the NAAQS of 125 µg/m^3 anywhere in the modelling domain. At the point of maximum ground-level concentration, the 99th percentile 1-hour SO_2 concentration is 191 µg/m^3, which is below the limit value of the NAAQS of 350 µg/m^3 (**Figure 46** and Table 6). The areas of highest predicted SO_2 concentrations occur over the central Highveld southwest of Witbank where four power stations are in relatively close proximity to one another, i.e. Kusile, Kendal, Matla and Duvha. The area extends south-eastward beyond Bethal because of the Tutuka and Majuba power stations. A south-westward extension of the relatively high concentrations results from the Lethabo power station.

3.7.2 Nitrogen dioxide (NO_2)

For actual monthly emissions of NO_X from the 7 coal-fired power stations the predicted annual average NO_2 concentration (which is 4.9 µg/m^3 at the point of highest impact in the domain) is significantly less than the national ambient NO_2 standard of 40 µg/m^3 (

Figure 47 and Table 6). At the point of maximum ground-level impact, the predicted 99th percentile of the 1-hour NO_2 concentration is 92.7 µg/m^3, which is below the limit value of the NAAQS of 200 µg/m^3 (**Figure 48** and Table 6). The areas of highest predicted NO_2 concentrations, albeit that these are relatively low, occur over the central Highveld southwest of Witbank where four power stations are in relatively close proximity to one another, i.e. Kusile, Kendal, Matla and Duvha. The area extends south-eastward beyond Bethal because of the Tutuka and Majuba power stations. A south-westward extension of the relatively high concentrations results from the Lethabo power station.

3.7.3 PM_{10}

In this scenario the emissions of PM are assumed to consist entirely of PM_{10}. For actual emissions from the 7 coal-fired power stations the predicted annual average PM_{10} concentration (which is 0.8 µg/m^3 at the point of highest impact in the domain) is significantly less than the national ambient PM_{10} standard of 40 µg/m^3 (**Figure 49** and Table 6). At the point of maximum ground-level impact, the predicted 99th percentile of the 24-hour PM_{10} concentration is 7.2 µg/m^3, which is well below the limit value of the NAAQS of 75 µg/m^3 (**Figure 50** and Table 6). The areas of highest predicted PM_{10} concentrations, albeit that these are relatively low, occur over the central Highveld southwest of Witbank where four power stations are in relatively close proximity to one another, i.e. Kusile, Kendal, Matla and Duvha. The area extends south-eastward beyond Bethal because of the Tutuka and Majuba power stations and south-westward to the Lethabo power station.

3.7.4 $PM_{2.5}$

In this scenario the emissions of PM are assumed to consist entirely of $PM_{2.5}$. For actual emissions from the 7 coal-fired power stations the predicted annual average $PM_{2.5}$ concentration (which is 0.8 µg/m^3 at the point of highest impact in the domain) is less than the national ambient $PM_{2.5}$ standard of 20 µg/m^3 (**Figure 51** and Table 6). At the point of maximum ground-level impact, the predicted 99th percentile of the 24-hour $PM_{2.5}$ concentration is 7.2 µg/m^3, which is well below the limit value of the NAAQS of 40 µg/m^3 (**Figure 52** and Table 6). The areas of highest predicted $PM_{2.5}$ concentrations, albeit that these are relatively low, occur over the central Highveld southwest of Witbank where four power stations are in relatively close proximity to one another, i.e. Kusile, Kendal, Matla and Duvha. The area extends south-eastward beyond Bethal because of the Tutuka and Majuba power stations and south-westward to the Lethabo power station.

3.7.5 Secondary Particulates with $PM_{2.5}$

For actual emissions of SO_2, NO_X and $PM_{2.5}$, from the 7 coal-fired power stations the predicted annual average secondary particulate with $PM_{2.5}$ concentration (which is 3.6 µg/m^3 at the point of highest impact in the domain) is low and significantly less than the national ambient $PM_{2.5}$ standard of 20 µg/m^3 (Figure 53 and Table 6). At the point of maximum ground-level impact, the predicted 99th percentile of the 24-hour secondary particulate with $PM_{2.5}$ concentration is 26.5 µg/m^3. This concentration is well below the NAAQS of 40 µg/m^3 (Figure 54 and Table 6). Noting that secondary particulates are a function of SO_2, NO_X and $PM_{2.5}$ emissions and atmospheric chemistry, the dispersion cannot be directly related to the emissions from individual power stations. Rather a regional effect is demonstrated, and the highest concentrations are predicted to occur over the central Highveld southwest of Witbank where four power stations are in relatively close proximity to one another, i.e. Kusile, Kendal, Matla and Duvha.

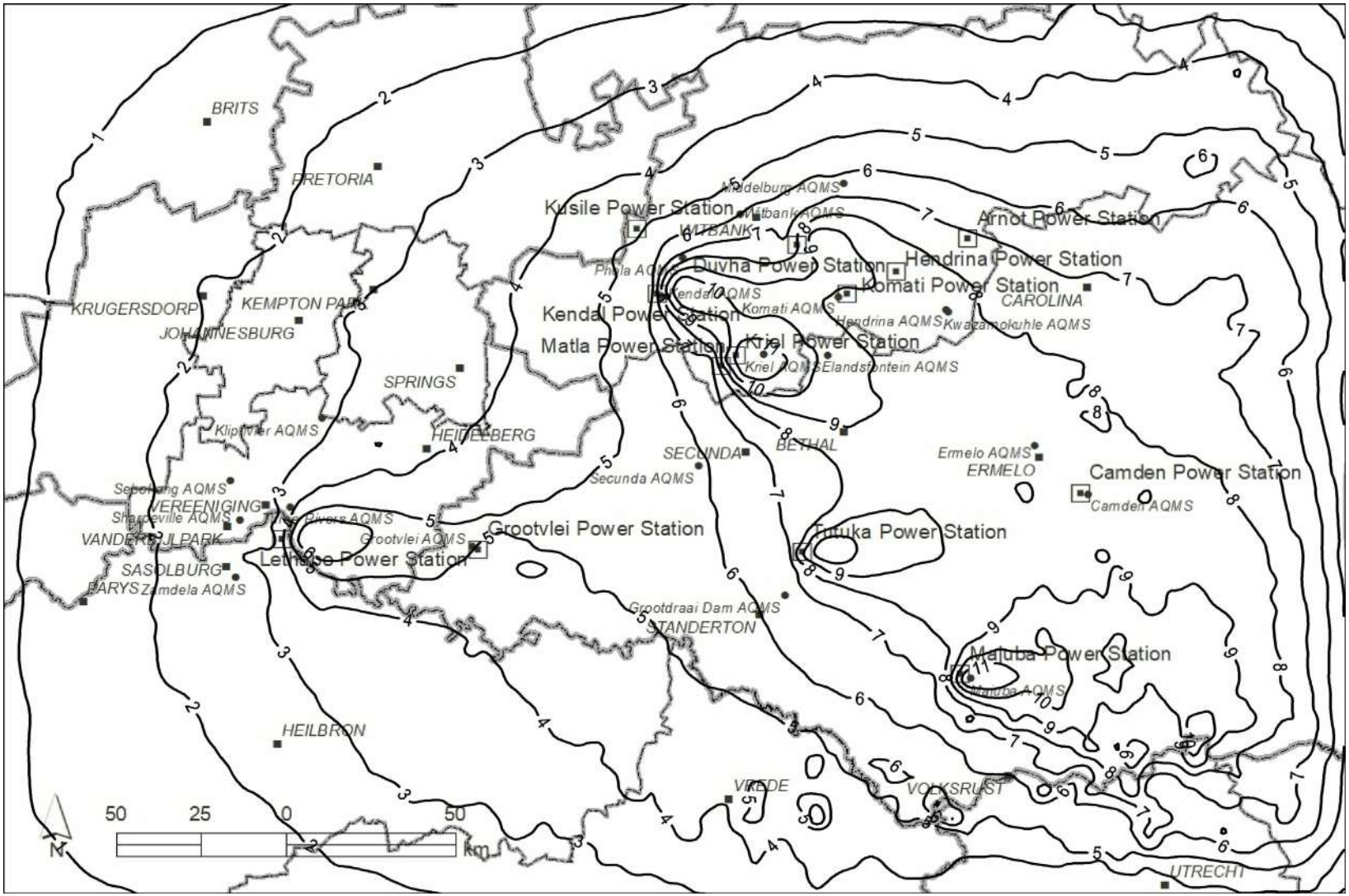

Figure 44: Predicted annual average SO_2 concentrations (µg/m^3) resulting from actual emissions from the 7 coal-fired power stations (2030 Emission Scenario)

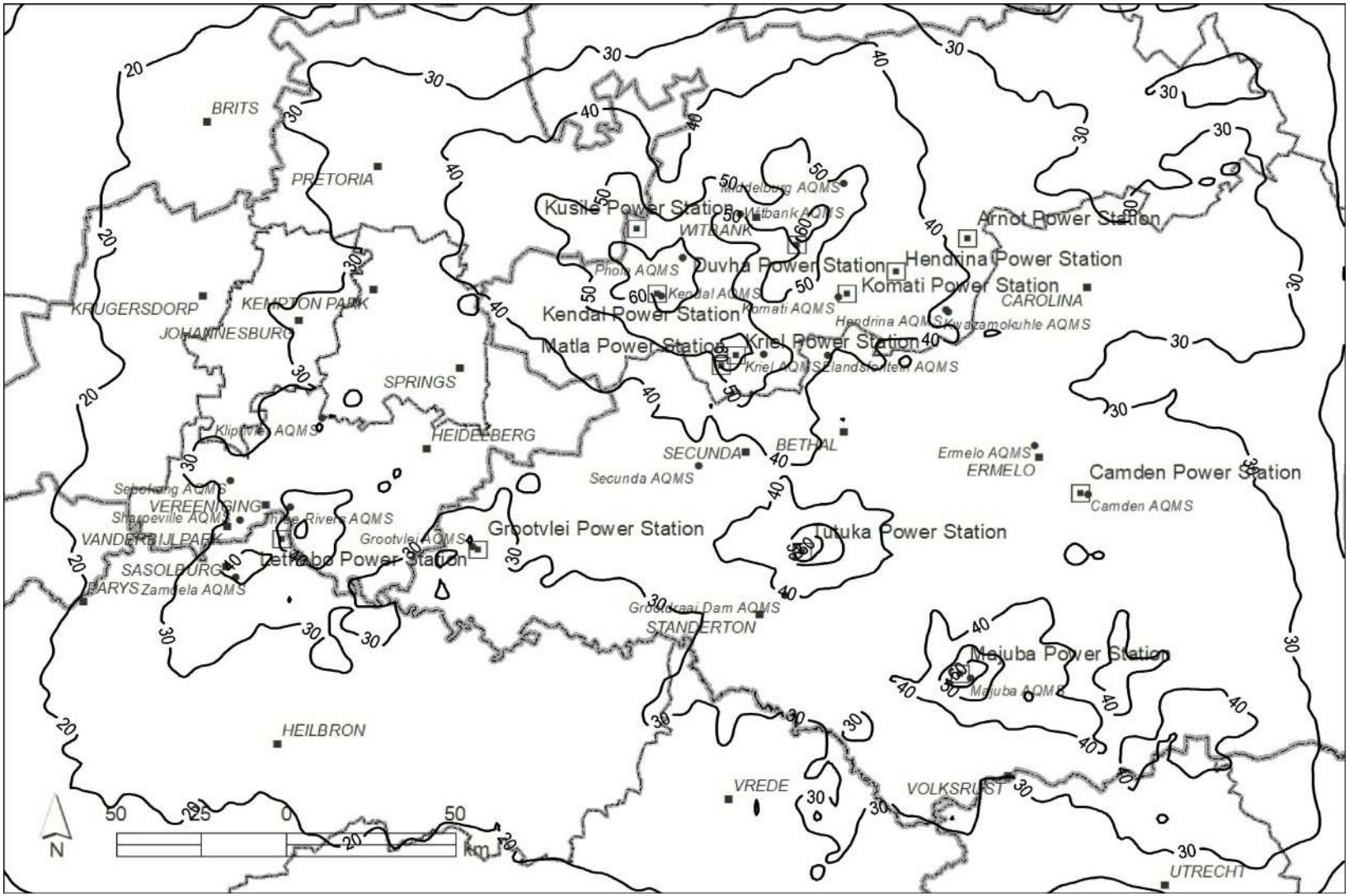

Figure 45: 99th percentile of the predicted 24-hour SO_2 concentrations for actual emissions from the 7 coal-fired power stations (2030 Emission Scenario)

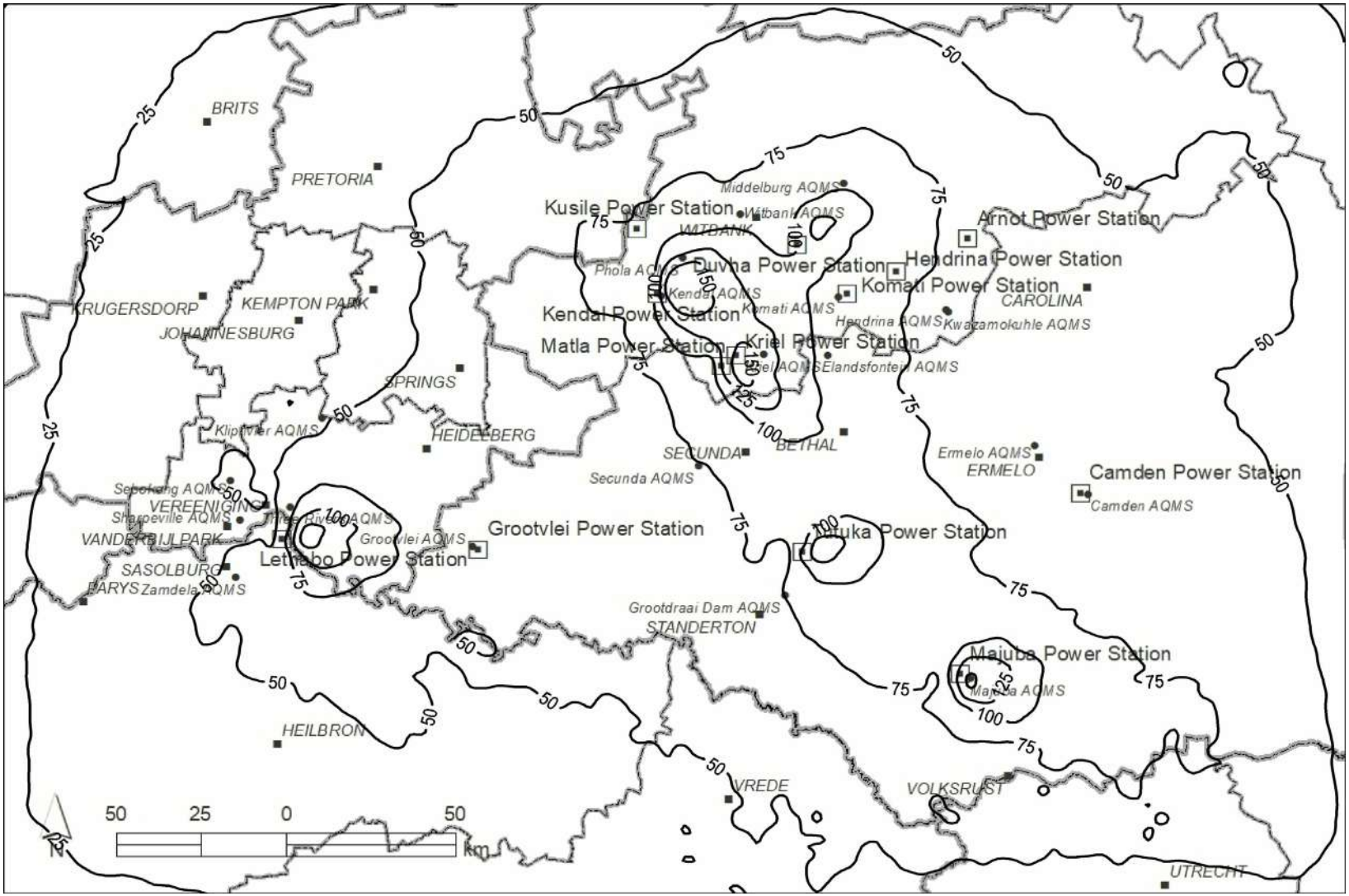

Figure 46: 99th percentile of the predicted 1-hour SO_2 concentrations resulting from actual emissions from the 7 coal-fired power stations (2030 Emission Scenario)

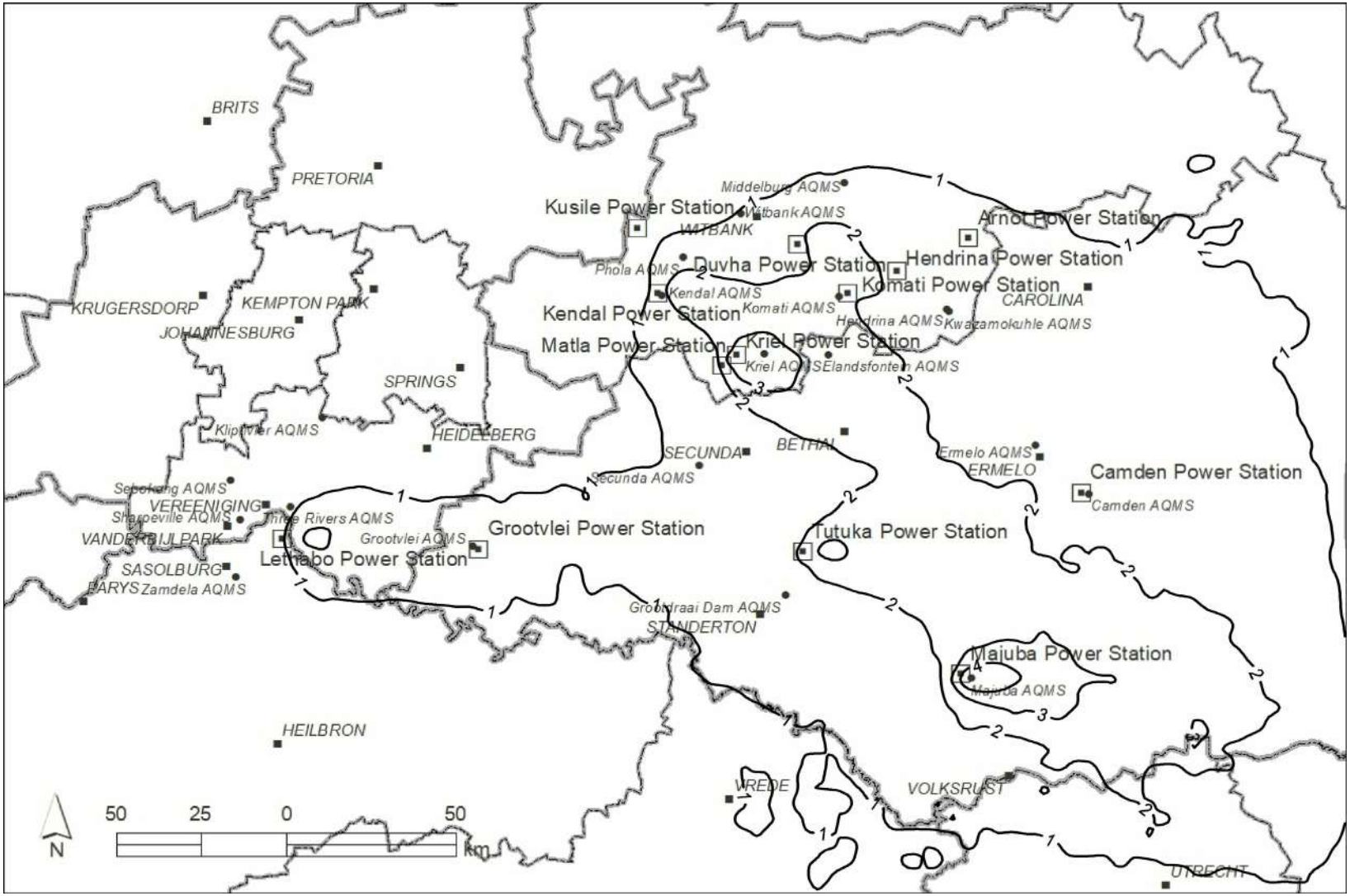

Figure 47: Predicted annual average NO_2 concentrations (µg/m^3) resulting from actual emissions from the 7 coal-fired power stations (2030 Emission Scenario)

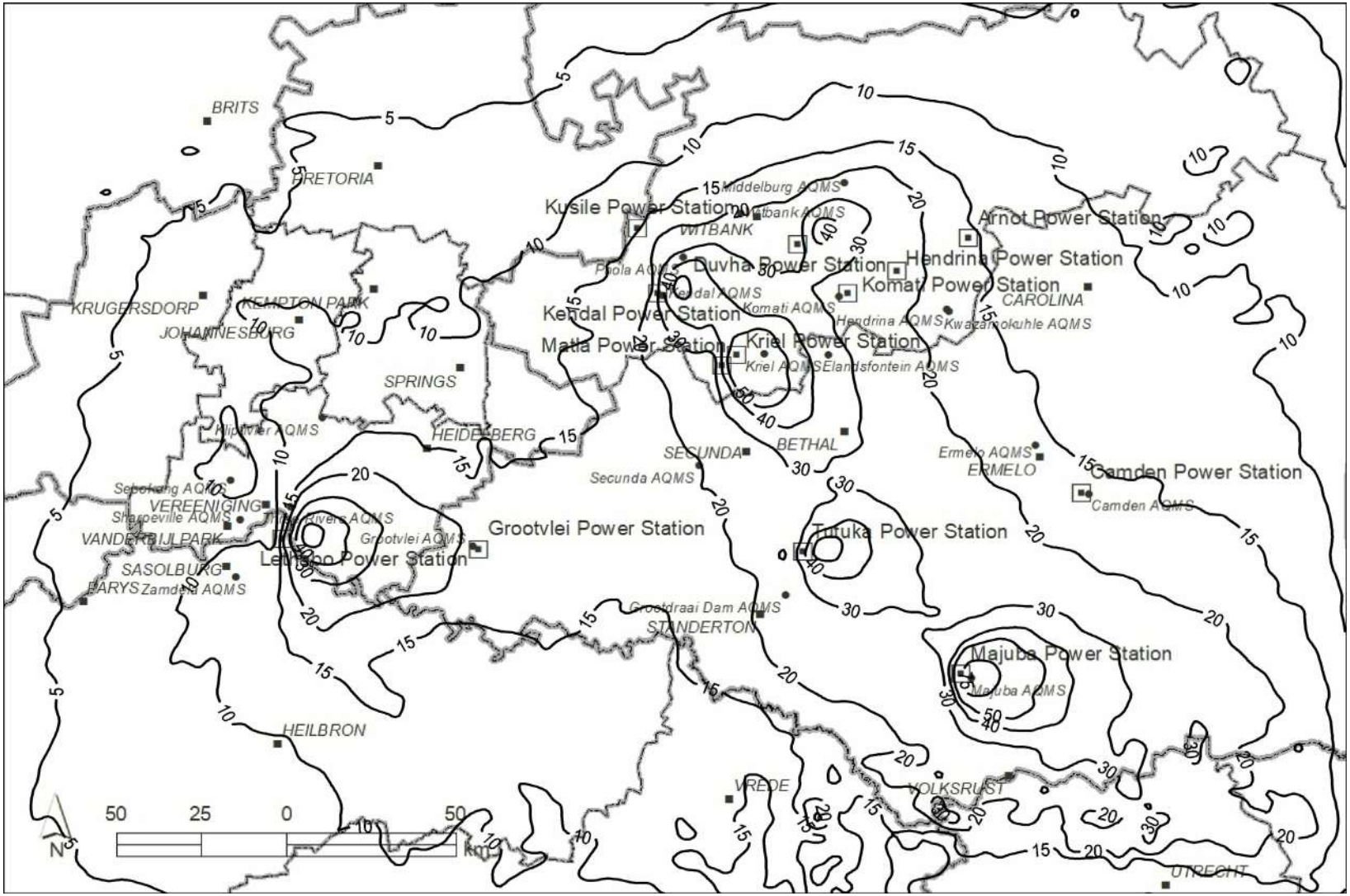

Figure 48: 99th percentile of the predicted 1-hour NO_2 concentrations resulting from actual emissions from the 7 coal-fired power stations (2030 Emission Scenario)

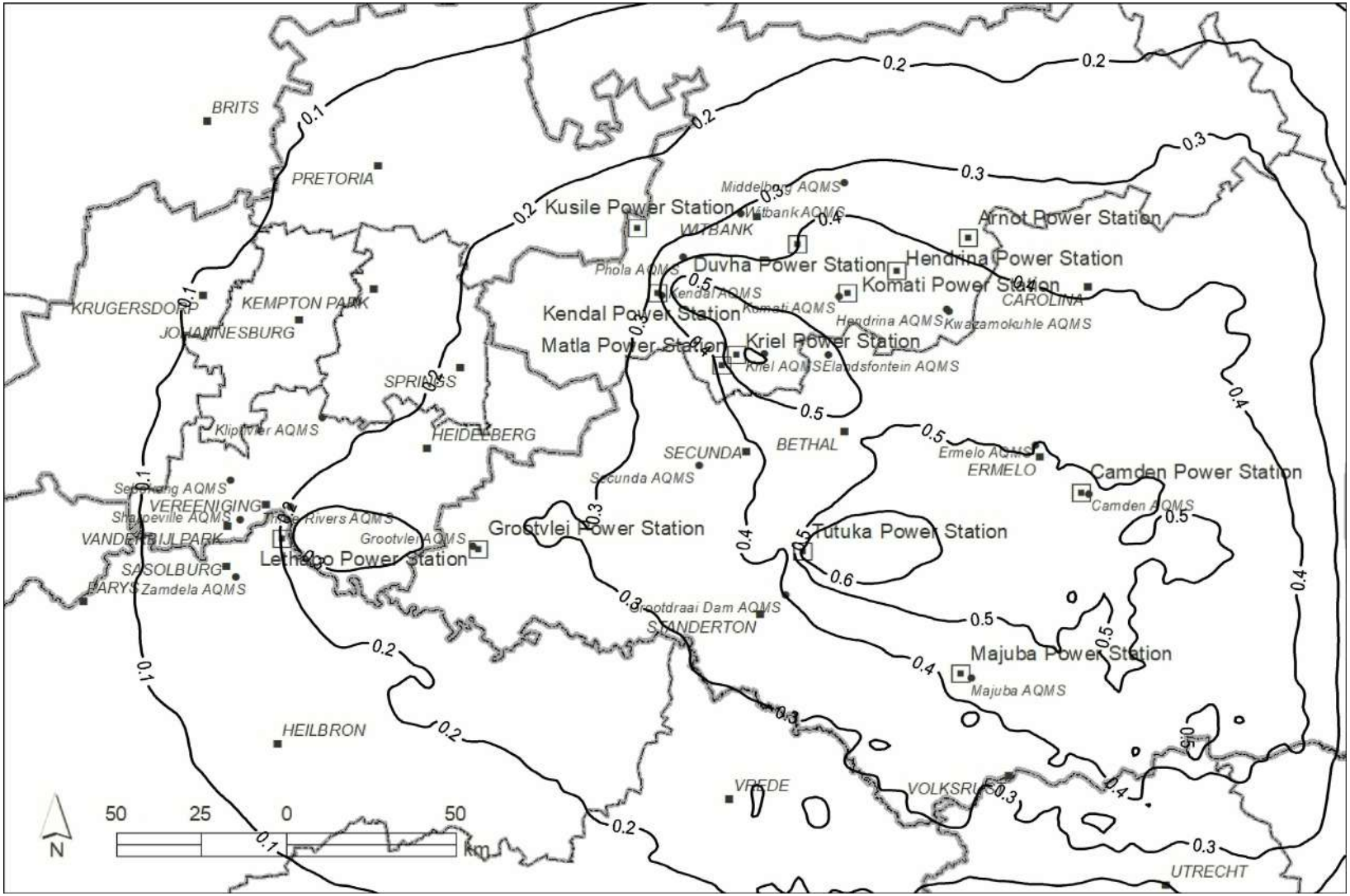

Figure 49: Predicted annual average PM_{10} concentrations (µg/m^3) resulting from actual emissions from the 7 coal-fired power stations (2030 Emission Scenario)

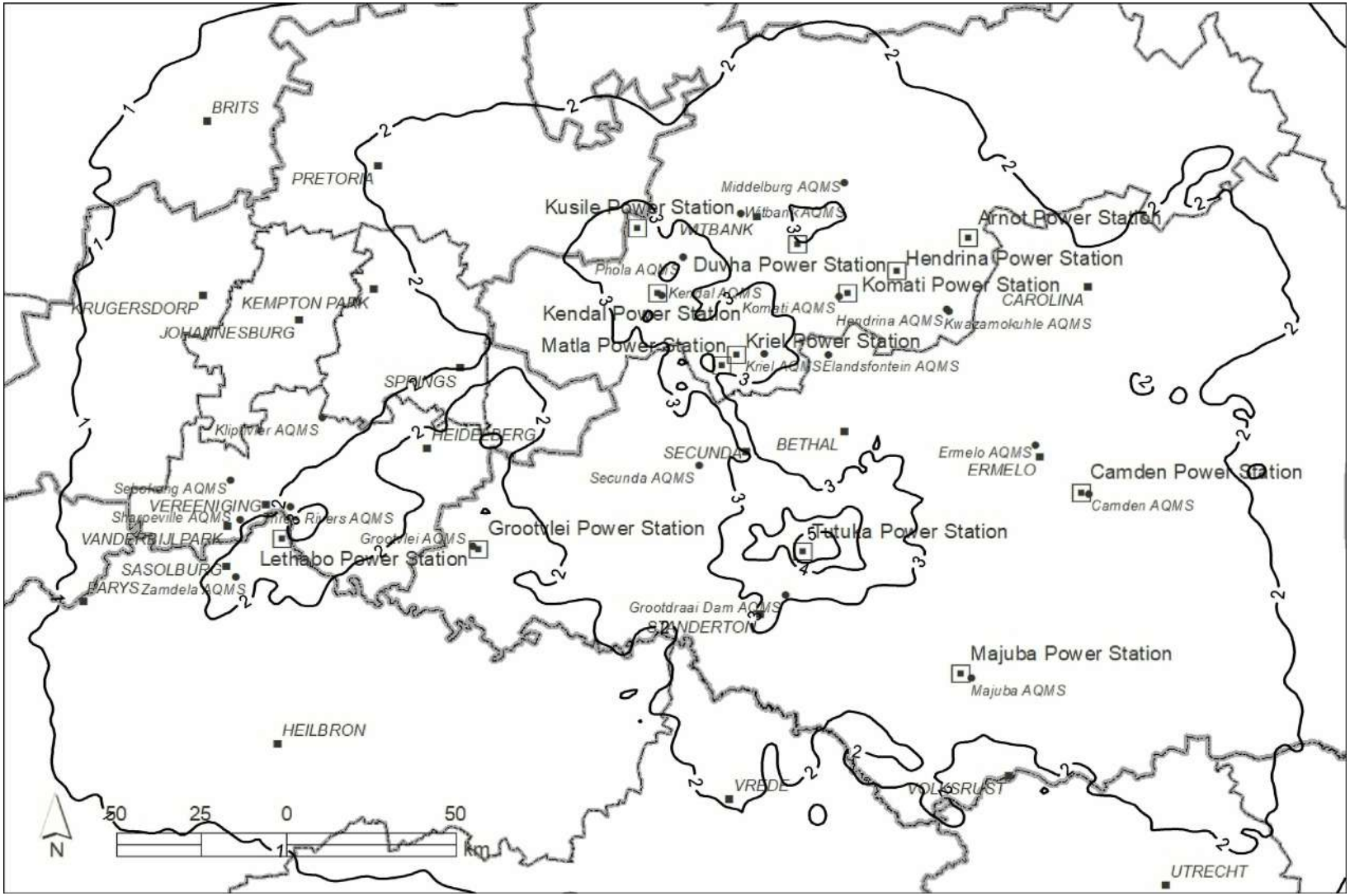

Figure 50: 99th percentile of the predicted 24-hour PM_{10} concentrations resulting from actual emissions from the 7 coal-fired power stations (2030 Emission Scenario)

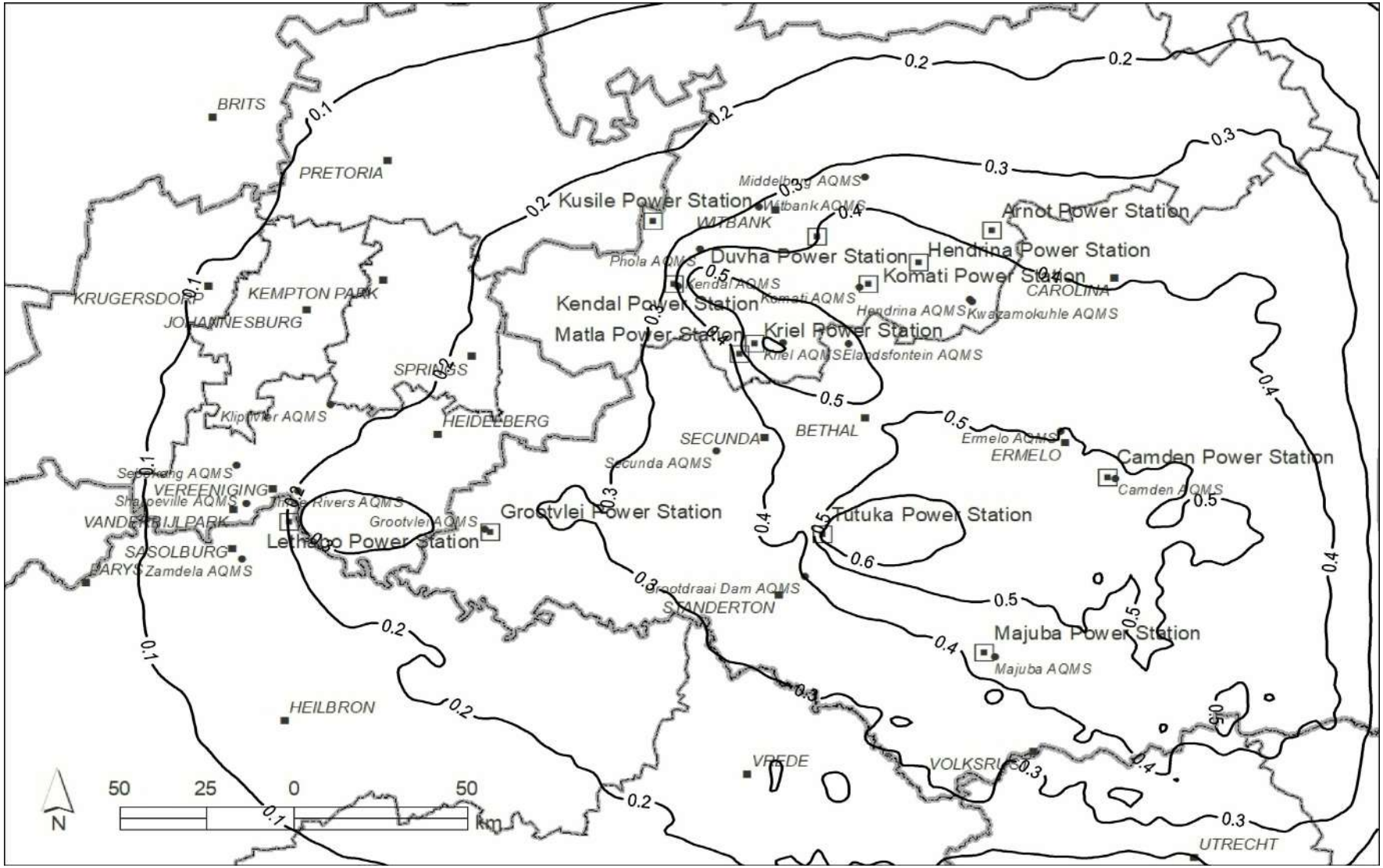

Figure 51: Predicted annual average $PM_{2.5}$ concentrations (µg/m³) resulting from actual emissions from the 7 coal-fired power stations (2030 Emission Scenario)

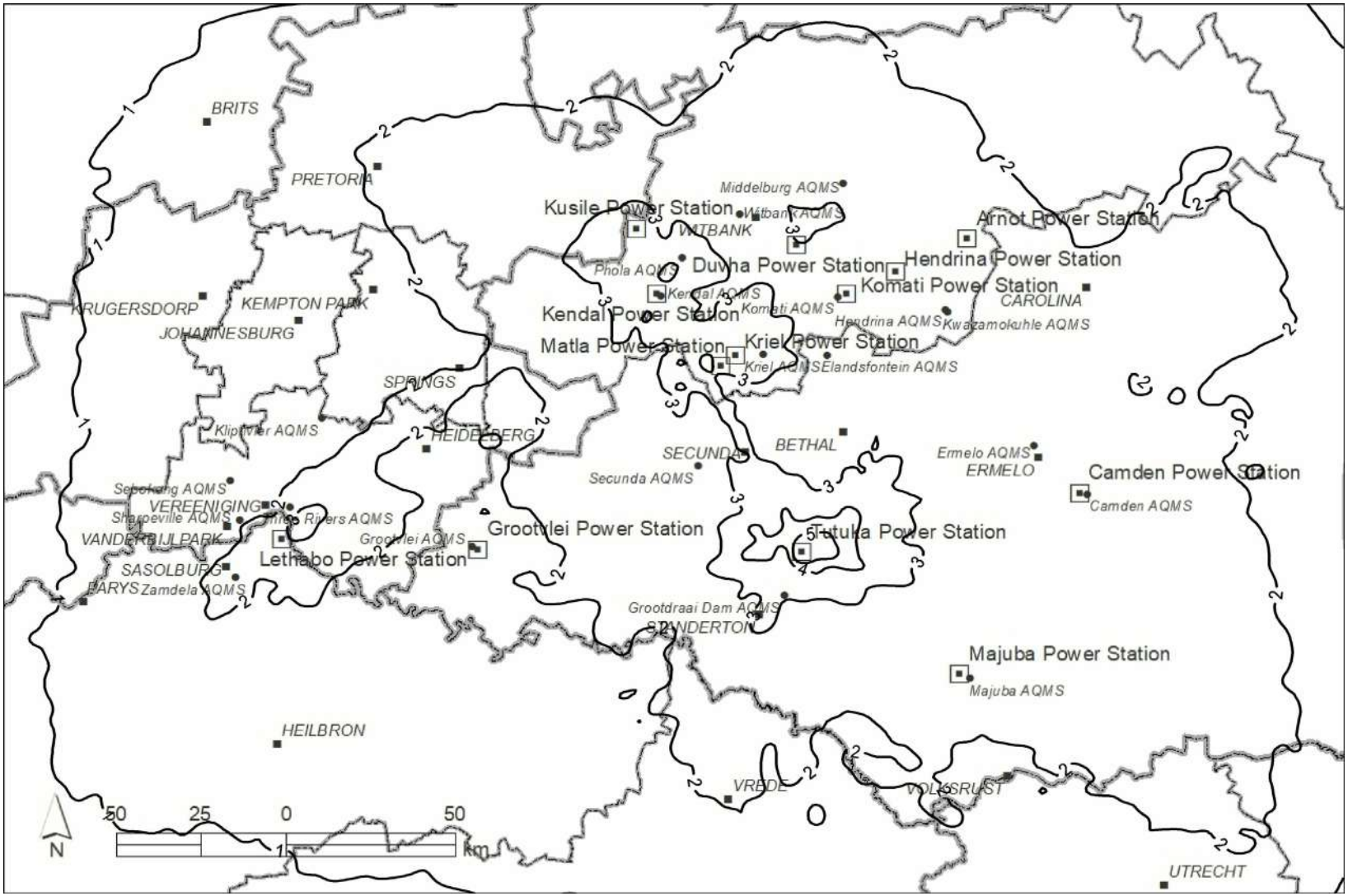

Figure 52: 99th percentile of the predicted 24-hour $PM_{2.5}$ concentrations resulting from actual emissions from the 7 coal-fired power stations (2030 Emission Scenario)

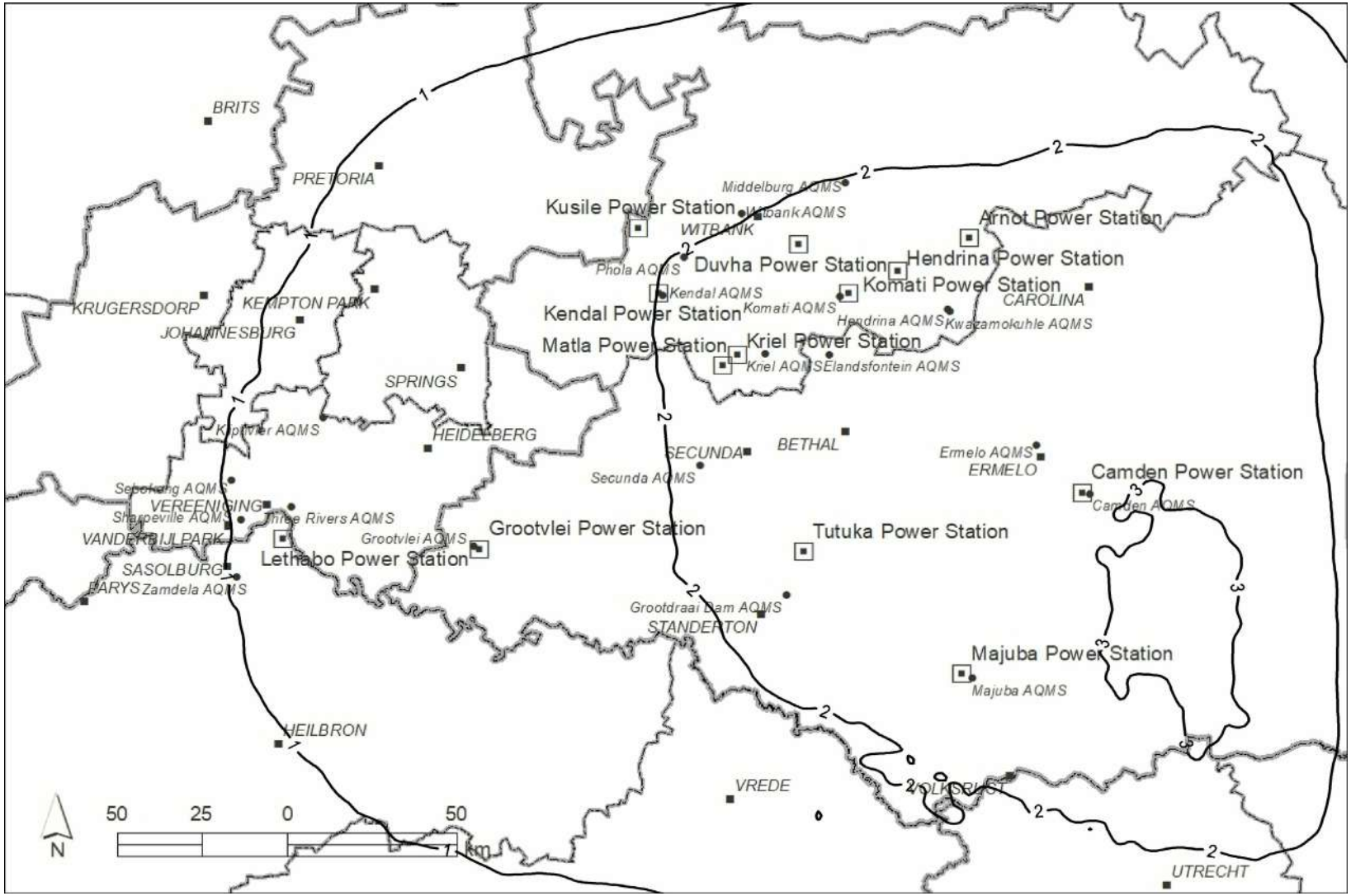

Figure 53: Predicted annual average secondary particulate with $PM_{2.5}$ concentrations (µg/m^3) resulting from actual emissions from the 7 coal-fired power stations (2030 Emission Scenario).

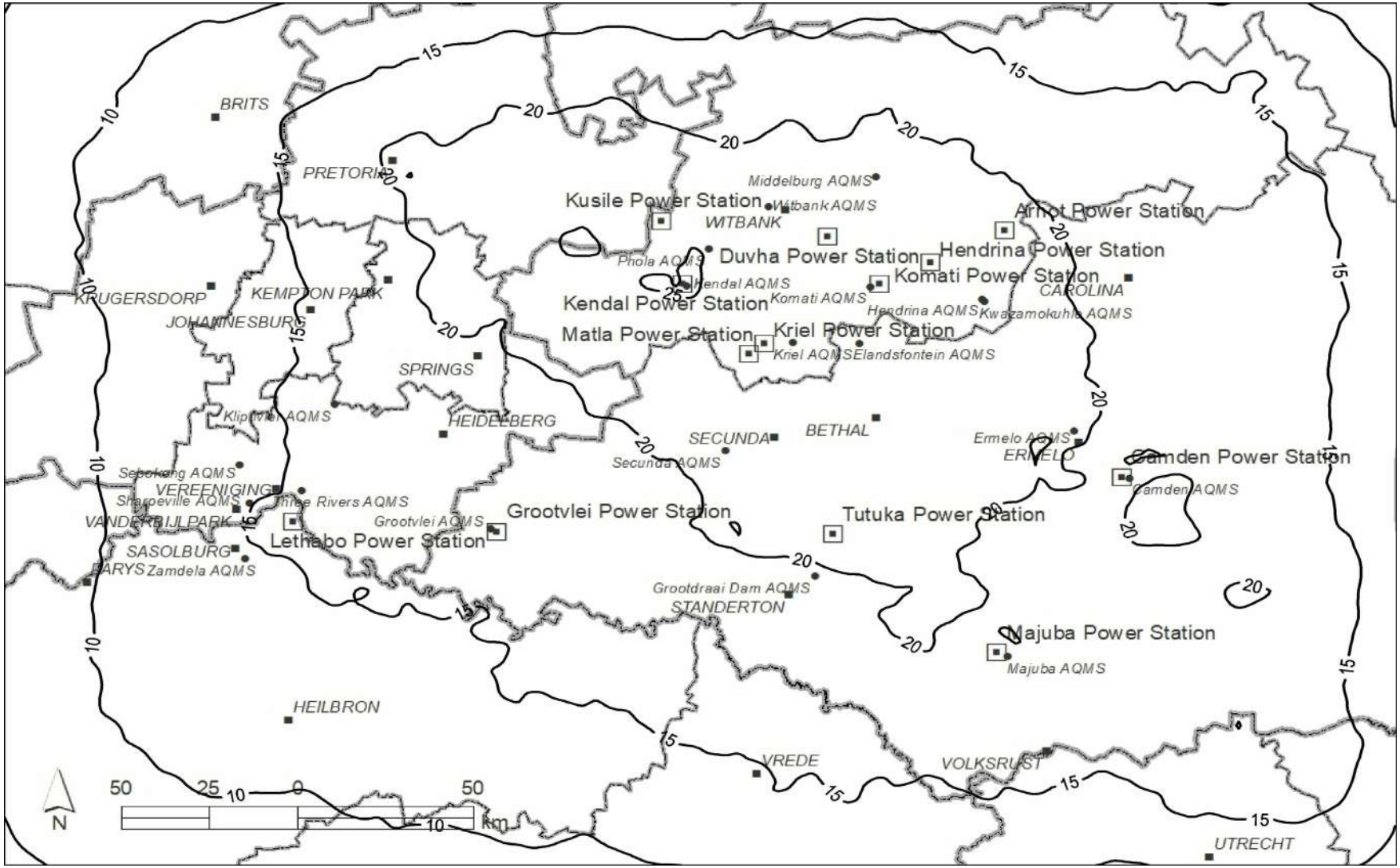

Figure 54: 99th percentile of the predicted 24-hour secondary particulate with $PM_{2.5}$ concentrations resulting from actual emissions from the 7 coal-fired power stations (2030 Emission Scenario).

4 ANALYSIS OF EMISSIONS' IMPACT ON HUMAN HEALTH

4.1 Overview

As previously described the key atmospheric emissions from coal and liquid fuel combustion at Eskom's power stations are SO_2, NO_x and particulates and the NAAQS for these pollutants have already been presented (see Table 1). The potential effect of these pollutants is described in the section that follows.

4.2 Sulphur dioxide (SO_2)

On inhalation, most SO_2 only penetrates as far as the nose and throat, with minimal amounts reaching the lungs, unless the person is breathing heavily, breathing only through the mouth, or if the concentration of SO_2 is high (CCINFO, 1998). The acute response to SO_2 is rapid, within 10 minutes in people suffering from asthma (WHO, 2005). Effects such as a reduction in lung function, an increase in airway resistance, wheezing and shortness of breath, are enhanced by exercise that increases the volume of air inspired, as it allows SO_2 to penetrate further into the respiratory tract (WHO, 1999). SO_2 reacts with cell moisture in the respiratory system to form sulphuric acid. This can lead to impaired cell function and effects such as coughing, broncho-constriction, exacerbation of asthma and reduced lung function.

4.3 Nitrogen dioxide (NO_2)

Exposure to NO_2 is typically inhalation and the seriousness of the effects depend more on the concentration than on the length of exposure. The site of deposition for NO_2 is the distal lung where NO_2 reacts with moisture in the fluids of the respiratory tract to form nitrous and nitric acids. About 80 to 90% of inhaled nitrogen dioxide is absorbed through the lungs (CCINFO, 1998). Nitrogen dioxide (present in the blood as the nitrite ion) oxidises unsaturated membrane lipids and proteins, which then results in the loss of control of cell permeability. Nitrogen dioxide caused decrements in lung function, particularly increased airway resistance. People with chronic respiratory problems and people who work or exercise outside will be more at risk to NO_2 exposure (EAE, 2006).

4.4 Particulate Matter

Particulate Matter (PM) is a broad term used to describe the fine particles found in the atmosphere, including soil dust, dirt, soot, smoke, pollen, ash, aerosols and liquid droplets. With PM, it is not just the chemical composition that is important but also the particle size. Particle size has the greatest influence on the behaviour of PM in the atmosphere with smaller particles tending to have longer residence times than larger ones. PM is categorised, according to particle size, into TSP, PM_{10} and $PM_{2.5}$.

Total suspended particulates (TSP) consist of all sizes of particles suspended within the air smaller than 100 micrometres (µm). TSP is useful for understanding nuisance effects of PM, e.g. settling on houses, deposition on and discolouration of buildings, and reduction in visibility.

PM_{10} describes all Particulate Matter in the atmosphere with a diameter equal to or less than 10 µm. Sometimes referred to simply as coarse particles, they are generally emitted from motor vehicles (primarily those using diesel engines), factory and utility smokestacks, construction sites, tilled fields, unpaved roads, stone crushing, and burning of wood. Natural sources include sea spray, windblown dust and volcanoes. Coarse particles tend to have relatively short residence times as they settle out rapidly and PM_{10} is generally found relatively close to the source except in strong winds.

$PM_{2.5}$ describes all Particulate Matter in the atmosphere with a diameter equal to or less than 2.5 µm. They are often called fine particles, and are mostly related to combustion (motor vehicles, smelting, incinerators), rather than mechanical processes as is the case with PM_{10}. $PM_{2.5}$ may be suspended in the atmosphere for

long periods and can be transported over large distances. Fine particles can form in the atmosphere in three ways: when particles form from the gas phase, when gas molecules aggregate or cluster together without the aid of an existing surface to form a new particle, or from reactions of gases to form vapours that nucleate to form particles.

Particulate Matter may contain both organic and inorganic pollutants. The extent to which particulates are considered harmful depends on their chemical composition and size, e.g. particulates emitted from diesel vehicle exhausts mainly contain unburned fuel oil and hydrocarbons that are known to be carcinogenic. Very fine particulates pose the greatest health risk as they can penetrate deep into the lung, as opposed to larger particles that may be filtered out through the airways' natural mechanisms.

In normal nasal breathing, particles larger than 10 µm are typically removed from the air stream as it passes through the nose and upper respiratory airways, and particles between 3 µm and 10 µm are deposited on the mucociliary escalator in the upper airways. Only particles in the range of 1 µm to 2 µm penetrate deeper where deposition in the alveoli of the lung can occur (WHO, 2003). Coarse particles (PM_{10} to $PM_{2.5}$) can accumulate in the respiratory system and aggravate health problems such as asthma. $PM_{2.5}$, which can penetrate deeply into the lungs, are more likely to contribute to the health effects (e.g. premature mortality and hospital admissions) than coarse particles (WHO, 2003).

4.5 Analysis

4.5.1 Sulphur dioxide (SO_2)

For the most part there is compliance with the SO_2 NAAQS, certainly for 10 minute and hourly average concentrations but with areas of non-compliance with the daily and even annual average SO_2 concentrations in areas of high SO_2 loading such as Emalahleni, downwind of Kendal power station, the Kriel and Komati areas and KwaZamokuhle. It is noteworthy that there are generally larger concentrations of SO_2 across the Highveld than seen to prevail in the Vaal Triangle with Majuba exhibiting the lowest ambient concentrations. Compliance with the NAAQS cannot be taken to mean that there is no health risk, but rather a permissible or a tolerable level of risk. It follows then that in areas where there is no-compliance with the NAAQS, that the health risk is intolerable.

Predicted concentrations of SO_2 for the current combined emissions from all Eskom power stations indicate general compliance with the NAAQS for all averaging periods with peak predicted hourly average concentrations being no more than 50% of the NAAQS limit value. The maximum predicted daily concentration is, however, almost a 100% of the NAAQS limit value implying that the combined SO_2 emissions from all the power stations play a material role in the non-compliances evident in the daily and annual average monitoring data. Predicted ambient concentrations under the new plant MES are very slightly higher for the hourly average concentrations but a roughly 20% reduction in daily and 32% reduction in annual predicted concentrations. Further reductions in predicted ambient concentrations are seen for the 2030 scenario with an approximate 20% reduction in hourly average concentrations, an approximate 34% reduction in daily averages and an approximate 32% reduction in annual average concentrations (compared to actual emissions).

4.5.2 Nitrogen dioxide (NO_2)

From the ambient air quality data for the Highveld and the Vaal Triangle it can be seen that there is general compliance with the NO_2 NAAQS for both hourly and annual average concentrations. Whereas SO_2 concentrations are seen to be generally larger over the Highveld than the Vaal Triangle, NO_2 concentrations are generally seen to be larger over the Vaal Triangle than the Highveld.

Predicted ambient NO_2 concentrations for the combined current emissions scenario are seen to be no more than 61% of the NAAQS hourly limit value and 18% of the annual average value. MES compliance sees a significant increase in predicted ambient concentrations to the point of non-compliance with the hourly NAAQS and an effective doubling of the annual average concentration. The 2030 emissions scenario sees a

material reduction in the predicted ambient concentrations to less than half of the limit value (hourly average) and less than 13% of the annual average limit value.

4.5.3 Particulate matter (PM_{10})

For PM_{10} there is almost ubiquitous non-compliance with the daily and annual average NAAQS with the highest number of exceedances of the NAAQS limit values being in low income dense settlements such as Phola, Sharpville, Kliprivier and Sebokeng. The measured concentrations demean the PM NAAQS with the daily NAAQS limit value being exceeded for as much as 185 days in the monitoring record. In similar vein, the annual average NAAQS is seen to be exceeded by more than two times in some instances. Diurnal variation in hourly average concentrations exhibits clear peaks in PM_{10} concentrations that occur in the early morning and the late afternoon a pattern that implies that the peak concentrations of PM_{10} are a function of domestic fuel use in low-income dense settlements.

Predicted PM_{10} concentrations as a result of PM emissions from the combined power stations result in no more than small concentrations (11% of the NAAQS limit value) of ambient PM_{10}. It is considered that the key source of the measured ambient PM_{10} concentrations is domestic fuel use with a relatively limited contribution by the combined power station emissions of PM. A modest deterioration in ambient air quality is evident when considering the predicted concentrations under the full MES compliance and a modest improvement in air quality when compared to the current emissions under the 2030 emissions scenario.

4.5.4 Particulate matter ($PM_{2.5}$)

The picture in respect of $PM_{2.5}$ is just as bleak as that for PM_{10} with universal non-compliance with the NAAQS for both daily and hourly averaging periods. The daily NAAQS limit value was seen to be exceeded more than 200 times (the allowable is 4) and the annual average NAAQS is exceeded by more than 4 times at two different monitoring stations. Diurnal hourly average concentrations also show pronounced early morning and later afternoon peaks mirroring the PM_{10} pattern and also indicating the role of domestic fuel use in low-income dense settlements in contributing to the measured concentrations.

The direct contribution to the measured ambient concentrations of $PM_{2.5}$ is small even on assuming that all PM emitted is $PM_{2.5}$. The relative contributions of the predicted $PM_{2.5}$ concentrations to the NAAQS limit value is automatically higher because of the tighter standards that apply for $PM_{2.5}$. Again there is a slight deterioration in air quality when moving to the MES compliance scenario and a slight improvement under the 2030 emissions scenario. The key issue with $PM_{2.5}$ is, however, the secondary particulates that occur as a function of emissions of SO_2 and NO_x that are converted into particulate form (principally $PM_{2.5}$). As previously described the predicted secondary $PM_{2.5}$ concentrations are seen to be at 50% of the NAAQS limit value under current combined emissions over most of the study area and at 75% of the limit value for an area around Emalenhle. This means that emissions from the power station are contributing a large background concentration of $PM_{2.5}$, which when combined with other source of SO_2 and NO_x and domestic fuel use emissions appear to result in the multiple exceedances of the limit value and the widespread non-compliance with NAAQS. There is certainly an improvement in the predicted secondary $PM_{2.5}$ under the MES compliance emissions scenario and the 2030 emissions scenario but the predicted daily concentrations are still seen to be at some 66% of the NAAQS limit value albeit over a smaller spatial area.

4.6 Analysis of Emissions' Impact on the Environment

In terms of impact on the environment, the pollutants in question pose the risk of a variety of potential non-health impacts. Of these impacts dry and wet acid deposition is considered to be the most significant but there are also concerns around potential impacts on vegetation and fauna. The most challenging part of assessing such impacts is the absence of defined damage thresholds (i.e. defined concentrations at which damage is known to occur) especially in a regulatory sense. As a result the assumption that is made here is that if there is compliance with the NAAQS that the damage risk will be considered permissible.

Various investigations have been conducted on regional acidification in both the Mpumalanga Highveld and escarpment areas, without any clear evidence emerging of significant negative impacts. These various investigations are cited in Josipovic (2009) who proceeded to investigate whether '*the impacts of emitted pollutants and relationally accumulated deposition of acidic air pollutants eventually exceed the carrying capacity of the natural environment*'. He further goes on to argue that: [bearing in mind the stated uncertainties][1] '*acidic pollution originating from the central industrial Highveld is not a current environmental threat to the environment in remote areas of South Africa, specifically the Mpumalanga Escarpment and forestry areas, and by implication neither is it a threat to adjacent countries. However, zones within north-west Mpumalanga and south to south east of the Witbank industrial area have indicated as areas exceeding critical loads of acidification, due also to local districts of sensitive soils. Although not extensive in spatial distribution, with one area only showing the highest exceedance level, these results indicate that areas in the vicinity of the central industrial zone that have susceptible soils are at risk of exceeding critical loads.'*

It is therefore clear that long-term emissions of acidic gases such as SO_2 and NO_2 pose a risk of acidification, but principally in areas of sensitive soils. Given the long-term nature of the effect it must be recognized that there will be an overall reduction in SO_2 and NO_2 emissions in the longer term across the fleet, as the RTS and older power stations are progressively decommissioned. In addition the significance of the acidification risk has not been presented so it is not possible to assess the potential consequences (biodiversity loss, reductions in land potential and so forth) in any meaningful way. More importantly perhaps it is simply not possible to weigh up the benefits of reduced acid gas emissions (that would occur if there was full compliance with the MES) against the financial and non-financial costs of full MES compliance.

5 CONCLUSIONS

In this summary AIR the combined ambient air quality data for 15 monitoring stations across the Mpumalanga Highveld and Vaal Triangle has been presented and analysed. The general conclusions of that analysis is the NO_2 is generally complaint with the NAAQS, but daily and even annual SO_2 concentrations are seen to be non-compliant in several 'hot spots' across the Highveld known to be large sources of SO_2. The fact that there are daily and annual average non-compliances indicates the large and sustained SO_2 loading in these areas. Daily and annual average PM_{10} and $PM_{2.5}$ concentrations are seen to be non-compliant at almost all the monitoring stations and for extended periods of time, well more than 100 days in the case of PM_{10} and more than 200 days for $PM_{2.5}$ for a given station and year when 4 is the allowable number of exceedances.

The net effect of all of the above is that PM is already and unequivocally resulting in unacceptable health risk for a large part of the Highveld. The direct contribution of the individual power stations in isolation to that situation is considered to be small and it is argued that ambient PM_{10} remains fundamentally a domestic fuel use problem. In respect of $PM_{2.5}$ which is clearly problematic from the monitoring data over the entire study area it can be seen from the predicted concentrations of secondary $PM_{2.5}$ that the combination of SO_2 and NO_x emissions from all the Highveld power stations is predicted to form a significant component of the $PM_{2.5}$ load especially over the Emalahleni Middelburg area where predicted 24 hour concentrations of secondary $PM_{2.5}$ are seen at some 75% of the NAAQS limit value and at 50% of the NAAQS limit value for most of the Highveld. In addition the combined SO_2 emissions from all Eskom power stations are predicted to contribute some 56% of the NAAQS limit value in and around the Emalahleni Middelburg areas and extending southwards to Komati power station where non-compliance with the 24 hour NAAQS is evident in the monitoring data. It is clear from the analysis that the non-compliance is not Eskom alone, but the power stations are significant contributors to the air quality seen to prevail across the Highveld. Full compliance with the MES is not seen to be the panacea for that circumstance although important improvements in air quality are evident under an MES compliant emissions scenario and indeed for the 2030 emissions scenarios that will see some five power stations having been taken out of operation.

[1] *As described in the PhD Thesis.*