# THE STATE OF SOUTH AFRICA'S AIR QUALITY MONITORING NETWORK, AND ITS AIR QUALITY

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Continuous monitoring of air pollutant concentrations at a network of locations is essential but not sufficient for a credible assessment of ambient air quality. A monitoring network has limited spatial representivity, but more spatially representative methods such as air quality modelling and remote sensing are reliant on monitoring for validation and calibration of their outputs. In preparation for the assessment of the contribution of air pollution to the burden of disease based on $PM_{2.5}$ and ozone exposure, the available monitored $PM_{2.5}$ and $PM_{10}$ data for the period 2012-2015 are analysed. Available monitored $PM_{2.5}$ and $PM_{10}$ data for the period 2012 to 2015 are analysed with respect to spatial distribution, data recovery, daily and annual average time trends, and compliance with South African National Ambient Air Quality Standards (NAAQS) and World Health Organisation guidelines. In 2012 only 11 stations, all in the Vaal Triangle and Highveld Priority Areas, of about 78 nominally active monitoring stations monitored $PM_{2.5}$. Annual data recoveries for these stations were mostly acceptable at >80%. Annual average $PM_{2.5}$ at 10 of these stations exceeded the current NAAQS; daily averages are generally also non-compliant. Available $PM_{10}$ data at a further 25 stations are used to estimate $PM_{2.5}$ concentrations, using appropriate $PM_{2.5}$:$PM_{10}$ ratios in each area. Annual data recoveries were poor (<25%) to acceptable (>80%). The current $PM_{2.5}$ NAAQS was exceeded, in 2012, at 11 of 12 monitoring stations in the Tshwane/ Johannesburg/ Ekhuruleni networks; in eThekwini two of four, in the City of Cape Town one of seven and Richards Bay two of four exceeded this standard. The data reveals insufficient development of a national air quality network, no evidence of improvement in air quality in the Highveld and Vaal Triangle Priority Areas during 2012-2015 and raise concerns about high levels of particulate matter in Tshwane and Ekhuruleni.

*Keywords*: air quality, $PM_{2.5}$, monitoring network, compliance, time trends, spatial distribution.

## 1. Introduction

The context of this analysis of South African particulate matter (PM) monitored data is the second South African National Burden of Disease (SANBD2) study by the Burden of Disease Research Unit of the South Africa Medical Research Council (SAMRC), specifically the health impacts attributable to ambient air pollution. The Global Burden of Disease (GBD) 2013 (GBD2013) estimated that globally about 2.9 million deaths in 2013 were attributable to exposure to $PM_{2.5}$ ($PM_{2.5}$: particulate matter with aerodynamic diameter less than 2.5 μm) and a further 217 000 deaths were attributable to long term ozone exposure (Brauer *et al*, 2015). GBD2013 selected $PM_{2.5}$ and ozone as indicators of exposure to ambient air pollution based on extensive epidemiologic and mechanistic evidence indicating independent adverse health impacts (Brauer *et al*, 2015). $PM_{2.5}$ is also both a primary pollutant, emitted directly from sources, and secondary pollutant formed in the atmosphere from gaseous precursors including sulphur dioxide and oxides of nitrogen (NOx) (for example, WHO 2013). Consistent with the GBD2013 methodology, the air pollution component of the SANBD2 uses the population weighted annual average concentrations of $PM_{2.5}$ and the long term exposure to ozone as the air pollution exposure metrics to calculate the disease burden attributable to air pollution in South Africa. The burden of disease attributable to long term exposure to $PM_{2.5}$ include, in adults, ischemic heart disease (IHD), cerebrovascular disease (stroke), chronic obstructive pulmonary disease

(COPD), and lung cancer (LC), and in children < 5 years of age acute lower respiratory infection (ALRI) (Burnett *et al*, 2014). The year 2012 is the selected base year for the study as the 2012 mortality estimates are available. This study focuses on monitored $PM_{2.5}$ concentrations only.

Ambient air quality data are an essential but by no means sufficient for assessing air quality and human exposure to air pollution. Monitored surface pollutant concentrations provide a spatially limited estimate of population exposure to ambient air pollution. The measured concentrations are only representative of exposure of the population in the immediate vicinity of a monitoring station. Steep population gradients, especially in urban areas, require highly spatially resolved exposure estimates to provide accurate estimates of population weighted exposure. The generally poor spatial distribution of South African monitoring stations – comparatively few are located in densely populated areas – means that an accurate estimate of population weighted exposure is additionally compromised if based on monitoring station data only.

The prospective use of remote sensing satellite data (aerosol optical depth, AOD, retrievals) and chemical transport modelling (CTM) to estimate ambient $PM_{2.5}$ (particulate matter less than 2.5 µm in aerodynamic diameter) concentrations provide greatly improved spatially resolved estimates of ambient $PM_{2.5}$ concentrations as well as the prospect of revealing long term trends (Brauer *et al*. 2013). Importantly, these methods still require monitored data, daily average $PM_{2.5}$ values, for the calibration and validation of their estimates, and CTM requires an accurate spatially and temporally resolved emissions inventory.

Ambient data alone provide a limited estimate of year to year air quality trends since this method alone cannot distinguish between year to year meteorological variability and moderate variability and trends in source emissions. The analysis of the Highveld and Vaal Triangle Priority Areas' (HPA and VTPA respectively) data is extended to 2015 to assess $PM_{2.5}$ trends over the period 2012-2015.

## 2. Methods

All data were supplied by the relevant networks via the South African Weather Service except that City of Cape Town data were provided directly. Some data clean-up was required. Consecutive days with values less than 1 µg/m$^3$ were regarded as invalid as were negative values (very few data points). These values were tabulated as 'nodata' to ensure the correct calculation of annual averages. All daily values were tabulated against Julian days.

In the absence of $PM_{2.5}$ data, available $PM_{10}$ (particulate matter less than 10 µm in aerodynamic diameter) data are used to estimate corresponding daily average $PM_{2.5}$ values using appropriate $PM_{2.5}$:$PM_{10}$ ratios selected according to Brauer *et al*'s protocol (Brauer *et al*. 2013). This protocol preferentially uses locally (within 50 kms) derived $PM_{2.5}$:$PM_{10}$ ratios where both PM10 and PM2.5 were measured, providing that these estimates are between 0.2 and 0.8.

The data recovery efficiency, the percentage of validated daily values for the year, was calculated for each monitoring station and compared with a benchmark of 80%. The South African National Accreditation System (SANAS) requirement for the accreditation of air quality monitoring stations is for data to be supplied for 90% of the monitoring period (not less than three months) (SANAS 2012) but "data supply" appears to refer to data recovered before application of validation checks.

Annual average $PM_{2.5}$ values, directly monitored and calculated from the $PM_{10}$ monitored values using area appropriate ratios, are compared with the current NAAQS. $PM_{2.5}$ trends over the period 2012-2015 in the two priority areas are assessed by plotting daily average values over the entire period, by examining annual average concentrations and trend analysis.

## 3. Results

The South African network of monitoring station comprises of several networks managed by local authorities, mostly by the metropolitan municipalities (Tshwane, Johannesburg, Ekuruleni, Cape Town and eThekwini), provincial authorities (Western Cape only), two private entities (Sasol and Eskom) and the Richards Bay Clean Air Association. The Nelson Mandela Bay metropolitan municipality did not, until recently, have a functioning air quality monitoring network. The priority area networks of the Vaal Triangle and the Highveld (and two background stations) are managed at the national level by the South African Weather Service (SAWS). Of about 80 monitoring stations in operation and reporting data in 2012, only 38 collected $PM_{10}$ data, and only the 11 priority area monitoring stations collected $PM_{2.5}$ (and $PM_{10}$) data. Since 2012 the national network has expanded - two background stations, three in the Waterberg-Bojana Priority Area and most recently (2015) two (privately owned) Nelson Mandela Bay municipality stations collecting particulate matter data have been added. The data quality assurance practises between the networks varies. Only the SAWS managed networks publish monthly reports detailing the quality assurance procedures applied to the data.

## 3.1 $PM_{2.5}$:$PM_{10}$ ratios

The $PM_{2.5}$:$PM_{10}$ ratios for the Priority Area monitoring stations, for 2012 and the multi-year average for 2012-2015, are summarised in Table 1.

Table 1: Priority Area $PM_{2.5}$:$PM_{10}$ ratios

| | | $PM_{2.5}$:$PM_{10}$ ratio, 2012 | Average $PM_{2.5}$:$PM_{10}$ ratio, 2012-15 |
|---|---|---|---|
| **VTPA** | Diepkloof | 59% | 57% |
| | Klipriver | 59% | 62% |
| | Sebokeng | 73% | 70% |
| | Sharpville | 59% | 57% |
| | Three rivers | 44% | 48% |
| | Zamdela | *37%** | 51% |
| **HPA** | Secunda | 45% | 45% |
| | Ermelo | 51% | 46% |
| | Hendrina | *39%** | 50% |
| | Middleburg | 43% | 47% |
| | Witbank | 48% | 48% |

* The year to year trends in $PM_{2.5}$:$PM_{10}$ ratios appear to be fairly constant except for these values.

Daily average and annual average concentrations for stations with only $PM_{10}$ measurements were calculated based on the respective $PM_{2.5}$:$PM_{10}$ ratio in accordance with Brauer et al's protocol (Brauer et al, 2015). For the eThekwini and Richards Bay $PM_{10}$ data, a $PM_{2.5}$: $PM_{10}$ ratio of 0.76 was calculated as the average ratio of a set of 207 simultaneously monitored Southern Works (Ethekwini network) daily PM2.5 and $PM_{10}$ values; for the Tshwane and Ekhuruleni networks, the average ratio, 0.58, of the Diepkloof and Klipriver values was used; for the City of Cape Town a ratio of 0.56 was used, the average ratio reported by S. Benson (Benson S, 2007). Note that although Benson reported seasonal ratios the limited number of data points and data scatter do not justify using the seasonal estimates of the ratio.

The 2012 annual average $PM_{2.5}$ concentrations for all available networks are presented in Table 2.

Table 2: 2012 annual average $PM_{2.5}$ concentrations and data recoveries, by area, network and monitoring station

| Area | Monitoring station | Coordinates: Latitude | Coordinates: Longitude | Data recovery | Annual average PM2.5 [µg/m3] | Network |
|---|---|---|---|---|---|---|
| Tshwane | | | | | | |
| | Bodibeng | -25.492833 | 28.093733 | 95% | **36** | Tshwane |
| | Booysens | -25.713650 | 28.132097 | 94% | **38** | Tshwane |
| | Mamelodi | -25.716567 | 28.336606 | ***28%*** | **35** | Tshwane |
| | Olievenhoutbosch | -25.911667 | 28.092939 | 98% | **63** | Tshwane |
| | PTA West | -25.755500 | 28.146108 | ***28%*** | **43** | Tshwane |
| | Rosslyn | -25.615356 | 28.088033 | ***69%*** | 16 | Tshwane |
| Ekurhuleni | Bedfordview | -26.178611 | 28.133194 | ***71%*** | **50** | Ekurhuleni |
| | Etatwa | -26.116611 | 28.476417 | ***71%*** | **51** | Ekurhuleni |
| | Germiston | -26.227313 | 28.177344 | ***45%*** | **29** | Ekurhuleni |
| | Thembisa | -25.9945 | 28.223306 | ***64%*** | **52** | Ekurhuleni |
| | Thokoza | -26.329528 | 28.142944 | ***30%*** | **65** | Ekurhuleni |
| | Wattville | -26.228056 | 28.301278 | ***72%*** | **54** | Ekurhuleni |
| eThekwini | City Hall | -29.96117 | 30.03883 | ***37%*** | **22** | eThekwini |
| | Ferndale | -29.77789 | 30.22211 | ***72%*** | 10 | eThekwini |
| | Ganges | -29.9485 | 30.0515 | ***64%*** | **33** | eThekwini |
| | Wentworth Reservoir | -29.93408 | 30.06592 | ***61%*** | 16 | eThekwini |
| Cape Town | Bellville South | -33.9155 | 18.643556 | 86% | 12 | Cape Town |
| | Foreshore | -33.913821 | 18.425122 | 100% | 12 | Cape Town |
| | Goodwood | -33.90243 | 18.565024 | 98% | 14 | Cape Town |
| | Khayelitsha | -34.038139 | 18.66965 | 91% | **23** | Cape Town |
| | Killarney | -33.834929 | 18.527485 | 97% | 12 | Cape Town |
| | Tableview | -33.819611 | 18.514297 | 80% | 10 | Cape Town |
| | Wallacedene* | -33.861685 | 18.727733 | 98% | 10 | Cape Town |

Table 2 (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| Richards Bay | Brakenham | -28.731331 | 32.039061 | 100% | 23 | RBCAA |
| | CBD | -28.7447 | 32.049242 | 100% | 20 | RBCAA |
| | St Lucia | -28.371828 | 32.4144 | 97% | 17 | RBCAA |
| | Mthunzini | -28.949334 | 31.75014 | 93% | 19 | RBCAA |
| HPA | Witbank | -26.49348 | 29.969002 | 72% | 22 | HPA |
| | Secunda | -26.131995 | 29.734349 | 81% | 27 | HPA |
| | Middleburg | -25.796061 | 29.463623 | 97% | 23 | HPA |
| | Hendrina | -26.548578 | 29.080055 | 87% | 18 | HPA |
| | Ermelo | -25.877812 | 29.188664 | 93% | 28 | HPA |
| VTPA | Diepkloof | -26.250733 | 27.956417 | 98% | 29 | VTPA |
| | Klipriver | -26.42033 | 28.084889 | 85% | 39 | VTPA |
| | Sebokeng | -26.587929 | 27.840996 | 85% | 34 | VTPA |
| | Sharpville | -26.689808 | 27.867771 | 97% | 41 | VTPA |
| | Three Rivers | -26.656976 | 27.999393 | 77% | 27 | VTPA |
| | Zamdela | -26.844889 | 27.855111 | 95% | 30 | VTPA |

The South African National Ambient Air Quality Standard (SA NAAQS) (GG35468, 2012) for annual average $PM_{2.5}$ is currently 20 µg/m3; the World Health Organisation (WHO) annual average guideline value is 10 µg/m$^3$ (WHO, 2006). Annual average values, calculated using valid daily values only, in red (25 of 36 values) exceed the current SA NAAQS. The data recovery values in blue (15 of 36) do not meet a benchmark of annual recovery greater than or equal to 80%.

## 3.2 Four year time series of Priority Areas' daily average $PM_{2.5}$ concentrations

The four year $PM_{2.5}$ data recoveries for the 9 of the 11 HPA and VTPA monitoring stations exceeded 80%; for Secunda it is 78% and for Hendrina 61%.

Time series plots of daily average (24h) $PM_{2.5}$ concentrations for each monitoring station in the two networks are shown in Figures 1 and 2. The South African 24h average AAQS for $PM_{2.5}$ of 40 µg/m$^3$ (GG35468, 2012) and the corresponding WHO guideline value of 25 µg/m$^3$ (WHO, 2006) are also shown for comparison.

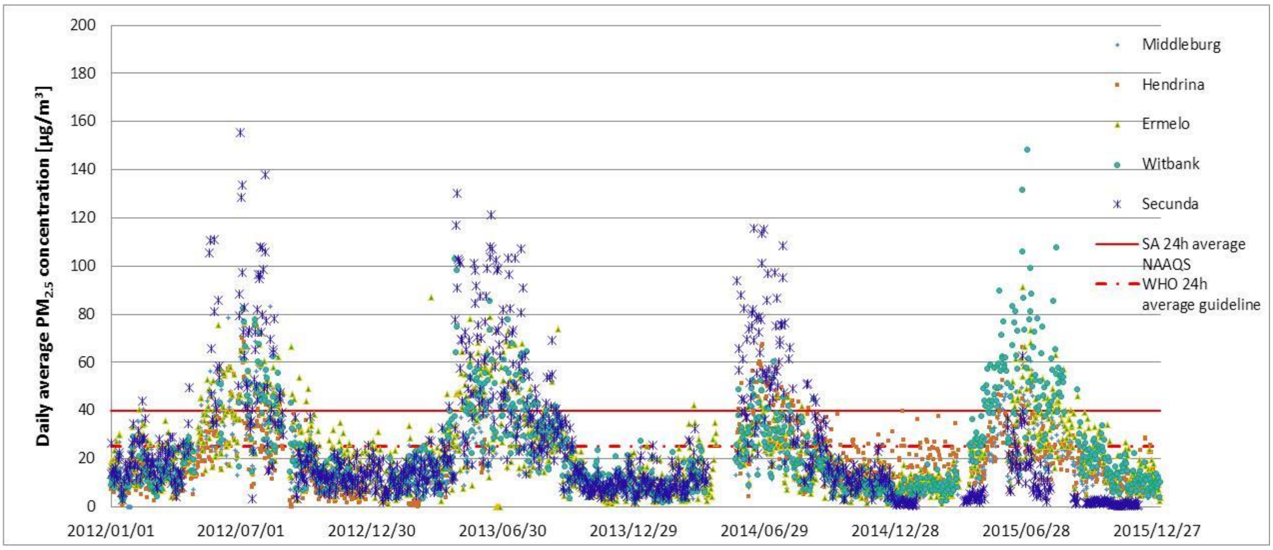



Figure 1: Highveld Priority Area daily average $PM_{2.5}$ concentrations, 2012-2015

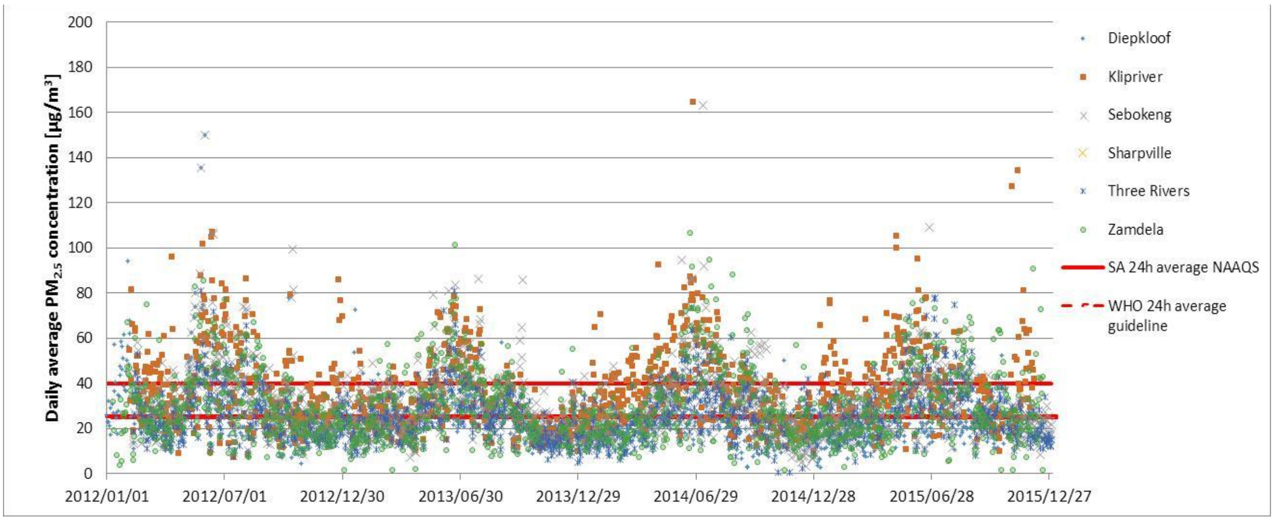



Figure 2: Vaal Triangle Priority Area daily average $PM_{2.5}$ concentrations, 2012-2015

Figures 1 and 2 show that in both priority areas numerous exceedences of the current 24h average $PM_{2.5}$ national standard occur, particularly during (but not limited) to the winter months.

To assess if an underlying trend is occurring a linear trend analysis for each station was done. The results are given in Tables 3 and 4.

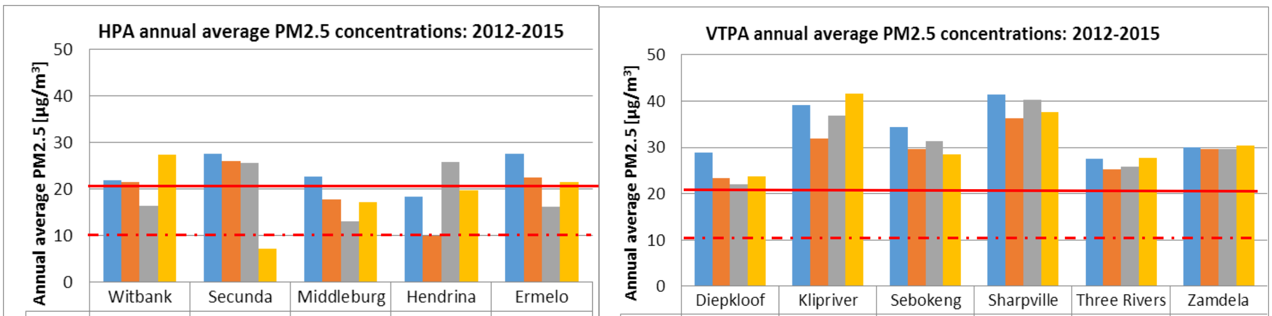
| Table 3: HPA linear trendlines | | |
|---|---|---|
| HPA | Trendline | R-squared |
| Secunda | y = -0.0165x + 709.53 | $R^2 = 0.0647$ |
| Witbank | y = 0.0025x - 81.465 | $R^2 = 0.0033$ |
| Ermelo | y = -0.0067x + 300.47 | $R^2 = 0.0310$ |
| Hendrina | y = 0.0020x - 63.317 | $R^2 = 0.0055$ |
| Middleburg | y = -0.006x + 269.55 | $R^2 = 0.0411$ |

| Table 4: VTPA linear trendlines | | |
|---|---|---|
| VTPA | Trendline | R-squared |
| Diepkloof | y = -0.0052x + 242.11 | $R^2 = 0.0312$ |
| Klipriver | y = 0.0004x + 18.221 | $R^2 = 0.0001$ |
| Sebokeng | y = -0.0056x + 262.53 | $R^2 = 0.0211$ |
| Three Rivers | y = 0.0009x - 13.067 | $R^2 = 0.0010$ |
| Zamdela | y = 0.0011x - 15.018 | $R^2 = 0.0008$ |

In all cases the R-squared (coefficient of determination) values are less than 0.1, indicating that each of the positive or negative x-coefficients is not statistically significant. That is, there has been no significant improvement in air quality (daily average PM2.5 concentrations) over the four year period at any of the Priority Area monitoring stations.

## 3.3 Priority Areas' annual average $PM_{2.5}$ concentrations

Figure 3 shows the annual average PM2.5 concentrations for both priority area networks over the four year period 2012-2015.




| | Witbank | Secunda | Middleburg | Hendrina | Ermelo |
|---|---|---|---|---|---|
| 2012 | 22 | 27 | 23 | 18 | 28 |
| 2013 | 21 | 26 | 18 | 10 | 22 |
| 2014 | 16 | 26 | 13 | 26 | 16 |
| 2015 | 27 | 7 | 17 | 20 | 21 |

| | Diepkloof | Klipriver | Sebokeng | Sharpville | Three Rivers | Zamdela |
|---|---|---|---|---|---|---|
| 2012 | 29 | 39 | 34 | 41 | 27 | 30 |
| 2013 | 23 | 32 | 30 | 36 | 25 | 30 |
| 2014 | 22 | 37 | 31 | 40 | 26 | 30 |
| 2015 | 24 | 42 | 28 | 38 | 28 | 30 |

SA annual average standard    WHO annual average guideline

Figure 3: Priority Areas' annual average PM2.5 concentrations, 2012-2015

The anomalously low (and invalid) annual average $PM_{2.5}$ values for Hendrina in 2013 (10µg/$m^3$) and for Secunda in 2015 (7µg/$m^3$) are associated with low annual data recoveries of 7% and 53% respectively.

## 4. Discussion and conclusions

The national air quality network remains poorly developed with respect to particulate matter monitoring – in 2012 only about 20% of the stations monitored $PM_{2.5}$ concentrations and about 50% monitored $PM_{10}$ concentrations. Some expansion of the network has occurred since 2012 and further deployment of $PM_{2.5}$ monitors is underway.

This analysis of data available from the national monitoring network highlights the need for consistent quality assurance and reporting practises. Data accessibility also needs to be streamlined.

Data recoveries (of PM monitors) in the priority Areas, Richards Bay and the City of Cape Town generally meet or exceed a benchmark of 80%; for the Tshwane network this standard is complied with inconsistently; none of the Ekhuruleni and eThekwini stations met the recovery benchmark in 2012. Nonetheless the 2012 monitored daily average $PM_{2.5}$ and $PM_{10}$ datasets, combined with satellite data and CTM, potentially provide a sound basis for estimating daily and annual average $PM_{2.5}$ concentrations for the largest (by population) metropolitan areas.

Further improvements in the accuracy of national estimates of exposure and the health risks posed by $PM_{2.5}$ require better spatial coverage of monitors, more monitors located in densely populated areas and consistently high data recovery.

The overwhelming majority of monitors (21 of 23 in 2012) in the more or less contiguous area covered by the Tshwane, Ekhuruleni, VTPA and HPA networks exceeded the current annual $PM_{2.5}$ AAQS of 20 µg/m$^3$, with the highest values (>60 µg/m$^3$) occurring in Tshwane and Ekhuruleni.

The daily average $PM_{2.5}$ concentrations time series' for all the priority area monitors over the period 2012-2015 show numerous exceedences of the daily standard and do not show a statistically significant decrease (or change) over this period. The annual average time series confirm that the two priority areas generally remain non-compliant with the annual average standard.

The lack of significant improvement in air quality in these areas over the four year period is of particular concern since the priority area system is supposed to focus management resources on bringing these areas into compliance with the NAAQS.

Both the hourly average and annual average $PM_{2.5}$ values in the Tshwane and Ekhuruleni areas show that particulate matter pollution levels in these two areas exceed the NAAQS and are higher than in the Priority Areas, a cause for concern given the large populations in these areas.

## 5. Acknowledgements

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