Chapter 5

Summary and Conclusions

In this study the air pollution hotspots of the Highveld were compared by utilising airborne data of O_3, NO_X, SO_2, and $PM_{2.5}$ aerosols. The air pollution hotspots which were compared are Secunda, Witbank, Rustenburg, and the Vaal Triangle. Similarities, contrasts, and seasonal variation in loading of these air pollutants in the atmosphere over the study sites were evaluated. The role of meteorology in the comparison of the levels of air pollution over the study sites was considered. A direct comparison between airborne and ground based air quality data has also been considered. This chapter highlights important findings of this study.

Comparison of the Highveld air pollution hotspots

Ozone

1. O_3 spatial average concentrations derived from baseline concentrations are relatively comparable over the Highveld air pollution hotspots in each season monitored in this study.
    - During the autumn season O_3 spatial average concentration was found to range between plus 20 to 30 ppb in the morning.
    - During the winter season O_3 spatial average concentration was found to range between plus 40 to 50 ppb in the morning and in the afternoon it ranges between plus 50 to 60 ppb.
    - During the spring season O_3 spatial average concentration was found to range between plus 50 to 60 ppb in the morning and plus 60 to plus 70 ppb in the afternoon.

2. Surface O_3 loading varies seasonally. In southern Africa it has peak concentrations in spring months from August to November. All the Highveld air pollution hotspots showed a spring O_3 spatial average concentrations peaks. For each Highveld air pollution hotspot there was a general seasonal increase in O_3 concentration loading. The minimum O_3 concentration occurred in autumn and the maximum in spring. The Secunda and the Vaal Triangle area which were monitored consistently at the same times of the day in all campaigns, in the morning and afternoon respectively, both showed approximately 10 ppb seasonal increment of O_3 concentration. The quantification of seasonal O_3 concentration increments over Witbank and Rustenburg was complicated by the fact that monitoring was done during different times of the day.

Nitrogen monoxide

3. During the autumn when there is less contribution of NO_X from veld fires and domestic fossil fuel burning, Secunda had the highest NO levels in the morning followed by Witbank then Rustenburg. The NO loading may be attributed to industrial and traffic emissions. Over the Vaal Triangle no NO was detected in parts per billion (ppb) measurement scale in the afternoon. The deep afternoon mixing layer and the relatively strong winds monitored at Vereeniging during the flight monitoring period may have enhanced NO concentration dilution through turbulent mixing. Leading to the impact of continuous industrial emissions not detectable in ambient air.

4. Meteorology plays an important role in influencing the atmospheric levels of pollutants. The morning NO average concentrations in winter derived from baseline concentrations over Secunda and Witbank are comparable and low. However NO average concentration over Witbank is slightly higher than over Secunda. The difference in the NO average concentrations over the two sites is likely due to the difference in the depth of the mixing layers during the monitoring of the two sites. During the Secunda monitoring the mixing height was at 1860 magl and during the Witbank monitoring it was at 1280 magl.

Though Secunda and Witbank mixing layers were capped by inversions, the relatively strong winds during their monitoring were enhancing air pollutants concentrations dilution through turbulent mixing. Leading to low morning NO concentrations over the two sites.

5. The winter NO loading over the Vaal Triangle area was higher than that over Rustenburg area. Both sites were monitored in the afternoon when emissions from domestic fires are reduced and air pollution dilution is maximum due to deeper mixing layer. The subsidence inversion which was at 1280 magl may have contributed to the relatively high afternoon NO levels over Vaal Triangle. Because there were no veld fires detected over the Vaal Triangle, the high NO levels over the Vaal Triangle may be attributed to industrial emissions which have less variation in their diurnal emission cycle.

6. The spring NO loading in the morning over the Secunda area was higher than that over the Rustenburg area. No veld fires detected directly over both sites during the monitoring, the loading must be from the characteristic sources of these areas.

7. The spring NO loading in the afternoon over the Witbank area was higher than that over the Vaal Triangle area. The higher Witbank NO average concentraton than that over the Vaal Triangle could be attributed to shorter mixing layer height at 1464 magl during the Witbank monitoring and deeper mixing layer at 3080 magl during the Vaal Triangle monitoring.

8. There is a general peak in surface NO concentrations in winter due to stronger emissions in this season. Only the Secunda area did not show peak winter spatial NO average concentration. The Vaal Triangle area showed the highest winter NO spatial average concentration peak, followed by the Rustenburg area, then the Witbank area. The Witbank area winter NO spatial average concentration peak height might have been diminished by the occurrence of relatively strong winds which were prevailing during its monitoring, diluting NO concentration. The NO

concentration winter peak was not observed over the Secunda area because of the occurrence of relatively strong winds which were prevailing during its monitoring, diluting NO concentration.

Nitrogen dioxide

9. The autumn relative NO_2 loading over the Highveld air pollution hotspots follow the same order as the NO loading. Secunda has the highest NO_2 level in the morning followed by Witbank then Rustenburg. Over the Vaal Triangle no NO_2 was detected in the parts per billion (ppb) measurement scale in the afternoon. This is due to the same reasons NO was not detected given in point 3.

10. During the winter case study days the morning spatial average concentrations derived from the baseline NO_2 concentrations over Secunda and Witbank areas were low, however the Witbank NO_2 loading was slightly higher than that over Secunda. This could be ascribed to the meteorological conditions described in point 4.

11. The winter NO_2 loading over the Vaal Triangle area was higher than that over Rustenburg area. Both sites were monitored in the afternoon when air pollution dilution is optimal due to deeper mixing layer. However the NO_2 levels over the two areas were higher than the ones over Secunda and Witbank which were monitored in the morning. The NO_2 levels over the Vaal Triangle were so high in a way that suggests they may be the highest in comparison with all the other sites. The inversion mentioned at point 5 may have contributed to the high NO_2 levels. Because there were no veld fires detected directly over the Vaal Triangle, the high NO_2 levels over the Vaal Triangle area may be attributed to industrial emissions which have less variation in their diurnal emission strength cycle.

12. The spring NO_2 loading in the morning over the Secunda area was higher than that over the Rustenburg area. No veld fires detected directly over both sites during the monitoring, the loading must be from a combination of domestic, traffic and industrial emissions.

13. The spring NO_2 loading in the afternoon over Witbank was higher than that over the Vaal Triangle. The high afternoon NO_2 levels over Witbank must be due to strong emission sources with less emitting diurnal strength cycle, which are likely to be industrial sources. The inversion at 1464 magl during the Witbank monitoring could have contributed to the high NO_2 level.

14. There is a general seasonal peak in surface NO_2 concentrations in winter due to stronger emissions in this season. Only Rustenburg and the Vaal Triangle showed peak winter spatial NO_2 average concentrations. The Vaal Triangle area winter spatial NO_2 average concentration was higher than the one over the Rustenburg area. The winter peak average concentrations were not observed for the Secunda and Witbank areas. This could be attributed to the relatively strong winds which were prevailing during the monitoring of these two sites diluting NO_2 concentration.

Sulphur dioxide

15. In autumn SO_2 spatial average concentrations derived from baseline concentrations were relatively comparable over the Secunda, Witbank and Rustenburg areas in the morning. The Vaal Triangle area afternoon minimum SO_2 concentration was comparable to the other sites minimum SO_2 concentrations monitored in the morning. This suggests that the morning SO_2 loading over the Vaal Triangle may have been higher than the other sites.

16. As in the case of NO_X over the Secunda and Witbank areas in winter, SO_2 morning concentration was diluted by the relatively strong winds that were prevailing during the monitoring of the two sites. The morning spatial average concentrations derived from the baseline SO_2 concentrations over the Secunda and Witbank areas were low and comparable, however higher than that over the Rustenburg area which was monitored in the afternoon.

17. The winter SO_2 loading over the Vaal Triangle area was higher than that over the Rustenburg area, both areas were monitored for SO_2 in the afternoon. The Vaal Triangle afternoon minimum and first quartile SO_2 concentration values were comparable with the ones over Secunda and Witbank monitored in the morning, a finding that is consistent with the autumn finding. The winter SO_2 levels over the Vaal Triangle were high suggesting to be the highest in comparison with all the other sites.

18. The spring SO_2 loading in the morning over Secunda area was higher than that over Rustenburg area.

19. The spring SO_2 loading in the afternoon over the Vaal Triangle area was higher than that over the Witbank area. The Vaal Triangle area afternoon SO_2 minimum concentration value was comparable with the one over the Secunda area which was monitored in the morning, a finding that is consistent with the autumn and winter finding. The spring SO_2 levels over the Vaal Triangle were so high that it suggests to be the highest in comparison with all the other sites.

20. There is a general seasonal peak in surface SO_2 concentrations in winter due to stronger emissions in this season as well as less efficient dispersion conditions. Only the Vaal Triangle area showed peak winter spatial SO_2 average concentrations. The winter peak average concentrations were not observed for the Secunda, Witbank and Rustenburg areas. The reason for this is that the Secunda and Witbank areas were experiencing relatively strong winds during their

monitoring, which were enhancing SO_2 concentration dilution through turbulent mixing. Resulting low morning SO_2 concentrations over the two sites. For Rustenburg the site was monitored in the afternoon in winter when SO_2 levels are at their diurnal minimum and in autumn and spring the site was monitored in the morning.

$PM_{2.5}$ aerosols

21. In autumn case study days the morning aerosols average concentrations over the Witbank and Secunda areas are relatively comparable but higher than that over the Rustenburg area. The afternoon $PM_{2.5}$ aerosols minimum concentration over the Vaal Triangle was comparable to the other sites minimum concentrations monitored in the morning, suggesting that in the morning the $PM_{2.5}$ aerosols loading over the Vaal Triangle area may be higher than the other sites.

22. The morning $PM_{2.5}$ aerosols loading over Witbank was higher than over Secunda during the winter case study days. This can also be attributed to the difference in the depth of the mixing layers during the monitoring of the two sites, described in point 4.

23. The winter $PM_{2.5}$ aerosols loading over the Vaal Triangle area was double the Rustenburg area aerosol loading, both sites were monitored for $PM_{2.5}$ aerosols in the afternoon. The inversion described in point 5 may have played a role in the high aerosols levels over Vaal Triangle. The $PM_{2.5}$ aerosols loading over the Vaal Triangle was so high that it suggests to be the highest in comparison with all the other sites.

24. The spring $PM_{2.5}$ aerosols loading in the morning over the Rustenburg area was higher than that over the Secunda area.

25. The spring $PM_{2.5}$ aerosols loading in the afternoon over the Witbank area was higher than that over the Vaal Triangle area. The inversion described in point 7 and 13 may have contributed to the high aerosols levels over Witbank. The high afternoon $PM_{2.5}$ aerosols levels over the Witbank area must be due to strong emission sources with a smaller diurnal emission cycle, which are likely to be industrial sources.

26. There is a general seasonal peak in surface $PM_{2.5}$ aerosols concentrations in winter due to stronger emissions from wide spread biomass burning, domestic fuel burning and power generation. Only the Vaal Triangle area showed peak winter spatial $PM_{2.5}$ aerosols average concentration. The winter peak average concentrations for $PM_{2.5}$ aerosols were not observed for the Secunda, Witbank and Rustenburg areas, for the same reasons these were not observed for SO_2 as mentioned in point 20.

Challenges in comparing airborne and surface air quality data

27. In the morning the low lying nocturnal inversion decouples the surface and the upper troposphere. This causes emissions released below it to be trapped within a shallow mixing layer and emissions from tall industrial stacks being prevented from mixing with the air below the inversion, creating a vertical gradient in air pollutants concentration distribution. This condition is unfavourable to compare airborne and surface air quality data.

28. Uneven spatial distribution of air pollutants sources, with different temporal emission cycles causes uneven distribution of air pollutants concentration in space. This situation leads to disagreements between airborne and surface air quality data.

29. Pollutants with short atmospheric lifetime are short range in distance of impact and don't have enough time to mix uniformly in space. This character of pollutants leads to poor comparison of airborne and surface air quality data.

30. Pollutants with long atmospheric lifetime are afforded time to mix uniformly in space, leading to good agreements between airborne and surface air quality data.

31. Sources emitting air pollutants at different heights cause a vertical gradient in air pollutants concentration. This leads to unfavourable comparison of airborne and surface air quality data.

Direct comparison of airborne and ground based data

32. The agreement between airborne and surface data for SO_2 comparison was less because:
    - The two data sets were being averaged over two different time scales, and it was established that SO_2 is temporarily highly variable.
    - SO_2 concentrations are not evenly distributed in space over the study sites because its sources are not evenly spaced and the pollutant is short-lived and short-ranged.
    - There is a vertical gradient in SO_2 concentrations over the study sites caused by emissions at different heights.

33. There is a good agreement between airborne and surface O_3 data. This is a result of O_3 being a secondary pollutant with a relatively long atmospheric lifetime that affords it more opportunity to be distributed in space uniformly, and it was established that O_3 is less temporarily and spatially variable.

For a comparison study on air pollution loading over different sites it is recommended that there is consistency in the time and meteorological conditions under which the sites are being monitored. Because both these factors affect the levels of air pollutants in the atmosphere. This study was faced with challenges of not having all sites monitored at the same time of the day and the meteorological conditions prevailing on the days these sites were monitored were not similar for some days. Another challenge was that the project from which this study is derived, was mainly aimed at establishing baseline ambient conditions for air pollutants over the hotspots. All the flights were primarily aimed at determining spatial distribution of air pollutants. Hence opportunities of flying within 20 km radius from a ground station were few. For future comparison experiments of airborne and ground based data, it is recommended that the flights are carefully planned so that they are conducted in the vicinity of ground stations. Preferably over places with a dense ground monitoring stations network and in the afternoon when the turbulent mixing is strong and the mixing layer depth is deep. But still some interesting findings were obtained from this study. O_3 a long-range pollutant because of its long atmospheric lifetime its levels are comparable over all the study sites on all seasons. It has a seasonal peak in spring and its seasonal change concentration increments are of about 10 ppb. The comparison of the study sites on NO_X, SO_2, and $PM_{2.5}$ aerosols loading was complicated by the difference in time of the day at which monitoring occurred and the occurrence of inversions at different levels. NO_X, SO_2, and $PM_{2.5}$ aerosols levels monitored when the sites were experiencing strong winds are low, and at times they are actually lower than the afternoon NO_X, SO_2, and $PM_{2.5}$ levels. The winter afternoon NO_X levels over the Vaal Triangle are high in such a way that suggest that the may be higher than morning NO_X levels over the other study sites. The Vaal Triangle was high in SO_2 and $PM_{2.5}$ aerosols loading in comparison to the other sites in all seasons, it only had lower than Witbank $PM_{2.5}$ aerosols loading in spring. There is less agreement between airborne and surface SO_2 data because of short atmospheric lifetime of SO_2, high temporal variation in SO_2 levels, uneven distribution of the pollutants sources in space and different height at which the pollutants are released. Airborne O_3 data compares well with surface data because of its relatively long atmospheric lifetime that affords it to mix uniformly in space.