DESIGN AND OPERATION OF AN AMBIENT AIR POLLUTION MONITORING NETWORK IN THE VAAL TRIANGLE AIR POLLUTION HEALTH STUDY

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ABSTRACT

An extensive ambient air pollution monitoring network was designed as part of the Vaal Triangle Air Pollution Health Study (VAPS). The objective of the outdoor study is to determine air quality levels in the Vaal Triangle region. The monitoring was designed simultaneously with the health component of the VAPS. The network was designed according to specific criteria and has been in operation since July 1991. Six monitoring sites, which are presently in operation, were gradually phased in over the last 12 months. The pollutants which are considered as important and which are monitored in the area on a continuous basis for 365 days a year are: sulphur dioxide, nitrogen oxides, ozone, non-methane hydrocarbons, particulates and hydrogen sulphide. Meteorological parameters are also monitored. The design of the network, as well as preliminary results from two monitoring sites, will be discussed.

INTRODUCTION

The effects of air pollution on the health of the South African population are not as yet known. South Africa, in one instance a developed and in another instance a developing country, provides a unique opportunity for the study of air pollution and its impacts.

To date, three South African studies on health and air pollution have been undertaken (1, 2, 3). The studies found some effects but could not draw any definite conclusions. This was primarily due to the fact that no direct measurements of air quality, both indoor and outdoor, were undertaken. The assessment of real exposure is critical for correlation with observed health symptoms to establish a cause-effect relationship. Thus the outdoor monitoring networks for the Vaal Triangle Air Pollution Health Study (VAPS) were launched in mid 1990.

The Vaal Triangle is one of the most diverse regions for industrial processes in South Africa. The industrial sources of air pollution include coal burning, chemical factories, petrochemical plants, metallurgical plants and various smaller multiple types of industries. Other major sources of emissions in the area are domestic coal burning and motor vehicles.

The proximity of the residential areas to industries and other sources of air pollution, in conjunction with the topography and meteorology of the region, raises concerns that residents may be exposed to high levels of pollution.

Therefore, the primary objective of the outdoor monitoring network is to provide sound scientific data which can be used to determine for dose response relationships.

During 1990/91 the monitoring network grew from one site in the south of region to the total complement of six sites presently being operated. This paper will present the first year's results from two monitoring sites, as well as adhoc studies undertaken during the course of 1990/91.

STUDY DESIGN

The single most important factor in determining the location of the VAPS monitoring sites was the location of the study population. In order to correctly characterize outdoor air quality, the monitoring sites had to be set up as close as possible to the study population.

The locations of the monitoring sites were decided according to the following criteria:

- location of study popultion
- location of major sources
- meteorological factors (wind direction, etc.)
- topography within the study area, ie valleys were given priority

MONITORING SITES

Based on the above criteria, the following sites (Figure 1) were commissioned:

a) Makalu, south of Sasolburg - this site will provide information for the southern border of the study area.

b) Sasolburg industrial area - this is an excellent monitoring point as it is located in the heart of the industrial area of Sasolburg.

c) Sasolburg residential area.

d) Vanderbijlpark residential area.

e) Three Rivers residential area.

f) Sharpeville - this site is an extremely important monitoring site and will provide data on air pollution caused by domestic coal burning.

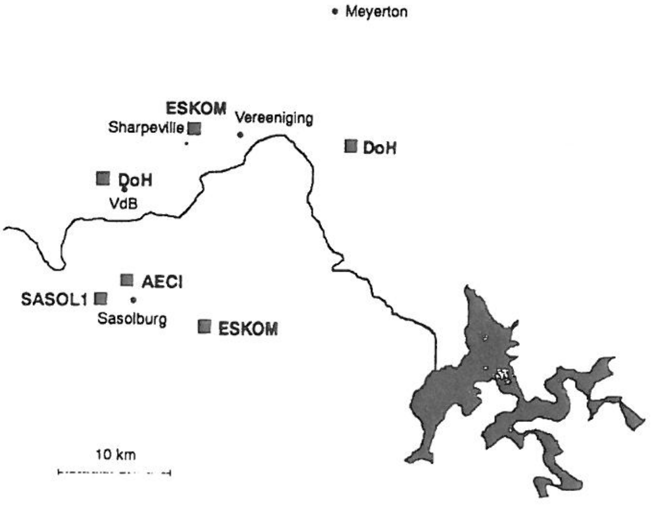


Figure 1

Each site is equipped with United States Environmental Protection Agency (EPA) approved instruments.

The decision on what to monitor in the whole array of possible pollutants was difficult and was made according to the following guidelines:

- a brief source inventory was done which identified the major sources of specific air pollutants.
- historic data on air quality (Eskom results) and/or pilot studies were used as guidelines.
- the Ambient Air Quality Standards (AAQS) of the USA were used as a major indicator for making the final decisions on what pollutants to monitor. The threshold values above which health effects can be expected, as given in the AAQS, are valuable reference values.
- the availability of funding was, however, an important factor in the final decision on what and where to monitor.

Based on the above guidelines the following pollutants are being monitored:

- sulphur dioxide (SO_2)
- oxides of nitrogen (NOx)
- carbon monoxide
- non-methane hydrocarbons
- hydrogen sulphide
- fine mode particulate matter (FPM)
- ozone
- total suspended particulates (TSP)
- meteorological parameters

CLIMATOLOGY

The study region lies within the Vaal River basin at an altitude of some 1500 m above sea level. General large scale surface airflows are dominated in summer by the presence of northerly to north-westerly winds and in winter by westerly to south-westerly winds. However, on most fine clear weather nights, the nocturnal flow over this region is likely to be easterly to south-easterly as a result of topographically induced drainage flows.

As shown by Tosen 1987 (4), boundary layer winds at 800 hPa, some 300 to 400 m above the region (Figure 2), showed that mean wind conditions were largely dominated by the latitudinal position of the high pressure (HP) system. In summer, the HP cell is weakly developed and displaces towards the south-east by the tropical low pressure trough over the western interior, resulting in northerly airflow conditions. By April, the pattern starts to shift to a winter mode, with the HP cell strengthening over the Northern Transvaal. The westerlies encroach northwards, increasingly affecting the winter circulation pattern. This causes the northerly wind in summer to back to westerly and increase in strength between April and September.

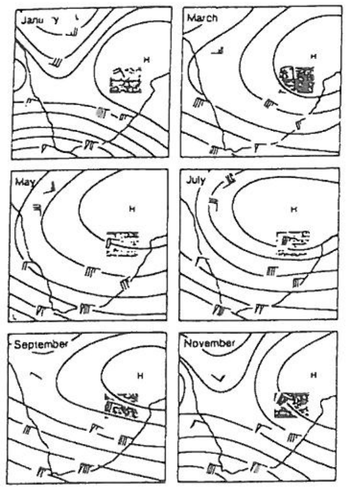


Figure 2

Subsidence produces adiabatic warming, drying of the atmosphere, increasing atmospheric stability, suppression of precipitation and, most important in dispersion terms, conditions highly conducive for the formation of surface and elevated inversions. When considering the frequency of anticyclonic circulations (5) over the PWV area (Figure 3), a clear maximum is reached in winter (May to October).

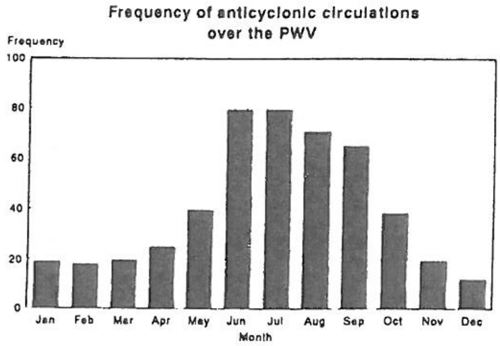


Figure 3

Nocturnal surface inversions over the VAPS study area occur for some 80% of the time during winter, with a mean depth and strength of 300 m and 5,0°C respectively (5).

During the day the stable boundary layer is eroded from below by heating and turbulence and a mixing layer develops. The maximum mixing layer depth varies from 1000 m in winter to more than 3000 m in summer (4). The seasonal variations of the mixing layer depth as well atmospheric stability greatly affects the pollution potential of the region and thus the seasonal ground level concentration of pollutants.

DATA ANALYSIS

This paper describes the results obtained from two continuous monitoring sites in the VAPS network, namely Makalu, which is located 5 km south-east of Sasolburg and Sharpeville, which is situated in the heart of Sharpeville.

The first data set comprises surface wind roses and the first year's results will be compared to the overall windflow climatology of the region.

The second data set comprises primary and secondary pollution data (SO_2, NOx, FPM and ozone) from the two sites, as well as TSP data from a site situated at the Afrikaans High School in Vanderbijlpark. This site was commissioned in September 1990 and measurement is by High Volume sampling over a 24 hr period.

In addition to this, diurnal and monthly mean concentration cycles will be discussed and compared to national standards. Comparisons between the air quality of Makalu and Sharpeville will be presented as well as the possible sources of the differences.

RESULTS

Surface Winds

Mean seasonal surface wind roses for the study area (Figure 4) clearly shows that the dominant airflow during the summer period of 1990/91 was from the north (60%). However, during the winter, two airflow components dominated, south-westerlies (35%) and south-easterlies (35%).

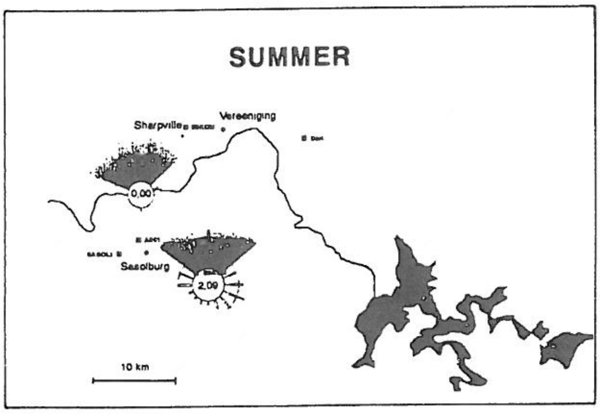
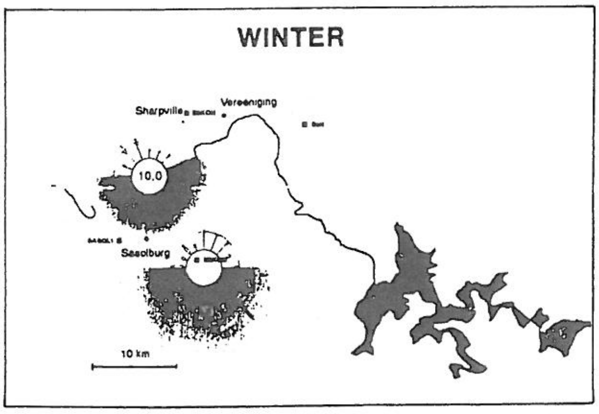


Figure 4



The relatively high occurrence of south-easterlies during winter and to a lesser degree during summer, can be ascribed to the local topography, in the form of drainage flows, which dominate during the stable night-time periods.

When comparing the seasonal (winter and summer) wind roses to that of the overall climatic mean, very little difference is noted. Thus, from an airflow point of view, it can be assumed that the period 1990/91 was normal and as such the overall boundary layer conditions were representative of averaged conditions.

Sulphur Dioxide

The monthly mean cycle for the southern site is shown in Figure 5. It can be clearly seen that the Department of Health (DoH) guideline of 50 ppb was not exceeded during the entire monitoring period.

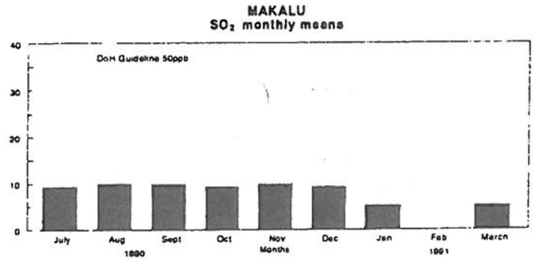


Figure 5

No definite seasonal cycle is observed. However, it is important to note that the mean values dropped by some 50% during the mid-summer period. This is primarily due to greater atmospheric instability and, as such, atmospheric mixing is at its maximum.

When analysing the diurnal cycle of SO_2, it is important to note that location and height of emission play a significant role in determining the overall 24 hr variation.

Figure 6 shows the diurnal hourly mean cycle for both Makalu and Sharpeville, for the autumn of 1991. It can be seen that when comparing the two sites, two significantly different cycles are observed. The Makalu SO_2 cycle shows ground level concentrations (GLCs) reaching a maximum of 17 ppb during the midday and a minimum of 5 ppb during the nocturnal period.

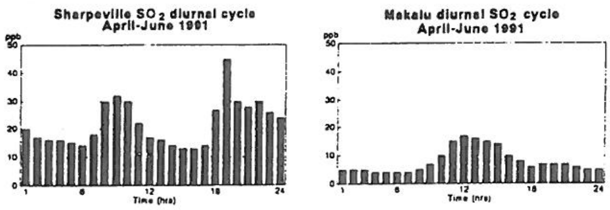


Figure 6

The Sharpeville data reveals a bi-modal distribution, in that two maximum GLCs occur. The first maximum reaches a peak of 32 ppb at 0900 hrs and the second of 45 ppb at 1900 hrs. However, a minimum of 15 ppb occurred during the afternoon period, compared to the overall higher GLCs which dominated the nocturnal periods.

It is obvious that Makalu and Sharpeville show completely out of phase cycles and as such have very little in common with regards to their diurnal SO_2 characteristics.

The Sharpeville site, which is located in the heart of Sharpeville, is primarily influenced by low level domestic and vehicle emissions in the area. It is not surprising, when taking into consideration the high frequencies of surface inversions and the dominant atmospheric stability within the first 250 m at night, that dispersion conditions for this area are inadequate. it is also important to note that the burning of coal and wood are the primary source of energy for this community.

Thus, the diurnal SO_2 cycle for Sharpeville follows closely the energy requirements of the people living there. Low level emissions are unable to penetrate the surface inversion and as such are emitted into a region of the atmosphere where the conditions for atmospheric mixing are extremely poor. This has the effect of causing high GLCs to occur close to the source during the stable night-time periods.

Makalu, on the other hand, due to its location, is mainly affected by high level emissions and as such GLCs during the stable nocturnal period are low. However, during the midday, when atmospheric conditions are unstable, high level plumes are brought down to the surface by turbulence and high short periods of GLCs occur.

Oxides of Nitrogen

The DoH monthly mean guidelines for Nox is 300 ppb. Figure 7 shows the monthly mean cycle from July to August 1991. It is evident from the results that at no time were these guidelines even remotely exceeded at Makalu. The progressive decrease in monthly mean concentrations from the winter to the summer period is clearly evident.

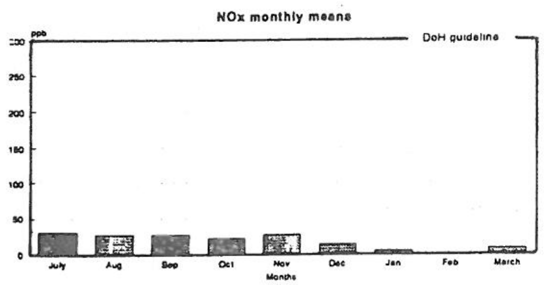


Figure 7

When comparing both sites' diurnal variation (Figure 8), a similar pattern to that of the SO_2 cycle is seen. The Sharpeville site is located very close to the main road and as such the maximum GLCs at this site are well correlated to peak traffic periods.

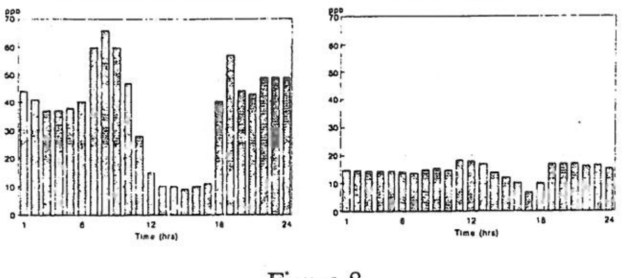


Figure 8

The overall NOx concentrations for Sharpeville are high, with maximum hourly means, reaching 65 ppb and 57 ppb at 0800 and 1900 hrs respectively and a minimum occurring at 1500 hrs. This greatly contrasts to that of the Makalu diurnal cycle, where maximum GLCs occurred during the midday period.

Again, it is obvious that the local effects of motor car and domestic emissions far exceed the regional impact of NOx emissions.

Particulate Matter

When comparing both sites with respect to the diurnal variation of FPM, a different pattern to that of the SO_2 and NOx cycle is noted (Figure 9). Both sites show a similar cycle, in that minimum GLCs occurred during the afternoon period, while generally higher concentrations prevailed for the rest of the time.

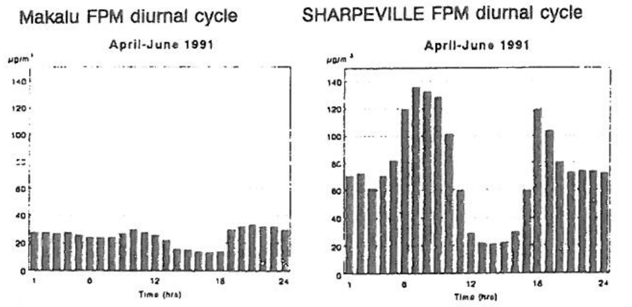


Figure 9

Due to the dominant usage of coal and wood in Sharpeville and the fact that these emissions are at low level, the impact of particulates in this area is severe relative to Makalu data.

Again, at Sharpeville, the maximum GLCs coincide with the living habits and energy requirements of the local inhabitants.

The significant difference between the two sites' maximum values, can once again be ascribed to the level of pollutant release and by the fact that the long range transport of particulates is relatively short.

The seasonal 24 hr results of the TSP monitoring which was carried out at the Vanderbijlpark High School are shown in Figure 10. Clearly seen is the seasonal differences in daily concentrations between the winter and summer periods.

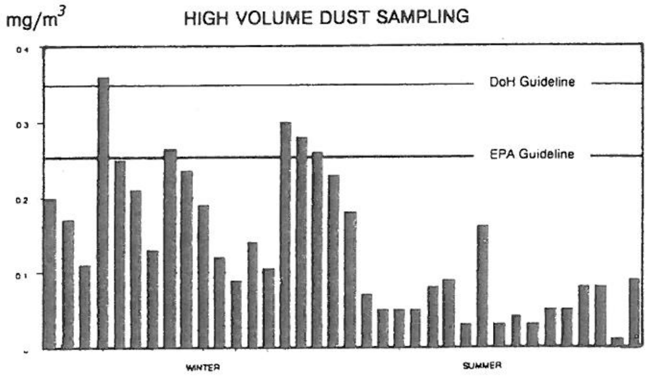


Figure 10

Winter is dominated by much higher concentrations. The DoH guideline of 350 micrograms/cubic metre for a 24 hr period was exceeded once during this period. However, the EPA guideline of 260 micrograms/cubic metre was exceeded some 5 times. During summertime, TSP concentration was significantly lower than that during winter, primarily due to the fact the atmospheric conditions during this period are most conducive for good atmospheric mixing and dilution.

Ozone

Ozone is a secondary pollutant and is formed when hydrocarbons and oxides of nitrogen react and convert in the presence of sunlight.

Thus it is not surprising to see, when comparing the results from Makalu and Sharpeville, that their overall diurnal cycle is similar. However, what is of importance is the fact that the period of maximum concentrations persisted for some 2 to 3 hours longer at Makalu than at Sharpeville (Figure 11).

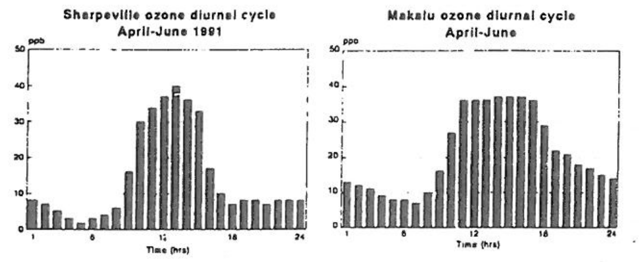


Figure 11

The monthly mean ozone concentrations vary between 20 and 30 ppb. It is also important to note that altitude plays an important role in ambient ozone levels. Since the region lies at an altitude of some 1500 m above sea level, ambient ozone values will be somewhat higher than those at sea level.

CONCLUSION

In this paper we have reviewed the climatology of the VAPS study area for the 1990/91 period. The climatological base showed on average, that seasonal airflow conditions for the monitoring period represented the overall climatic mean, in that northerlies dominated during summer and westerlies to south-westerlies in winter. Local drainage winds also play a major role in the dispersion climatology of the region.

During winter, the region is dominated by the formation and collapse of a stably stratified inversion layer occurring for some 80-90% percent of the time to a depth of 250 m. However, during daytime conditions, atmospheric mixing is dominant and as such, the dispersion potential of the region is greatly enhanced.

Therefore, from a climatic point of view, the year 1990/91 was normal and results obtained during this period can be viewed as such.

Generally, seasonal differences between the stable winter period and unstable summer period could be seen with regards to GLCs. It is important to note that, with respect to monthly SO_2 and NOx concentrations, no DoH guidelines were exceeded. However, guidelines were exceeded with respect to TSP daily concentrations.

In reviewing the diurnal variation from both Sharpeville and Makalu, it was evident that the Sharpeville results showed strong diurnal variations, whereas Makalu's cycle was very much weaker. This variation is primarily due to their location and to the height of local emissions sources.

The Vaal Triangle is characterised by extremely stable conditions within the first 250 m during the night-time period. This is due to the presence and persistence of very strong stable ground based inversions. The mixing and ventilation potential of this layer is extremely poor and as such, the potential for the accumulation of low level pollutants emitted into this layer is high. Thus all low level emissions, such as the domestic emissions of Sharpeville, will be trapped within this stable layer, resulting in high GLCs which have major impacts on the local environment.

Results from Makalu show diurnal characteristics typical of high level emissions, especially with respect to SO_2. Maximum levels are recorded during the midday period when atmospheric instability is greatest.

This is a common feature (6) of high level emissions, as emissions penetrate the surface inversion and do not come to ground during the night-time period. However, with the onset of increased atmospheric turbulence, which is greatest at midday, looping plumes occur, resulting in relatively high GLCs. This is typical of what we see at Makalu.

In general, pollution concentrations measured at Sharpeville are very much higher than those at Makalu. This highlights the urgency for smoke control in black residential areas.

Finally, it can be concluded, from the limited data reported in this paper, that the monitoring network established in the Vaal Triangle provides important information concerning local, as well as the regional perspectives on air quality.

Once all the monitoring sites are fully operational, the data and results obtained will go a long way in achieving the programme objectives, thereby furthering the understanding of the cause and effect relationship between air quality and health effects.

ACKNOWLEDGEMENTS

It is important to note that the outdoor monitoring study is a co-operative study and as such many logistic hurdles had to be overcome in the preparation and setting up of such a major outdoor network.

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