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Full Length Research Paper

Inhalable particulate matter associated with mining and smelter activities

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The objective of this study was to determine the mass concentration levels of the inhalable air particulate matter (PM10) and the effect of meteorological parameters on the dilution and dispersion thereof. The PM10 was collected using Tapered Element Oscillating Microbalance (TEOM) and the concentrations were determined at two sampling sites RMINE and RCBD within the Rustenburg area. The hourly levels for RMINE (closer to the mining industry) were high (6.5 to 215.7 µg/m^3); the daily levels were higher (44.4 to 151.7 µg/m^3) than at RCBD (10.3 to 81.7 µg/m^3); and the monthly levels were also higher (94.1 to 131.0 µg/m^3) than RCBD (44.2 to 49.3 µg/m^3). The high levels experienced by RMINE were also shown to be highly dispersed (~100 Km) with low dilution (X 10^{-1} of the initial). RCBD also experienced high levels of concentrations that get diluted quickly (X 10^{-4} of the initial) and are dispersed over large area (~120 Km). The results showed an increase in PM10 as wind speed and relative humidity decreases; and an increase in PM10 as temperature increases. Numerical values in the air quality index showed that, the hourly levels in RMINE range from moderate to very unhealthy, the daily levels from moderate to unhealthy, and the monthly levels from moderate to unhealthy for sensitive groups.

Key words: PM10, meteorological parameters, dispersion.

INTRODUCTION

Air pollution is aesthetically offensive and can be a genuine health hazard to humans as well as their environment (Onder and Dursun, 2006). Airborne particles in the atmosphere have also shown serious environmental impacts on climate (Broecker, 2000; Prospero et al., 2002), biogeochemical cycling in ecosystems (Nriagu, 1988; Nriagu and Pacyna, 1988), and visibility (Husar, 1997). Particulate matter (PM) is a complex mixture of multicomponent particles of which the size distribution, composition, and morphology can vary significantly in space and time (Khlystov, 2001). The PM is composed of carbon species, condensed acidic species and trace elements (Lee et al., 2002). Many metal smelters emit significant amounts of heavy metals into the atmosphere. Lead for instance, occurs in the atmosphere mainly in the particulate form (in the fine particle fraction), but a small part occurs in vapour as organic lead compounds (European environment agency, 1996).

Elevated levels of metals (Na, Pb, Cd, and Se) and by-products of petroleum combustion (S, Ni, V) are normally found in the emissions of oil-fuelled plants (Watson and Chow, 2001). The problem of metal concentrations in dust deposition became important with the advent of high temperature processes like smelting and fossil fuel combustion. The major source of crustal elements (e.g. Al, Si, Ca, Ti, and Fe) is the wind-blown dust suspended from construction sites, roads and natural surfaces. Heavy metals originate from a variety of industrial processes such as incineration, manufacturing, and smelting (Pinto and Lester, 1998). Exposure to ambient particulate matter has been associated with a range of adverse health effects including: premature mortality, aggravation of existing respiratory conditions, changes to lung tissues and structures, and altered respiratory defence mechanisms. These responses to exposure are a function of the exposure concentration, the duration of the exposure, and the amount absorbed in the body (that is dose over time) (Gulflink, 2002). People exposed to

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higher concentrations of air particulate matter for long periods increase their chances of serious health effects such as cancer, damages to the immune system, neurological damages, reproductive problems (that is reduced fertility), development problems and respiratory problems. Health effects of PM associated with endocrine disruption include reduced fertility, birth defects and breast cancer (Provincial Health Office, 1993).

The Rustenburg municipal area is located at 25°39'00''S and 27°13'59''E and Rustenburg is one of the biggest mineral producing districts in South Africa. South Africa produces 68.3% of the world's chromium ores and roughly 86% of the chrome ores are mined within the Rustenburg mining area (Viljoen and Reimold, 1999). Five of the 12 platinum group metal producing mines in South Africa are situated in the Rustenburg area on what is known as the Bushveld Igneous Complex. This contains the world's richest platinum reserves and is situated in the north-eastern part of the North West Province.

Most of the villages are just a walking distance (less than 5 km) away from the mines. It is therefore expected that activities within the mines and smelters in the area contribute to the emissions to the environment and affect human health in the area.

Meteorological observations are critical for analysing and predicting atmospheric dispersion of gases and particles. Depending on which dispersion variables (e.g. transport, diffusion, stability, deposition, plume rise) are important for a particular problem, a corresponding suite of meteorological parameters must be quantified through observation, modeling or a combination. These parameters include wind speed and direction, temperature, humidity, precipitation type and intensity, mixing height, turbulence, and energy fluxes (Dabberdt et al., 2004). Meteorological variability typically accounts for 40 to 70% of ozone variability and 20 to 50% of PM variability (Wise and Comrie, 2004). The meteorology of an area influences both the hourly, daily and seasonal variations of PM. This has been evident in several studies including the one by Kukkonen et al. (2005), where detail analysis in four selected episodes involving substantially high concentrations of PM10 that occurred in Oslo on 4 to 10 January 2003, in Helsinki on 3 to 14 April 2002, in London on 18 to 27 February 2003 and in Milan on 14 to 19 December 1998 was performed, and all four episodes addressed were associated with areas of high pressure (Oslo, Helsinki and London) or a high-pressure ridge (Milan). The best meteorological prediction variables were found to be the temporal evolution of the temperature inversions and atmospheric stability and, in some of the cases, wind speed.

The objective of this study is to determine the mass concentration levels of the inhalable air particulate matter and the effect of meteorological parameters like temperature, wind speed and wind direction on the dilution and dispersion of PM within the mining areas of the Rustenburg district of the North West Province, in South Africa.

MATERIALS AND METHODS

The PM samples were collected onto Teflon-coated boroscilicate fibreglass filters, using the tapered element oscillating microbalance (TEOM Series 1400A), which is composed of the control unit and the sensor unit. The ambient sample stream was allowed to passes through the PM10 inlet at the flow rate of 16.7 L/min, which was then isokinetically split into a 3 L/min sample stream, that is sent to the instruments mass transducer and a 13,7 L/min exhaust stream (Rupprecht and Patashnick, 2002). The equation that describes the behavior of the TEOM system derives from the equations of motion for a simple harmonic oscillator:

$$\Delta m = K_0\left(\frac{1}{f_b^2}-\frac{1}{f_a^2}\right) \qquad (1)$$

where Δm is the mass of the collected sample, f_b is the frequency of the oscillating element after sample collection, f_a is the frequency before sample collection, and K_0 is a constant (spring constant) unique to each tapered element. As the collection medium collects aerosol, the mass increases, thereby decreasing the frequency of oscillation. By measuring only the change in frequency, one can determine the gain in the aerosol mass on the collection medium. Although this expression for Δm is nonlinear, it is monotonic (single valued), independent of m, and depends only on the constant K_0. For subsequent measurements, f_b becomes f_a, a new initial frequency that reflects the total mass of the system. The new f_b after sampling will differ from f_a only because of the new mass uptake, Δm, collected during sampling. The TEOM device can calculate the mass concentration of the sample stream in real-time by maintaining a flow rate of 3 L/min through the instrument and measuring the total mass accumulation on the filter cartridge. The South African Weather Services (SAWS) provided the meteorological data used in this study.

Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model, an air quality dispersion model which serves as a complete system for computing simple air particle trajectories to complex dispersion and depositions was used to determine the dispersion and dilution of PM10 from the sampling area to the nearest communities (Draxler and Hess, 1997). In this model, the dispersion of a pollutant is calculated by assuming either puff or particle dispersion. In the puff model, puffs expand until they exceed the size of the meteorological grid cell (either horizontally or vertically) and then split into several new puffs, each with its share of the pollutant mass (Draxler, 1998). In the particle model, a fixed number of initial particles are advected about the model domain by the mean wind field and a turbulent component. The model's default configuration assumes a puff distribution in the horizontal and particle dispersion in the vertical direction (Draxler and Hess, 1997).

Sampling of PM was done at two sites namely RMINE located near a ferrochrome mine with latitude 25°43′03,0″E and longitude 27°23′57,8″S and RCBD, closer to the central business district with latitude 25°40′01,3″E and longitude 27°16′38,5″S. The sites RMINE and RCBD are given as A and B respectively in Figure 1.

DISCUSSION OF RESULTS

The sampling of PM was performed for 12 months that is from February 2004 to January 2005, but could not be performed simultaneously at the two sites, since the

TEOM had to be moved from one site to another. The daily PM10 levels were computed from the 39 days of sampling for RMINE and a 55-day sampling period for RCBD. The monthly levels were determined for the months of June to December for RCBD. For the entire study period, the mean, standard deviation and standard error for the entire Rustenburg area were computed as 63.79, 32.37 and 10.24 respectively. Daily PM10 statistics (mean, standard deviation and standard error) were obtained as 79.00, 47.50 and 6.93 for RMINE; and 13.79, 22.16 and 3.23 for RCBD. The monthly statistics for RCBD were obtained as 44.39, 5.64 and 2.13 for mean, standard deviation and standard error respectively.

PM10 and domestic and industrial activities

The daily and hourly PM10 levels are vital in determining the contribution of domestic and industrial activities in the vicinity of the study area. The busiest times of the day have high levels of PM, whilst the times when there is less anthropogenic activities have low levels linked to them. Weekdays (Monday to Friday) are also expected to have higher levels than the weekends (Saturday and Sunday) since there is less industrial activity during weekends.

Figure 2 shows the PM10 levels during different time intervals of a typical day. It can be observed that the hourly PM10 levels were high mostly between 6 and 18 h00, which shows a correlation between the activities at the sources (household and industrial) and the PM10 levels. The peak average concentrations observed in the morning (8 to 9 h00) and evening (18 to 19 h00) hours on 7 June 2004 are in agreement with studies (Munishi, 2002), where peak concentrations of NO_2 and PM were observed in the morning and evening hours. The guideline of 120 µg/m^3 set by the World Health Organisation (WHO) was exceeded twice during the day (7 June, 2004). Figure 2 shows that the hourly concentration in the morning, at 8 h00 was 161.5 µg/m^3 and the afternoon concentration was 195.8 µg/m^3 at 12 h00, 135.8 µg/m^3 at 14 h00, and 202.1 µg/m^3 at 15 h00 on 29 May, 2004. These exceeded the hourly particulate matter guideline of 120 µg/m^3 set by WHO.

Meteorology and dispersion of PM10

Table 1 shows the meteorology of the Rustenburg area for the entire study period. There seem to be little or no trend in the wind direction measured during the study, since for the year 2004, the winds were mainly NNW while for 2005 they were mainly SSW. This makes it difficult for one to accurately determine the sources of pollution within the area, since the directions stated below may imply that RMINE and RCBD were downwind in 2004 and upwind in 2005. According to Figure 1, RMINE was in 2004, downwind to the smelters and human settlements in the area, while RCBD was downwind to the central business district (urban area).

Meteorology and dispersion at RMINE

The meteorology of an area can change many times in one day. It is thus important to use daily PM10 mass concentrations in assessing the impact of meteorology on the PM10 levels. Figure 3 shows the daily PM10 levels and relative humidity at RMINE. The relation between relative humidity (RH) and mass concentrations of PM10, though weakly portrayed, shows from 3 to 10 May 2004 in Figure 3, that a decrease in relative humidity is linked with an increase in levels of PM10. PM10 contains hygroscopic components (sulphates, nitrates and sea-salt) that attract water (Al-Momani, 2003), and thus cause particles in the PM10 to become so large, that they cannot be collected using a PM10 sampler.

This normally causes concentration losses that account for a decrease in PM10 concentrations as relative humidity increases. The effect of temperature changes was ignored at this site, since it remained almost constant throughout the sampling period. Other contributory factors to the high levels of PM10 at RMINE can be wind speed and direction. The wind speed and direction for the months of April and May 2004 were on average, 16.3 m/s (3370 from true north - NNW) and 8.7 m/s (3370 from true north - NNW) respectively. The frequently changing wind direction during the month may be the cause of fluctuations in PM10 levels as shown in Figure 4.

The figure shows the typical changes in wind direction that can occur almost every day in the Rustenburg area. The winds can practically come from about three different directions in one day, thus causing hourly fluctuations in the PM10 levels. The days, 6th to 9th May 2004 are chosen as examples. The levels of inhalable particulate matter and the wind directions during these days were measured as 132 µg/m^3 (SSE to NNW), 149 µg/m^3 (NE and ENE), 146 µg/m^3 (SE and ESE) and 104 µg/m^3 (ESE to SW) respectively. These agree well with what is portrayed in a map showing the location of RMINE within the Rustenburg municipality in Figure 1. The smelters within the vicinity of RMINE are located at the North, North-East (NE) and North-West (NW) side relative to the site. This may be the reason for the highest levels that are observed when there are NE and ENE winds, as well as when the winds are mainly NNW. The monthly PM10 levels have a high but negative correlation ($r = -0.99$) to wind speed compared to the $r = -0.12$) for the daily levels.

This implies that high wind speeds favour the dilution and dispersion of pollutants, thus reducing all possible health risks. The average monthly profile for March to June 2004 is shown in Figure 5. The dispersion occurs more to the South of South Eastern (SSE) direction. High concentration of particles is noted as indicated by the

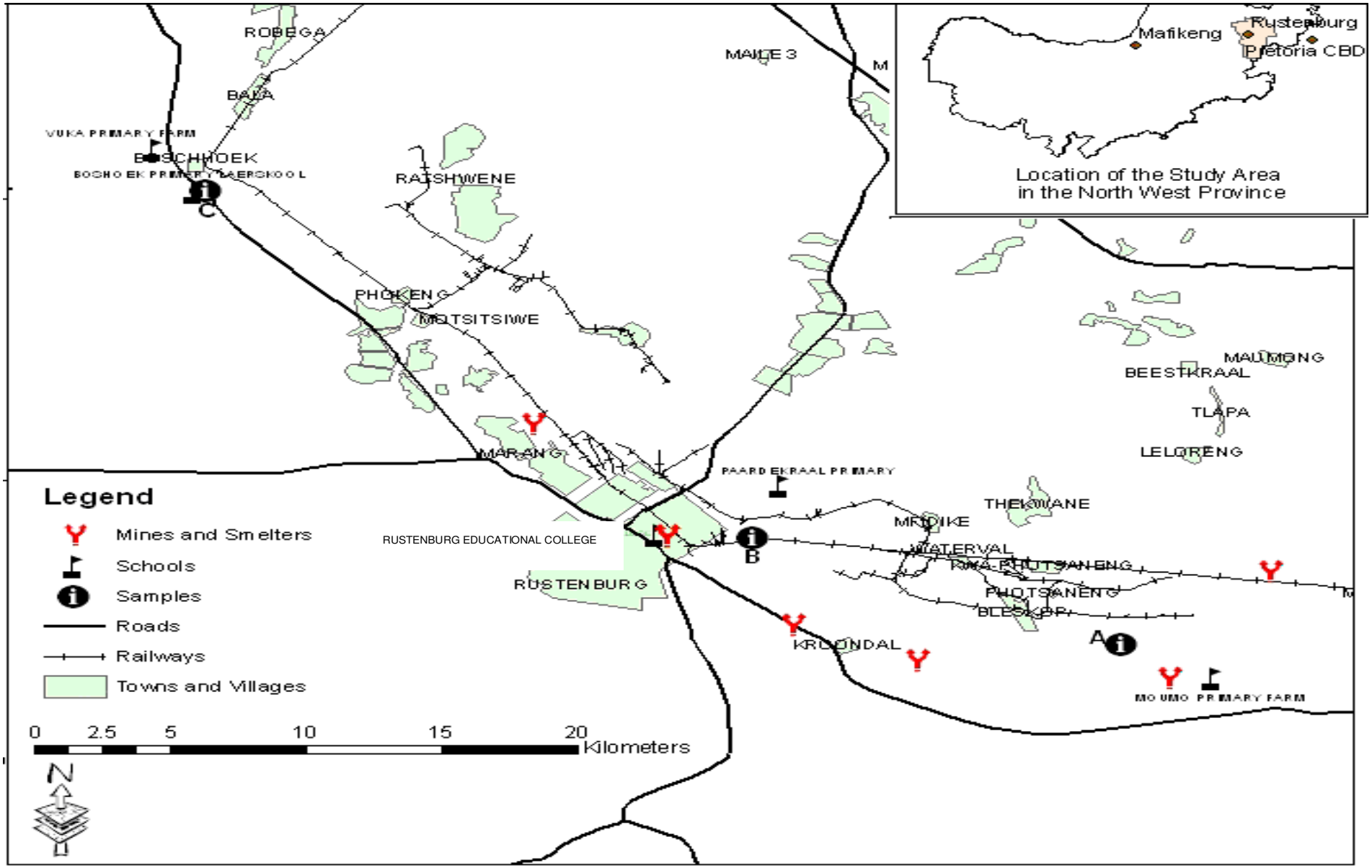

Figure 1. A map showing sampling sites RMINE and RCBD (given as A and B respectively) within the Rustenburg municipality.

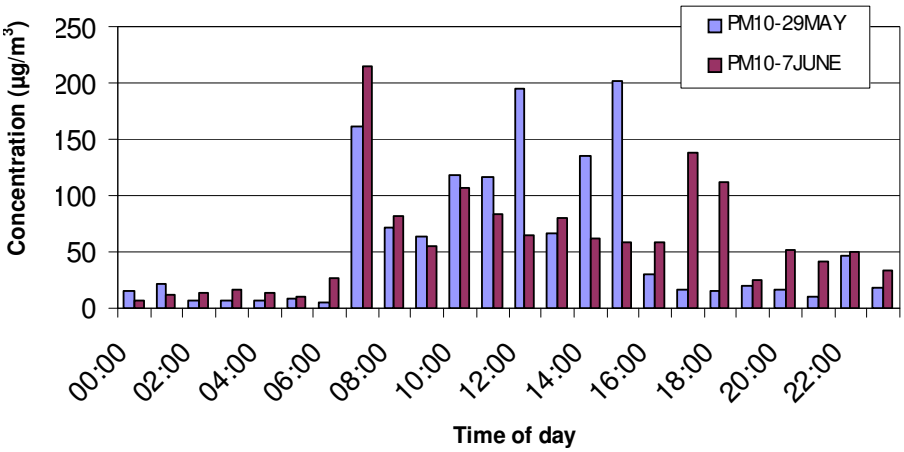

Figure 2. Hourly PM10 levels at RMINE on 29 May and 7 June 2004.

Table 1. Monthly average meteorological data for the Rustenburg area supplied by the South African Weather Services (SAWS).

Season	Month	Temperature (°C)		Rainfall (ml)	Wind speed (m/s)	Wind direction (degrees from true north)
		Min	Max			
Autumn	Mar -04	14.7	25.9	11.0	15.5	347 (NNW)
	Apr -04	12.4	25.4	27.4	16.3	337 (NNW)
	May –04	7.0	24.3	0.2	8.7	337 (NNW)
Winter	Jun –04	2.7	19.4	5.2	12.2	354 (NNW)
	Jul –04	1.0	19.6	0.0	13.3	349 (N)
	Aug –04	6.5	23.8	1.6	15.7	349 (N)
Spring	Sep –04	7.5	25.7	0.2	16.7	340 (NNW)
	Oct –04	12.5	28.8	39.4	9.4	176 (S)
	Nov –04	15.3	31.5	38.2	10.2	165 (SSE)
Summer	Dec –04	16.0	29.2	83	10.4	163 (SSE)
	Jan – 05	17.4	29.4	160	9.0	204 (SSW)
	Feb - 05	16.5	29.7	78.6	8.5	161 (SSE)
Autumn	Mar - 05	14.1	27.3	42.4	8.8	190 (S)
	Apr – 05	11.5	23.2	91	7.3	196 (SSW)
	May - 05	6.4	23.5	0.8	6.7	188 (S)
Winter	Jun – 05	4.4	22.6	0.0	6.8	205 (SSW)
	Jul - 05	2.8	22.0	0.0	6.0	164 (SSE)

yellow coloring (initial/measured concentration X 10^{-1}) is observed from the source (sampling point) to a distance of over 100 km. This could be due to the fact that, during March and April, there was some form of precipitation (11 ml for March and 27.4 ml for April rain, Table 1) and that from May through June is winter period with low temperatures (between 1 to 20°C). The two parameters normally cause particles to be denser and heavier, thus yielding slow dilution of particles.

Meteorology and dispersion at RCBD

Figure 6 shows a decrease in PM10 levels as wind speed increases from 19 to 25 September, 2004. The decrease is in agreement with the fact that, the diffusion of atmospheric pollutants into a greater volume of atmosphere reduces the concentration of a polluting material. The negative correlation between wind speed and monthly PM10 was also observed from a correlation matrix (r =

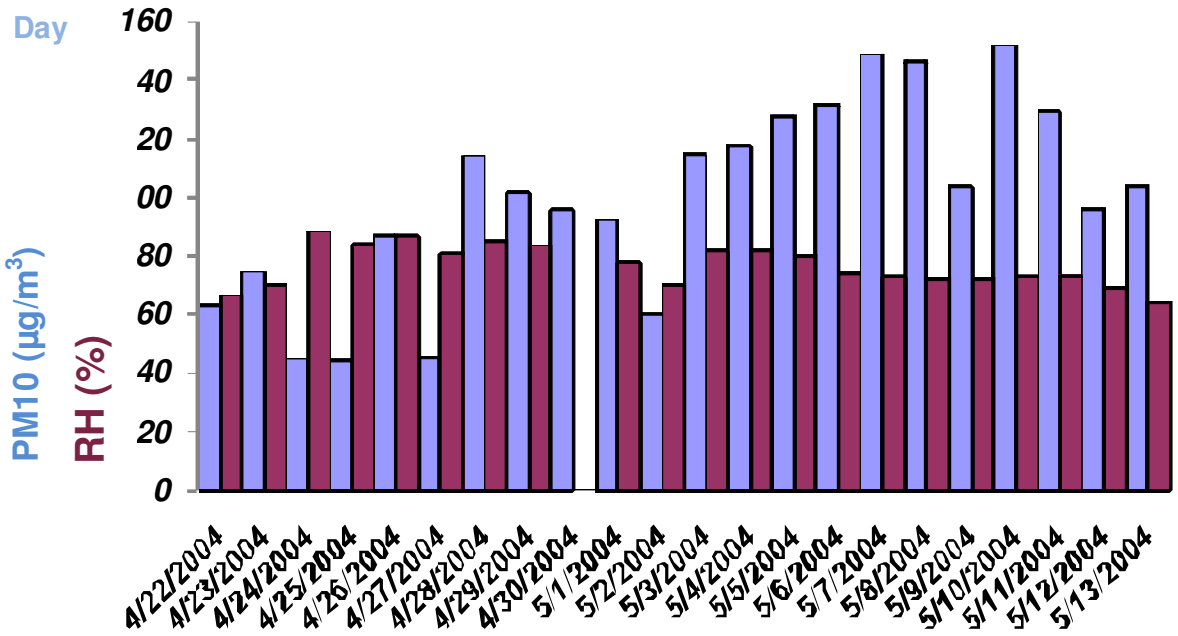

Figure 3. PM10 mass concentrations and relative humidity at RMINE.

unstable conditions of free convection, when the mixing layer is deep, and the occurrence is frequent in summer during the day (Preston-Whyte and Tyson, 1988).

The data for the 17 and 25th of September 2004 however, show a different pattern. The highest value of PM10 (81.68 µg/m^3), observed on 17 September corresponds to high temperature (31.2°C) and low wind speed (8.9 m/s). The lowest value of PM10 (10.3 µg/m^3), observed on 25 September corresponds to high temperature (28.1°C) and high wind speed (16.7 m/s). These trends could not be explained, since there was no rainfall as shown in Table 2, which could have been considered as a contributory factor to the low levels on 25 September. There was practically, no rainfall in September 2004, except for the 0.2 mm rainfall recorded on 27 September. The daily variations in wind speed and temperature are more reliable in explaining the PM10 concentrations. Dilution and dispersion of daily PM10 for September 2004 is given in Figure 7.

The dispersion of pollutants that develop into two puffs moving towards the South was observed. It can also be observed that dilution of concentrated particles occurred a short distance from the source/sampling area. The blue area shows concentration of about (initial concentration X 10^{-2}) which disperses over 60 km south. The one puff moves towards SSE whereas the other moves towards SSW direction. In general, the pollutants disperse to over 120 km south. The wind direction of 340 degrees (NNW), wind speed of 9.7 m/s and temperatures of about 27°C was measured. The puff travelling in SSW direction may have reached the southern part of Rustenburg area (Figure 1) as it travelled more than 120 km, but at low concentration levels (initial/measured Concentration X 10^{-4}).

Seasonal variations of PM10

South Africa has clearly defined climatic seasons. Each of the seasons lasts for a period of approximately three months, and are defined as Autumn (February to April), Winter (May to July), Spring (August to October) and Summer (November to January). Each season is characterised by a unique pattern of meteorological parameters, which govern the dispersion, transport and deposition of particulate matter. The discussions here are thus intended to establish the relationship between the seasons (in the form of months) and the concentration levels of particulate matter observed.

RMINE, is located close (< 5 km) to a ferro-chrome mine, and ~4 km away from an informal human settlement. The period of sampling of PM10 at this site covered mainly one season, autumn (February to April), even though some sampling was done at the beginning of winter (May and June). The beginning of winter (low temperatures) also encourages biomass burning and other types of fuel combustion within the area described. The monthly levels observed at this site are generally very high (95 to 130 µg/m^3). This may be due to the location of the site, since it is located within the 5 km radius to the ferrochrome smelter and to an informal settlement. Activities surrounding this site relate to resuspension of dust, fuel burning, and biomass burning. The levels can be justified, since there is no electricity at the informal

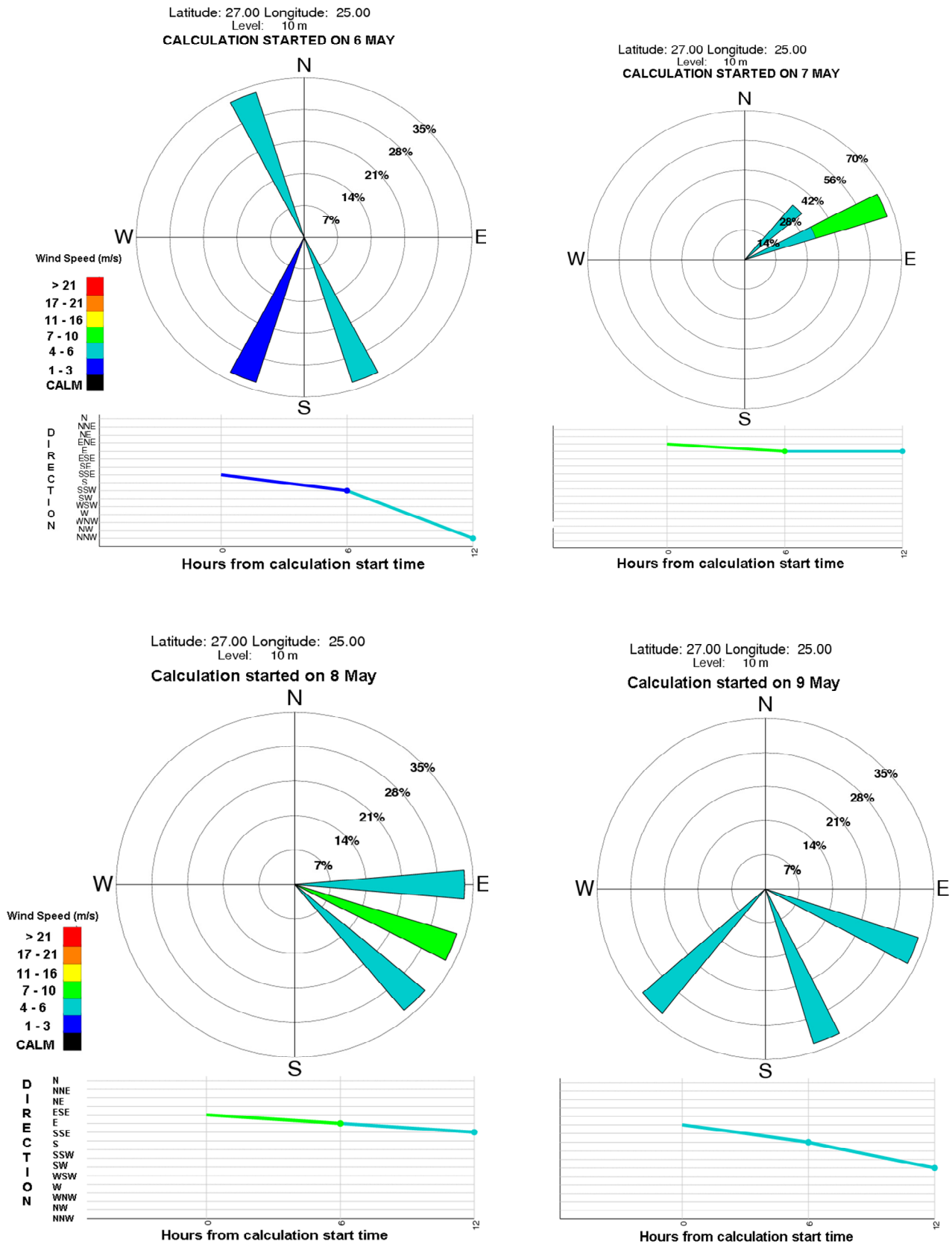

Figure 4. Wind roses for the sampling days 6 to 9 May 2004 at RMINE (NOOA, 2006)

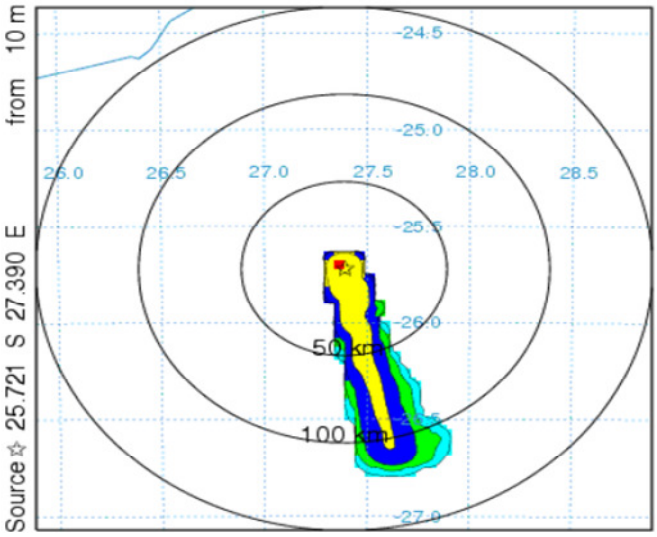

Figure 5. Monthly dilution and dispersion at RMINE – March to June 2004.

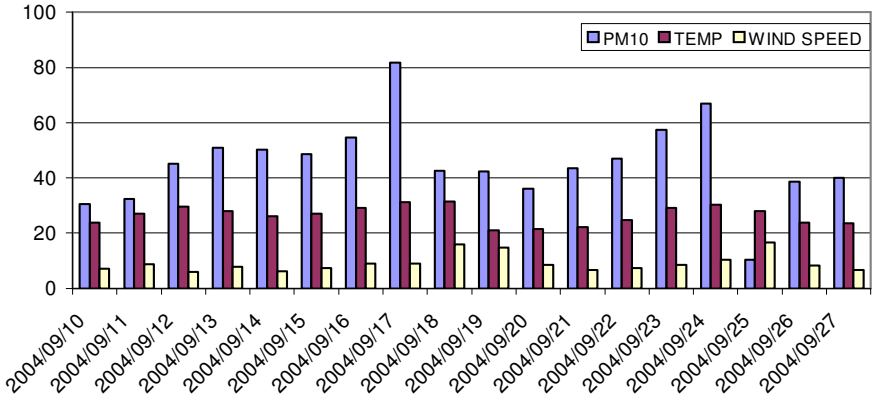

Figure 6. Daily mass concentrations of PM10, temperature and wind speed.

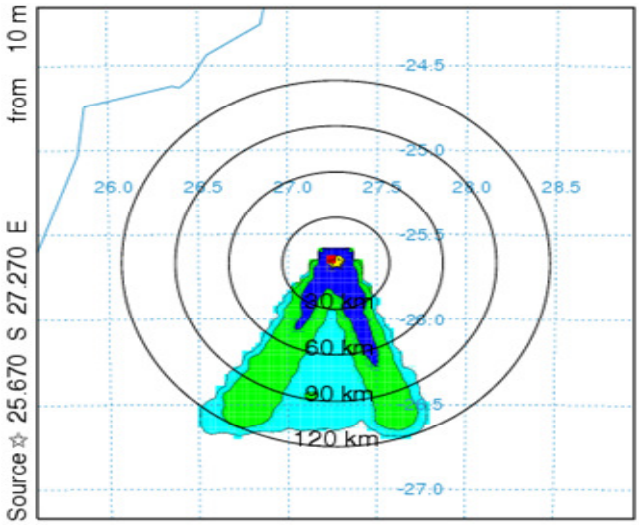

Figure 7. Dilution and dispersion of daily mass concentrations for September 2004.

Table 2. The daily rainfall at Rustenburg during 2004 (in mm) measured by the South African Weather Services (SAWS).

Day	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1												0.2
2												
3	2.2	0.6										5
4				0.2				1.6				
5			1.6	0.2								
6		0.8	0.2	0.2							0.4	26.2
7		2.6		1.2							2.8	1.2
8		3	0.2									11.2
9			0.8								0.4	
10												
11	1.6									32.8	14.2	1.2
12			0.4							3.8		
13		53.6								2.8		
14		9.2										0.2
15												
16												
17			0.4									
18	1.8	2										
19	42.2			25.6								8.4
20	74				0.2	3.4						
21	21.8					1.8					3.4 |	
22	18	7.4	0.2									
23		23.4										3.8
24		55.4	7.2									1.4
25		0.4										
26	0.8	17.2										0.8
27									0.2		7.8	11
28											1.2	12
29											7.4	
30											0.6	
31												0.4
Total	162.4	175.6	11	27.4	0.2	5.2	0	1.6	0.2	39.4|	38.2|	83

the informal settlement, and open-pit mining activities are also prevalent. RCBD is located closer to the central Business District (CBD) of the Rustenburg municipal area (~5 km), and further away from the platinum mine (~10 km). The sampling procedure for seasonal levels at this level was done from June to December 2004.

Relatively high levels of PM10 were observed for the winter season (June and July). This could be expected, since the low wind speed and temperature in winter favors the accumulation of pollutants (Chow et al., 2003), while the high temperature in summer favors the air convection and the dispersion of pollutants. In addition, the barer surface in winter would re-suspend more dust while more wet precipitation in summer would wash out more particles. The fact that most parts of the country experiences dry winters may also account for the high levels of particulate matter, since re-suspension of dust is favored. Figure 8 shows a decrease in PM10 levels from winter to summer seasons at RCBD. The effect of wind speed seems to be minor. If it increases with 50%, the PM10 concentration increases with only 10%. The perceived wind speed effect can actually also be due to the seasonal effect. A peak in PM10 levels was expected during spring (October) mainly due to the high wind speeds associated with this season. The levels were however low but can be explained by the amount of rainfall, as reported by the SAWS in Table 2, which was 39.4 mm for October 2004, and was more or less the same as in November (38.2 mm). This month was characterised by high rainfall and low wind speed (Table 2). The lowest levels of PM10 (32.63 $\mu g/m^3$) measured during the month December (summer) can also be due to the high amount of rainfall (83.0 mm) measured.

The average PM10 levels observed for winter, spring

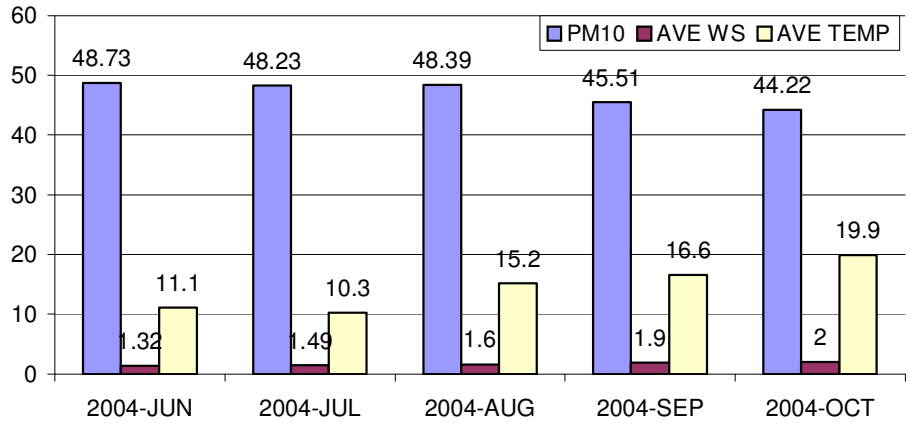

Figure 8. Monthly mass concentrations of PM10 (µg/m^3), temperature (℃) and wind speed (m/s) at RCBD.

Table 3. Air quality index for inhalable particulate matter (Peters and Dockery, 2001)

Levels of health concern	Numerical Value	Meaning
Good	0-50	Air quality is considered satisfactory, and air pollution poses little or no risk.
Moderate	51-100	Air quality is acceptable however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy for sensitive groups	101-150	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
Unhealthy	151-200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
Very unhealthy	201-300	Health alert: everyone may experience more serious health effects.
Hazardous	> 300	Health warnings of emergency conditions. The entire population is more likely to be affected.

and summer are given as 48.48, 46.04 and 37.85 µg/m^3 respectively. There is a decrease in PM10 levels from winter to summer. This can be explained by the fact that, the climate of South Africa is characterised by summer rainfalls. Table 2 shows a rainfall of 38.2 and 83 mm for November and December 2004, and 5.2 and 0 mm for June and July 2004, respectively. The decrease in PM10 levels from winter to summer seasons at RCBD, is in agreement with a study where analysis of airborne particulate samples, showed a seasonal variation of the PM mean concentration from 56 µg/m^3 ± 50% in the winter season to 41 µg/m^3 ± 30%, in the summer season (Marconi et al., 2003).

Health implications of the PM10 levels

The hourly, daily and monthly PM10 levels are highest at RMINE than in any of the study sites. The hourly and the 24-hourly PM10 standards of limitation have been exceeded several times during the study. The PM10 levels obtained can be evaluated against the air quality index given in Table 3 (Peters and Dockery, 2001). The index gives an indication of the health implications of various concentration levels. The numerical values in the air quality index described show that, the hourly levels in RMINE can range from moderate to very unhealthy, the daily levels from moderate to unhealthy, and the monthly

levels from moderate to unhealthy for sensitive groups. The daily levels at RCBD range from good to moderate, while the monthly levels can be classified as good.

The 'good' and 'moderate' categories in Table 3 may not necessarily suggest that there are no health implications, since the elevated risk of acute heart attack after short-term exposure to elevated levels of PM10 (Peters and Dockery, 2001) is 51% for increase of 40 $\mu g/m^3$ within 2 h, and 66% for increase of 30 $\mu g/m^3$ within 24 h. It has not been possible to identify a threshold for PM10 below which no health effects are observed. Serious health effects still occur at pollutant concentrations that are well below the existing air quality guidelines and standards (Polyak and Johnson, 2005). The PM10 levels measured in this study are below the 24 h limit of 180 $\mu g/m^3$ set as a South African guideline and the 150 $\mu g/m^3$ set by the United States Environmental Protection Agency (US EPA).

Conclusions

The hourly, daily and monthly PM10 levels were successfully determined. These were correlated to meteorological parameters like temperature, relative humidity and wind speed. The dispersion and dilution of these particles was determined to check if the measured concentrations do reach the neighbouring communities. The levels were further assessed against the air quality index, to determine whether they can be hazardous to human health.

The hourly levels for RMINE are high (6.5 to 215.7 $\mu g/m^3$); the daily levels are higher (44.4 to 151.7 $\mu g/m^3$) than at RCBD (10.3 to 81.7 $\mu g/m^3$); and the monthly levels are also higher (94.1 to 131.0 $\mu g/m^3$) than RCBD (44.2 to 49.3 $\mu g/m^3$). This suggests that the anthropogenic activities in the Rustenburg area are linked with industry because RMINE is closer to smelters. The study has also shown that the same level of pollution can result from urbanisation and industrialisation. It is however worth noting that the industrial activities in the vicinity of a sampling site play a major role in determining the PM levels.

RMINE experienced high levels of concentrations which were also shown to be highly dispersed (~100 Km) with low dilution (X 10^{-1} of the initial concentration). This implies that more people around that area are at risk of getting respiratory diseases, due to high levels of pollutants since the study site is located within the ferrochrome mining areas. RCBD also experienced high levels of concentrations which gets diluted quickly (X 10^{-4} of the initial concentration) dispersed over large area (~120 km).

The hourly, daily and monthly PM10 levels are highest closer to the mining industry (at RMINE) than at RCBD. The numerical values in the air quality index described show that, the hourly levels in RMINE range from moderate to very unhealthy, the daily levels from moderate to unhealthy, and the monthly levels from moderate to unhealthy for sensitive groups. The results showed an increase in PM10 as wind speed and relative humidity decreases; and an increase in PM10 as temperature increases. It is evident from this study that the levels of particulate matter depend on the meteorology, the time of day, activities around the sampling area, the distance from the source, as well as seasonal variations such as wet precipitation.

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