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An Evaluation of Atmospheric Aerosols in Kanana, Klerksdorp Gold Mining Town, North-West Province of South Africa

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1. Introduction

Atmospheric aerosols have posed a health challenge by their presence in the atmosphere. In order to control them, they have to be understood in terms of their interactions in the air, their length of suspension and their transportation. It is true to say aerosols have been in the atmosphere since the beginning of time itself. As long as there has been wind, particulate matter has found itself in the air, attributed to nature aerosol emissions. Atmospheric aerosols technically are considered to be suspension of fine solid or liquid particles in a gas (Hinds, 1999). Particles in the air can change their size and composition by condensation of vapour species or evaporation, coagulating with other particles by chemical reaction, or by activation in the presence of water.

The production of atmospheric aerosols or atmospheric particulate matter is of great concern. The effects of inhaling particulate matter which have been widely studied in humans and animals include asthma, lung cancer, cardiovascular issues, and premature death (Pope & Burnett, 2002). The size of the particle is a main determinant of where in the respiratory tract the particle will come to rest when inhaled. Larger particles are generally filtered in the nose and throat and do not necessarily cause problems, but particulate matter smaller than about 10 micrometers (μm), referred to as *PM10*, can settle in the bronchi and lungs and cause health problems. The 10 micrometer (μm) particle size does not represent a strict boundary between respirable and non-respirable particles, but has been agreed upon for monitoring of airborne particulate matter by most regulatory agencies (Seinfeld & Pandis, 2006). Similarly, particles smaller than 2.5 micrometers, *PM2.5*, tend to penetrate into the gas-exchange regions of the lung, and very small particles (< 100 nanometers) may pass through the lungs to affect other organs. *PM2.5* leads to high plaque deposits in arteries, causing vascular inflammation and atherosclerosis – a hardening of the arteries that reduces elasticity, which can lead to heart attacks and other cardiovascular problems (Pope & Burnett, 2002).

Airborne particles undergo various physical and chemical interactions and transformation (i.e. atmospheric aging), changes of particle size, structure, and composition (coagulation, restructuring, gas uptake, chemical reaction). Particularly efficient particle aging occurs in clouds, which are formed by condensation of water vapour on pre-existing aerosol particles (cloud condensation and ice nuclei). Most clouds re-evaporate, and modified aerosol

particles are again released from the evaporating cloud droplets or ice crystals (cloud processing). If, however, the cloud particles form precipitation which reaches the Earth's surface, not only the condensation nuclei but also other aerosol particles are scavenged on the way to the surface and removed from the atmosphere. This process, termed "wet deposition", is actually the main sink of atmospheric aerosol particles. Particle deposition without precipitation of hydrometeors (airborne water particles) – that is, "dry deposition" by convective transport, diffusion, and adhesion to the Earth's surface – is less important on a global scale, but is highly relevant with respect to local air quality, health effects (inhalation and deposition in the human respiratory tract), and the soiling of buildings and cultural monuments (Pöschl, 2005). Depending on aerosol properties and meteorological conditions, the characteristic residence times (life-times) of aerosol particles in the atmosphere range from hours to weeks.

Emission of particulate matter by natural means did not present as much health hazards as compared to man-made activities. Natural emissions sources were wind dust, sea sprays and natural fires or biomass burning. But this changed when man began to develop himself; trying to make himself comfortable. The more he became comfortable the more population increased, prompting new developments that consequently led to activities that are now responsible for health threatening atmospheric aerosols. These activities included the improved transportation system, industrial transformation, and consumption of fuel etc. This pattern can be seen in the study area of interest, Kanana in South Africa.

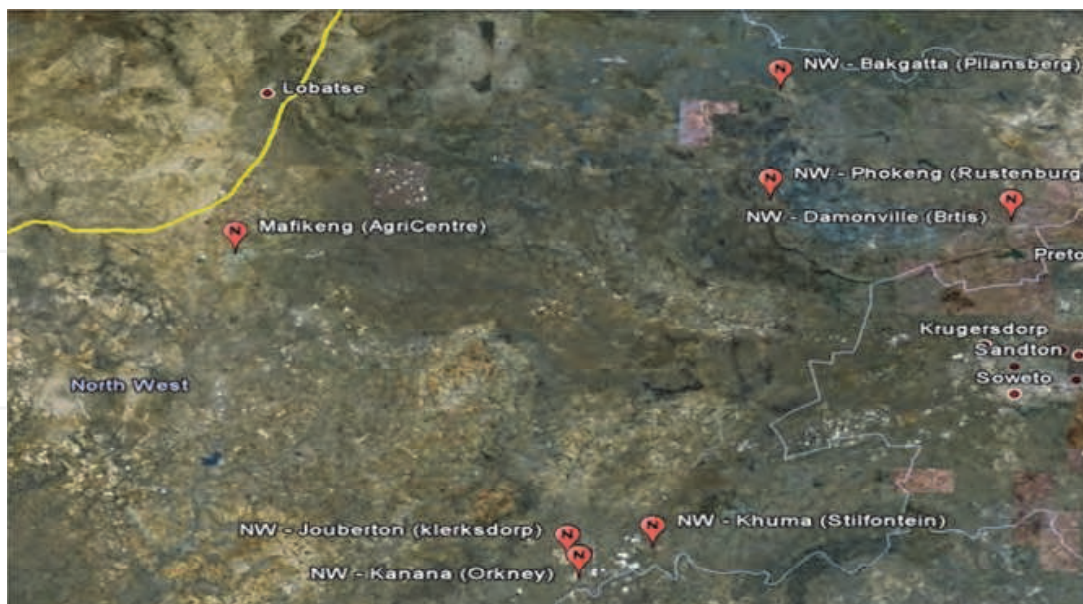
2. Purpose of the research study area

Literature shows that air pollution continues to threaten public health despite tighter emission standards, closer monitoring of air pollution, and reduction of levels of certain types of air pollutants. Averaged over the globe, *anthropogenic* aerosols (those made by human activities) currently account for about 10 percent of the total amount of aerosols in our atmosphere, (Pope and Burnett, 2002). The increased levels of fine chemical particle concentration and composition in the air are linked to health hazards such as heart disease, altered lung function and lung cancer. It is for this reason that an evaluation of the air quality with regard to particulate matter was undertaken in Kanana area in the Klerksdorp gold mining town of the North-West province of South Africa.

2.1 The case of Kanana, Klerksdorp (South Africa)

The North West Province, with its favourable geographical location close to the provincial capital of South Africa, as well as its eco-tourism potential and the mining industry, is one of South Africa's most visited provinces. Touristic attractions include:

- The Sun City/Pilanesberg complex, Magaliesberg, and Hartbeespoort. Recommended new nodes include: Borakalalo Game Reserve, Vredefort Dome, Vaalkop Dam, and Ganyesa /Kalahari.
- Both foreign and local tourists visit the North-West Province. As such international tourist bring in foreign exchange and so contribute greatly to the economy of the country. Map of Kanana and description is shown below. Kanana lies in what is called Orkney gold mining area, within Klerksdorp as can be seen in the map above (26° 58' 0" South, 26° 38' 0" East).



2.2 Environmental strains of the North-West Province

According to the State of the Environment Report overview (2002), North West Province, South Africa is under pressure especially from:

- The Ga-Rankuwa, Brits, Hartebeespoort and Rustenburg area due to industrial mining and other developments. This area is also one of the tourism nodes in the Province that needs to be sustained.
- The main corridors for tourism are: Hartebeespoort-Rustenburg-Sun City-Madikwe Game Reserve; Hartebeespoort-Rustenburg-Zeerust-Mafikeng-Lehurutshe, and Gauteng-Potchefstroom-Klerksdorp-Wolmaransstad-Bloemhof.

The State of the Air Report in South Africa (2005), list polluting sources as industrial and commercial activities; electricity generation especially coal-fired and fuel-turbine power stations; waste treatment and disposal that includes incineration; residential activities that includes burning of coal, paraffin, liquid petroleum (LP) gas, dung and wood; transport (petrol-diesel driven exhaust emissions, road dust raised by vehicles, etc); and agriculture. On the other hand, there are admissions of health-risking particulate matter emissions into the environment by industrial giants like the mines such that the public raised complaints because of poor visibility and too much dust from the smelters and refineries, as well as dust fallout from various tailings dams (Bullock, 2006).

3. Information on sources of particulate matter emissions

Like any other settled areas of the world, Rustenburg, another mining city in the North West Province, has had its effects of human development on the quality of air. Before the onset of industrialization, the air in the town was influenced by the natural phenomenon occurrences; particulate matter in the atmosphere as a result of wind dust, fire-raised atmospheric aerosols and particulate matter emissions as a result of human activities. But the advent of increased population, pressures on the atmosphere also increased as a result of increased human needs. The functioning and quality of the environment got affected as the result of increased human needs. Increased population meant increase in land use such as settlements, agriculture, and industry, to mention but a few.

Industrial development in the form of mining appears to have had more influence in the settlement in Rustenburg and the surrounding towns like Klerksdorp.

3.1 Mining

According to the North-West Freight Transport Databank, Rustenburg town alone contributes about 70% platinum mining of the world. Chrome is also mined extensively. Klerksdorp is mostly a gold mining town. South Africa as a whole is the largest producer of gold in the world. The gold mining sector provides about 56% of miner's employment in the country. Mining activities produce toxic metals like mercury (Roulet et al., 1999) and so it is important to establish the contribution of particulate matter in the atmosphere.



A



B

Fig. 1. (A & B): Mining processes as a source of particulate matter
Source: State of Air Report in South Africa (2005)

3.2 Transport sector

As a result of large scale mining of platinum and gold, the transport sector has grown tremendously. This includes public as well as commercial vehicles.



Fig. 2. Haulage track with particulate matter emissions
Source: State of Air Report in South Africa (2005)

3.3 Human sector

Mining sector offered great employment opportunities. This attracted people from even surrounding areas thereby putting pressure on municipalities in terms of housing. As a result all forms of settlements mushroomed – both planned and unplanned. Settlements used fuel for cooking and warmth and so produced aerosols that reduced quality of the air in the environment (figure 3).



Fig. 3. Domestic cooking as a source of particulate matter emissions
Source: State of Air Report in South Africa (2005)

3.4 Agricultural sector

Agricultural activities also produced atmospheric aerosols resulting into degradation of air quality in the environment. The burning of agricultural refuse especially is a major source of particulate (Figure 4).



Fig. 4. Agricultural burn offs

Source: State of Air Report in South Africa (2005)

3.5 Environmental refuse treatment

When waste is collected, some of it is burnt as a form of reducing its volume as can be seen in Figure 5 below. Such activities emit particulate matter into the atmosphere thus contributing to the degradation of the air quality.



Fig. 5. An industrial burning activity producing particulate matter (burning tyres).

Source: State of Air Report in South Africa (2005)

3.6 Air quality

The air quality in Kanana is dependent on emissions of pollutants from a variety of activities. The fact that the area is located in a mining town, development as a result of the mines affect it markedly. An example is the change in population levels of the area and how the population becomes distributed. Unplanned or informal settlements arise. These in most cases are of low income group. Generally, the low income group tends to use biofuels and burning of wood for cooking purposes as well as for keeping themselves warm especially during winter. Low income group engage in small time-farming. Since they do not have

adequate resources, their methods of preparing land contribute to production of and emission of particulate matter – especially during burning vegetation for clearing land.

There is some contribution of particulate emissions from such activities as incineration of waste from health institutions, boiler operations by industry and so on. The household use of coal, paraffin, Liquefied Petroleum Gas (LPG) as a source of fuel result into particulate matter being emitted into the air.

The expanded economic activities promote an improvement of road network. Some roads are tarred and others are gravel roads. It is the untarred roads that are a major concern. They become a source of particulate matter emission as a result of the dust that is disturbed by both commercial and private vehicles – trucks hauling material from one place to another cause entailment of dust. Mechanical forces (between the tire and the road surface) for example re-suspend particulate matter that had been deposited thereby increasing aerosol particulates. Re-entrainment of deposited particulate matter can also occur as a result of air blow from vehicle exhausts pipes during operations.

Development translates into more vehicles on the road; the consequence is that both diesel and petrol vehicles produce particulate matter that eventually end up in the atmosphere thereby degrading its air quality. Inter-dependent industry spring up (one manufacturer produces one thing that the other needs in order to proceed with their production), each producing waste in one way or another. Miscellaneous sources of emissions of particulate matter that could be considered are the burning of tires, and dust generated at construction sites.

The mines themselves have a number of activities that produce particulate matter, pollution that is dangerous to communities especially those that live in within areas where mining takes place. Some examples of such activities include operations in the open cast mines, blasting activities, crushing activities, waste discarded as rock dumps, slimes and tailings dams.

3.7 Deposition of particulate matter

The degraded air quality varies throughout each day as more aerosols are emitted and also as they get deposited to the surface of the ground as a result of a number of mechanisms. Some known particulate matter deposition methods include gravity settling, and wet deposition. Particulate matter can also be transported far from their point of emission. Particulate matter gets easily deposited as a result of their particle size diameter. The larger the diameter the better they get deposited by the force of gravity. This phenomenon is further enhanced when aerosol particulates adhere to one another as they get into contact with each other in the atmosphere. This results into formation of agglomerates or large particles having large size diameter. The main forces that cause particulate matter to agglomerate include the London forces – or the van der Waals forces, the electrostatic force and the surface tension of liquids in the atmosphere (Hinds, 1999). The formation of particulate matter of large size diameter is promoted when the atmospheric relative humidity increases to a certain level. As a result, the aerosol particles get scavenged. Aerosol particles experience deposition in still air. This is different from scavenging in conditions of high wind speeds. In this case particulate matter gets blown or transported and get deposited far from the point of emission. High temperatures on the other hand create some air turbulence. This can cause aerosol particle dilution due to air movement.

3.8 Particulate matter and health

The state of the air is of the utmost importance to the health of human beings and living things at large. It is a known fact that particulate matter plays a big role in our physiology;

e.g. breathing particulate matter of size ten micrometres (PM₁₀) or less can affect the respiratory system amongst other health problems. It has been reported from previous studies for instance, that esophageal cancer is high among men and women in northern Iran (Azin et al., 1996). Clearly, the air we breathe does not just contain oxygen, carbon dioxide, nitrogen, water vapor anymore but more other complicated substances. The composition of the air has changed tremendously over the years, more especially with the onset of industrialization on a large scale. Metal mining for example is the leading contributor of toxic emissions to the environment (Earthworks and Oxfam, 2007). Other information that come to mind regarding toxic emissions from the mines are that mining and dust are inseparable. As a consequence, air pollution also comes mainly from silicate dust from ore mining and crushing. The inhalation of aerosol particulates causes a serious health hazard such as development of fibrotic lung disease (Ogola et al., 2001). Some alarming pictures about presence of metals in the atmospheric aerosols have been presented by various researchers. United Nations expressed their concerns regarding toxicity effects of lead even in the lowest doses can impairing the nervous system (UN, 1998). Lead is known to also affect an unborn child (the fetus), infants, as well as young children.

Mercury is known to also attack the central nervous system. It could lead to a disease called Minamata (United Nations University, 1993). Arsenic on the other hand has the ability to attack different sites in the body. It is reported to attack the stomach, the respiratory system, the lungs and others (Harada, 1996).

Both natural and anthropogenic sources of particulates have been discussed above. It is clearly apparent from the data presented below that the concern about the presence of aerosol particulates is very much evident; and that the air quality has been compromised in this chosen area of study.

4. Methodology of data collection

4.1 Sampling of atmospheric aerosols

Sampling of atmospheric aerosols was done using a German Ambient Dust Monitoring instrument Grimm # 180 over a period of 3 months in 2009. The Ambient Dust Monitor is a stationary monitor installed in a measuring shelter (Figure 6), at a clinic for security reasons. This site is about 5 kilometers from the nearest mine. It was chosen for the fact that many people live around the site. It measures continuously concentrations of PM₁₀, PM_{2.5}, and PM₁. In this research work, only PM₁₀ measurements were done. This was decided upon because South Africa Air Quality Guidelines talks only about PM₁₀. The dust monitor presents the airborne dust particulates in micrograms per cubic meter ($\mu\text{g}/\text{m}^3$). The resolution of the mass calculation set by the manufacturer is $0.1 \mu\text{g}/\text{m}^3$ with a flow rate of 72 l/h. The Grimm #180 dust monitor takes continuous air samples by means of a flow controlled pump. In the monitor, the particles are measured by the physical principle of orthogonal light scattering. Particles are illuminated by a laser light and the scattered signal from the particle passing through the laser beam is collected at approximately 90° by a mirror and transferred to a recipient diode. Each signal of the diode is fed, after a corresponding reinforcement, to a pulse height analyzer then classified to size and transmitted in each size channel. These counts are converted each 6 seconds to a mass distribution from which the different PM values are derived. Results of the measurement are shown on the display as mass distribution in $\mu\text{g}/\text{m}^3$: PM₁₀, PM_{2.5}, and PM₁. The collected data is stored on an AQWeblogger data logger. The data is then retrieved on site or by remote access.

The equipment is shown in Figure 7.



Fig. 6. Measuring station for taking particulate matter measurements
Source: State of Air Report (2005)



Fig. 7. Measuring equipment for taking particulate matter measurements
Source: Grimm # 180 dust monitor manual

5. Results

Results obtained from air samples in the months of April, May, and June 2009 for Kanana, Klerksdorp Gold Mining Town are as presented in the various figures below. In South Africa, April and May are autumn months. June is one of the months in winter season. In the month of April high values (above $70 \mu\text{g}/\text{m}^3$) of particulate matter appear 18 times as

can be seen from Fig. 8. The highest value of particulate matter recorded was about 130 $\mu\text{g}/\text{m}^3$ on 20 April, 2009. On the days 18 – 20 April winds blowing were mostly South easterlies as can be seen in Fig. 9. The probability that these winds are responsible for the high particulate matter values are high. Low wind speeds were recorded during these three days – Fig. 10. Low wind speeds favour high particulate matter values. In the month of May, high values (above 70 $\mu\text{g}/\text{m}^3$) of particulate matter appear 11 times as can be seen from Fig. 11. The highest value of particulate matter recorded was about 200 $\mu\text{g}/\text{m}^3$ on 29 May, 2009. Northwest winds prevailed during the time of high recorded values of particulate matter – Fig. 12. Wind speed for this period were below 2ms^{-1} , favouring high particulate matter values – Fig. 13. Wind direction appear not to be the conclusive contributor of high recorded values of particulate matter as can be seen in Fig. 8, 11 and 14. The winter month of June shows the highest value of particulate matter recorded was about 206 $\mu\text{g}/\text{m}^3$ on the 4th day of the month. However high values (above 70 $\mu\text{g}/\text{m}^3$) of particulate matter appear 9 times as can be seen from Fig. 14. In April, on the average winds were mostly southeast for most of the month. These winds appear to have caused the high values of the particulate matter recorded. From Fig. 10, it can be noted that these winds were mostly having speeds of about 2 m/s. The month of May experienced winds blowing from southeast as well. In this month the high values for the particulate matter appear to be blown in from all directions. Wind speeds for these high values were relatively low, less than 2 m/s (Fig. 15). June, just like April and May, on average winds were mostly southeast for most of the month. Again, these winds appear to have caused the high values of the particulate matter recorded. From Fig. 16, it can be noted that these winds were mostly having speeds of less than 2 m/s as in May. It can be noted from the PM10 graphs and wind speed graphs that wind speeds above 2 m/s had a scouring effect – that is they tended to lower the values of the particulate matter recorded in all the three months.

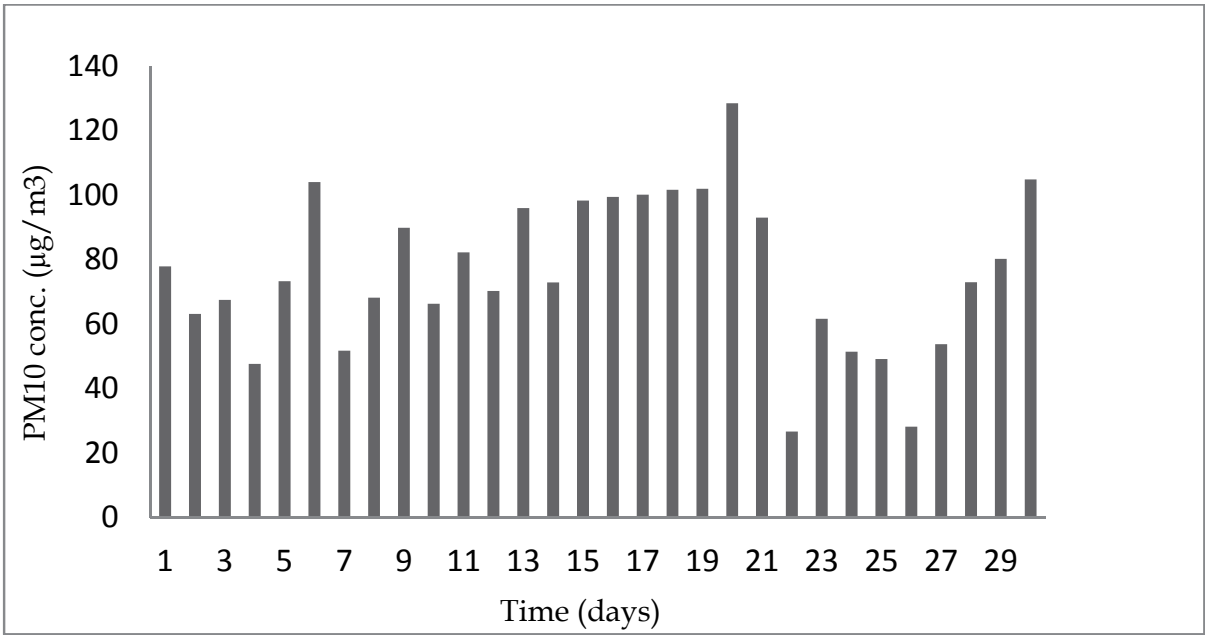


Fig. 8. Daily averages of PM10 concentrations for each day in the month of April 2009 in Kanana

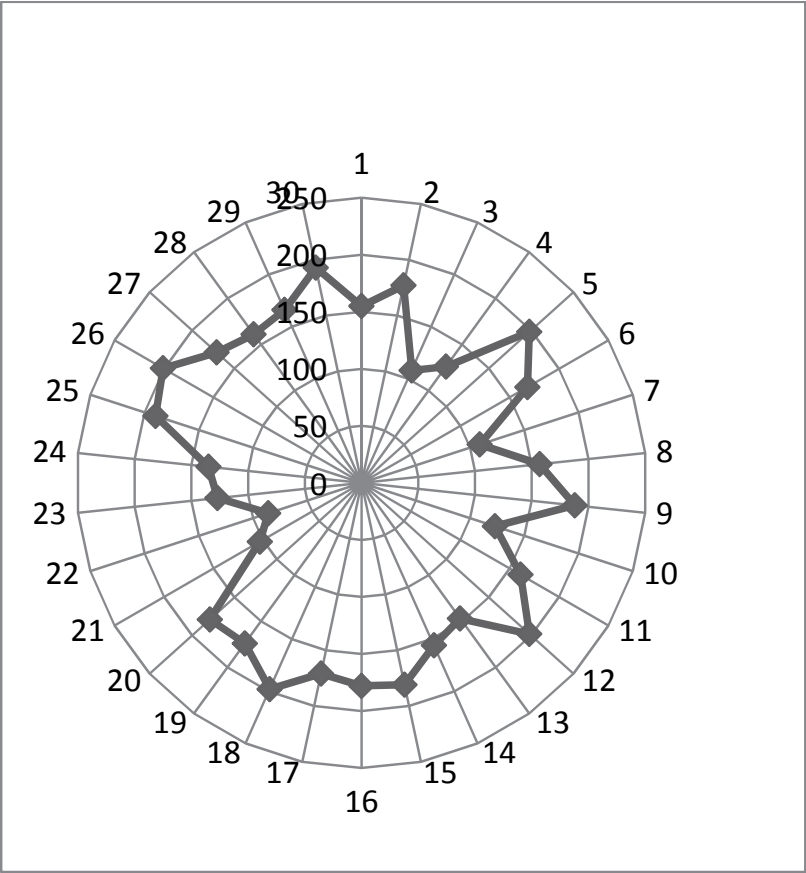


Fig. 9. Wind direction conditions for each day in the month of April 2009 in Kanana

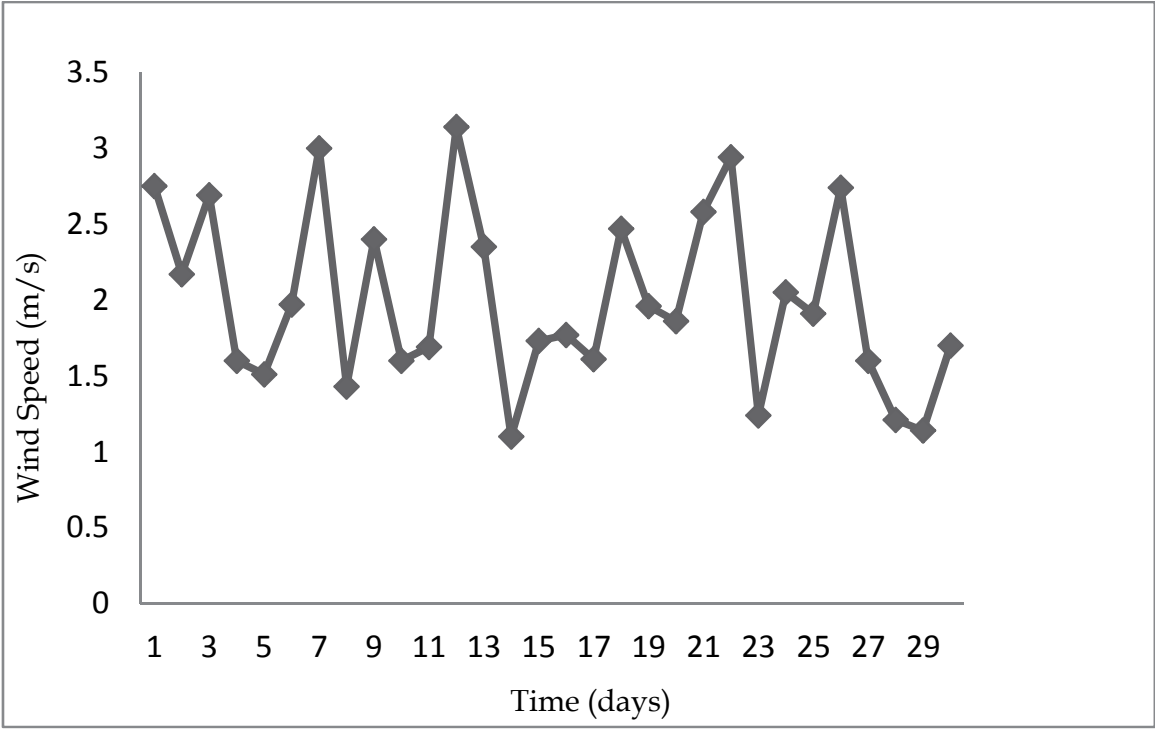


Fig. 10. Wind speed conditions for each day in the month of April 2009 in Kanana

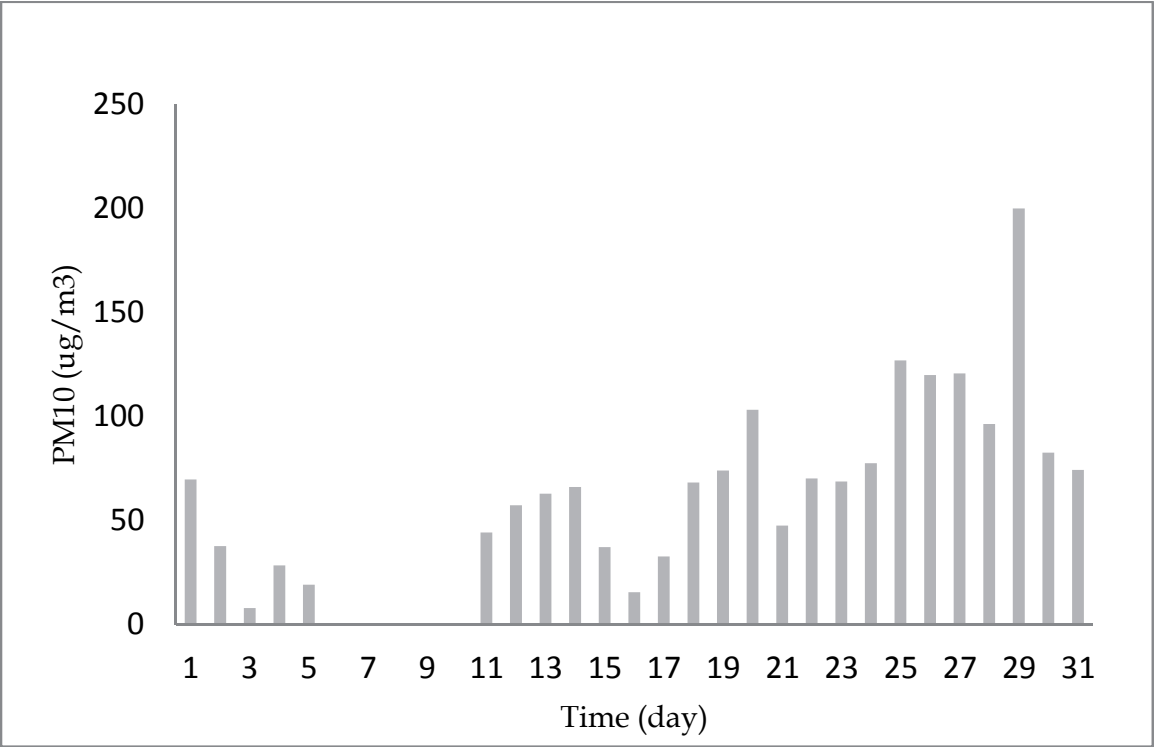


Fig. 11. Daily averages of PM10 concentrations for each day in the month of May 2009 in Kanana

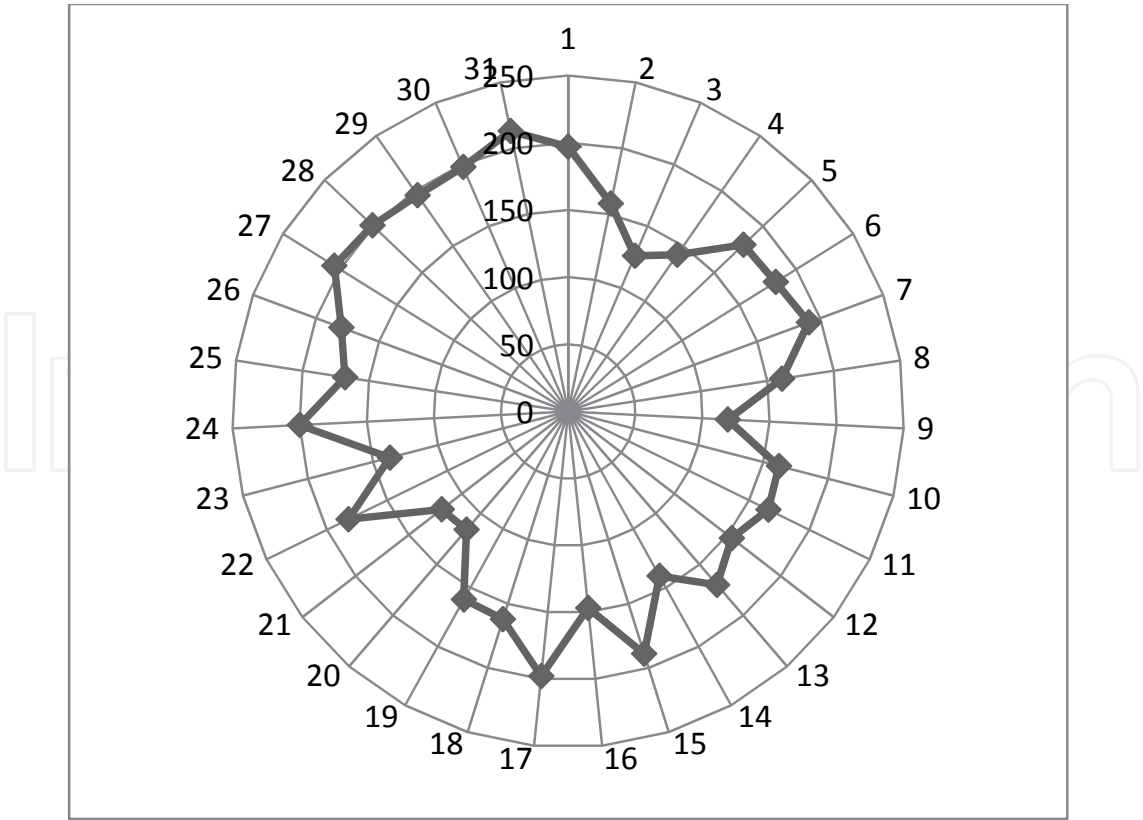


Fig. 12. Wind direction conditions for each day in the month of May 2009 in Kanana

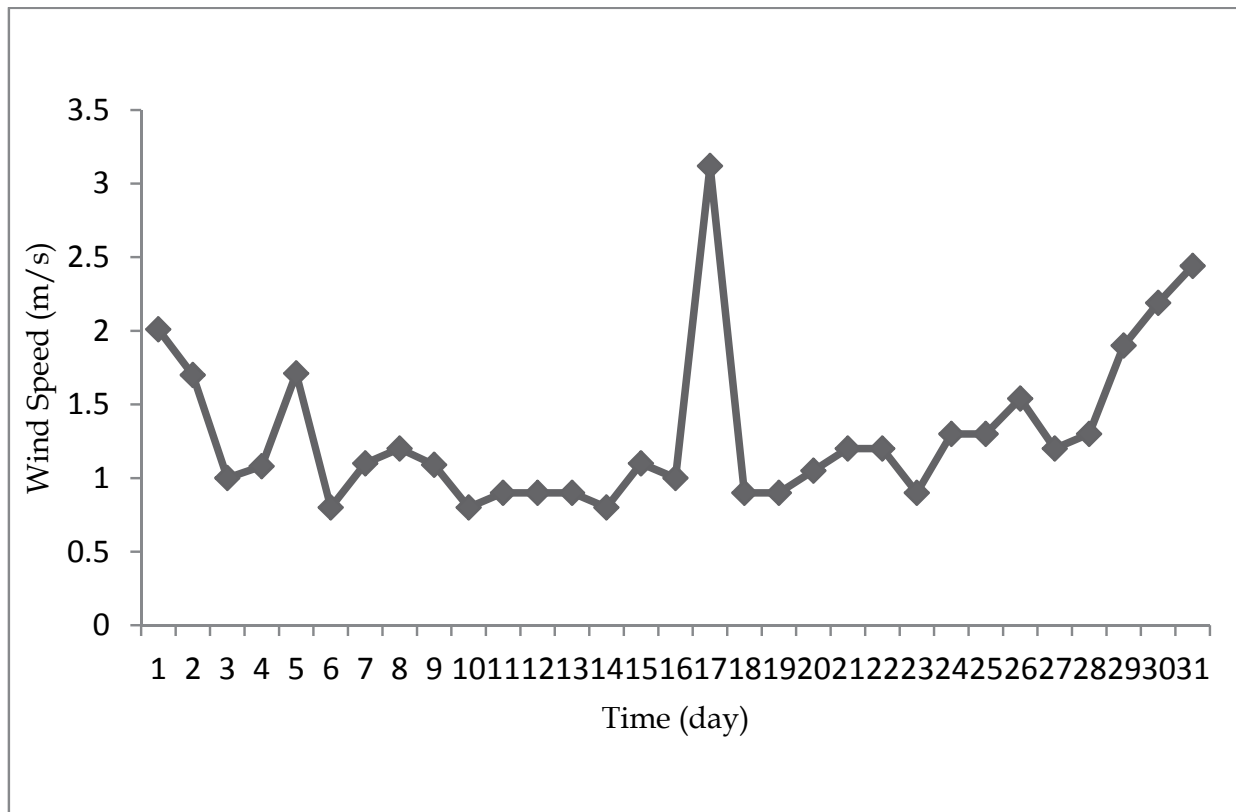


Fig. 13. Wind speed conditions for each day in the month of May 2009 in Kanana

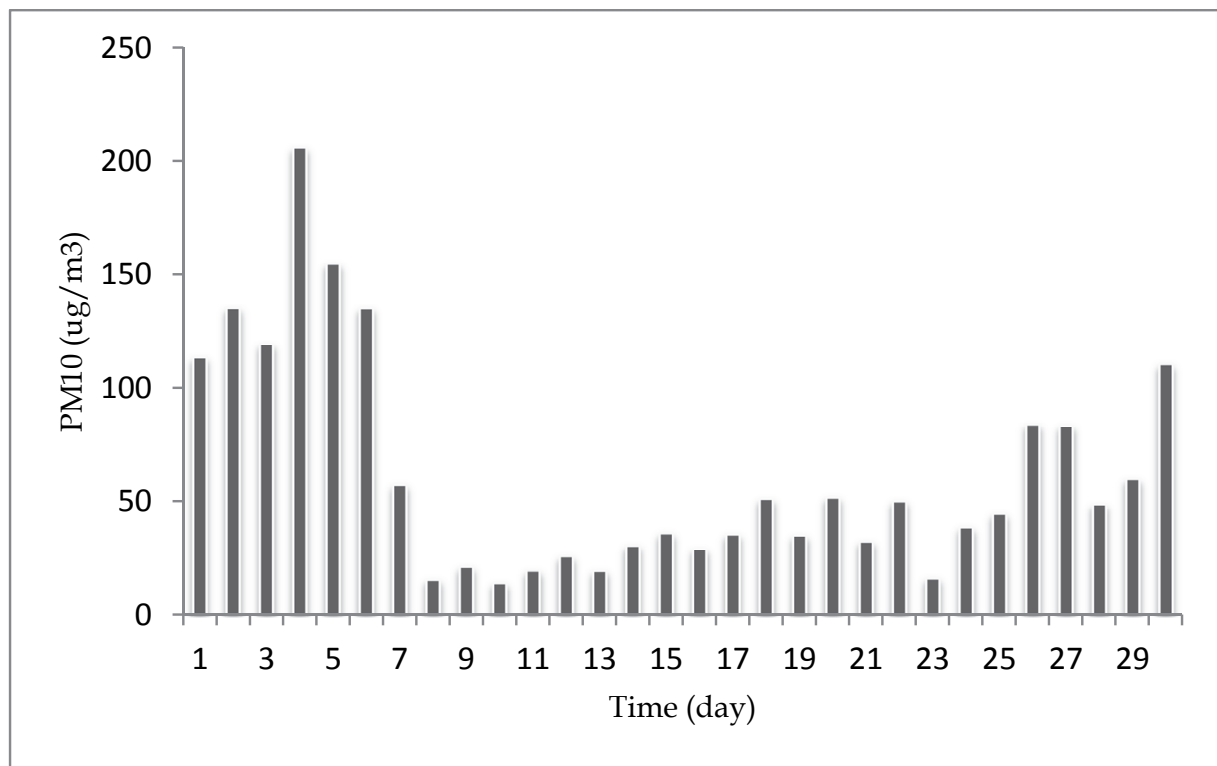


Fig. 14. Daily averages of PM10 concentrations for each day in the month of June 2009 in Kanana

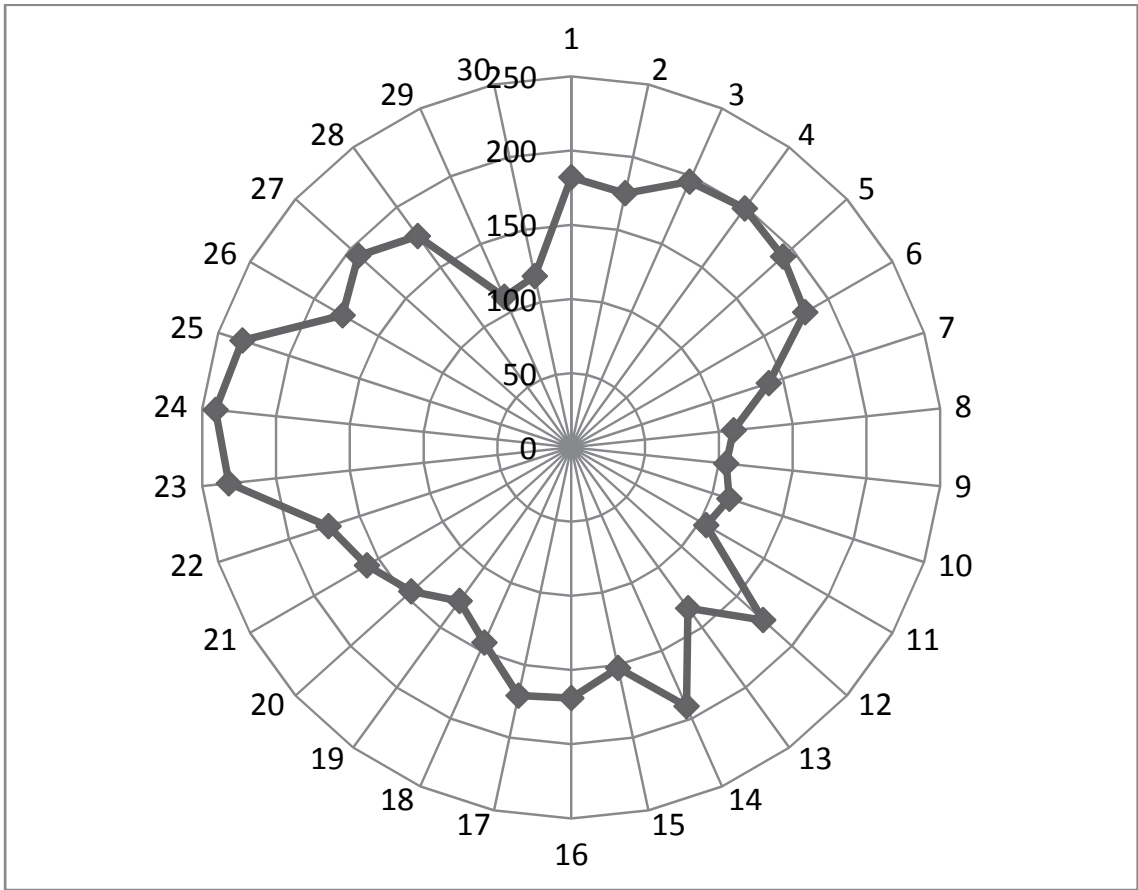


Fig. 15. Wind direction conditions for each day in the month of May 2009 in Kanana

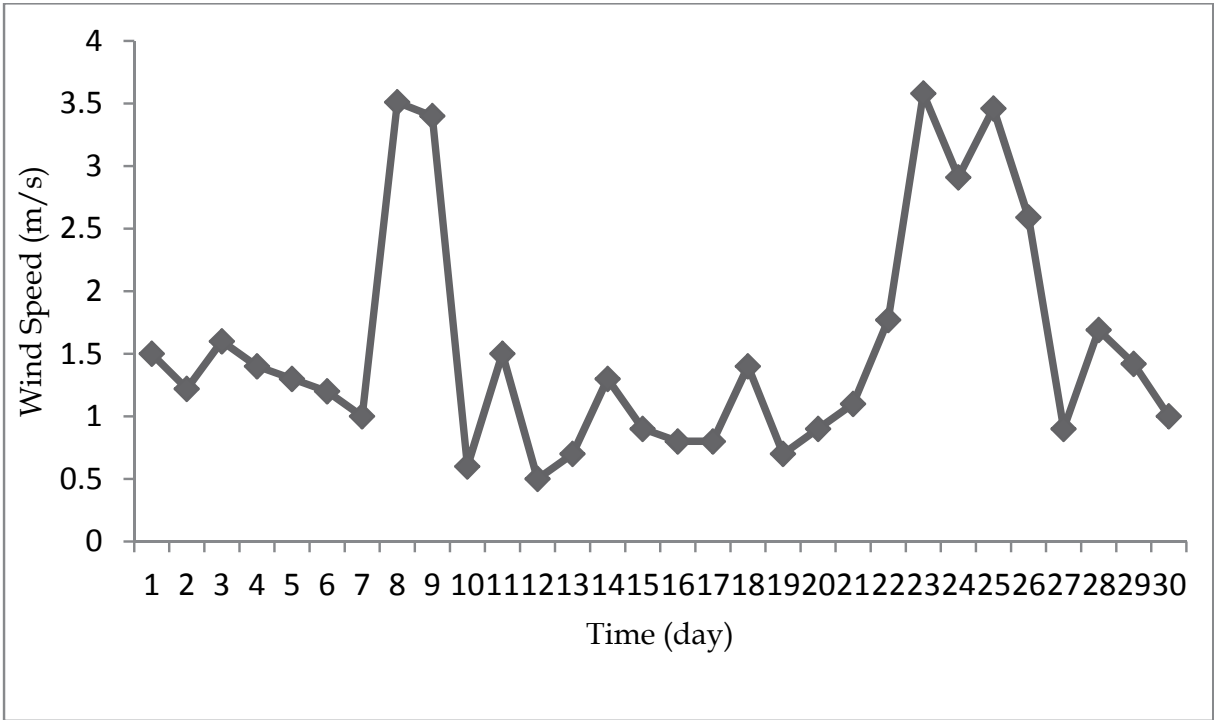


Fig. 16. Wind speed conditions for each day in the month of June 2009 in Kanana

5.1 A comparison – Gold mining and platinum mining PM10 emissions

A comparison of particulate matter emissions between a gold mining area and a platinum mining area for July 2010 was made. As it could be seen from Fig. 17 below, more particulate matter emissions were recorded for Kanana (a gold mining area in Klerksdorp) than for Phokeng (a platinum mining area in Rustenburg). This is not known why it should be so. Perhaps a logical explanation might be as forwarded by report by Earthworks and Oxfam America (2007) that ‘gold mining is one of the dirtiest industries in the world’. From the figures below, Kanana showed the highest recording for particulate matter emissions of 180 $\mu\text{g}/\text{m}^3$ on the 20 of July 2010. The highest value for particulate matter emission for Phokeng was 78 $\mu\text{g}/\text{m}^3$ on the 21 of July 2010. Daily average wind speeds for this particular day for Kanana are as shown in Fig. 18.

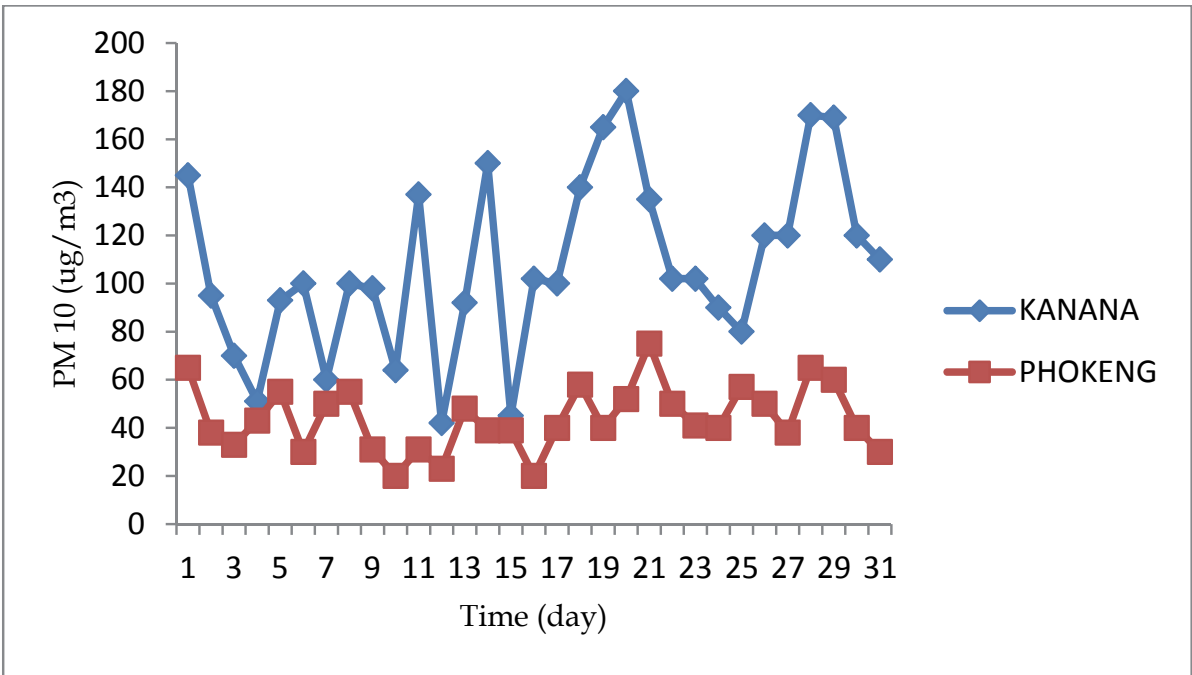


Fig. 17. Comparison of daily averages of PM10 concentrations for each day in the month of July 2010 for Kanana and Phokeng.

Daily average wind speeds for Phokeng are also shown in Fig. 22. Daily average wind speeds for Kanana were generally lower than those of Phokeng. Daily average temperatures for July 2010 for both areas (Kanana and Phokeng) are indicated in Fig. 21 for Kanana and Fig. 23 for Phokeng. There was no precipitation recorded in both places, but relative humidity values are shown in Fig. 20 for Kanana in Klerksdorp, and Fig. 22 for Phokeng in Rustenburg. Relative humidity for Phokeng (the platinum mining area) on a number of days was above 60% where as relative humidity values for Kanana (in the gold mining area) were mostly below 60%. It is possible that this could explain the lower values in the particulate matter recorded in Phokeng the platinum mining area than in Kanana the gold mining area. This is not the case though between the second and the fourth day. But between the ninth and tenth day, the explanation appears to be valid – that high relative humidity could have been responsible for low particulate matter. Low values of relative humidity have corresponded to high values of recorded particulate matter during period 17th to 20th in Kanana gold mining area. These conditions are similar for those prevailing in

Phokeng platinum area and yet particulate matter values for this period 17th to 20th day do not rise as compared to Kanana gold mining area. The explanation that washdown has resulted into lower values of particulate matter recorded because of high relative humidity does not hold.

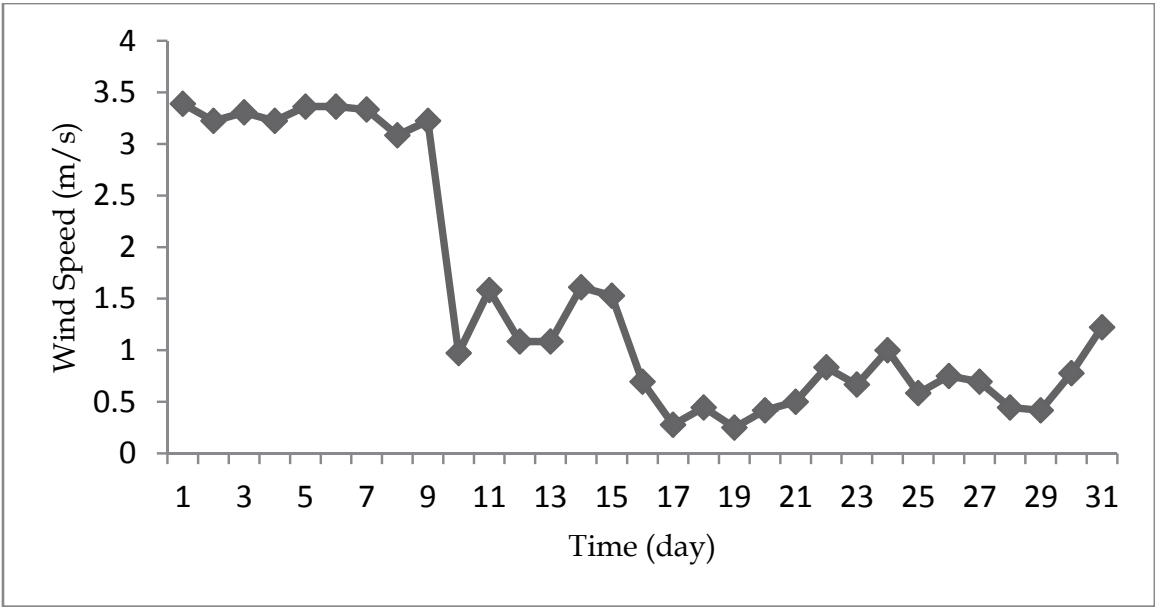


Fig. 18. Wind speed conditions for each day in the month of July 2010 Kanana, in Klerksdorp

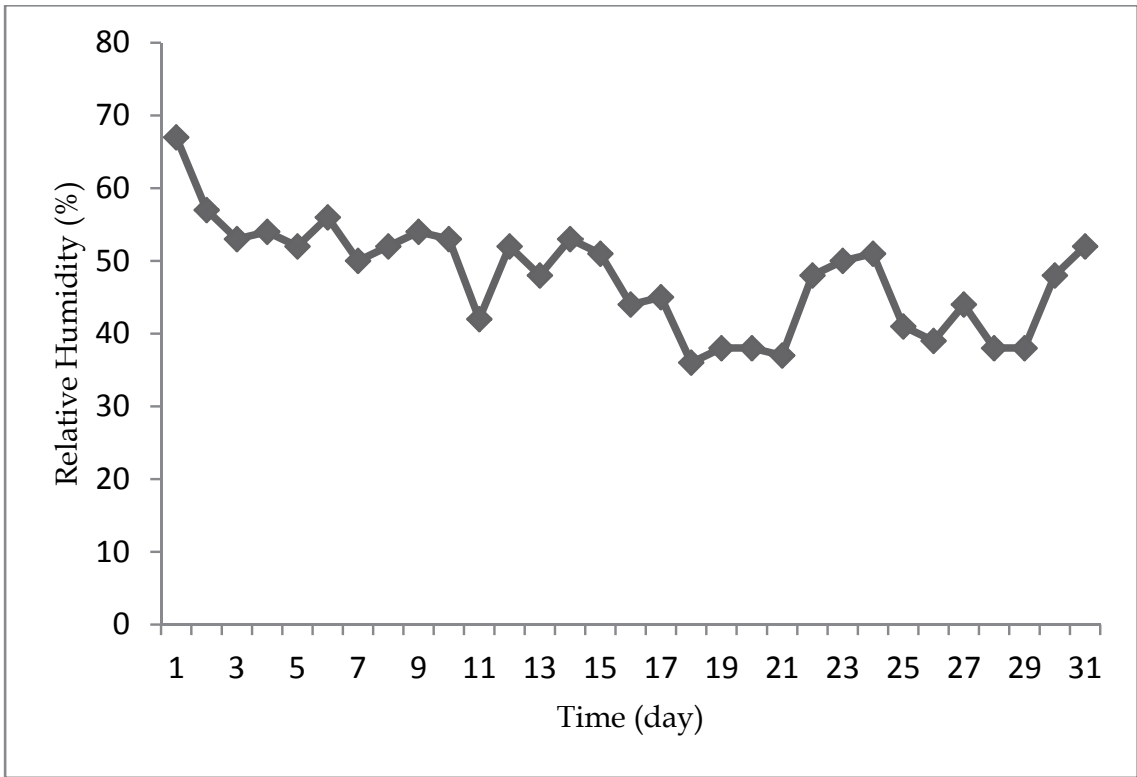


Fig. 19. Relative Humidity conditions for each day in the month of July 2010 Kanana, in Klerksdorp

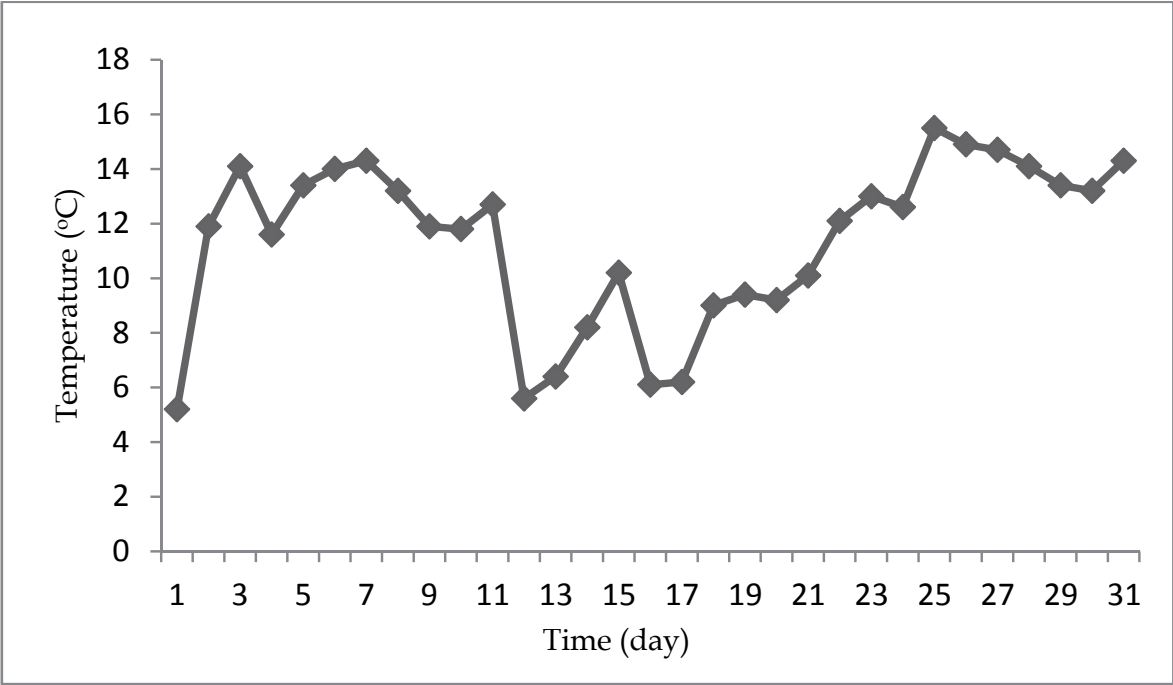


Fig. 20. Temperature conditions for each day in the month of July 2010 Kanana, in Klerksdorp

Fig. 21 and Fig. 23 show temperature variation for each day in July 2010 in each of these two areas. The temperature ranges are similar and so the difference in particulate matter recorded cannot be deduced from temperature comparison either.

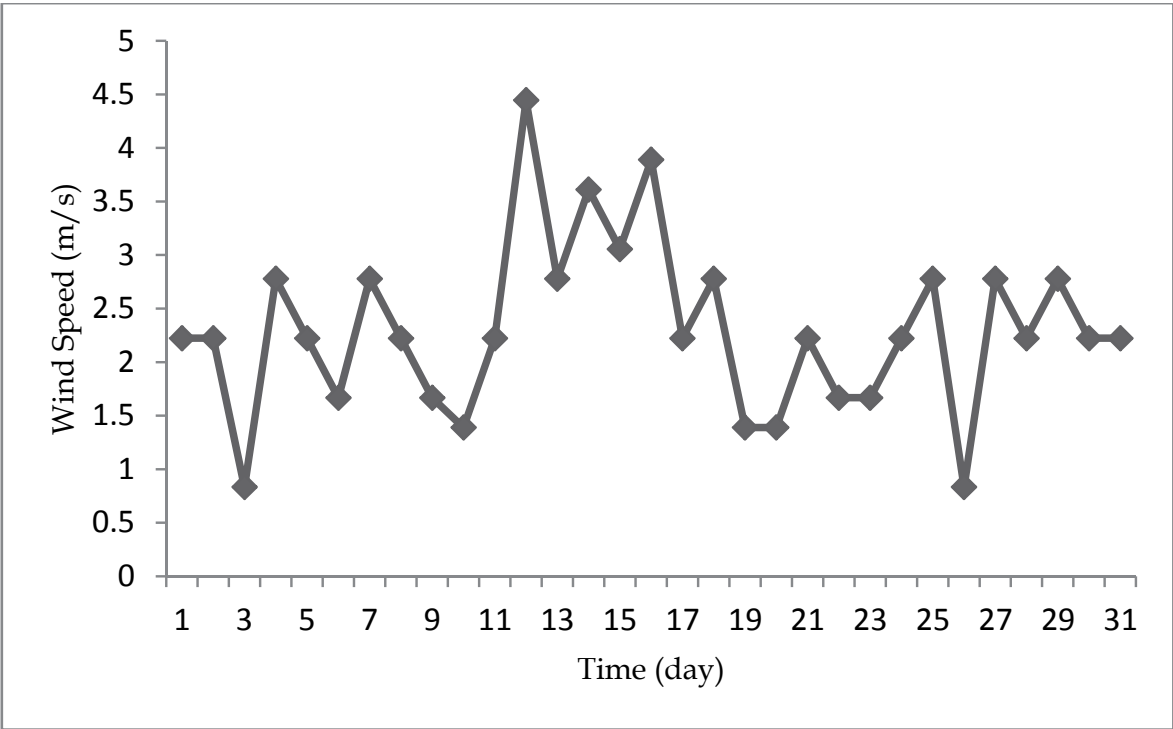


Fig. 21. Wind speed conditions for each day in the month of July 2010 Phokeng, in Rustenburg

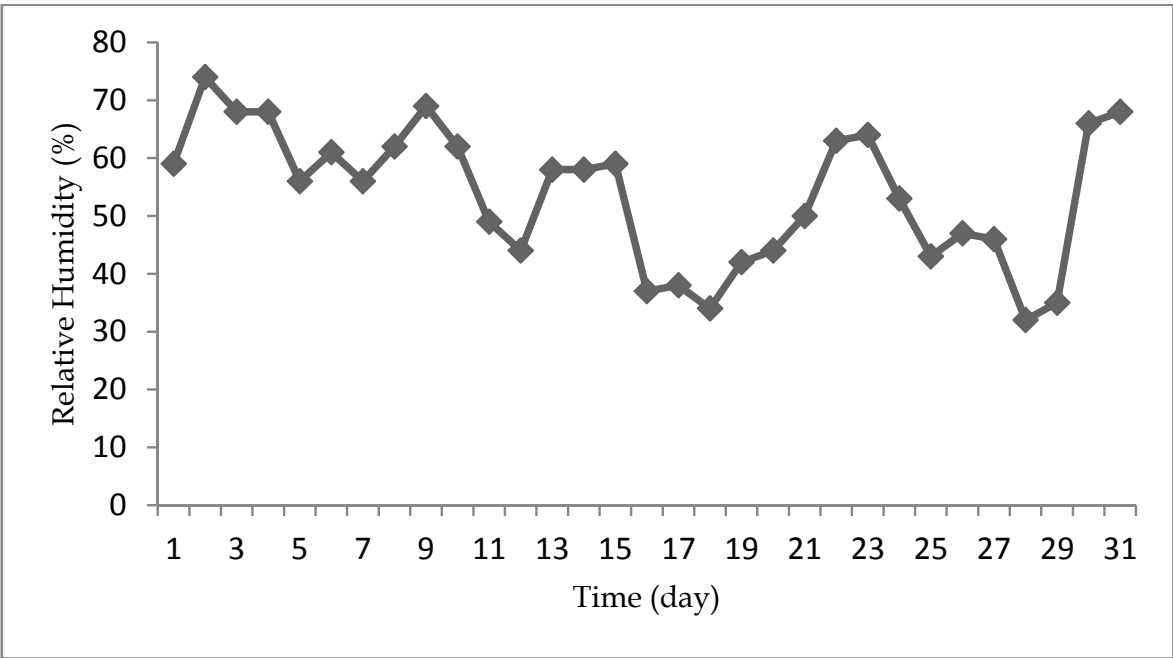


Fig. 22. Relative Humidity conditions for each day in the month of July 2010 Phokeng, in Rustenburg

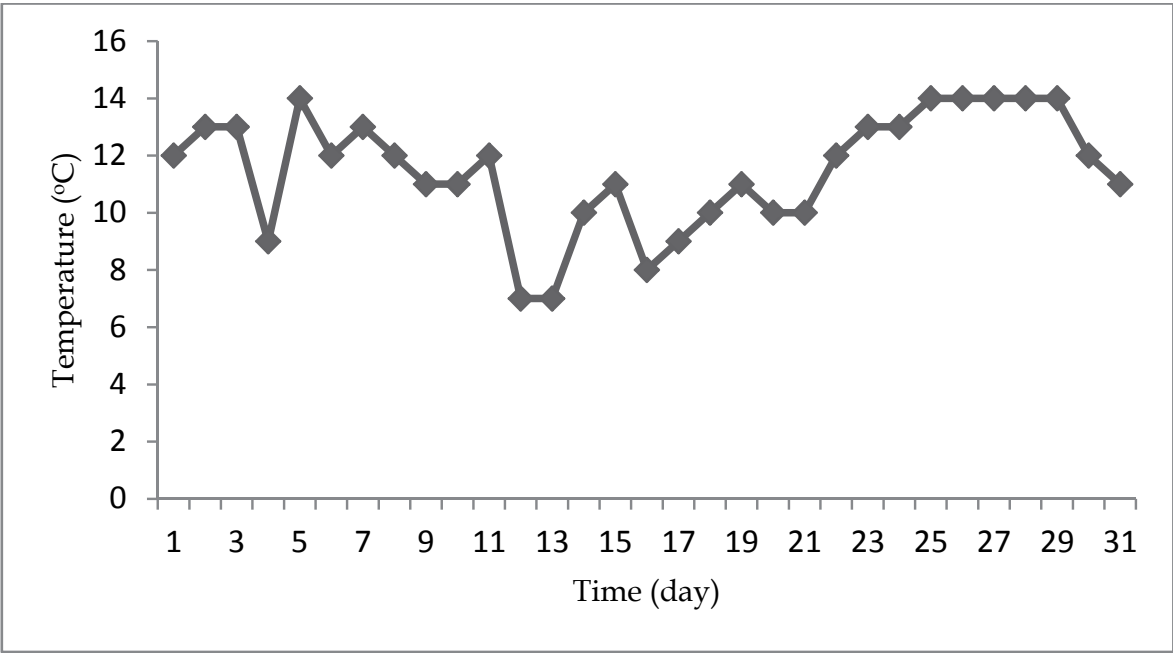


Fig. 23. Temperature conditions for each day in the month of July 2010 Phokeng, in Rustenburg

6. Conclusion

From the results obtained from this study, the following conclusions can be drawn. The results obtained were compared to the South African Air Quality Guidelines (2005) and the World Health Organization, WHO (2005). It was observed that the PM10 values for 24

hourly periods exceeded the $75 \mu\text{g}/\text{m}^3$ maximum permissible limit for the South African Guidelines, for almost half the month (14 days) in April, 8 days in May, and 9 days in June. According to the World Health Organization Guidelines, WHO (2005) the results obtained in the month of April (26 days), May (17 days), and June (14 days) exceeded the maximum permissible limits of $50 \mu\text{g}/\text{m}^3$. The emissions of particulate matter in the study area are not acceptable, thereby degrading the air quality in the area. This evaluation therefore points towards the possible health risks from presence of particulate matter as can be seen from the experimental data obtained in the study area.

The comparison made between aerosol particulates in Kanana area and aerosol particulates in Phokeng area made interesting revelations. The gold mining area appears to be emitting more particulate matter into the atmosphere than the platinum mining area. It cannot be concluded from this once comparison that gold mining generates more atmospheric aerosols than platinum mining. There could probably be many more activities in Kanana that generate more atmospheric aerosols than in Phokeng. Certainly detailed source point measurements could help determine the causes of the difference in atmospheric aerosols in these two areas. Further studies are ongoing.

7. Acknowledgements

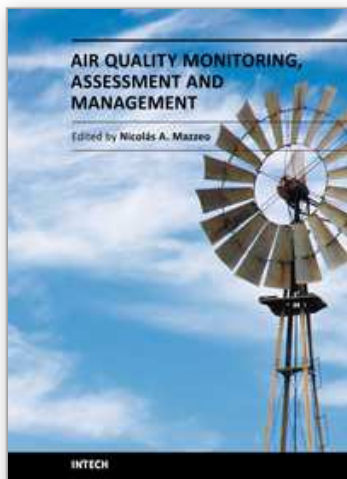
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Human beings need to breathe oxygen diluted in certain quantity of inert gas for living. In the atmosphere, there is a gas mixture of, mainly, oxygen and nitrogen, in appropriate proportions. However, the air also contains other gases, vapours and aerosols that humans incorporate when breathing and whose composition and concentration vary spatially. Some of these are physiologically inert. Air pollution has become a problem of major concern in the last few decades as it has caused negative effects on human health, nature and properties. This book presents the results of research studies carried out by international researchers in seventeen chapters which can be grouped into two main sections: a) air quality monitoring and b) air quality assessment and management, and serves as a source of material for all those involved in the field, whether as a student, scientific researcher, industrialist, consultant, or government agency with responsibility in this area.

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