

Air Quality and Human Health among a Low Income Community in the Highveld Priority Area

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Abstract

Human exposure to poor air quality is linked to adverse health effects. The largest burden of air pollution-related diseases is in developing countries where air pollution levels are also among the highest in the world. In South Africa, two geographic areas, the Vaal Triangle and the Highveld, have been identified for air quality management interventions to ensure compliance with National Air Quality Management Standards and to control potential harmful air pollution impacts on human health. The Highveld Priority Area (HPA) is characterised by intense mining, coal-fired power plants, industries, including iron and steel manufacturing, chemical plants, agricultural activity, motor vehicles and domestic fuel burning. Apart from two previous studies, no respiratory health studies have been carried out in the HPA. This paper describes the results of a recent, comprehensive study of ambient air quality, potential exposure to air pollution and air-related human health among a low income community living in the HPA in order to better understand the impact of air pollution on human health in South Africa.

Key words: Air quality, respiratory health, Highveld Priority Area.

Introduction

Human exposure to poor air quality is linked to adverse health effects, ranging from acute symptoms, such as nose and throat irritation, to chronic and debilitating illness and disease. The World Health Organization (WHO) states that chronic respiratory diseases, (i.e. asthma, chronic obstructive pulmonary disorder, and pneumonia), are among the leading causes of mortality and morbidity (WHO, 2007; WHO, 2010), and while not all of these adverse health effects are caused by air pollution, they are all exacerbated by the presence of poor air quality. Empirical evidence suggests that the largest burden of air pollution-related diseases is in developing countries where air pollution levels are also among the highest in the world (Krzyzanowski, and Cohen, 2008). In some developing countries, the burden of disease is said to have 'quadrupled' due to the HIV/AIDs epidemic, emerging diseases (especially as they relate to climate change), crime and poverty-driven environmental health outcomes such as diarrhoea. Furthermore, observations in developing countries have indicated that effects of air pollution on these nations may be greater because they are more vulnerable as a result of their nutritional status and lifestyle (Romieu and Hernandez-Avila, 2003).

In South Africa, the National Environmental Management: Air Quality Act (Act 39 of 2004) allowed for the development of priority areas for air quality management interventions to ensure compliance with national air quality management standards and to control potential harmful air pollution impacts on human health. To date, the *Vaal Triangle Air-Shed Priority Area* (DEAT, 2006) and the *Highveld Priority Area* (HPA) (DEAT, 2007) have been declared as

priority areas (Figure 1). The main towns in the HPA are eMalahleni (previously Witbank) and Middelburg in the Mpumalanga province. The HPA is characterised by intense mining, coal-fired power plants, industries, including iron and steel manufacturing, chemical plants and agricultural activity. In addition to industrial sources, motor vehicles and domestic fuel burning also contribute to air pollution. Since these two sources emit pollutants at ground level, they may contribute more to human exposure than other sources.

To date, two studies have assessed the human health risks posed by air pollution potentially impacting upon communities living in the HPA. In 1990, the respiratory health of children living in the HPA was compared to that of children living further east in an environment deemed to have less air pollution (Zwi *et al.*, 1991). The 'Highveld' children were found to be more likely to have a morning cough, wheeze, chest colds and asthma compared to the other group. Factors that were identified to increase the risk of children developing these symptoms included attendance of school in the exposed area, cigarette smoking, and not using electricity for cooking in the home. A smaller, cross-sectional study (involving 377 households) was also undertaken in 2006 in eMbalenhle, near Secunda (John *et al.*, 2008). One of the aims of this study was to identify risk or vulnerability factors that may be significantly associated with respiratory health outcomes. The prevalence of health outcomes (including asthma, chronic asthma and pneumonia) were surprisingly low. Apart from these two studies, no further respiratory health studies have been performed thus far in the HPA.

To fill this gap, and to build onto knowledge generated in the previous studies, a more comprehensive study was initiated to understand the potential impacts of environmental pollution, both air and water pollution, on communities in the HPA. This paper describes one part of this study pertaining to ambient air quality and addresses potential exposure to air pollution and air-related human health among a low income community living in the HPA in order to better understand the impact of air pollution on human health.

Methods

Study design

This paper reports on air quality, personal exposure risk and air-related human health outcomes of a dual arm, cross-sectional study that also examined water-related health in a sample of households in a low income community in the HPA. Participating households answered a questionnaire about demographics, possible exposure to water and air pollutants, use of the local river, sanitation, solid waste removal, nutrition, energy use, health and healthcare, personal hygiene and socio-economic factors. A pilot study among 96 households was done prior to implementation of the full study. Ambient air quality monitoring was done at a safe location in the community measuring ambient levels of particulate matter, sulphur dioxide (SO₂), nitrogen dioxide (NO₂), lead (Pb) and transition metals: mercury (Hg) and manganese (Mn). The first three pollutants are National Criteria Pollutants for which recent National Standards have been set under the Air Quality Act (Act No. 39 of 2004) (DEA, 2009). It was decided to include some transition metals in the analysis, since it is known that these metals may cause oxidative and inflammatory reactions in cells (Di Pietro et al., 2009). Mercury was included since it is emitted through the combustion of coal. There are coal-fired power plants, industries using coal, as well as domestic coal use in the area. Manganese was included, because methylcyclopentadienyl manganese tricarbonyl (MMT) is a fuel additive, while Pb is being phased out. There are also industries in the area emitting Mn. This air quality monitoring coincided with the questionnaire survey. Ethical approval for this study was granted by the CSIR Research Ethics Committee (No 04/2010).

Study area

The study area constituted a geographical area of approximately 10 km² and is referred to as the town of KwaGuqa (25° 51' 46.23" S 29° 07' 13.88" E) in the Mpumalanga Province (Figure 1). The HPA Baseline Assessment (DEA, 2010) showed that the area with the most air pollution in the HPA was the Witbank / Ferrobank area including the low-income communities of KwaGuqa. KwaGuqa town comprises informal dwellings and low cost housing. Some sections of the town are electrified, have water reticulation and water-borne sewerage, while other sections, especially newly inhabited sections, have no electricity or services (Balmer, 2007). Participating households were drawn from three suburbs within KwaGuqa town, namely, KwaGuqa Extension 5,

Vosman and Empumelelweni. KwaGuqa Extension 5 and Vosman are located alongside the Brugspruit (a small river), but represent two different socio-economic groups, while Empumelelweni is located further away from the Brugspruit. The estimated population size by suburb was 2 627 for KwaGuqa Extension 5; 3 857 for Vosman (including Vosman and Vosman Extension 15, 16 and 17); and 7 435 for Empumelelweni (including Empumelelweni A and B, and KwaGuqa Extensions 10 and 11).

Participants and procedures

A multi-stage probability sample was implemented. An equal number of household interviews was planned for each of the three suburbs (n = 334). Street blocks were randomly selected and therein a random starting point was selected (i.e. North-east, North-west, South-east or South-west). A random starting house was selected choosing one of the first three houses using a random number list. From the starting house, the fieldworker walked around the block in a clockwise direction and interviewed every third house. When respondents refused to participate or were not present, the next house in the sequence was selected. Inclusion criteria stipulated that participants must be older than 18 years of age and not be under the influence of any substance at the discretion of the fieldworker.

Sixteen fieldworkers were recruited from the three study suburbs and attended a 6-day training period, with the last day used for piloting. A training manual used in similar studies was adapted and applied. Fieldworkers were familiarised with the questionnaire, protocol for administering the questionnaire and the electronic device used to ask the questions and record responses. Fieldwork was carried out by the fieldworkers using consistent principles from the protocol from 11 - 26 October 2010.

Questionnaire

The household questionnaire was derived from previously applied questionnaires (Terblanche et al., 1992; Richards et al., 1996). The questionnaire was transferred to mobile electronic devices beforehand for ease of data capture and data quality assurance. Each participant was read an information sheet about the study and asked to give written consent prior to administering of the household questionnaire. The questionnaire asked each respondent about demographics, possible exposure to water and air pollutants, use of the local stream, sanitation, solid waste removal, nutrition, energy use, health and healthcare, personal hygiene and socio-economic factors.

Ambient AQ monitoring

Ambient air quality monitoring was done for one month at a safe location (community member's house) to monitor concentrations of particulate matter SO₂, NO₂, Pb and the transitional metals Hg and Mn. Particulate matter mass was monitored using a TOPAS (Turnkey Instruments SA) real-time airborne particulate matter monitor. The instrument

can simultaneously monitor the mass concentrations of total suspended particulate matter (TSP), PM₁₀ (particulate matter with a diameter equal to or smaller than 10 µm), PM_{2.5} (particulate matter with a diameter equal to or smaller than 2.5 µm) and PM₁ (particulate matter with a diameter equal to or smaller than 1 µm), as well as local wind speed and local wind direction. The instrument has an internal data logger that records the mass concentration every second and averages the particle mass concentrations at 15-minute intervals. A pump continuously draws an air sample (flow rate = 0.6 L/min) through the instrument, and the particle size and mass concentrations were measured using a light-scattering technique that analysed the individual particles as they passed through a laser beam. These same particles were then collected on a reference filter. After the first two weeks of monitoring, the filter was analysed for Mn (a neurotoxic compound) and Pb by atomic absorption spectroscopy. Monitoring then continued for another two weeks, after which the filter was again analysed for Mn and Pb.

The gases SO₂ and NO₂ were sampled using Radiello passive samplers. Samplers were exposed for two weeks at a time. After exposure, samples were leached with water containing hydrogen peroxide according to the CSIR method SOP WI-FARAE-011, and the solution was analysed for sulphate, nitrite and nitrate anions by ion chromatography. Atmospheric SO₂ and NO₂ concentrations were calculated taking into account the exposure time, uptake rate as stipulated by Radiello, and ambient temperatures which were obtained for the station at Witbank Airport from the South African Weather Service. Mercury was also monitored for two weeks at a time using SKC Carulite 200 mg tubes. The tubes were opened and connected to a vacuum pump operating at 0.2 L/min. The tube content was analysed for mercury by cold vapour atomic absorption spectroscopy. It should be noted that this method will only provide total atmospheric mercury values comprised of elemental, oxidised and particulate-bound mercury (Trüe et al., 2010).

Quality control and data assurance

Quality control and data assurance for the survey data was performed by means of follow-up interviews with participants. A random sample (15%) of records was drawn from the full dataset to achieve a realised sample of 10% for telephonic follow-up interviews. Systematic sampling was performed by using a random record in the full dataset as the starting point and selecting every 7th record thereafter. A shortened version of the original structured interview was repeated over the phone and 50 key variables were captured. This was done by a single evaluator fluent in multiple languages to ensure consistency. A total of 174 participants were telephoned. Of these, 127 answered, 121 completed the telephonic shortened version of the questionnaire (6 of those who answered the telephone call did not participate in the face-to-face interview). Only 10% of the follow-up records contained one deviation in the 50 fields

checked, demonstrating sound intra- and inter-rater reliability. In cases where deviations from original responses were found during quality control, corrective action was taken to update records accordingly.

The air quality monitoring equipment was installed and maintained by the supplier according to standard protocols. The applicability of SO₂ and NO₂ analyses as sulphate and nitrate determination by ion chromatography was guaranteed by the use of independent reference materials (certified standards) as well as participation in the World Meteorological Organisation–Global Atmospheric Watch (WMO–GAW) inter-comparison scheme. Certified standards were also used during metal analyses.

Data analysis

Questionnaire data were imported into STATA and analysed to determine descriptive statistics. The primary unit of analysis was the household.

Results and Discussion

Community demographics, services and amenities

The distribution of households selected for the survey by sub-area is indicated in Table 1. A total of 1 639 household interviews were attempted by the 16 fieldworkers. From these, 1 180 interviews were possible because in 375 instances no one was at home, 74 people refused to participate and 10 people did not feel safe to answer the questions. Following quality control and data assurance procedures, the final workable dataset comprised 1 003 households (final response rate = 61.2%) reflecting a total number of 4 190 respondents.

The oldest person-age recorded was 98 years, with the average age being 26.3 years. There were slightly more males (53%) than females in the study sample. About 16% of respondents had not completed any schooling while 5% indicated that they had a tertiary education. Individuals who were unemployed and looking for work constituted 20% of the sample, 19% had full-time paid employment and 31% were school pupils or full-time students.

The main source of water supply was piped water into the house (70%), or a stand pipe or borehole in the yard (21%). A communal pipe or borehole outside the yard was used by 4% of households. About 14% of those households which used a communal source of water indicated that it was used by more than 75 households. Where water was collected in containers (i.e. no piped water into the house) these were cleaned with detergent by 92% of households, with 80% of households having cleaned them during the past week. Just over 20% of all households indicated that they treated their water, mostly by boiling (66%). A total of 72% of all households interviewed indicated that they were storing drinking water in their house. Of the 78% of households who indicated that they used a scoop to take water from the storage container, 77% indicated that they may drink from the scoop, too.

Responses indicated that 97% of households had at least one toilet in the yard. Almost 70% of these toilets were a flushed-to-pipe sewer system. Refuse was collected from 63% of households, of which 82% had weekly-collection. Where refuse was collected, 85% of households paid for the removal service. If refuse was not collected, 63% of households indicated that refuse was mostly disposed of outside the yard, of which 91% disposed in a waste pit or dump site. Houses were mostly constructed of brick or blocks (80% of households), with 23% of households having 3 bedrooms, 45% having 2 bedrooms and 19% having 1 bedroom in the house. The majority of respondents (76%) indicated that there were between 1 and 6 people living in the house on a day-to-day basis.

Health and wellbeing

Survey results suggested that approximately 77% of households perceived their health to be good. This corroborates the results of a previous study in which 90% of respondents considered the health of family members living in their household to be good (John et al., 2008). The reported prevalence of health outcomes was generally low. Sinus-reported symptoms were the most frequent (42% of households had at least one case), followed by high blood pressure (36% of households) and arthritis (18% of households). Approximately 10% of households reported the presence of at least one case of asthma in their household. According to the South African Demographic Health Survey (SADHS, 1998), the prevalence of asthma in the South African adult (age 15+) population was 7% for men and 9% for women at the time. A total of 17% of respondents indicated that a member of the household has been absent from work or studies because of an illness in the past month. Almost 23% of households indicated that at least one member had access to medical care through medical aid or through a clinic at work. Regarding transport and health facility accessibility, most households were close to a transport mode but not close to a hospital. About 90% (n = 1 217) of children (aged 15 years or less) had been immunised.

Almost 45% of households indicated that their members usually ate fruit and vegetables daily and most produce had been bought from a nearby shop. Protein such as fish and chicken were being consumed daily by 61% of households. Of the 65% of households with school-going children, 32% indicated that children got food at school regularly.

Ambient air quality

Figure 2 displays time series of the real-time 15-minute average mass concentrations of PM₁₀, PM_{2.5}, and PM₁, as well as the 15-minute average local wind speed measurements from 21 September to 19 October 2010 (spring months) measured at the community member's house in KwaGuqa. During this measurement period, the PM measurements were highly variable. The minimum and maximum values for PM₁₀, PM_{2.5}, and PM₁ were all measured on the same days; the minimum values were recorded on 15

October 2010 in the morning and the maximum values were recorded on 10 October 2010 in the late morning/early afternoon. The PM₁₀ concentrations ranged from 0.6 µg/m³ on 15 October 2010 to 490.3 µg/m³ on 10 October 2010. The PM_{2.5} concentrations ranged from 0.19 µg/m³ on 15 October 2010 to 239.83 µg/m³ on 10 October 2010. The PM₁ concentrations ranged from 0.06 µg/m³ on 15 October 2010 to 85.63 µg/m³ on 10 October 2010. The local wind speed was also variable and on average peaked in the morning (6:00) and had a minimum value in the evening (19:00). Measured PM concentrations, however, did not show a strong dependence on local wind speed.

The average daily concentrations of monitored PM₁₀, PM_{2.5}, and PM₁ mass concentrations are given in Figure 3. Under the South African Air Quality Act, only PM₁₀ ambient concentrations are regulated, and not PM_{2.5} or PM₁ mass concentrations. None of the PM₁₀ daily averages exceeded the South African National 24-hour standard of 120 µg/m³ during the monitoring period, although the 15-minute averages were above 120 µg/m³ on several occasions (Figure 2). The average 24-hour PM₁₀ concentration for the measurement period was 59.6 µg/m³ and maximum 24-hour PM₁₀ concentration was 107 µg/m³ on 30 September 2010, which is slightly lower than the national 24-hour standard.

The diurnal variation of the normalized PM₁₀ mass concentration measurements is shown in Figure 4. To normalize the PM₁₀ values, each 15-minute average point was divided by its respective daily average. Thus, a value of 1 in Figure 4 indicates the daily average. The PM₁₀ mass concentration during this campaign peaked at midday (12:00-13:00), but also had smaller peaks in the early morning (1:00-2:00) and evening (17:00). The minimum occurred in the late evening (22:00). The diurnal variation for the duration of the study, suggests that during this time period, local sources of PM₁₀ contributed throughout the day. Since there is no build-up of pollution in the evening and decrease in the day, the PM₁₀ mass concentration for this month of measurements was not dictated by daytime convective mixing followed by the formation of a night time boundary layer.

A pollution rose (Figure 5) compiled from the monitored 15-minute averaged PM₁₀ mass concentrations and wind direction data shows that measured PM₁₀ mass concentrations up to 200 µg/m³ were seen at all local wind directions. The highest levels (>200 µg/m³) were generally, though not exclusively, seen when the wind came from the north-west and north-east. In addition, no strongly evident relationship was seen between local wind speed and PM₁₀ mass concentrations (not shown); however with high local wind speeds (u ≥ 3 m/s) the PM₁₀ mass concentrations measured were all below 200 µg/m³. This lack of a strong correlation with local wind speed and wind direction, together with the highly variable particulate mass concentrations, suggests a variety

of sources of PM throughout the area.

Results of the passive samplers (SO₂ and NO₂) are given in Table 2. The averages of the two-week SO₂ and NO₂ concentrations analysed were relatively low. The maximum concentration for SO₂ and NO₂ were 10 µg/m³ and 22 µg/m³, respectively. No two-weekly or monthly standards for SO₂ or NO₂ exist. However, should these maximum concentrations prevail, the annual standards of 50 µg/m³ and 40 µg/m³ for SO₂ and NO₂, respectively, are unlikely to be exceeded.

Analysis of the PM₁₀ filter after the first two weeks of exposure showed a concentration of 14.7 µg/m³ of Mn while Pb concentrations were below the detection limit of 0.01 µg/m³. Analysis of the second filter (after the second two-week period) showed that both Mn and Pb concentrations were below the detection limit of 0.01 µg/m³. It is possible that the difference in these results could have been caused by changes in predominant wind direction between the two-week periods. There is no South African National standard for Mn in ambient air, while an annual standard of 0.5 µg/m³ exists for Pb. In the absence of a National standard for Mn, the WHO guideline of 0.15 µg/m³ may be used (WHO, 1999). This guideline was based on a no observed effect level (NOEL) (for neurological effects in workers) of 30 µg/m³. However, this guideline is for an annual average and the monitoring period for this study was one month

Total Hg concentrations were 2.0 ng/m³ during the first two-week period and 2.4 ng/m³ during the second two-week period. The main source of Hg in the area is likely to be coal burning. These concentrations correlate with results of a study by Trüe et al. (2010) where Hg was monitored on a weekly basis between 29 October 2009 and 3 December 2009 in eMalahleni town; the average Hg concentration for that monitoring period was found to be 1.8 ng/m³. South Africa does not have a National standard for Hg. The WHO guideline (WHO, 1999) for inorganic mercury in air is 1000 ng/m³ (1 µg/m³), which is an annual guideline based on a lowest observed adverse effect level (LOAEL) of 20 µg/m³ due to renal effects in humans. This guideline was not exceeded in this study or in the study by Trüe et al. (2010).

In terms of indoor air pollution exposure, tobacco smoking was prevalent in 24% of households. Coal was used for cooking and heating in 6% and 29% of households, respectively. In a study by Balmer (2007) coal used in this area was found to be of a low quality. The 'Basa njengo Magogo' or top-down method of lighting a fire was used at 13% of households. Electricity was mostly used for cooking (75%) and heating (52%).

Conclusions

From the relatively limited ambient air monitoring campaign measuring PM, SO₂, NO₂, Hg, Pb and Mn in the study area, preliminary evidence suggests that ambient air quality during September - October 2010 was highly variable with a variety of local sources. In

addition, the ambient air quality was not in excess of National standards. This may be because these months fall within spring when temperature inversions are less common and ambient temperatures are milder than during winter months, hence less coal is burnt for household heating. In Josipovic et al. (2009), SO₂ and NO₂ were monitored by passive sampling at 37 different sites over the HPA to determine the spatial distribution of these gases and their seasonality. Monitoring sites were situated mostly in rural areas away from urban centres, industrial point sources, main roads or other influences of air pollution. They found the highest concentrations directly over the Mpumalanga industrial Highveld. In the same study, a seasonal trend was more obvious for SO₂ than for NO₂, although NO₂ was slightly elevated in summer. The concentrations of SO₂ were higher in winter (Josipovic et al., 2009). The higher concentrations of SO₂ in winter were most probably as a result of an increase in domestic coal use for heating during the cold winter months. Lourens et al. (2011) also studied the spatial and temporal distributions of gaseous air pollutants, including SO₂ and NO₂ in the HPA over the course of one year. The highest concentrations for SO₂ and NO₂ measured at any of the eight stations, were at eMalahleni (Witbank) especially during winter months. Annual averages were, however, below the National Standards.

Descriptive community demographic and health status statistics suggested that household members tended to be relatively young (i.e. average = 26 years of age) and perceived themselves to be in good health. Some individuals did suffer from sinusitis and asthma; however, further statistical analyses will determine risk factors associated with these health outcomes. Together with a better understanding of local issues, which includes stakeholder concerns and community inputs, these results will improve understanding of risks in the community and provide useful information for improved decision-making.

Acknowledgements

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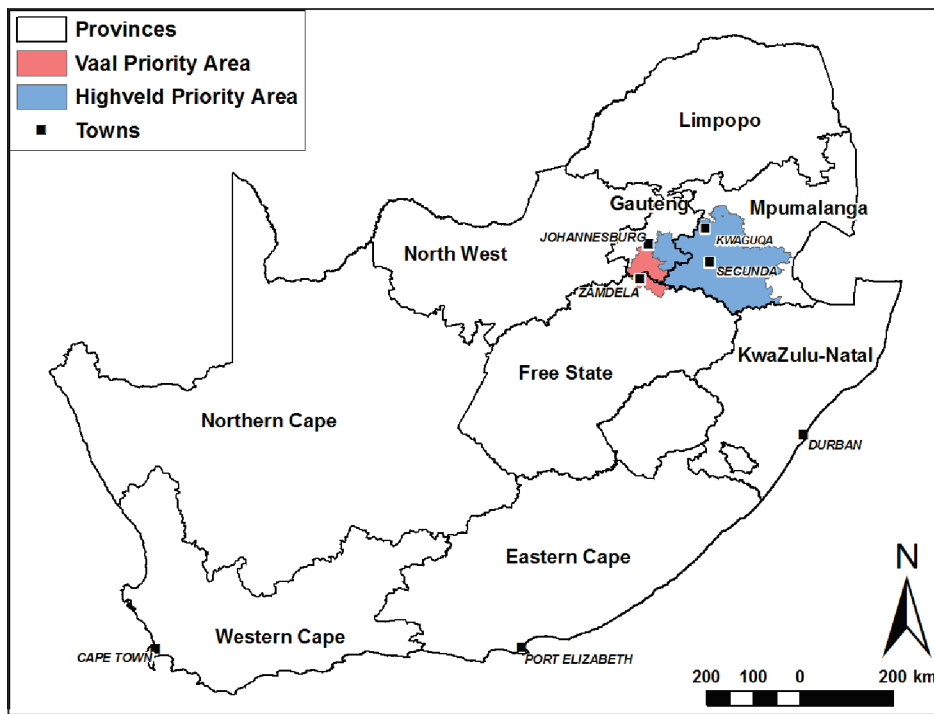


Figure 1. Detailed boundaries of the Highveld Priority Area (HPA) in blue and the Vaal Triangle Priority Area in red. KwaGuqa is located in the north-west of Mpumalanga Province.

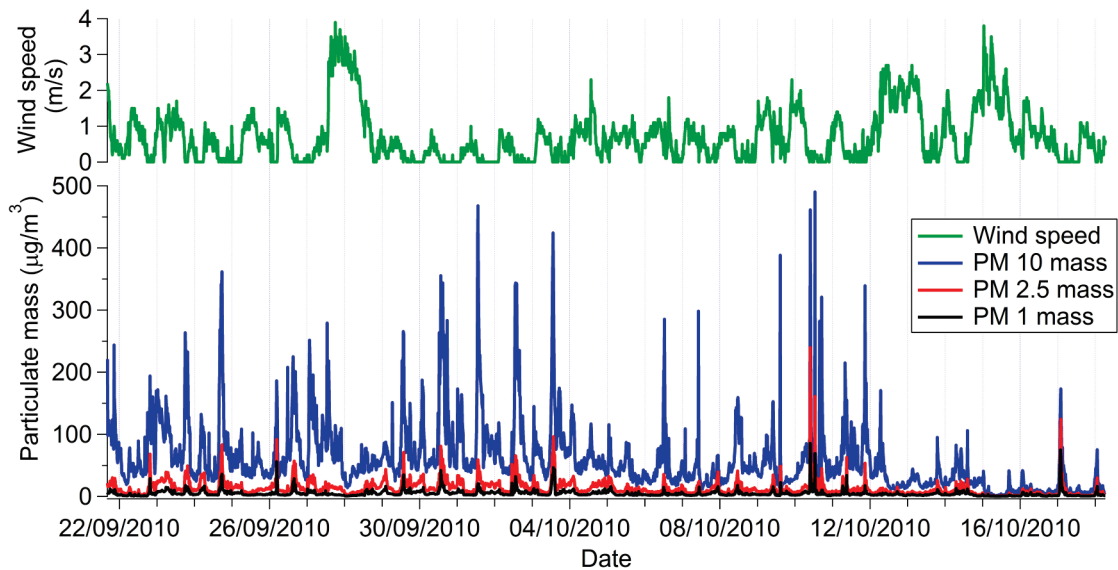


Figure 2. Time series of 15-minute average PM_{10} , $PM_{2.5}$, and PM_1 mass concentrations ($\mu\text{g}/\text{m}^3$) and local wind speed monitored at the community member's house in KwaGuqa.

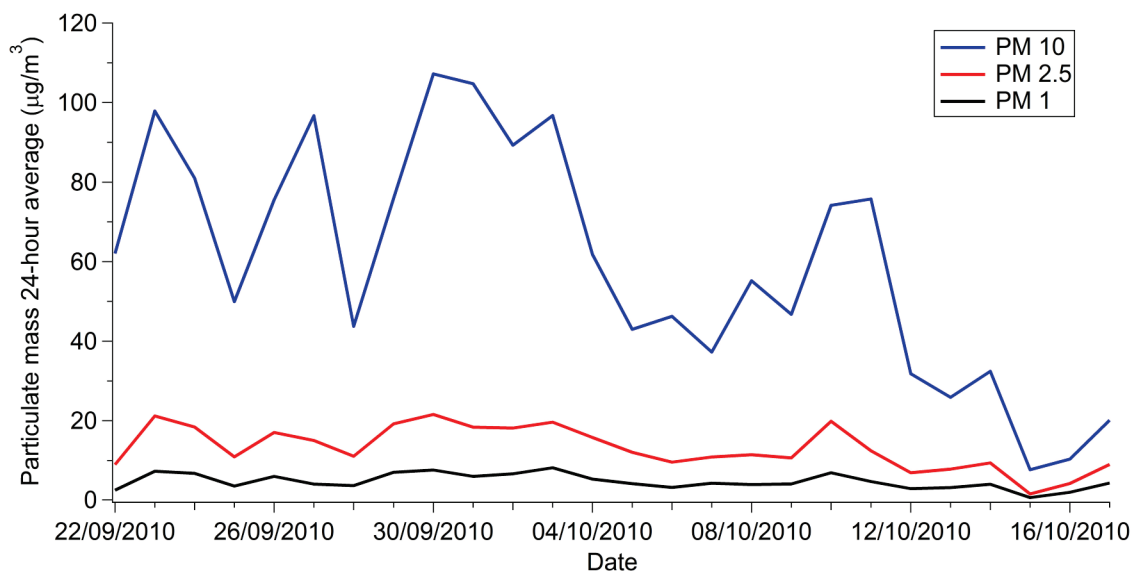


Figure 3. Time series of daily 24-hour average PM₁₀, PM_{2.5}, and PM₁ mass concentrations (µg/m³) in KwaGuqa. The 24-hour South African National Ambient Air Quality Standard for PM₁₀ is 120 µg/m³.

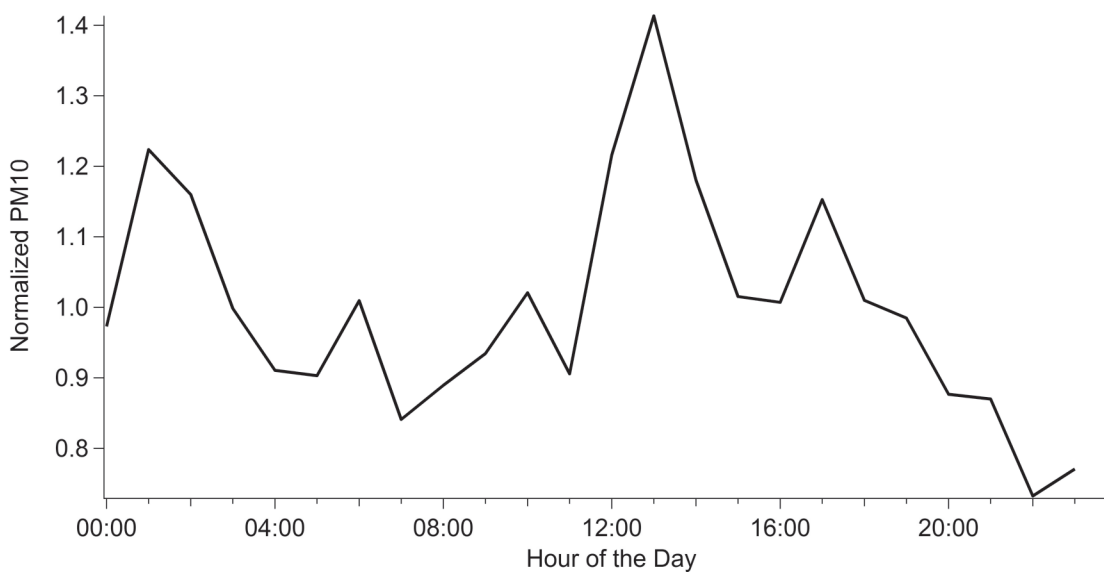


Figure 4. Diurnal variation of normalized PM₁₀ mass concentrations.

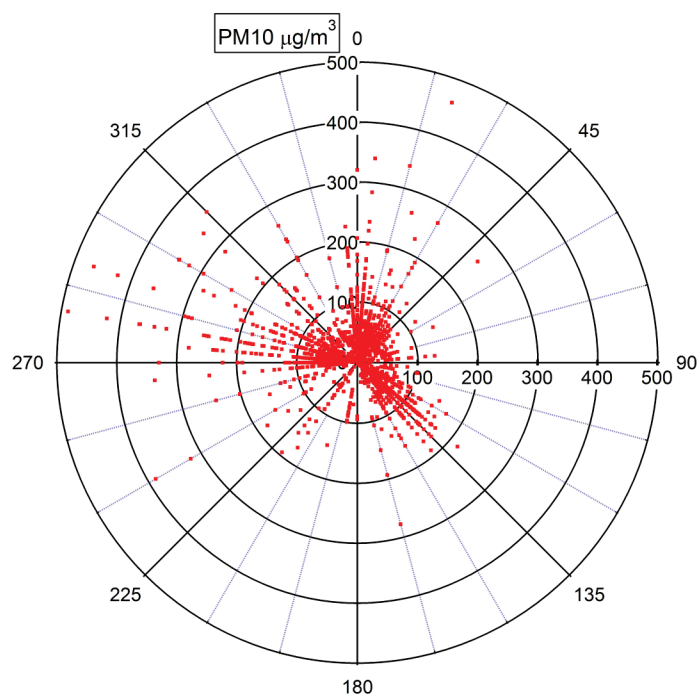


Figure 5. Pollution rose showing local wind direction versus the 15-minute averaged PM₁₀ mass concentrations for 21 September to 19 October 2010 in KwaGuqa.

Table 1: Distribution of households in the different sub -areas.

Suburb	Number of households (n)	Percentage of total households surveyed (%)
Vosman	353	35
KwaGuqa Ext 4	186	19
KwaGuqa Ext 5	140	14
Empumelelweni	324	32
Total	1003	100

Table 2. Results of passive SO₂ and NO₂ monitoring (two-week averages).

Exposure duration	SO ₂ concentration (µg/m ³)	NO ₂ concentration (µg/m ³)
21 Sep - 5 Oct 2010	10	22
5 Oct - 19 Oct 2010	6.6	17