AMBIENT AIR QUALITY IN A LOW INCOME URBAN AREA ON THE SOUTH AFRICAN HIGHVELD: *A CASE STUDY OF LEANDRA TOWNSHIP*

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Declaration

I, Charles Mugabo, declare that this research report is my own, unaided work. It is being submitted for the degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

Charles Mugabo

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ABSTRACT

Air pollution in residential areas is a problem in South Africa. The connection of low income households to the national electricity grid is perceived as one of the strategic measures taken by the government to solve the issue. In Leandra/Lebohang, a low income residential area on the Highveld, 1034 households were provided with electricity in 2001. Ambient PM_{10} and SO_2 concentrations monitored in Leandra show that the electrification resulted in a significant reduction in PM_{10} concentrations particularly during the morning and evening peaks. There was also somewhat of a reduction in SO_2 concentrations, although a non-local, probably industrial source, also contributes to SO_2 levels in Leandra. PM_{10} and SO_2 concentrations increased steadily again after the electrification, as the township expanded and the domestic use of coal increased. Annual PM_{10} concentrations were above the national annual limit (50 $\mu g/m^3$) for all years during the 1999-2005 monitoring period except during 2001 and 2002. The number of exceedances of the PM_{10} daily limit was as high as 141 in 2000 and dropped to 0 in 2001. The SO_2 annual national limit (19 ppb) was never exceeded during the 1999-2008 monitoring period. However, SO_2 daily average national standard (48 ppb) was exceeded several times at Leandra with up to twelve exceedences measured in 2000. Effectively, electricity use reduces domestic emissions in low income residential areas by replacing coal and other dirtier fuels used for cooking and space heating and improve ambient air quality.

To my dearest mother

Mrs. Consolate NYIRAMONGI

This work is dedicated

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LIST OF ABBREVIATIONS

CEG	: Clean Energy Group
COPD	: Chronic Obstructive Pulmonary Disease
DEA	: Department of Environmental Affairs
DME	: Department of Minerals and Energy
IEA	: International Energy Agency
NACA	: National Association for Clean Air
NAQMP	: National Air Quality Management Program
NO	: Nitric Oxide
PM_{10}	: Particulate Matter smaller than 10 microns
SABS	: South African Bureau of Standards
SAM	: Soweto Air Monitoring
SANS	: South African National Standards
SAS	: Statistical Analysis Software
SO_2	: Sulfur Dioxide
TSP	: Total Suspended Particulates
US-EPA	: United States Environmental Protection Agency
VOC	: Volatile Organic Compounds
WHO	: World Health Organization
WRI	: World Resources Institute

CHAPTER ONE: GENERAL INTRODUCTION

This chapter addresses air pollution issues globally and a particular emphasis is put on South Africa. The domain, the aims and objectives of the study are presented.

1.1 Introduction

Approximately half the world's population, around 3000 million people, and 75 % of households in developing countries are reliant on biomass fuels (such as wood, cow dung and crop residues) and coal for their domestic energy requirements (WRI,1998). In many African countries, household energy is derived primarily from solid biomass fuels (Bailis et al., 2003; Mdluli, 2007). In sub-Saharan Africa the energy is largely derived from wood fuel burned in simple stoves with poor combustion characteristics, with the exception of South Africa where domestic energy consumption is dominated by coal (Bailis et al.,2003).

In South Africa, all households are at least indirectly reliant on coal for their domestic energy requirements as 95% of South Africa's electricity is generated from the combustion of coal and about 3% of the national coal production is directly combusted for domestic energy needs (South Africa, 2005).The coal used contains approximately 1.0% sulphur and up to 45% mineral matter (South Africa, 2005).

Air pollution from human settlements is mainly associated with domestic fuel burning as an energy source in South African low income townships (Annegarn et al 1996; Annegarn 2006). Domestic fires emit pollutants at a maximum height of 3m above ground which increases health risks for exposed populations (South Africa, 2005). Source apportionment studies indicate that coal domestic fires contribute 70% and 35% to total particulate matter in Soweto and the Vaal Triangle respectively (Annegarn and Sithole, 1999).

In Leandra (Figure 1), the Department of Environmental Affairs' (DEA) annual fine particulate matter (PM_{10}) guideline value ($40\mu g/m^3$) was exceeded in 1999 (Eskom, 2000). This has been attributed to the continued burning of coal for domestic heating and cooking at Lebohang Township in Leandra. After 1999, Lebohang, like many other townships, benefitted from the massive electrification programme funded by the Department of Minerals and Energy (DME). Particulate and sulphur dioxide (SO_2) concentrations from recently electrified townships are expected to reduce, as electrical appliances replace traditional coal and wood stoves. Since the programme started, air quality in Leandra has been monitored.

The evolution of the air quality in Leandra in the period 1999-2008 is assessed in this research in order to identify the impact of the electrification of 1034 households in 2001 on the local ambient air quality. Other factors influencing air quality in such a low income urban area on the South African Highveld are addressed, and the domestic and industrial impacts on local air quality separated out in order to determine source contributions. The main findings of this research were presented in a paper at the 2009 National Association of Clean Air (NACA) Conference.

This study will contribute to the knowledge of what levels of ambient air pollution are and what factors are contributing to the situation in Leandra, a typical low income urban area, located on the Highveld of South Africa.

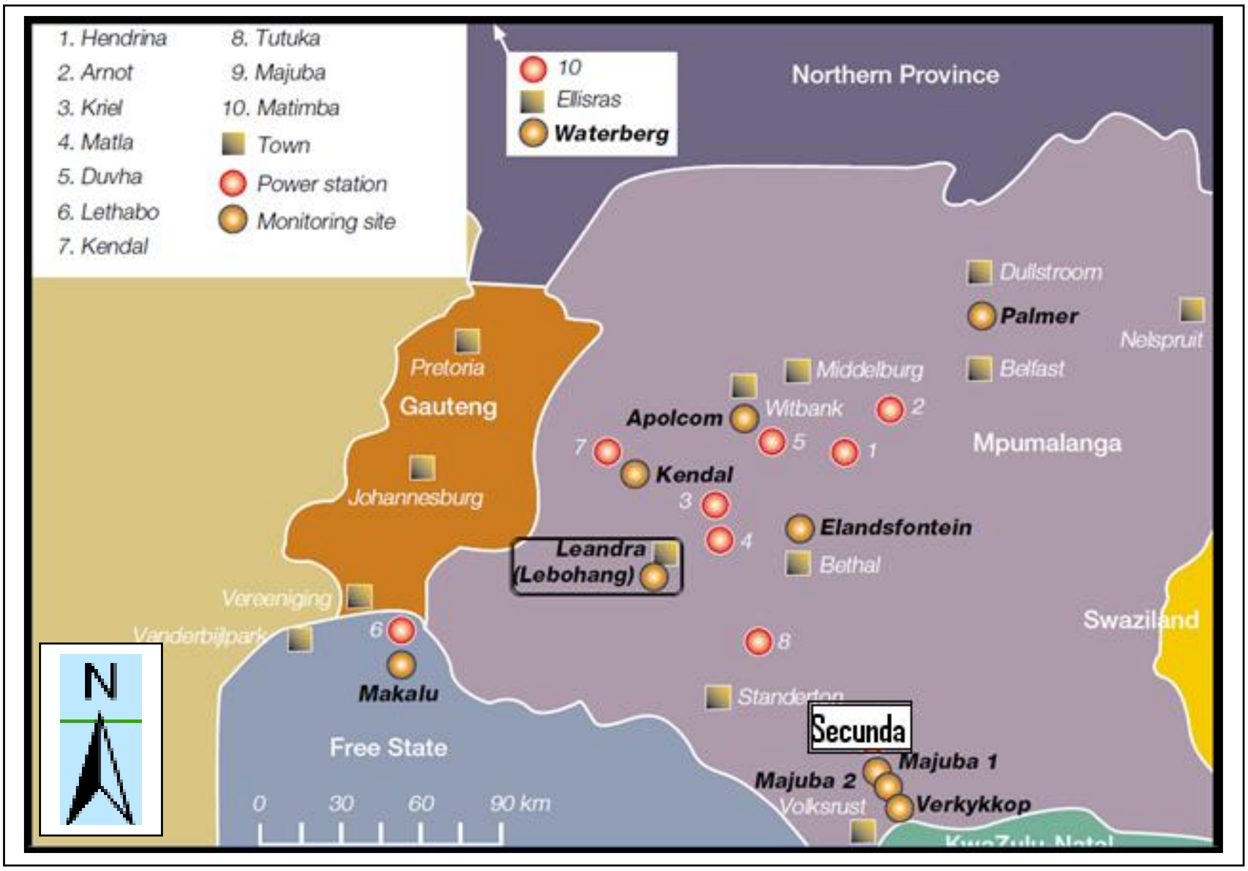

Figure 1 : Location of Leandra and major pollution sources and cities in the vicinity (Eskom, 2000).

1.2 Aim and Objectives

1.2.1 Aim

The aims of this study are to characterise ambient air quality in Leandra Township, and assess the effect of electrification on local air quality.

1.2.2 Hypotheses

It is hypothesized that electrification in Leandra Township has resulted in measurable reductions in SO_2 and PM_{10} concentrations and that local domestic fuel burning is the main source of air pollution in Leandra

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1.2.3 Objectives

The specific objectives of this study are to:

- Assess the level of ambient pollutant concentration and its acceptability according to the proposed South African ambient air quality standards for SO_2 and PM_{10}
- Identify industrial and domestic impacts on air quality in Leandra.
- Assess the impact of electrification on ambient air quality

CHAPTER TWO: LITTERATURE REVIEW

In this chapter, an overview of coal combustion and its applications on the Highveld is given and the current air pollution situation and resulting effects on human health and the environment are discussed.

2.1 Coal and ambient air quality

2.1.1 Air pollution and its sources

Air pollution is the presence in the atmosphere of one or several contaminants (pollutants) in quantities and for a duration that can injure human, plant, animal life or property (materials) or which unreasonably interferes with the enjoyment of life or the conduct of business (David et al., 1999).

Major traditional contaminants include: sulphur dioxide, nitrogen oxides, carbon monoxide, hydrocarbons volatile organic compounds (VOCs), hydrogen sulphide and particulate matter. These pollutants can be divided into pollutants that are gases or particulates. Gases such as sulphur dioxide or nitrogen oxides exhibit diffusion properties and are normally formless fluids that change to the liquid or solid state only by a combined effect of increased pressure and a decreased temperature. Particulates represent any dispersed matter, solid or liquid in which the individual aggregates are larger than single small molecules (about 0.0002µm in diameter) but smaller than about 500 micrometers (µm). Particulate matter equal to or less than 10 µm in size (PM_{10}) is of particular concern for potential human health effects (Claire and Fathi, 2008).

Air quality literature for the last two decades has contributed to an extensive knowledge of some of the natural and anthropogenic sources of air pollutants in Southern Africa region (Annegarn and Sithole, 1999). Natural sources of atmospheric particles include natural biomass burning, biogenic interactions, volcanic eruptions, lightning and natural dust storms.

The important manmade air pollution sources are industrial furnaces, power station boilers and other industrial processes, traffic emissions, small scale businesses, domestic fuel combustion as well as special sources such as animal confinement systems (feedlots) and spray cans (Kalabokas et al.,2001).

Sources of air pollution in Mpumalanga include: power generation, mining, domestic fuel burning, coal heated boilers in hospitals, agriculture, synthetic fuel production, other industrial processes and transportation sources (Mpumalanga province, 2002).

2.1.2 Coal as energy and an air pollution source

Coal is a fossil formed in swamp ecosystems where plant remains were saved from oxidization and biodegradation by water and mud. During the coal formation process, the deposited plant remains undergo a sequence of physical, biochemical and chemical changes, which include dehydration, loss of oxygen containing functional groups, alkylation, and oligomerization (Van Krevelen, 1961). This results in coals of increasing rank of geologic maturity depending on the degree of completion of this series of chemical reactions (Oros and Simoneit, 2000).

Coal rankings with increasing progression of maturity are peat, lignite or brown coal, subbituminous, bituminous, anthracite and graphite. Peat is considered to be a coal precursor and has only limited application as a fuel in some countries. Lignite is the lowest rank of coal and used almost exclusively as fuel for steam-electric power generation. Sub-bituminous coal has variable properties ranging from those of lignite to those of bituminous coal and is also used almost primarily as fuel for steam-electric power generation. Bituminous coal is a dense black or brown coal used in steam-electric power generation, heat generation and power applications in manufacturing. Bituminous coal is used for power generation in South Africa. Anthracite is a harder glossy black coal used primarily for residential and commercial space heating. Graphite, technically the highest rank of coal, is difficult to ignite and therefore not commonly used as fuel (Oros and Simoneit, 2000).

About 41.5% of electricity produced worldwide comes from coal combustion. Furthermore, coal is the fuel of choice for most heat-intensive industrial processes, such as production of steel, aluminium, concrete and wallboard (IEA, 2009). Many developing countries are more reliant than developed countries on coal for their energy needs. More than 70% of electricity generated in China, India and Greece comes from coal. South Africa and Poland rely on coal for about 95% of their electricity (Finkelman, 2000).

The combustion temperature determines the molecular alterations and transformations of the organic material within the coal. The higher the temperature, the better combustion results you get. Industries and coal fired-power generation use furnaces with high temperature (>300ºC) combustion processes which improve combustion results. However, due to impurities available, the non combustible components of coal remain behind as bottom ash (Querol et al., 1997).

The composition of fly ash is determined by the composition of the coal burned. The normal composition of fly ash from combustion of various rank of coal is given in Table 1 (McKerall et al., 1982).

Table 1: Chemical composition of fly ash from coal combustion expressed as a percentage by weight (McKerall et al., 1982).

Component	Bituminous	Sub-bituminous	Lignite
SiO_2	20-60	40-60	15-45
Al_2O_3	3-35	10-30	10-25
Fe_2O_3	10-40	4-10	4-15
CaO	1-12	5-30	15-40
MgO	0-5	1-6	3-10
SO_3	0-4	0-2	0-10
Na_2O	0-4	0-2	0-6
K_2O	0-3	0-4	0-4

In South African Highveld townships, coal is an important source of domestic energy. It is used for cooking and space heating. Most low income families choose coal because it is the lowest priced, efficient energy available and it provides extended heat release and is desirable for space heating. Often, the coal used is the cheapest and very low in quality with a high level of impurities (Dahl and Knipping, 2000).

Mostly, households' stoves use low temperature (<300ºC) combustion processes which produce a lot of emissions. This contributes significantly to atmospheric pollutants in both informal and formal township settlements in South Africa (Zunckel et al., 2006). Under stable meteorological conditions, the emissions from coal burning accumulate in the boundary layer and often exceed ambient air quality guidelines set by the Department of Environment Affairs (Zunckel et al., 2006).

2.1.3 Characteristics of selected air pollutants

Several pollutants result from coal combustion. The characteristics of the criteria pollutants particulate matter, sulphur dioxide, nitrogen oxides and carbon monoxide will be reviewed below. However, the results presented in chapter four of this report only concern particulate matter (PM_{10}) and sulphur dioxide (SO_2).

A. Particulate matter (PM_{10})

Coal-derived PM is formed from inorganic matter present in coal, which occurs in the form of minerals of various types and sizes. These minerals can be closely associated with the organic matter (included minerals), or separate from the organic matter (excluded minerals). PM can be separated into three classes: total suspended particulates (TSP), PM_{10} (particles with an aerodynamic diameter less than 10µm), and $PM_{2.5}$ (particles with an aerodynamic diameter less than 2.5µm).

Generally, particulate matter affects visibility due to its ability to scatter radiation and is usually associated with a layer of haze and smoke (WHO, 2006). Different health effects are associated with particular particles. Smaller particles, $PM_{2.5}$, are recognized to have the most adverse health effects because they can travel further into the respiratory system than the coarse particles associated with PM_{10}. They also have long atmospheric residence times and can therefore travel long distances because the diffusion and depositional loss mechanisms are at a minimum in this size range (Finlayson-Pitts and Pitts, 1986). Although the mechanism is unknown, epidemiological evidence has shown that PM_{10} is implicated in the development of exacerbations of asthma and chronic obstructive pulmonary disease (COPD).

Most fine particulates are generated through combustion processes such as space heating and domestic cooking and burning of fossil fuels for steam generation. Some agro-industrial activities and road traffic represent other anthropogenic sources of coarse particulate concentrations. (Lung et al., 2007). Major sources of particulate in townships of developing countries include fuel combustion from individual stoves for cooking and space heating, road dust and imported long range transport from outside the township and natural sources such as pollen, wind-borne soil, volcanic eruptions and evaporated sea spray (Lung et al., 2007).

B. Sulphur Dioxide

Sulphur dioxide (SO_2) is a toxic, irritating, colourless gas soluble in water, alcohol and ether. The gas can be detected by taste and smell in the range of 1000 to 3000µg/m^{-3} (US-EPA, 2003). It is the predominant form of sulphur containing gases found in the low atmosphere. Sulphur dioxide can be a secondary pollutant when formed from other gases like hydrogen sulfide (H_2S) and dimethyl sulfide (CH_3SCH_3) or a primary pollutant when emitted directly to the atmosphere. Sulphur dioxide is produced from the combustion of fossil fuels, volcanic eruptions, ocean spray, and organic decomposition. The production of SO_2 from coal combustion and other fossil fuels occurs from direct oxidation of sulphur contained in the fuel and is therefore dependent on the sulphur content of the fuel (US-EPA, 2003). The fact that sulphur dioxide dissolves easily in water enhances the ability of the gas to form sulphurous acid (H_2SO_3) which is rapidly converted into sulphuric acid (H_2SO_4). SO_2 is also a precursor of sulphates (SO_4^{2-}) which are secondary aerosols. Sulphur dioxide is an important component in the creation of acid precipitation (Hidey, 1994). The most health and vegetation damage caused by air pollution is believed to be the result episodes of very high concentrations of sulphur dioxide (US-EPA, 2002).

Sulphur dioxide can affect the respiratory system, the functions of the lungs and irritate eyes. When sulphur dioxide irritates the respiratory tract it causes coughing, mucus secretion, aggravates conditions such as asthma and chronic bronchitis and makes people more prone to respiratory tract infections. Sulphur dioxide can attach itself to particles and, if these particles are inhaled, they can cause more serious effects. High SO_2 levels are frequently associated with high particulate matter levels as they may come from a common source. Children are the most affected by SO_2. Other vulnerable population groups include the elderly, asthmatics and those with chronic lung disease such as bronchitis and emphysema (WHO, 2005).

C. Nitrogen oxides

The term nitrogen oxide (NOx) is used to mean a mixture of nitric oxide (NO) and nitrogen dioxide (NO_2), produced from natural sources or anthropogenic sources such fuel combustion processes. Nitric oxide is known as the unique form primary pollutant of NOx in air pollution. It is a colourless and odourless gas which forms nitrogen dioxide (NO_2) once oxidised in the atmosphere. Nitrogen dioxide (NO_2) is an odorous, brown, acidic, highly-corrosive gas that can affect human health and environment. Nitrogen oxides are critical components of photochemical. Nitrogen dioxide (NO_2) produces the yellowish-brown colour of smog (Lin and Cheng, 2007).

Nitrogen dioxide (NO_2) is harmful to vegetation, can fade and discolour fabrics, reduces visibility, and reacts with surfaces and furnishings. Vegetation exposure to high levels of nitrogen dioxide can be identified by damage to foliage, decreased growth or reduced crop yield. Indoor domestic appliances (gas stoves, gas or wood heaters) can also be significant sources of nitrogen oxides, particularly in areas that are poorly ventilated (WHO, 2003).

Elevated levels of nitrogen dioxide cause damage to the mechanisms that protect the human respiratory tract and can increase a person's susceptibility to, and the severity of, respiratory infections and asthma. Long-term exposure to high levels of nitrogen dioxide can cause chronic lung disease. It may also affect sensory perception, for example, by reducing a person's ability to smell an odour (WHO, 2003).

D. Carbon monoxide

Carbon monoxide, or CO, is a colourless, odourless gas that is formed when carbon in fuel is not burned completely. It is a component of motor vehicle exhaust and that of other non-road engines and vehicles (such as construction equipment and boats).

Higher levels of CO generally occur in areas with heavy traffic congestion. In developed country cities, 85 to 95 percent of all CO emissions may come from motor vehicle exhaust (Ramanathan, 1987).

Other sources of CO emissions include industrial processes (such as metals processing and chemical manufacturing), residential wood burning, solid waste disposal and natural sources such as forest fires. Woodstoves, gas stoves, cigarette smoke, and unvented gas and kerosene space heaters are sources of CO indoors.

The highest levels of CO in the outside air typically occur during the colder months of the year when inversion conditions are more frequent. The air pollution becomes trapped near the ground beneath a layer of warm air (Ramanathan, 1987).

Carbon monoxide can cause harmful health effects. When CO enters the bloodstream it combines with haemoglobin in red blood cells and reduces oxygen delivery to the body's organs (like the heart and brain) and tissues (WHO, 2003). CO can cause cardiovascular effects; the health threat from lower levels of CO is most serious for those who suffer from heart disease, like angina, clogged arteries, or congestive heart failure. For a person with heart disease, a single exposure to CO at low levels may cause chest pain and reduce that person's ability to exercise; repeated exposures may contribute to other cardiovascular effects. Even healthy people can be affected by high levels of CO (>30ppm). These effects include drowsiness, irritability, headaches and rapid breathing. People who breathe high levels of CO can develop vision problems, reduced ability to work or learn reduced manual dexterity, and difficulty performing complex tasks. At extremely high levels, CO is poisonous and can cause death (WHO, 2003).

2.2 Meteorological parameters and pollutant behaviour

2.2.1 Wind

Wind carries air contaminants away from their source, causing them to disperse. In general, the higher the wind speed, the more contaminants are dispersed and the lower their concentration. However, high wind can also generate dust – a problem in dry, windy, rural areas (Egami et al., 1989). The wind is present in a three dimensional field and acts during the transport and diffusion of pollutants in both horizontal and vertical ways. Inside the atmospheric boundary layer, where the majority of pollution dispersion and diffusion happen, the interplay of three forces determines horizontal wind speed and direction. These forces are the pressure gradient force, the Coriolis force and surface friction. Wind direction as determined by the three forces mentioned above controls the direction of pollutant transport (Preston-Whyte and Tyson, 1988).

The South African Highveld present stagnant conditions for up to 60% of days throughout the year. These conditions dominate as a result of the persistence anticyclonic circulation that characterizes the subcontinent. Apart from stagnant conditions and ventilation, atmospheric conditions such as down mixing from a postulated pool of pollutants and washout events have a marked impact on surface concentrations (Scheifinger and Held, 1997).

2.2.2 Turbulence

As the ground heats during the day the air becomes more turbulent, especially in the middle of the day. Air turbulence causes polluted air to disperse as it moves away from its source. In contrast, stable conditions often occur at night when the air is cooler (Tyson et al., 1988).

The two turbulence components which can only be separated according to their different meteorological causes are: Thermal turbulence which is considered significant for the vertical exchange because it goes deep to very high altitudes and only occurs in unstable temperature layers. The other one is friction turbulence which manifests itself in rapid changes of wind direction and speed (Baumbach, 1996)

2.2.3 Inversion layers

Air usually cools with increasing height in the atmosphere. However, sometimes an upper air layer is warmer than a lower one. This is called an inversion. Inversions often form on clear, calm nights when the ground cools rapidly. Inversions are important because the upper warmer layer acts like a lid. The inversion layer traps air contaminants underneath. Inversion layers are usually dispersed by wind or by warm air rising as the ground heats up. But if the inversion layer stays in place for a long time pollutants can build up to high levels. Air contaminants build up when inversion layers form close to the ground (Tyson at al., 1988).

Surface inversion occurs when the surface loses radiation during the night and cools down; an inversion layer develops in first few ten meters. Above the surface layer, a further less intense inversion forms usually to a depth of a few hundred meters, then follows the formation of an isothermal layer (Tyson et al., 1988). Surface inversions are most likely to occur in winter months over South Africa.

The average inversion over the Highveld is 280 m deep in winter. Such inversions occur on every four out of five nights. It is only when the atmosphere is disturbed (with clouds and strong winds) that the surface inversion will not form (Tosen and Pearse, 1987). Inversion frequencies are least in spring when winds are strongest. In summer, they may occur more than two out of three nights (Von Gogh et al., 1982).

Very stable anticyclonic conditions exist over Southern Africa throughout the year (more than 80% of time during winter in the interior plateau). These conditions inhibit vertical exchanges in the atmospheric column and stratify the troposphere into persistent layers in which residence time is prolonged over days to weeks. This may force the air in a given volume to return to its original point of departure or achieve more than one recirculation cycle. Atmospheric states under such anticyclonic conditions are typically free or nearly free of clouds for long periods of the year which gives maximum day time insolation (Tyson and Preston- Whyte, 2000).

Leandra is also located on the interior plateau and has a very stable and well-defined inversion layer during winter, which in combination much more coal being burnt; result in very high levels of pollution during winter months. In contrast, during summer, whilst the sources of air pollution are largely in place except for a reduction in domestic coal usage, the increase in summer rainfall and change in wind patterns results in lover levels of air pollution (Scheifinger, 1997).

2.2.4 Ground temperature

Air pollution and local meteorology are affected by ground temperature. Ground temperature affects horizontal wind speed where hot surfaces increase convection, causing surface air to mix with air aloft faster and vice versa. Faster near surface, winds result in greater dispersion of near surface pollutants but cause the re-suspension of soil dust and other particles from the ground (Rotach, 2004). A different effect is observed in the case of cooler ground temperatures, which result in increased near surface pollution and reduced near surface wind speed (Rotach, 2004). Rates at which several processes occur will change as the ground temperature changes. These include carbon monoxide emissions from vehicles, chemical reactions and gas to particle conversion (Mark, 2002). Hot ground surfaces result in high inversion base heights and lower pollution mixing ratios. In contrast, ground surfaces with low temperature; produce shallow mixing depths and high pollution mixing ratios (Mark, 2002).

2.3 Climatology of the South African Highveld

The Highveld region is influenced to a great extent by the subtropical anticyclonic belt of the general circulation (Tyson and Preston-Whyte, 2000). Strong subsidence of air prevails over the region through the year but is most pronounced in winter which ensures that the atmosphere is highly stable for most of the time. During winter, temperature inversions occur almost nightly at the surface and, with high frequency, elevated inversions occur. However, even during summer, nocturnal surface inversions are as frequent as 70% of the time, although they are not as strong as in winter (Tyson and Preston-Whyte, 2000).

The moist, unstable conditions and rainfall are almost exclusively confined to the summer period when the anticyclonic belt is located further south. These conditions in addition to increased ambient temperature and solar radiation are favourable for the formation of secondary pollutants (Tyson and Preston-Whyte, 2000).

Five pollution transport pathways over Southern Africa with regards to wind direction were determined according to wind directions over South Africa (Tyson and Preston-Whyte, 2000). The most relevant transport pathways over the Highveld are anticyclonic conditions (51% likely to occur) and westerly disturbances (41% likely to occur) which produce conditions conducive for the transport of aerosols and trace gases away from Africa to the east over the Indian Ocean (Garstang et al.,1996). These regional climatic conditions control the transport of air pollutants both within the Mpumalanga province and between neighbouring provinces and countries.

2.4 Electrification as a strategy to reduce domestic coal emissions

Low income communities suffer from a deficit of electricity, forcing reliance on dirtier fuels such as coal, wood and paraffin for cooking and heating in their homes, which cause health-damaging indoor emissions.

Electricity use reduces domestic coal emissions by replacing coal and other dirtier fuels used for cooking and space heating and improves ambient air quality especially when produced from cleaner technology such as hydropower and nuclear. Although coal is not a clean fuel for electricity production, emissions from coal-fired power generation can be better controlled than emissions from individual's stoves. Furthermore, emissions from accidental fires caused by the use of energy sources other than electricity can be eliminated once electricity is adopted

CHAPTER THREE: DATA AND METHODS

A description of the characteristics and sources of data used in this research is given in this chapter. The methods used to analyse raw data are provided.

The following approaches were employed in this study:

- A site visit was made by the researcher to the monitoring station;
- Measurements of ambient SO_2 and PM_{10} concentrations were analysed;
- Annual, seasonal and diurnal trends in pollution concentrations were identified.

3.1 Study site

Mpumalanga Province is the second smallest province in South Africa. It occupies approximately 6% (79 490 km^2) of the total surface area of South Africa and is bordered by Mozambique and Swaziland to the east, by the Limpopo Province to the north, by Gauteng to the west and by KwaZulu-Natal and the Free State to the south (Figure 2). The province is divided into three regions: the Highveld, the Lowveld and the Escarpment, each having its own distinct characteristics in terms of rainfall, temperature and topography (Mpumalanga province, 2002).

The economy of the province is based primarily on mining, agriculture, forestry and tourism. The province is rich in natural minerals, of which coal is the most important. The province produces approximately 95% of the country's total coal production. The coal produced is primarily used to generate electricity (Mpumalanga province, 2002).

Leandra (Figure 2) is situated on the Highveld, in Mpumalanga Province, South Africa at 26°22'0"S, 28°55'0"E. With a total number of 10000 households, Leandra and Lebohang are relatively low income communities located on the Highveld in the southern part of

Mpumalanga Province. In 2007, the number of inhabitants of the Leandra/Lebohang suburb was estimated to be sixty thousand, with an average of six people per household (http://www.gsibande.gov.za/statistics_demographics.asp).

In Leandra and Lebohang trends in household energy use provides an insight into domestic reliance on fossil fuels. The majority of households in Leandra rely on electricity from the national grid, with a small percentage of households using coal. However, in Lebohang Township, coal is the primary source of domestic energy and very few households use electricity (http://www.gsibande.gov.za/statistics_demographics.asp).

The air quality monitoring station is located at Leandra Junior School, 2 km from the centre of Lebohang, a neighbouring township (Figure 2 and 3). The choice of the site was influenced by the fact that the monitoring station is located in the middle of the suburb and surrounded by recently electrified houses.

Local domestic emissions can be measured at the monitoring station independent of the wind direction. The Sasol coal-to-liquid plant located in Secunda is 30 km south east of Leandra. Kriel and Matla coal-fired power stations are situated to the north-east of Leandra with Kendal power station to the north-north-west.

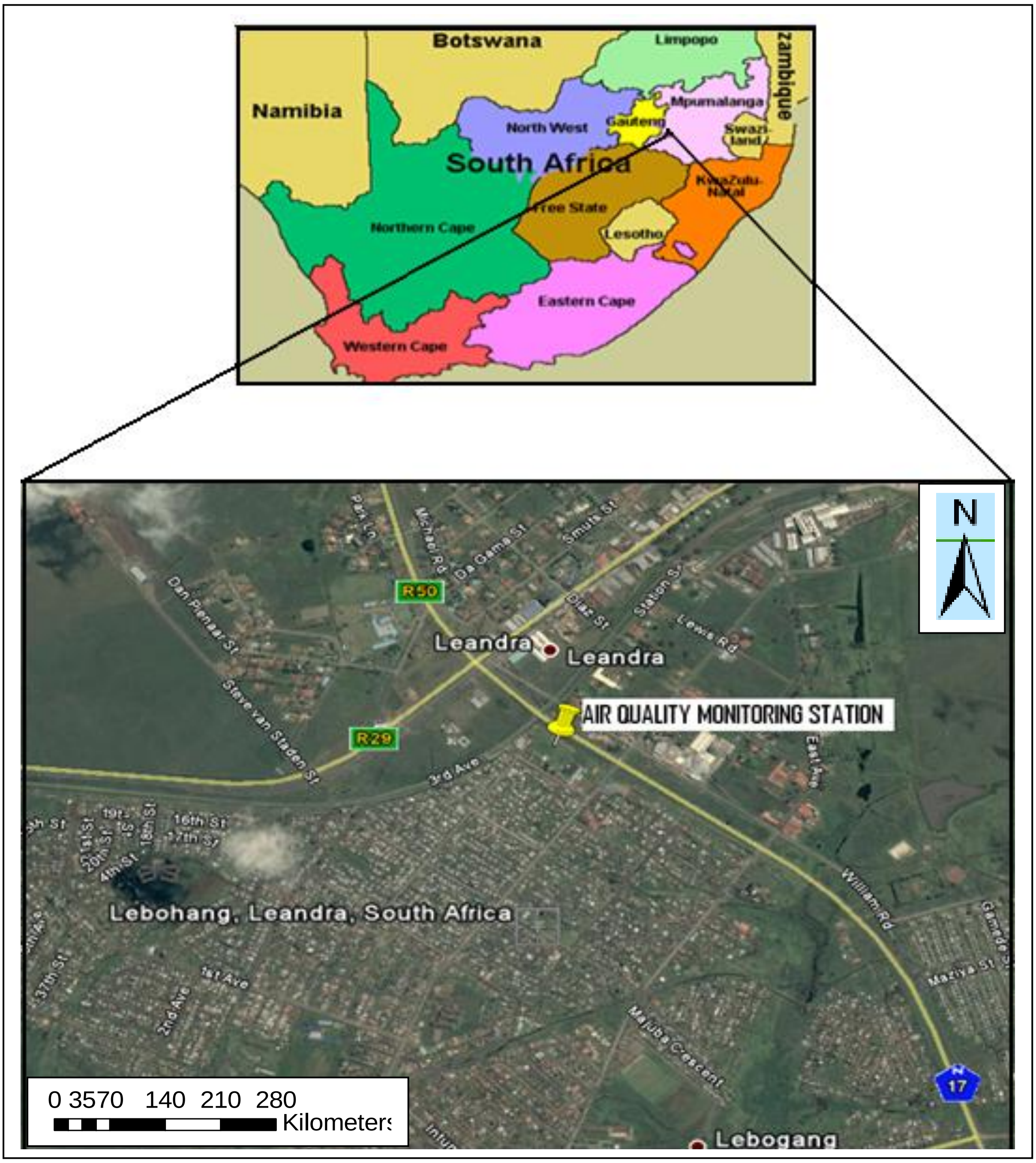


Figure 2: Location of the study area (Leandra) on the South African map (photo: goggle earth).

Figure 3: Leandra monitoring station located in the premises of Leandra Junior School (Photo: C.Mugabo).

3.2 Data

3.2.1 Parameters measured at Leandra monitoring station

The Leandra ambient air monitoring station was established in 1999 and was designed to monitor the reductions in ambient air pollution as a result of an increasing number of low income households being connected to the national electricity grid. A field trip was carried out to see where the monitoring station is located and check which parameters are monitored at the station. The air pollution parameters monitored at Leandra are: sulphur dioxide (SO_2) and particulate matter (PM_{10}); meteorological parameters include: wind speed, direction and ambient temperature.

The instruments used to monitor the air quality and meteorological parameters are listed in Table 2. Hourly averages are automatically calculated by data loggers and recorded for each parameter monitored at Leandra monitoring station. In this study, hourly averages of PM_{10} and SO_2 measured at Leandra monitoring station for a period of seven years (1999-2005) for PM_{10} and ten years (1999-2008) for SO_2 were analysed.

Table 2: Air pollution and meteorological parameters measured at Leandra monitoring station (ESKOM, 2000).

	Measured Parameter	Instrument type	Units	Range
Air pollution parameters				
1	Sulphur dioxide (SO_2)	Monitor Labs 8850	ppb	0-1000
2	Particulate matter (PM_{10})	Eberline Beta Gauge	$\mu g.m^{-3}$	0-1000
Meteorological parameters				
3	Wind Speed	Met One	$m.s^{-1}$	-
4	Wind direction	Met One	degree	-
5	Ambient temperature	Met One	°C	-10 - +50

PM_{10} data capture was sometimes inadequate and no PM_{10} measurements were made from 2006 to 2008 (Table 3). This period was not considered in the analysis. The available data nevertheless give a good idea of how PM_{10} behaves in the Leandra atmosphere .Very good data, with more than 85% capture, were recorded for SO_2 and therefore analysed for the entire monitoring period of 1999-2008.

Table 3: Seasonal PM_{10} and SO_2 data availability (%) at Leandra monitoring station for the period 1999-2008

Year / Season		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Winter (April to August)	***PM_{10}***	96.4	27.4	88.5	16.9	36.8	99.2	98.2	no data available	no data available	no data available
	SO_2	99.3	99	97.5	96.6	99.3	99	99.3	70	87	96
Summer (September to March)	***PM_{10}***	79	48.5	51	53.4	9.3	56	85.5	no data available	no data available	no data available
	SO_2	97	87	99.5	97.7	98.6	98	98.5	83.3	90	94

To test the normality, data were plotted in histograms (Figure 4 and 5) and p value was calculated using Statistical Analysis Software (SAS 2006). Data are normally distributed if $p>0.05$ and data are not normally distributed if $p<0.05$ (Galpin, 2009). Leandra PM_{10} and SO_2 data are not normally distributed as they have p values of 0.001 and 0.01 respectively. The arithmetic mean was used to calculate all averages.

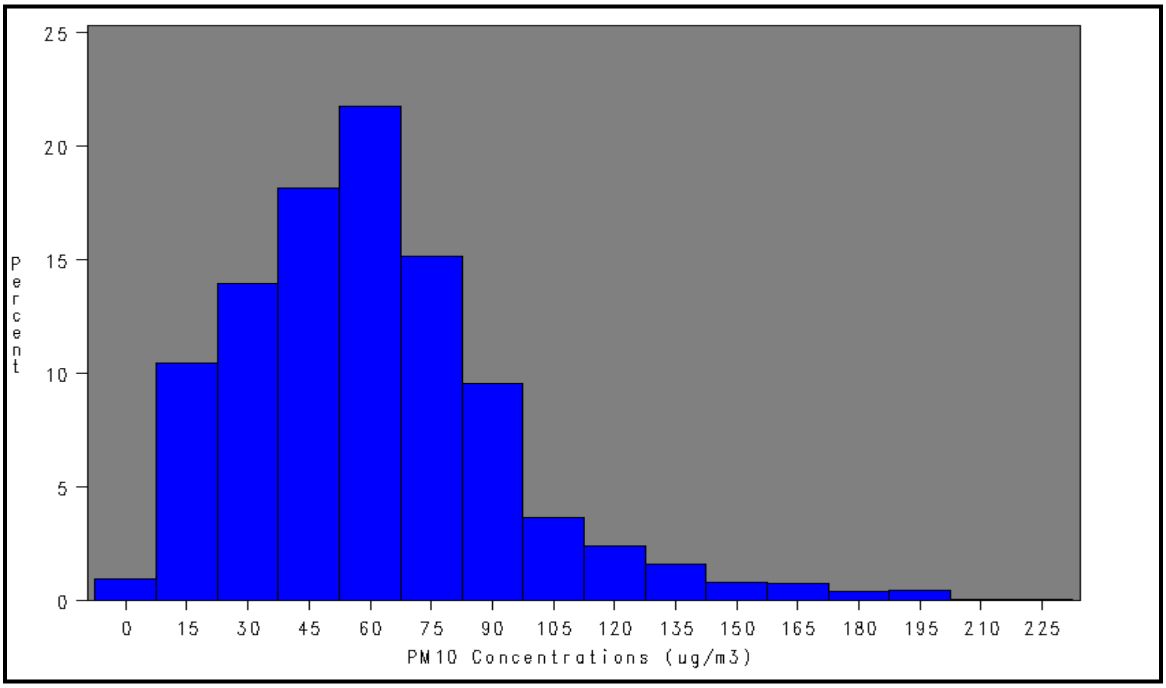


Figure 4: Leandra PM_{10} data distribution for 1999-2005.

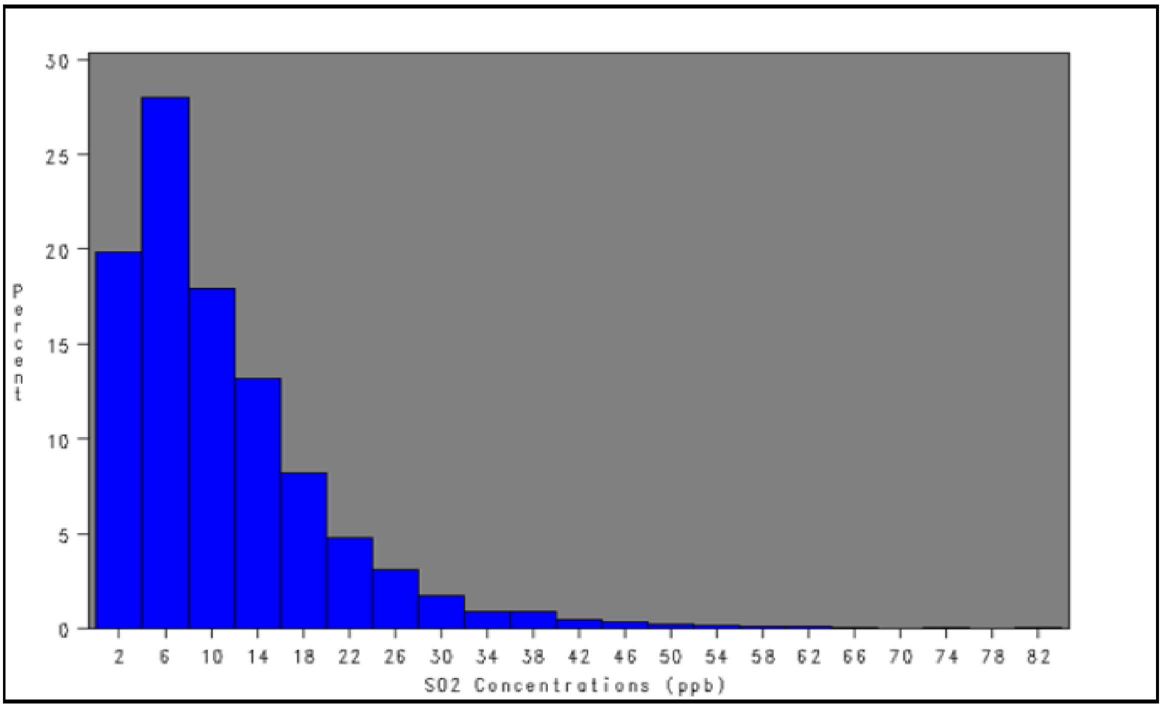


Figure 5: Leandra SO_2 data distribution for 1999-2008

3.2.2 Air quality monitoring equipment at Leandra monitoring station.

The instruments installed at the Leandra monitoring station are as follow:

The Monitor Labs Model 8850 Fluorescent SO_2 analyser

The measurements of the Monitor Labs SO_2 analyser (Figure 6) are based on the principle that SO_2 molecules absorb ultraviolet(UV) light and become excited at one wavelength, they then decay to a lower energy state emitting UV light at different wavelength. The sample goes into the analyzer through its bulkhead. It passes a pressure sensor and then flows through a capillary and a flow sensor.

The sample then flows into a fluorescence chamber. SO_2 molecules are excited selectively by wavelengths reflected by four mirrors. Then, the sample flows to the pump and is released through the exhaust bulkhead of the analyser. The analyser outputs the SO_2 concentration to the front panel display and the output channel (Monitor labs, 1994).

Figure 6: Monitor Labs Model 8850 Fluorescent SO_2 analyser, used at Leandra monitoring station (Photo: C.Mugabo).

Eberline FH 62 I-R Beta Gauge particulate monitor,

Eberline FH 62 I-R Beta gauge particulate monitor (Figure 7) is a measuring device for continuous monitoring of the concentrations of particles in the ambient air. It is used to monitor PM_{10} concentration at Leandra Monitoring station. Like many other particulate monitors, the beta gauge's measuring principle is based on direct mass collection and simultaneous measurement during sampling by a two-beam compensation method and single filter-spot position (no step-wise response with pre-selected time and range intervals). The filtering system is a glass fiber filter type GF 10 one roll (width 40 mm; length: 42 m) which is good for approximately one year (without potential free separation).Its air flow rate is $1 m^3/h$ through the filter spot measured with an internal pressure drop orifice. The time between calibration checks and maintenance is 12 months-if used as specified (Seung et al., 2001).

Figure 7: Eberline FH 62 I-R Beta Gauge particulate monitor, used at Leandra monitoring station for PM_{10} measurements (Photo: C. Mugabo).

Electrification information

In 2001, 1034 houses which are 90% of households without electricity and 21.5% of the total households in Leandra back in 2000, were connected to the national electricity grid in Leandra as part of a programme funded by the Department of Mineral and Energy and implemented by Eskom. The aim of the programme is to improve the living conditions of the poor. Electrification information used in this research was provided by Eskom through its department in charge of electricity distribution, Northern Region.

3.3 Methods

This work is aimed at establishing whether a clear decrease in PM_{10} and SO_2 ambient concentrations could be established when a large number (1034) of houses were connected to the national electricity grid at Lebohang, near Leandra in 2000. It is hypothesised that the use of cleaner energy (electricity) for cooking and space heating by households as compared to the conventional coal and wood burning for the same purpose results in noticeable reductions in PM_{10} and SO_2 concentrations and therefore improvements in ambient air quality. It was assumed that if more houses were supplied with electricity, the total concentration of both PM_{10} and SO_2 would be reduced.

PM_{10}, SO_2, ambient temperature, wind speed and direction raw data was acquired from Eskom's Sustainability and Innovation Department for the 1999-2008 monitoring period. The data was filtered to remove over-range values, zero records and negative values. Entire days of data were rejected where long data segment were missing. The analysis tools and pivot table available in Microsoft Excel® and in Statistical Analysis Software (SAS 2006) were used for this purpose.

Diurnal averages to identify source of pollution, seasonal averages to identify seasonal influence on pollution level and annual averages to identify long-term trends were then calculated using the same methods. We compared averages calculated using arithmetic mean with the New South African Ambient Air Quality Standards (Table 4) to identify exceedances.

Table 4: New South African Nation Ambient Air Quality Standards (Government Gazette, December 2009).

Pollutant	Averaging Period	Concentration	Frequency of Exceedance	Compliance Date
PM_{10}	24 hours	120 µg/m^3 (191 ppb)	4	Immediate-31/12/2014
	24 hours	75 µg/m^3 (191 ppb)	4	1/1/2015
	1 year	50 µg/m^3 (191 ppb)	0	Immediate-31/12/2014
	1 year	40 µg/m^3 (191 ppb)	0	1/1/2015
SO_2	10 minutes	500 µg/m^3	526	Immediate
	1 hour	350 µg/m^3	88	Immediate
	24 hours	125 µg/m^3	4	Immediate
	1 year	50 µg/m^3	0	Immediate

In 2001, the year when electrification was completed, there were no South African ambient air quality standards. These only came into effect in 2005.

CHAPTER FOUR: RESULTS

Ambient PM_{10} and SO_2 levels in Leandra are presented in this chapter. Where possible, a comparison of the monitored data has been made with the relevant ambient air quality standards. Sources of pollution as well as the effects of electrification on ambient in Leandra are discussed in this chapter.

4.1 Annual and seasonal variations in pollution concentrations

4.1.1 Particulate matter (PM_{10})

PM_{10} concentrations were measured and analyzed from January 1999 to December 2005. The annual averages (Figure 8) were above the national annual average standard of 50µg/m^3, except during 2001 and 2002. The highest annual average PM_{10} concentration was observed in 2000 and the lowest annual average concentration in 2001, following the connection of 1034 households to the national electricity grid. After 2001, PM_{10} concentrations steadily increased as the township grew and the number of households burning coal increased (Segopa, 2009).

Higher concentrations of PM_{10} were recorded during winter (April to August) than during summer (September to March) in all years (Figure 9). This is a result of more intensive coal burning in winter than in summer coupled with temperature inversions and calm winds that lead to a build-up of contaminants in the air in the winter months. Lower PM_{10} concentrations are observed during the summer as a result of less coal burnt and due to the mixing of pollutants.

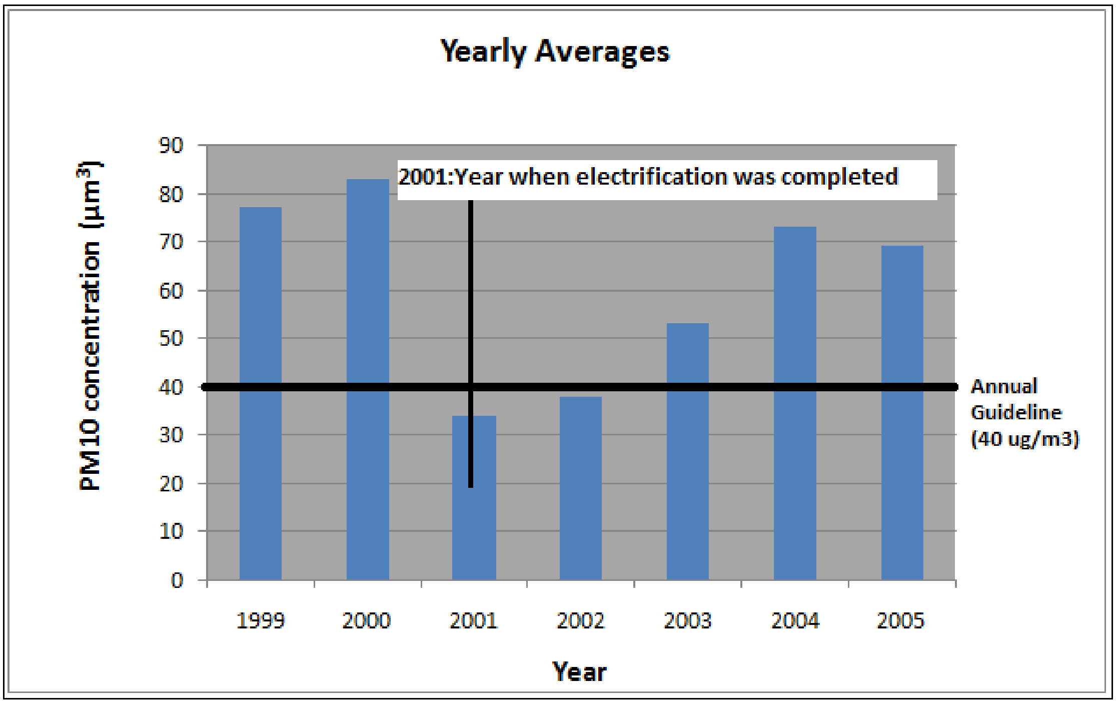


Figure 8: Annual PM_{10} concentrations at Leandra for the period 1999-2005.

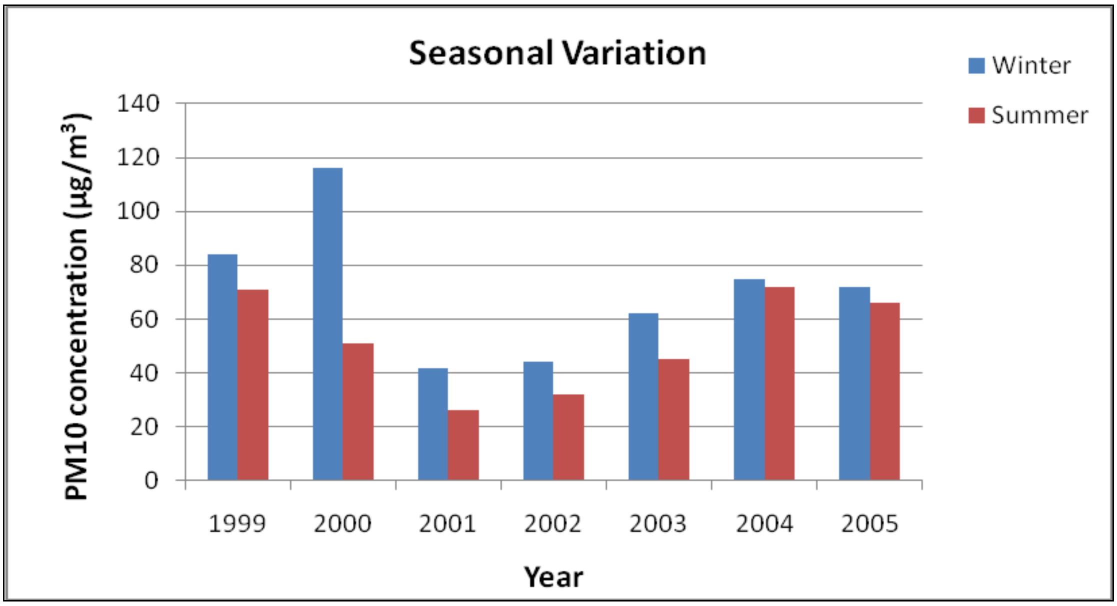


Figure 9: PM_{10} Seasonal variations at Leandra for the period 1999-2005.

4.1.2 Sulphur dioxide (SO_2)

The highest annual average concentration of SO_2 (Figure 10) observed at Leandra for the 1999-2008 period was 16.3 ppb and was recorded in 2000. None of these years experienced SO_2 levels greater than the national annual standard of 19 ppb for annual average SO_2 concentrations. The electrification in 2001 did not have such a marked impact on SO_2 ambient concentrations, implying that other sources in the region, probably industries and power stations, also contribute to ambient SO_2 levels. The progressive increase in SO_2 concentration from 2002 suggests that more coal was burnt as the township expanded.

There was a pronounced seasonal variation in SO_2 concentrations at Leandra for the entire monitoring period (Figure 11). Higher concentrations of SO_2 were recorded during winter, lower SO_2 concentrations are generally observed during summer due to the mixing of pollutants.

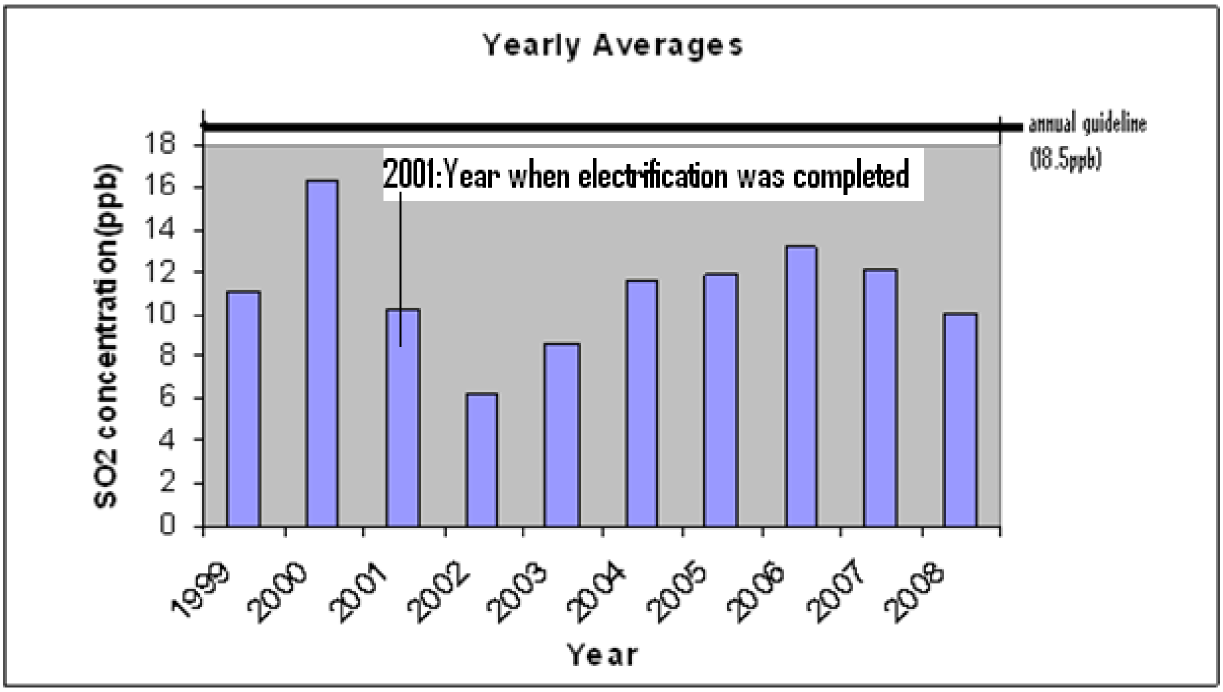


Figure 10: SO_2 annual concentration at Leandra for the period 1999-2008

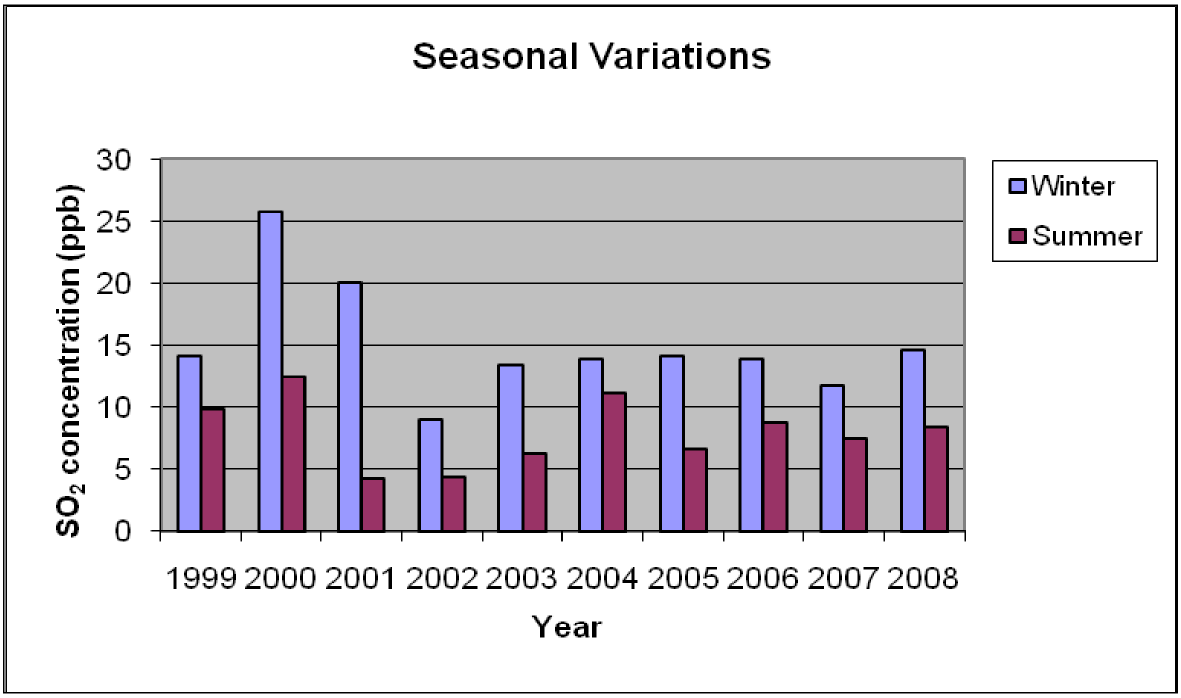


Figure 11: SO_2 Seasonal variations at Leandra for the period 1999-2008.

4.2 Diurnal variations

4.2.1 Particulate matter (PM_{10})

Mean diurnal concentrations of PM_{10} at Leandra (Figure 12) were calculated before (1999, 2000) and after (2001, 2003) electrification. Peaks in PM_{10} concentrations are evident in the early morning and evening as a result of domestic coal burning. A significant decrease in PM_{10} is observed after electrification. This decrease is particularly marked in the morning and evening peaks, showing that the amount of PM_{10} produced by domestic coal combustion was reduced after electrification.

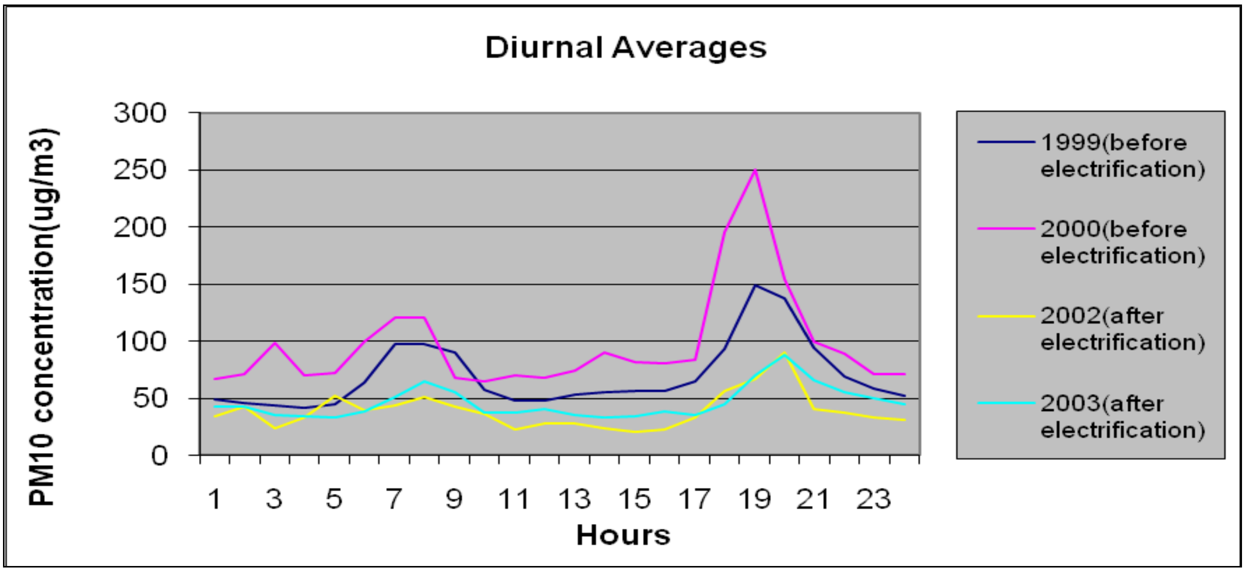


Figure 12: PM_{10} diurnal averages before and after electrification in Leandra.

4.2.2 Sulphur dioxide (SO_2)

Mean diurnal SO_2 concentrations (Figure 13) were calculated before (1999, 2000) and after (2001, 2003) electrification at Leandra. Like PM_{10}, peaks in SO_2 concentrations are evident in the early morning and evening as a result of domestic coal burning. However, the additional peak in SO_2 concentrations in the late morning hours (11:00-12:00) suggests that non-local sources such as tall stack industrial emissions also affect the area. A significant decrease in the SO_2 morning and evening peaks is also observed after electrification.

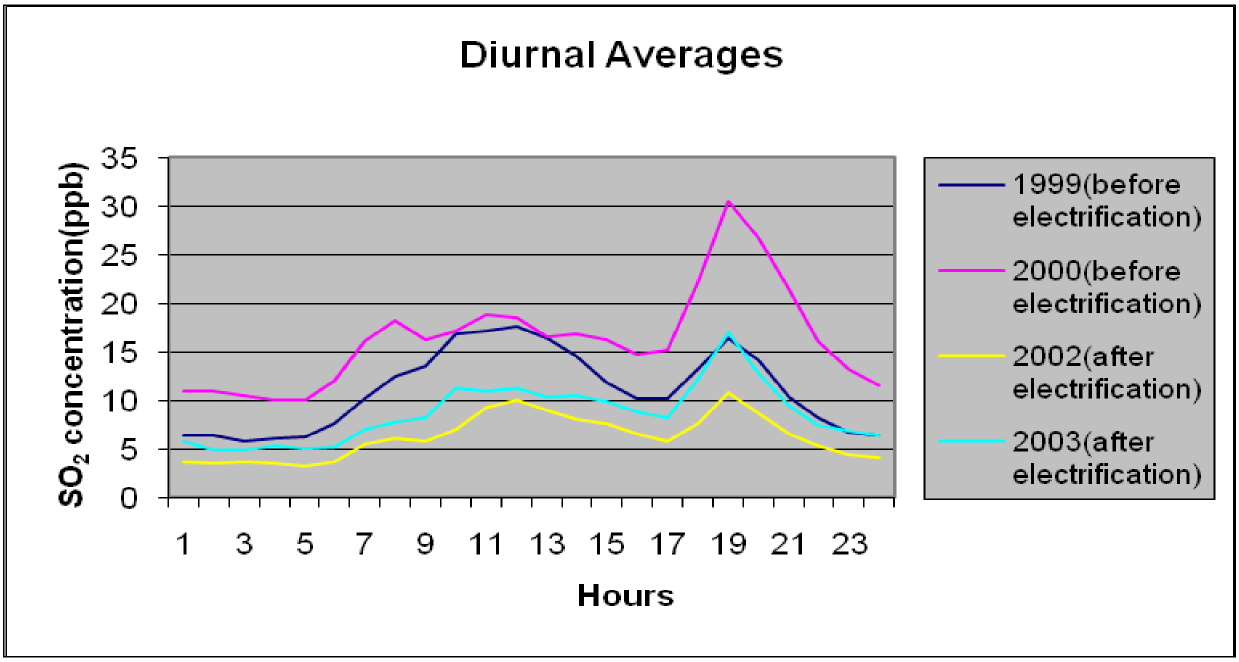
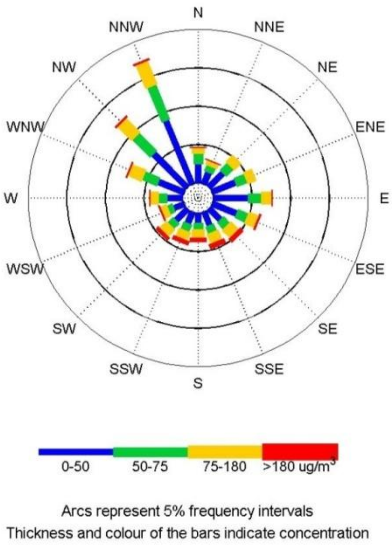


Figure 13: SO_2 diurnal averages before and after electrification in Leandra.

4.3 The effect of wind direction on PM_{10}, SO_2 concentrations.

Pollution roses are a useful tool to illustrate pollution concentration as a function of wind direction. Pollution roses are given for pollutant concentrations recorded over the monitoring period (Figure 14).

PM_{10} (Figure 14, left) concentrations are highest in association with southerly winds. This suggests that PM_{10} concentrations come from a local source because most homes are located south of the monitoring station. SO_2 concentrations (Figure 14, right) are highest in association with north-easterly wind flow from the direction of Kriel and Matla coal-fired power stations and in association with southerly wind flow where most homes and the Secunda coal-to-liquid plant are located.



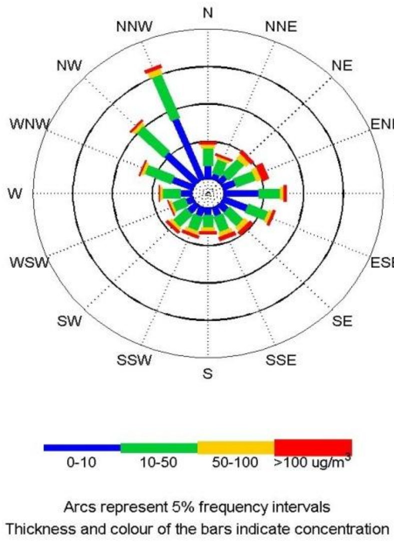


Figure 14: Leandra pollution roses indicating the wind directions with which PM_{10} (left) and SO_2 (right) highest concentrations were associated.

4.4 Electricity supply and Leandra air quality

As soon as households are connected to the national grid, an improvement in ambient air quality was observed in Leandra. The number of exceedances of the daily PM_{10} and SO_2 concentrations to the standards (Figure 15) reveals that before the electrification of 1034 houses along 2001 in Leandra, the daily average national PM_{10} ambient air quality standard of 120µg/m^3 was often exceeded with 47 and 141 daily exceedances in 1999 and 2000 respectively. Only four exceedances of the daily limit are permitted in terms of the standards. PM_{10} concentrations exceeded the daily guideline in 2000 more than in any other year monitored in Leandra. The daily average national SO_2 ambient air quality standard of 48ppb was exceeded 12 times in 2000; in this case, only four exceedances per year are permitted in terms the ambient air quality standards. There were twelve exceedances of the 24-hour SO_2 limit in 2000; four in 2006; three exceedances in both 2001 and 2007 and two exceedances in 2004 and 2005.

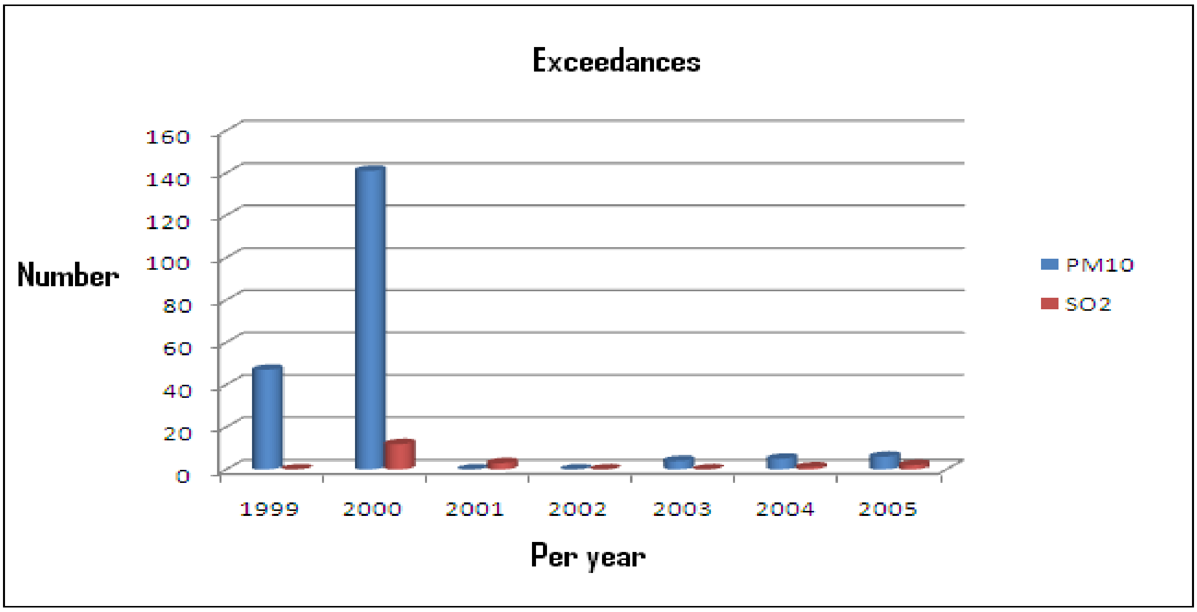


Figure 15: Yearly number of exceedances of the 24-hours limit for PM_{10} and SO_2 for the period 1999-2005 at Leandra monitoring station.

CHAPTER FIVE: SUMMARY AND CONCLUSION

This chapter gives a summary of main findings with a conclusion and a recommendation for further investigations regarding the people's behaviour towards electricity use after being supplied with it.

5.1 Summary

The major objectives of this research were:

(i) assess the level of ambient pollutant concentrations in Leandra, a low income residential area on the Mpumalanga Highveld, and the acceptability of the air quality according to the South African ambient air quality standards for SO_2 and PM_{10};

(ii) identify industrial and domestic impacts on air quality in Leandra;

(iii) assess the impact of electrification on ambient air quality in Leandra.

According to the analysis available from this report, PM_{10} annual averages exceeded the national annual average standard (50µg/m^3) for the most of 1999-2005 monitoring period, except in 2001 and 2002. The highest annual average PM_{10} concentration was observed in 2000 and the lowest annual average concentration in 2001, following the connection of 1034 households to the national electricity grid.

SO_2 annual averages were below the national annual average standard (19 ppb) for the entire 1999-2008 monitoring period. Unlike PM_{10}, SO_2 did not show a sharp decrease after electrification which suggests that other sources in the region; probably industries and power stations, also contribute to ambient SO_2 levels.

PM_{10} concentrations were higher in winter than in summer for the entire monitoring period due to intensive coal burning in winter than in summer coupled with temperature inversions and calm winds that lead to a build-up of contaminants in the air in the winter months. Lower PM_{10} concentrations are observed during the summer as a result of less coal burnt and due to mixing of pollutants.

The seasonal variation is similar for SO_2 except in 2006, when the SO_2 average concentration was higher in summer than in winter. Again, this suggests that in additional to local source, SO_2 concentrations are influenced by remote sources.

Mean diurnal concentrations of PM_{10} reveal that peaks are evident in the early morning and in the evening as a result of domestic coal burning. SO_2 diurnal graph shows a same trend with an additional peak that occurs in late morning hours (11:00-12:00); this peak is attributed to a non local source such as industrial emissions. High PM_{10} concentrations were associated with southerly wind flow where most homes are located while in addition to the southerly flow; SO_2 high concentrations were associated with north-easterly flow where Kriel and Matla coal-fired power stations are located and south-easterly flow where Secunda coal-to- liquid plant is located.

The South African annual average ambient PM_{10} limit of 50 $\mu g/m^3$ was exceeded on 57% of the monitored years and the 24-hour ambient PM10 limit of 120 $\mu g/m^3$ was exceeded on 8% of the monitored days. The annual average ambient SO_2 limit of 19 ppb was never exceeded during the monitoring, but the daily average limit of 48 ppb was exceeded on 1% of the monitored days.

Electrification had a positive impact on Leandra's ambient air quality. Before the electrification of 1034 houses was completed in 2001, the daily average national PM_{10} ambient air quality standard of 120 µg/m^3 was often exceeded with 47 and 141 exceedances in 1999 and 2000 respectively**.** After electrification, the number of exceedances of the daily average limit dropped from 141 in 2000 to 0 in 2001 for PM_{10} and from 12 exceedances in 2000 to 3 in 2001 for SO_2.

5.2 Conclusion

A significant reduction in PM_{10} concentrations was observed in Leandra following the electrification of 1034 households in 2001. Annual average PM_{10} levels dropped from 97µg/m^3 in 2000 to 37 µg/m^3 in 2001, and steadily increased thereafter as the township expanded. In Leandra, the annual PM_{10} average was above the national annual limit of 50µg/m^3 every year from 1999 to 2005, except during 2001 and 2002. The number of exceedances of the PM_{10} daily limit was as high as 141 in 2000, the year before the massive electrification was done in Lebohang, and as low as 0 in 2001, the year in which the electrification was completed. The SO_2 annual guideline was never exceeded during 1999-2008 monitoring period. However, the SO_2 daily national standard was exceeded several times at Leandra.

The diurnal patterns suggest that PM_{10} and SO_2 are derived from a local source (domestic coal burning), and SO_2 concentrations are further enhanced by tall stack sources such as industry. The connection of 1034 households to the national electricity grid in 2001 resulted in significant improvements in ambient air quality for the following two years. However, the air quality was negatively affected as the township expanded with more houses without electricity and therefore more coal being burnt. The results obtained from this study show that South African Highveld Township, especially Leandra, still face air pollution problems with much more negative health implications from high levels of suspended particulate matter. It would be recommended that electrification of areas where coal is being burnt for domestic be intensified in order to solve current non-compliance issues.

A relationship between PM_{10} concentrations due to domestic coal combustion and a possible sustainable solution, electrification, has been established. This information provides a valuable tool for decision makers who aim to improve the lifestyle of communities with low income. It is a real pity that new homes were allowed to be built without an electricity supply. Ultimately, infrastructure must keep pace with growth.

Although it was observed that after the 2001 massive electrification more houses were built without electricity supply that resulted in more PM_{10} emissions in Leandra, a field based socio economic research is recommended to find out to what extent connected families afford the use of electricity.

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