EFFECTS OF GASEOUS EMISSIONS FROM THE NAMAKWA SANDS MINERAL SEPARATION PLANT NEAR LÜTZVILLE ON THE ADJACENT SUCCULENT KAROO VEGETATION – A PILOT STUDY

BY

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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

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ABSTRACT

A pilot study was conducted at the Namakwa Sands Mineral Separation Plant, to investigate the effects of acidic gaseous emissions from the Mineral Separation Plant on the adjacent Succulent Karoo vegetation. Sulphuric acid fumes, a major gaseous emission of the mineral processing, was the subject of investigation of the present study, due to the potential high negative impact of elevated concentrations thereof on vegetation in the ecosystem.

Permanent sample plots along three transects radiating from the Mineral Separation Plant were laid out in the eastern, south-eastern and southern directions following the prevailing wind directions and practical consideration of land accessibility.

The ecological components assessed as indicators of possible pollution levels in the environment included percentage plant mortality, foliar sulphur content of selected plant species, chemical composition of solubles in mist and dust samples, and soil pH. In addition, the vegetation was screened for plant species suitable to be used as potential bioindicators.

Potential bioindicator plant species were selected on the basis of their relatively wide distribution in the study area and apparent sensitivity to the ambient air pollutants. The percentage of dead plants of each species that occurred on the sample plots was used as a criterion of the possible sensitivity of the plant species towards air pollution. The bioindicator plant species selected for potential monitoring purposes were: *Galenia fruticosa*, *Lampranthus suavissimus*, *Lycium ferocissimum* and a *Ruschia* sp. (SP 9). Plant mortality was greater nearer the emission source, with 28 ± 5 % dead plants at 400 m, 19 ± 6 % at 800 m and only 10 ± 4 % at 1,200 m from the Mineral Separation Plant. Data summed for all species recorded and pooled for all three transects per sampling distance.

With the methods used in this study, in the case of all sample plots on the three transects, no significant difference was found between the mean pH values of soil samples collected from open spaces without plant cover (8.01 ± 0.46) and those collected underneath shrubs (8.91 ± 0.96). Subsequently only the pH values of soil samples collected on open spaces were used to investigate the variation in soil acidity with distance and direction from the emission source. The means represent total number of samples from open space versus those collected from underneath shrubs.

The pH of soil samples increased with distance from the emission source along the transects to the south and south-east of the emission source. Eastward of the emission source, soil pH values remained relatively low at all sample distances. This pilot study could not determine whether the continuous acidity of the soil along the eastern transect in the direction of the prevailing wind, was caused by increased deposition of gaseous emissions on the higher lying hilly terrain in this area, or by the underlying geology.

Ion chromatographic analysis of mist and dust samples collected on each sample plot indicated the presence of several chemicals that had probably originated from the gaseous emissions from the Mineral Separation Plant as well as wind blown constituents from the adjacent surroundings of the sample plots. Of these chemicals, only the sulphate concentrations of the mist and dust samples were further evaluated, since that could be related to the emission of sulphuric acid fumes by the Mineral Separation Plant. Results indicated that the mean sulphate concentration of mist and dust samples collected from sample plots relatively close to the Mineral Separation Plant, 118.8 ± 31.6 mg/litre (400 m), were higher than further afield, decreasing to 57 ± 30.1 mg/litre at 800 m and 43.1 ± 19.6 mg/litre at 1,200 m. These values, representing the mean sulphate concentrations of mist and dust samples at each sampling distance (data of the three transects pooled), differ significantly at the 85 % confidence level.

Statistical evaluation of the data of the mist and dust pH measurements, pooled for the three transects on the basis of distance, indicated a gradual increase of the mean values from 400 m (7.3 ± 0.26), through 800 m (7.7 ± 0.34), to 1,200 m (8.2 ± 0.83), although these values were not significantly different.

A decreasing trend in accordance with that in the case of the sulphate concentrations of mist and dust samples with distance from the mineral processing plant, was also observed in the sulphur content of the leaves of selected plant species, with mean sulphur content higher at 400 m sampling distance (0.29 ± 0.091 %) than at 800 m (0.264 ± 0.086 %) and a further decline at 1,200 m (0.232 ± 0.079 %), data of the three transects pooled. However, these values were also not significantly different.

Although not significantly so, the decreasing trend in the results of the sulphate concentration of mist and dust samples, the sulphur content of plant leaf samples as well as plant mortality observed, and increasing soil pH values with distance from the Mineral Separation Plant, suggest that the gaseous emissions from the Mineral Separation Plant could probably have had a detrimental effect on the adjacent Succulent Karoo vegetation. A more detailed study is necessary to confirm this trend. In addition it is recommended that in order to clarify the soil pH measurements outcome along the eastern transect that were contradicted by the results of the mist and dust pH measurements, a more intensive survey over a greater distance (at least further than 1.2 km from the Mineral Separation Plant), be conducted to quantify vegetation damage and acid deposition to the east of the emission source.

UITTREKSEL

'n Voorlopige studie is naby die Namakwa Sands Mineraalskeidingsaanleg onderneem om die invloed van suur gas-vrylatings vanaf die aanleg op die aanliggende Sukkulente Karoo plantegroei te ondersoek. Swaelsuurdampe, 'n belangrike gas-vrylating vanaf die mineraalskeidingsproses wat potensieel 'n ernstige negatiewe invloed op plantegroei in die ekosisteem he, was die spesifieke onderwerp van die huidige studie.

Permanente proefpersele is in drie transekte vanaf die mineraalskeidingsaanleg uitwaarts, in die oostelike, suid-oostelike en suidelike rigtings uitgelê. Hierdie rigtings is gekies na aanleiding van die heersende windrigtings, asook praktiese oorwegings rondom die toeganklikheid van die area.

Die volgende ekologiese komponente is as indikatore van moontlike besoedelingsvlakke in die omgewing geasseseer: persentasie plantsterftes, die swaelinhoud van die blare van sekere plantsoorte, die chemiese samestelling van opgeloste stowwe in mis- en stofmonsters en die pH van die grond. Daarbenewens is die plantegroei ook deursoek vir plantsoorte wat as potensiële bio-indikators gebruik kan word.

Plantsoorte met 'n relatief wye verspreiding in die studiegebied en wat skynbaar sensitief teenoor die teenwoordige lugbesoedeling vertoon het, is as potensiële bio-indikators gekies. Die persentasie dooie plante van elke spesie wat op die proefpersele voorgekom het, is as kriterium van moontlike sensitiwiteit van die plantsoort teenoor lugbesoedeling gebruik. Die plantsoorte wat hiervolgens as bio-indikators geselekteer is om vir potensiële moniteringsdoeleindes gebruik te word, was: *Galenia fruticosa*, *Lampranthus suavissimus*, *Lycium ferocissimum* and a *Rushia* sp. (SP 9). Meer plantsterftes het op die persele nader aan die vrylatingsbron voorgekom, nl. 28 ± 5 % dooie plante op 400 m, 19 ± 6 % op 800 m, en slegs 10 + 4 % op 1,200 m vanaf die mineraalskeidingsaanleg (data van alle plantsoorte is bymekaargetel en die van al drie transekte per monsterings-afstand is saamgegroepeer).

Met die metodes wat in hierdie studie gebruik is, kon geen statisties betekenisvolle verskil tussen die gemiddelde pH-waarde van grondmonsters wat op al die persele en transekte, op oop terrein sonder plantbedekking (8.01 ± 0.46) en dié wat onder struike versamel is (8.91 ± 0.96), aangedui word nie. Vervolgens is slegs die pH-waardes van grondmonsters wat op oop terrein versamel is, in ag geneem vir 'n ondersoek van die variasie in grondsuurheid met afstand en rigting vanaf die vrystellingsbron.

Die pH van grondmonsters geneem vanaf die proefpersele op die transekte suid en suid-oos vanaf die mineraalskeidingsaanleg het met afstand vanaf die aanleg toegeneem. Ten ooste van die vrylatingsbron het die grond pH waardes op alle monsteringsafstande relatief laag gebly. Hierdie voorlopige studie kon nie vasstel of die volgehoue relatiewe suurheid van die grond wat langs die oostelike transek in die rigting van die heersende wind gemeet was, deur moontlike verhoogde neerslag van gasvrylatings op die hoër liggende heuwels veroorsaak was en of dit moontlik 'n gevolg van die onderliggende geologie van die area is nie.

Ioonchromatografiese analise van mis- en stofmonsters wat vanaf elke perseel versamel is, het die teenwoordigheid van verskeie chemikalië aangedui wat vermoedelik vanaf die mineraalskeidingsaanleg, sowel as windgedrewe stowwe van die omliggende omgewing, afkomstig kon wees. Van hierdie chemikalië is slegs die sulfaat konsentrasies van die mis- en stofmonsters verder ge-evalueer, aangesien dit waarskynlik met die vrylating van swaelsuurdampe vanaf die mineraalskeidingsaanleg verbind kon word. Die gemiddelde sulfaatkonsentrasies van monsters vanaf proefpersele relatief na aan die mineraalskeidingsaanleg (400 m), was hoër (118.8 ± 31.6 mg/l) as verder weg,waar dit afgeneem het na 57.0 ± 30.1mg/l by 800 m en 43.1 ± 19.6mg/l by 1,200 m vanaf die aanleg. Hierdie waardes (data van die drie transekte saamgevoeg), kan met 85 % sekerheid as betekenisvol verskillend beskou word.

Data van die bepalings van die suurgehalte van die mis- en stofmonsters wat vir die drie transekte per afstand van die proefpersele vanaf die mineraalskeidingsaanleg saamgevoeg is, het aangetoon dat daar 'n geleidelike toename in die gemiddelde pH waardes van 7.3 ± 0.26 (400 m), tot 7.7 ± 0.34 (800 m) en 8.1 ± 0.83 by 1,200 m was, alhoewel hierdie toenames nie betekenisvol was nie.

'n Ooreenstemmende afnemende neiging as wat vir die sulfaatkonsentrasies in mis- en stofmonsters met afstand vanaf die aangleg waargeneem is, is vir die swaelvlakke in die blare van geselekteerde spesies waargeneem. Die gemiddelde swaelinhoud van blaarmonsters geneem 400 m vanaf die aanleg was hoër (0.290 ± 0.091 %) as die geneem op 800 m (0.264 ± 0.086 %), met 'n verdere afname in die geneem op 1,200 m (0.232 ± 0.079), data van die drie transekte saamgevoeg. Hierdie waardes was egter ook nie betekenisvol verskillend nie.

Alhoewel nie betekenisvol nie, dui die dalende neiging van die sulfaatkonsentrasies in mis- en stofmonsters, die swaelinhoud van blaarmonsters, en die persentasie plantsterftes, asook die toename in grond pH met afstand vanaf die minderaalskeidingsaanleg, aan dat die suur gasvrylatings deur die aanleg moontlik 'n skadelike invloed op die aanliggende sukkulente Karoo plantegroei kan hê. 'n Meer intensiewe studie is nodig om hierdie neigings te bevestig. Verder word aanbeveel dat, ten einde die weersprekende resultate van die grond pH metings en die pH metings van mis- en stofmonsters ten opsigte van die oostelike transek uit te klaar, 'n meer omvattende opname oor 'n groter afstand (minstens verder as 1 km vanaf die aanleg) uitgevoer word om skade aan die plantegroei sowel as suur neerslag ten ooste van die vrylatingsbron te kwantifiseer.

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1. INTRODUCTION AND BACKGROUND TO STUDY AREA

1.1 Introduction

Atmospheric emissions from industries do not only affect the balance of gases in the atmosphere, they also cause environmental pollution on the earth's surface. These result in deleterious effects that can endanger human health, harm living resources, or upset the amenities or other legitimate use of the environment (Reeves 1996). Fifield and Haines (2000) contend that air pollutants can be divided into two categories. The first consists of pollutants that can change their chemical composition on reaction with radiation or other atmospheric elements to form a secondary pollutant. According to Dässler and Börtitz (1988) secondary pollutants are formed in the atmosphere by the mutual reaction with vapour, under the influence of sunlight, or by oxidation and condensation. The second category consists of stable primary pollutants that remain unchanged in the atmosphere and are consequently comparatively easily traced to their source. The primary pollutants normally arise from industrial, commercial, domestic transport, agricultural activities and are in the form of dust, smoke, fumes and droplets (aerosols). Radiative heat loss can affect the temperature and concentration of the pollutants to change their chemical composition (Zhu and Gore 2005)

Air movement determines the transportation of the emissions in the atmosphere. The effect of the pollutants in the emissions depends on their persistence and lifespan and can either be local or global (Torvela 1994). Some of the chemical elements occur naturally in the environment. However, in polluted areas their concentrations tend to rise to lethal levels, gradually killing organisms. Hence, the decline in diversity and species richness is usually the first indication of pollution effects in an environment (Begon *et al.*1996).

The mining of heavy minerals in the Succulent Karoo by Anglo American Corporation's Namakwa Sands Mine, is an important undertaking for the economic development of South Africa. In South Africa strip-mining is expanding in the arid winter rainfall areas of the country and although this is economically important and a provider of employment and training for local people, it has a detrimental effect on vulnerable biological diverse environments where vegetation growth is restricted by aridity, wind and nutrient-poor soils (Milton 2001). With this kind of venture we must not forget that South Africa is committed to sustainable development, so that the development process should not be done at the expense of the environment and of future generations. This is in accordance with the National Environmental Management Act (NEMA, Act No 107 of 1998), which stipulates that development must be sustainable. This calls for an urgent action to formulate approaches to combat ecological habitat destruction and promote sustainable development. There is a limit to which any company can be allowed to release emissions into the atmosphere (Manly 1997, Milton 2001). The present study provides recommendations to promote ecosystem conservation. Despite the economic justification for establishing the Mineral Separation Plant, environmental management requirements have to be considered. Economic theories do not inform us about what should be done to alleviate pollution problems (Field and Field 2002). Scientific research provide a framework in which, if sufficiently useful information is obtained, a decision can be reached that is based on an impartial view of the consequences of environmental pollution (Burrows 1979). The results of this pilot study could be used as a basis for monitoring the effects of the gaseous emissions on the vegetation around the Namakwa Sands Mineral Separation Plant.

The Namakwa Sands Mineral Separation Plant emits gaseous substances that could be having negative effects on the adjacent Succulent Karoo vegetation. To alleviate this problem Namakwa Sands Mine management has been making efforts to ensure that the potential effects of the gaseous emissions on the surrounding ecosystems are monitored. "The responsibilities of the mining industry pertaining to environmental management stems mainly from the requirements of the Minerals Act, 1991, that is administered by the Department of Minerals and Energy. Other legislation, such as the Environment Conservation Act of 1989, the Water Act of 1956, and the Atmosphere Pollution Prevention Act of 1965, play an important role in the management philosophy" (Namakwa Sands 2002).

An adaptive approach to ecosystem management is vital. Adaptive management consists of four basic components: monitoring, assessment, decision making and implementation of the programme (Jensen and Bourgeron 2001). Hence, explicitness and clarity of ecosystem management goals and principles need to be recognised. The interaction of ecological, socio-economic, political and institutional perspectives has an effect on biodiversity conservation. Decisions should be based on the clear understanding of the total pollutant movement and effects on the environment (McCormac and Varney 1971). Air pollutants are transported by wind and transformed into other species by radiation. This pilot study will provide information on the characteristics of the pollutants from the Mineral Separation Plant and their effects on the surrounding vegetation.

The present pilot study is directed towards providing baseline information on a) plant species composition b) present condition of plant communities and c) whether present/past emissions can be readily quantified. The study was carried out along 3 transects, within 1,200 m radius from the Namakwa Sands Mineral Separation Plant. The identification of potential indigenous bioindicator plant species for monitoring the effects of any contamination on a long-term basis will assist in avoiding the exceeding of critical pollution levels. This pilot study endeavours to put into context the interactions between various ecological components which include: soil pH, wind direction, mist and dust sulphate concentration, topography and possible effects of the gaseous emissions on the vegetation (Figure 1.1). It should be remembered that the investigation of atmospheric air pollutants is complex and multidisciplinary by nature (McCormac and Varney 1971). Meffe and Carroll (1997) emphasised that biodiversity conservation is not just species diversity conservation, but that it must address multiple levels of organisation at various spatial and temporal scales. The pilot study provides ecological approach to evaluating the effects of emissions from the Mineral Separation Plant on the surrounding vegetation. Ecophysiological reactions of plants in response to environmental stimulus provide the fundamental basis for the use of the indicator properties found within the ecosystems (Zonneveld 1982). In the present study area, there is a dumping ground for the mineral processing by-products in the eastern direction, about 500 m from the Mineral Separation Plant. These are in the form of loose dust that is constantly blown into the surroundings and has the potential of affecting the soil pH investigations due to their iron content.

During the present study an attempt was made to identify potential plant bioindicator species. This approach is required, because Namakwa Sands Management is concerned about both the functional aspects of the ecosystem as well as the potential effects of the present levels of gaseous emissions on the ecosystem. Apart from the presence of the toxic pollutants, it is essential to consider the abiotic environmental factors such as precipitation and topography and the biotic factors such as plant mortality, crown density and herbivory, in each particular ecological assessment scenario. Biotic/abiotic factors have potential biological effects and could influence bioindication (Schebert 1982).

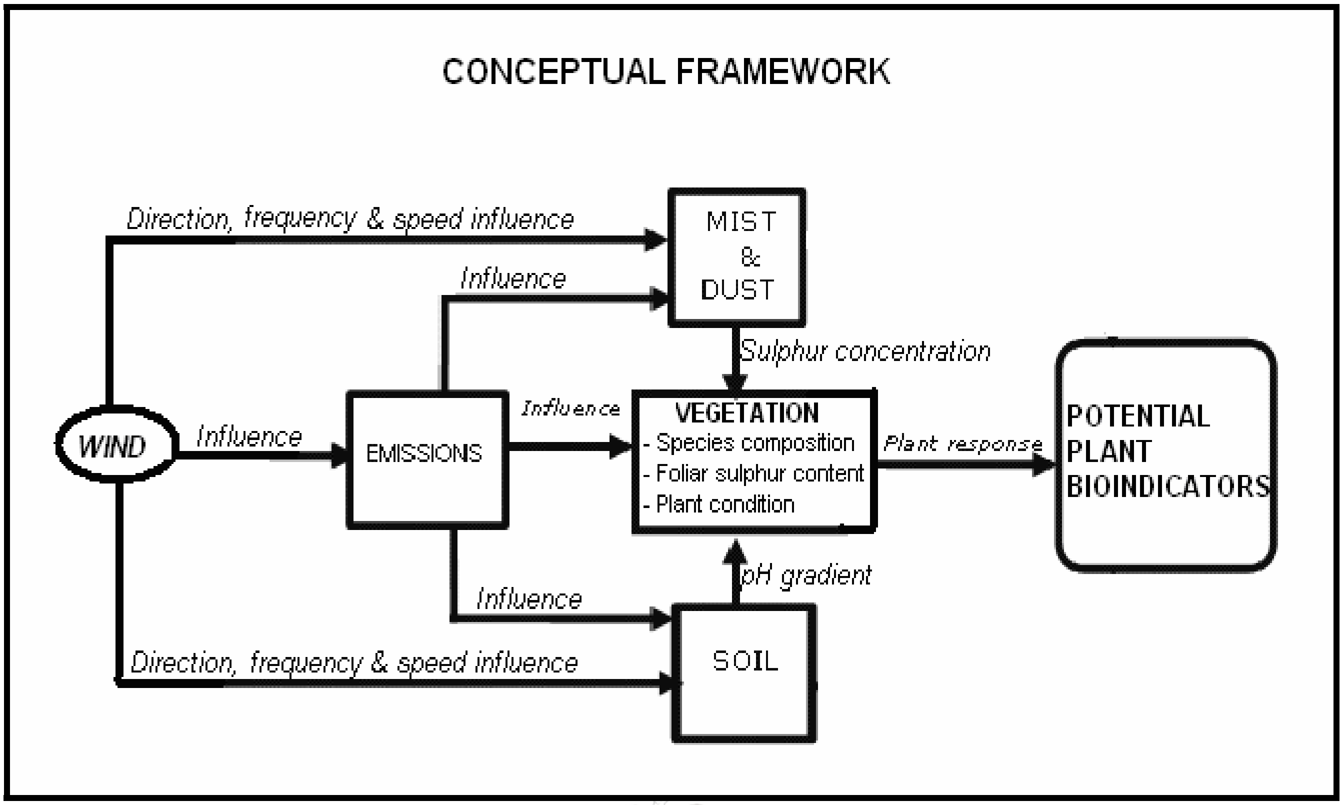

Figure 1.1: **Flow chart of the important ecological components evaluated to aid in the identification of potential plant bioindicator species during a pilot study at the Namakwa Sands Mine Mineral Separation Plant and to determine the effects of the gaseous emissions on vegetation.**

Potential acid fume pollution is present in the area and this requires assessing. The Namakwa Sands Mineral Separation Plant, through the processing of the various heavy minerals, emits acidic fumes into the atmosphere. The wind rose data suggests that the emissions are blown eastwards, from the Mineral Separation Plant by the prevailing westerly winds. Experimental sites immediately to the east of the Mineral Separation Plant were selected for this pilot study. The control sample plots could not be established in the western direction of the Mineral Separation Plant, because the area is reserved for depositing radio active materials that result from processing the minerals.

1.2 Location and topography of study area

The study area is in Succulent Karoo vegetation adjacent to the Namakwa Sands Mine Mineral Separation Plant, a heavy mineral processing plant located relatively close to the north western coast of the Western Cape Province, South Africa (Figure 1.2). The Mineral Separation Plant is 60 km south-east of the open strip mining area, about 10 km south of Koekenaap a small village to the north-west of Lützville, and about 300 km north of Cape Town (De Villiers *et al.* 1999). The study area covers approximately 1.12 km^2 to the immediate east and south of the Mineral Separation Plant. The Mineral Separation Plant is situated within the Jaagleegte River valley, which, according to Desmet and Helme (2003) forms the boundary between two distinct types of the south Namaqualand vegetation, namely Sandveld and Knersvlakte. The topography is undulating punctuated with a number of hills. According to Cowling and Hilton-Taylor (1999) the geographical gradients around the Mineral Separation Plant are considered a unique feature of this environment.

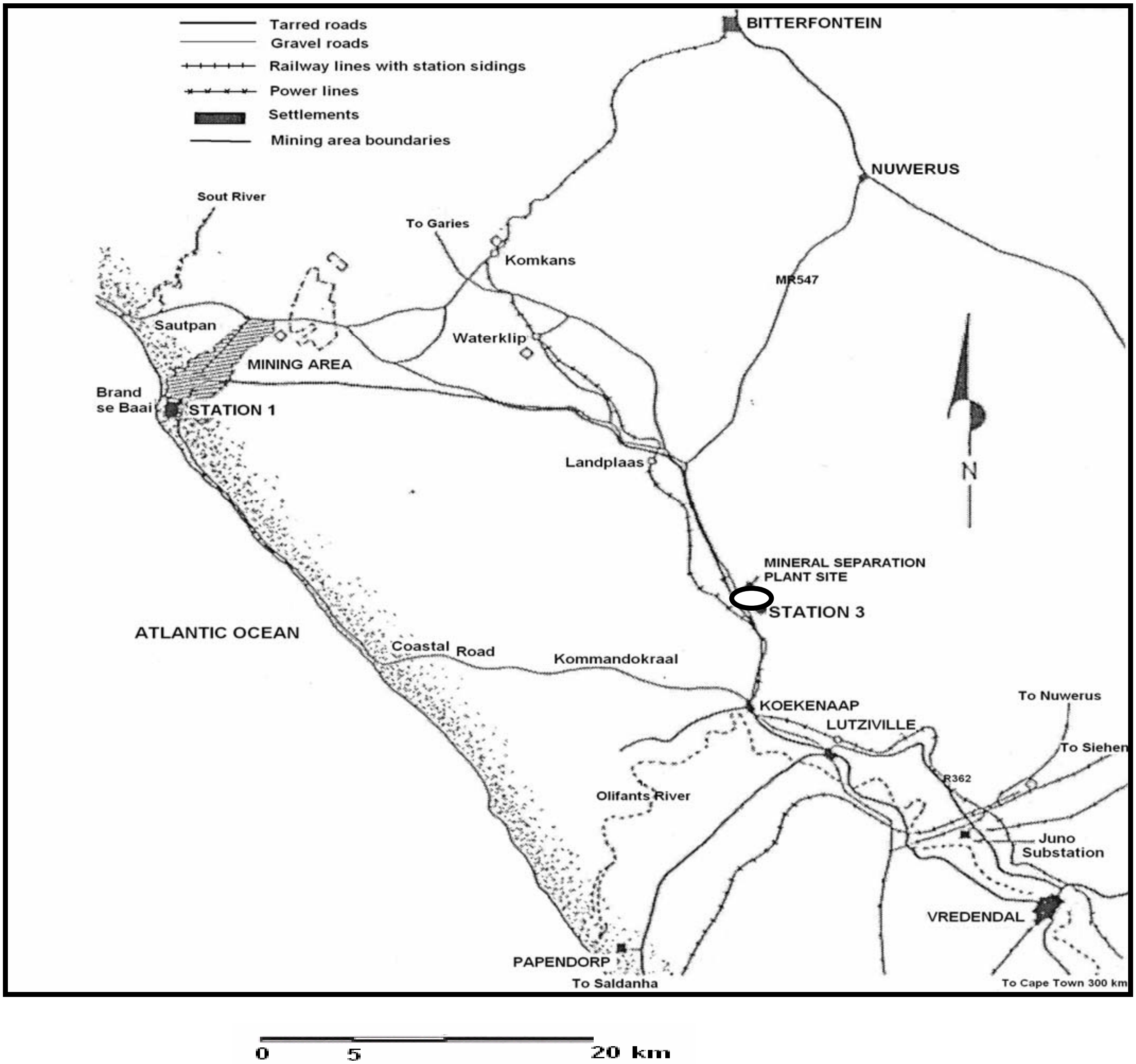

Figure 1.2: **Location of the Namakwa Sands Mineral Separation Plant near Lützville, Western Cape Province, South Africa. Stations 1 and 3 are the local weather stations for Namakwa Sands Mine. Weather station 2 is situated in the Cape Peninsula (Struthers and Watt 2001)**

1.3 Geology of the study area

The western Cape coast has predominantly granitic catchment soils, with pan water evaporation that leads to precipitation of calcite, dolomite, gypsum and halite a markedly stratigraphic progression in pan sediments (Smith and Compton 2004). Around the Mineral Separation Plant there are quartz patches that are acidic in higher elevations and saline at the bottom of slopes (Desmet and Helm 2003).

1.4 Sources of pollution in the study area

Industrial emission sources utilise various inputs and apply different types of technologies in production and consumption. During the industrial operation process residuals are produced, whose handling has a critical effect on ecosystems (Field and Field 2002). The Mineral Separation Plant uses sulphuric acid (H_2SO_4) to allow effective electrostatic separation of the mineral particles. This involves hot acid leach treatment of zircon and rutile ore to strip off the magnetic iron coating. Apart from the production of minerals, this treatment supposedly result in the emission of acid fumes of sulphate ($SO_4^{=}$), fluoride (F^-), chloride (Cl^-), nitrate (NO_3^-), phosphate ($PO_4^{=}$) and bromine (Br^-), are released into the atmosphere via two smoke stacks, as was evident from the mist and dust samples chemical analysis. These emissions are likely to affect the biodiversity downwind, as plant wilting had been observed in patches around the Mineral Separation Plant (Hälbich 2004, pers. Comm.). This served as the rationale for Namakwa Sands management to facilitate research into the local effect of the acidic gaseous emissions on the adjacent vegetation.

Hälbich T- Environmental Management Manager, Namakwa Sands Mine (Pty) Ltd, Saldanha.

The present study was launched to provide preliminary information on the effect of the sulphuric acid fumes (H_2SO_4) on the vegetation around the Mineral Separation Plant. These fumes are emitted from the hot acid leach treatment. The present investigation is based on the apparent acid output produced by two of four smoke stacks at the plant. Our investigation uses the finding that two of the four stacks, which are about 80 m apart and 100 m height, yield different amounts of H_2SO_4 emissions. Stack A (North) yields 3 $\mu g/m^3/s$ and stack B (South near the railway line) yields 4.2 $\mu g/m^3/s$ according to a survey conducted in 2003 (Hälbich 2004 pers. Comm.). The smoke stacks have been constructed with a height well above the other structures to facilitate the release of the gaseous emissions into the atmosphere, to reduce the effect of the pollutants in the immediate surrounding.

1.4.1 Mineral processing procedures

Anglo American Corporation under the subsidiary name of Namakwa Sands owns approximately 14,992 hectares of land, within the Western Cape Province. Currently the mining operations relevant to this study are taking place in an area of approximately 4,700 hectares. Open cast mining is used to remove mineral-rich sands from which the heavy minerals ilmenite, rutile and zircon are extracted. The operational area is divided into two separate sectors, Graauwduinen east with approximately 3,370 hectares and Graauwduinen west with approximately 1,400 hectares (EEU 1990).

The Primary Concentration Plant (PCP) is the West Section of this mine. In this section the total heavy mineral, of typically 15% content percent of volume is concentrated by a gravity separation method to 90% total heavy mineral concentrate. This product is then sent to the Secondary Concentration Plant (SCP), situated at a distance of about 60 km. The SCP was commissioned in 1994, principally to mineralise the magnetic (ilmenite) from the non-magnetic (zircon, rutile and leucoxene) products (Namakwa Sands 2002).

Hälbich T- Environmental Management Manager, Namakwa Sands Mine (Pty) Ltd, Saldanha.

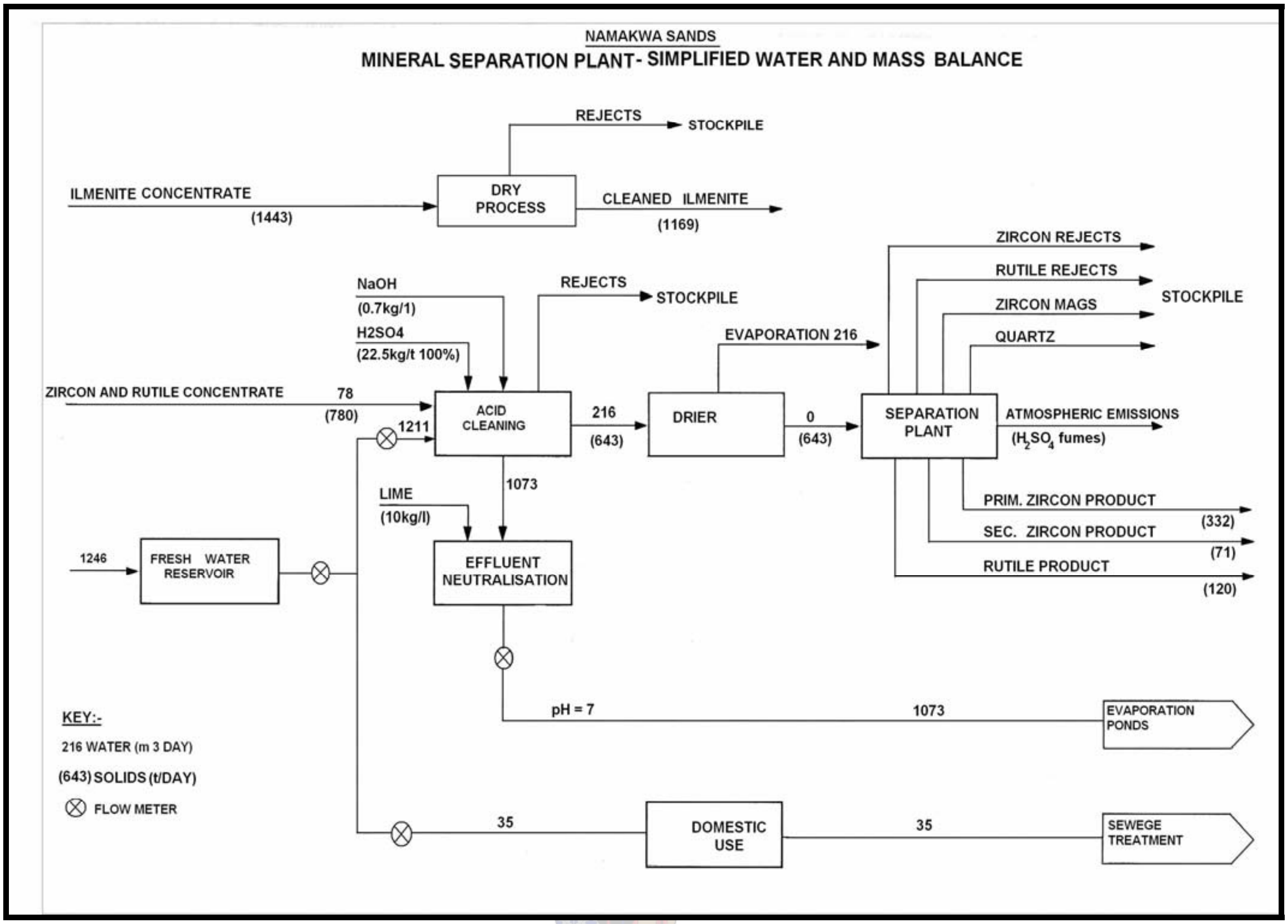

Figure 1.3: **Flow chart to illustrate the material flow from inputs to the outputs in the Mineral Separation Plant. (source: Hälbich 2004 pers. Comm.).**

The magnetic and non-magnetic minerals are then sent to the Mineral Separation Plant (Figure 1.3). One of the activities conducted at the Mineral Separation Plant is to process the magnetic stream to produce an ilmenite stream, while the non-magnetic stream is processed into rutile and zircon for the export market. The ilmenite is transported to the smelter and titanium dioxide slag is produced, leaving sulphate and iron slag as by-products (Namakwa Sands 2002). The purification of rutile and zircon by stripping off the iron coating requires the application of a hot acid leaching treatment (sulphuric acid leach, 40% H_2SO_4, 23 gram H_2SO_4/liter, at reactor temperature of 150^o C input and 85^oC output). It is from this process that the acid fumes are emitted to the atmosphere (Hälbich 2004 pers. Comm.). In metal industries, such as that conducted by Namakwa Sands Mine (Pty) Ltd, the most important emissions of environmental concern are of sulphur dioxide (SO_2) and particulates (Jacobson 2002).

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During the production process of some non-ferrous metals, the oxidation of sulphide concentrates raises the concentration of SO_2 in the emissions (Torvela 1994). The procedure of handling residuals has a critical impact on subsequent stages, as some residues can be recycled, while others can be treated to render them benign on emission (Field and Field 2002). Apart from the release of sulphur dioxide from the Mineral Separation Plant, in the gaseous emissions, there are additional chemical compounds released from other operations that take place at the Mineral Separation Plant (Appendix 1). These chemical compounds includes; F^-, Cl^-, NO_3^-, $PO_4^=$ and Br^- found in the mist and dust captured from the study area.

1.5 Meteorological conditions of the study area

With air pollutants there is no uniform distribution path. The mixture of gases is affected by constant dynamic changes with vast quantities being added or removed from the atmosphere by various natural and industrial processes (Lyons and Scott 1990). According to McCormac and Varney (1971) it is necessary to consider meteorological as well as topographical factors when assessing air pollution. The meteorological and topographical factors have an influence on the dynamics of the gaseous emissions in the atmosphere. Air pollution meteorology focuses on the destiny of these pollutants once emitted into the atmosphere (Lyons and Scott 1990). Once the gases are released into the atmosphere they undergo transportation, dispersion, transformation and deposition. Samson (1994) indicated that, the capacity of the atmosphere to absorb gaseous emissions from a point source depends on the mechanisms of pollution transportation, dilution and dispersion.

The average wind transports the pollutants away from the source, whereas dispersion results from the turbulent characteristic of the atmosphere to diffuse the pollutants in various directions (Lyons and Scott 1990). Disturbances of the energy balance of the atmosphere are caused by the rapid heating of the earth's surface in comparison to the water body (Samson 1994). The heated air rises giving a localised low pressure system over the landmass. This leads to the flow of air from a high pressure cell over the water body, resulting in a sea breeze. In the study area the sea breeze flows over the supposed pollution source at the Mineral Separation Plant transporting the pollutants and depositing them downwind in an eastern direction.

1.5.1 Wind pattern

The wind pressure gradients are the driving force for air movements. However, the wind pattern is influenced by many factors on the earth surface, causing it to differ from original predictions. These factors include topography, seasonal and diurnal variations in surface heating, changes in surface heating as determined by ground cover and proximity of large water bodies (Torvela 1994). Wind is one of the environmental forces that influence plant growth (Begon *et al.* 1996).

Ecologically, the westerly sea breeze (Appendix 2) and the frequent warm dry berg wind play an important role in the arid coastal system (Desmet 1996) of which the present study area forms a part. Determination of the actual wind movement has been crucial to the setting of the transects and permanent sample plots in the study area. Wind direction, frequency, velocity and mist content have a direct influence on the effect of the acidic gaseous emissions from the Mineral Separation Plant fume stacks on the surrounding vegetation.

The weather data used to summarise the wind factors (Figure 1.4) were obtained from the Namaqualand Sands Mining, weather station 3, located at S 31°28.14', E18°08.02' at 58 m above sea level (Struthers and Watt 2001). The recording of weather information at this station dates back to March 1991

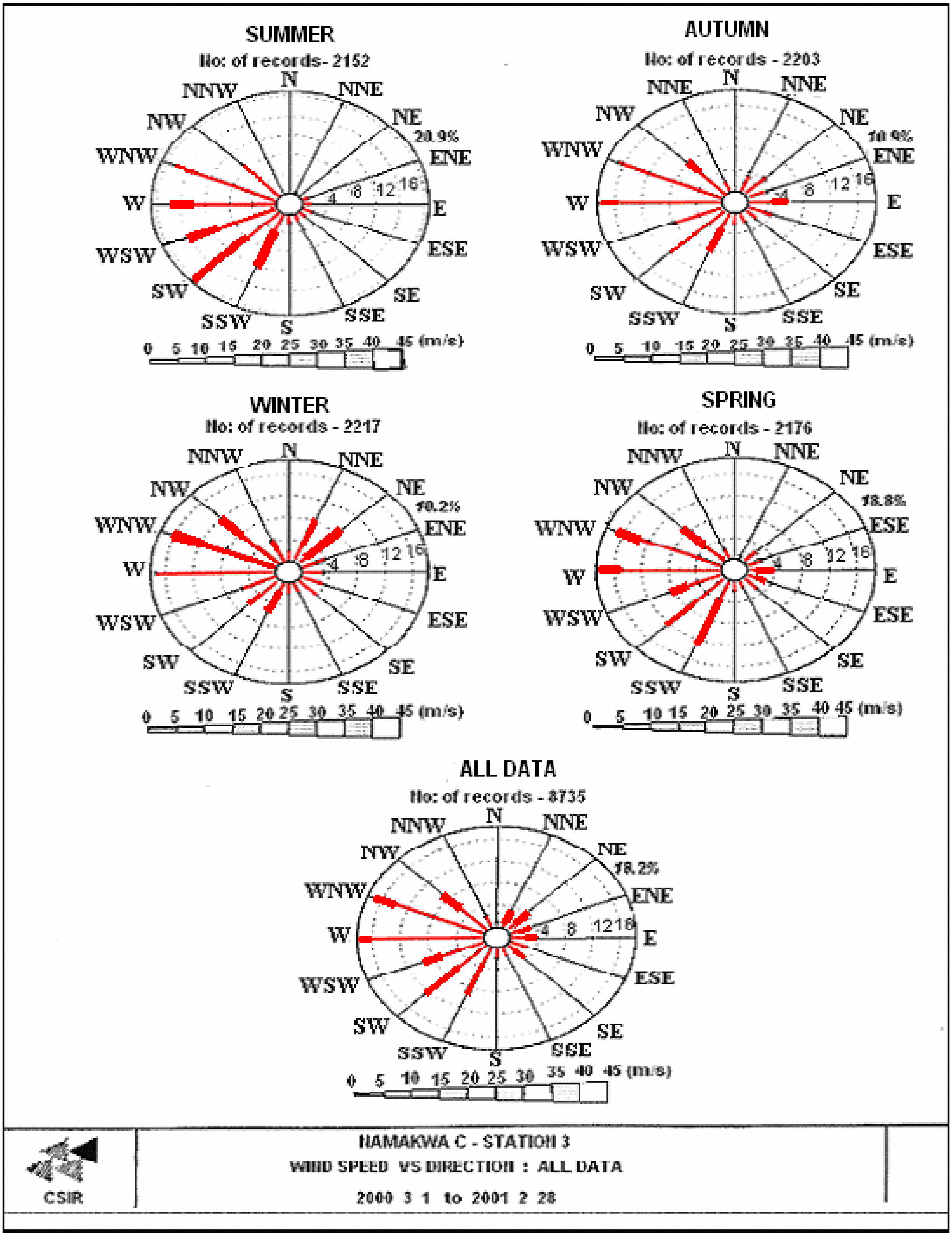


Figure 1.4: **Wind rose for winter, autumn, summer and spring for 2000/2001. The isoclines (concentric circles labelled 4, 8, 12, etc) in the wind rose represent the percentage of observed records at that particular wind speed over the monitoring period. (source: Struthers and Watt 2001)**

Severe ecological pressures in the ecosystem, emanating from wind forces and contents, precipitation levels, soil characteristics and plant competition determine the plant species that can grow in a given area. The Namaqualand coastal area experiences one of the most forceful wind regimes in the world (Mahood 2003). The prevailing wind in the present study area provides stress factors that only well adapted plant species can withstand. These plant species have morphological characteristics with ruderal or stress-tolerant strategies, to survive the harsh conditions (Vadal 1999). Prevailing winds that blow parallel to the coast, have less influence on the ecosystem of the study area, than frequent on-shore westerly (Appendix 2) and off-shore easterly winds (Evenari *et al.* 1985). The critical winds for pollution are the stronger winds particularly those that occur during dry episodes, such as the north-easterly pre-frontal berg winds (generally north-east changing to north-west) and the strong summer winds (generally east and south winds) (Boucher 1988). There is an increase in pollution concentration in areas of stable wind regimes as compared to places with strong wind regimes (Raga *et al.* 1999). The strong winds provide a dilution effect on the pollutants, reducing the negative impact on the ecosystems.

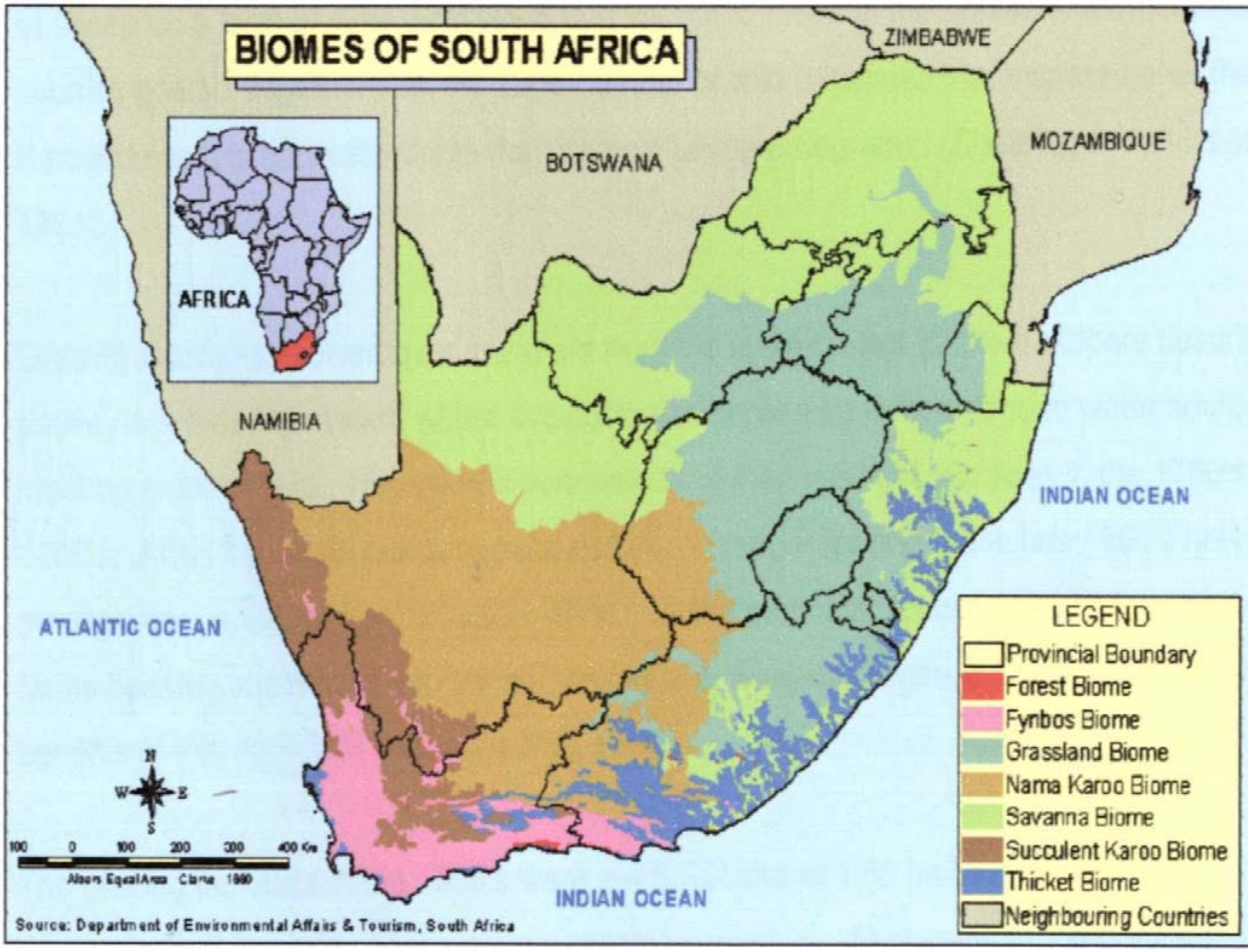
Wind is an important agent in the transportation of potential pollutants from the Mineral Separation Plant into the surrounding environment. The rapid mixing and dispersal of pollutants are facilitated by the atmospheric turbulence (Boeker and Van Grondelle 1995). At the present study area, it is anticipated that the gaseous emissions will be deposited to the immediate east of the Mineral Separation Plant, because the frequent on-shore westerly winds have an influence in that direction. (Figure 1.4). The diurnal fog which rolls in the study area from the west has the potential effect of transporting mist and dust with high pollutant concentrations.

1.5.2 Temperature and rainfall

The Succulent Karoo lies in a transition zone between the Namib Desert to the north and the Cape Mediterranean-type climate to the south and receives an average of 160 mm of rainfall per year, which increases from north to south (Mahood 2003). According to De Villiers *et al.* (1999) rainfall, sea fog and dew amounts to a cumulative average annual precipitation of 282 mm per annum in the region, measured over a four-year period in the region.

1.6 Vegetation of the study area

The Succulent Karoo Biome (Figure 1.5), is so-named due to the large variety of unique succulent plant species that dominate the area. Plants that conspicuously store water in there organs are commonly referred to as succulents (Von Willert *et al.* 1990). The main morphological feature of a true succulent is its storage organs (leaves, stems or roots), which allow the plant to survive dry periods, when ground water is no longer available to the roots (Van Jaarsveld *et al.* 2002). The Karoo flora contains an astounding variety of growth forms, and the plants thereof range widely in size, shape, type and degree of succulence, leaf consistency and persistence, thorniness, woodiness and below ground structure (Midgley and Van der Heyden 1999). As we analyse the effects of the gaseous emissions on the Karoo flora, the national, regional, and international importance of this vegetation must be considered.



Source: Department of Environmental Affairs & Tourism, South Africa

***Figure 1.5*: The Succulent Karoo Biome in relation to other biomes of South Africa. (Source: Department of Environmental Affairs and Tourism)**

The study area falls within the Succulent Karoo Biome. The biome has International recognition, due to the diversity of plant life in the ecosystem. Despite the small size of the biome (351,100 km^2), the Succulent Karoo contains more than 30% of the World's succulent species. This feature makes the area a unique biome of global importance (Esler *et al.* 2002). There are 4,949 plant species, of which 1,940 are endemic to the Succulent Karoo (Cowling and Hilton 1999). Biodiversity hotspots have been considered at global level as geographic regions of conservation priority based on the criterion that these regions consist of exceptional numbers of endemic species packed within relatively small areas that face significant threats of habitat loss (Myers *et al.* 2000).

The pilot study area falls within the Namaqualand Strandveld (Figure 1.6) that has been classified as Inland Tall Strandveld (Boucher and Le Roux 1989). The strandveld vegetation as a whole occupies an area of 3,817 km^2, within the sandy western coastal plains that are dominated by scattered leaf succulent and drought-deciduous shrubs (Low and Rebelo 1996). The vegetation of the area is highly influenced by the interaction between the climatic and edaphic factors (Evenari *et al.* 1985). The present study area was used mainly for grazing purposes, before the establishment of the Mineral Separation Plant (Marx 2004 pers. Comm.). The arid winter rainfall climate of the Succulent Karoo, explains the prevalence of succulent plants and geophytes in the western part of the Biome (Desmet 1996). The winter rainfall of the Succulent Karoo is reliable and favours leaf succulents (Desmet and Cowling 1999). However, the occurrence of the extensive droughts in recent times also contributes to the stress factors that characterise the plant species distribution in the area. Clumped vegetation patterns are a dominant feature in the arid ecosystems (Eccles *et al*. 2001).

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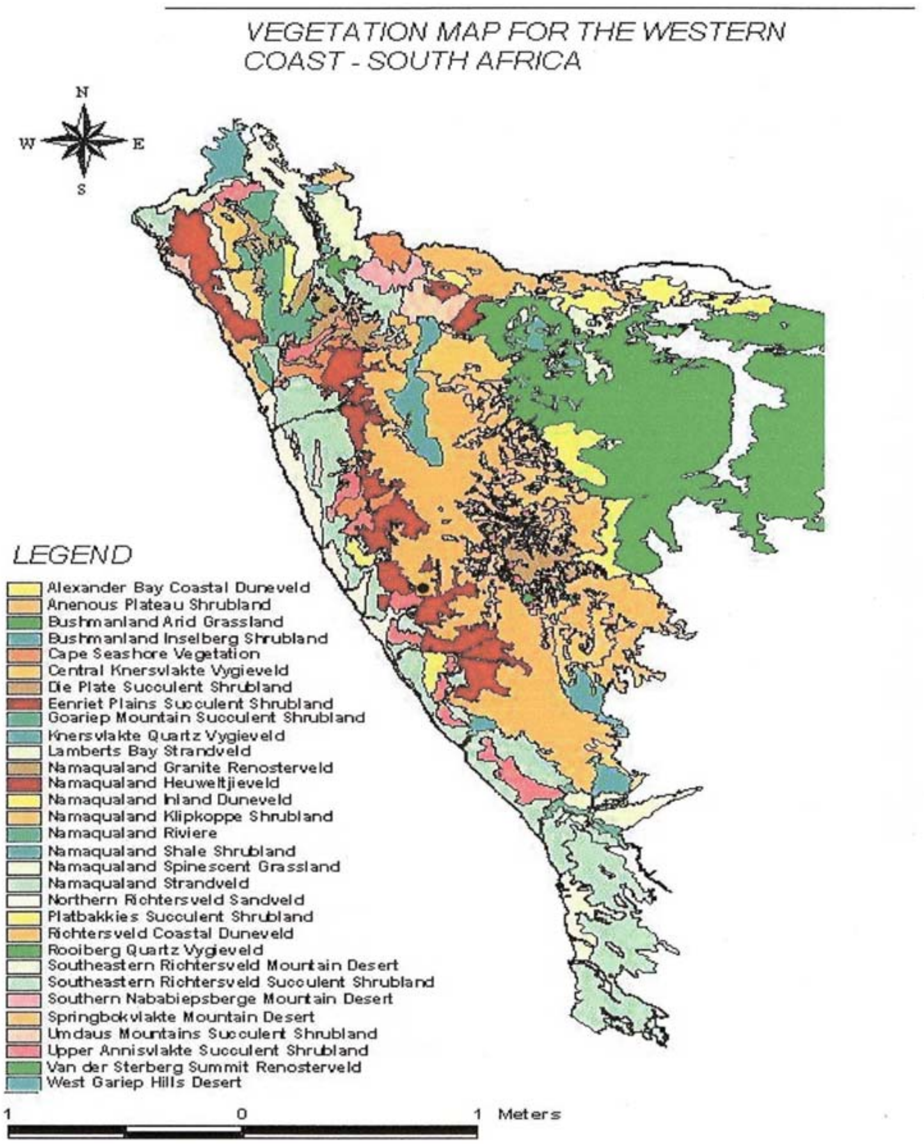

Figure 1.6: **Vegetation map of the South African west coast illustrating the various vegetation types that fall within the Succulent Karoo Biome. The Namaqualand Strandveld vegetation is in light-blue adjacent to the coast and the Namakwa Sands Mineral Separation Plant falls within that locality (Mucina *et al.* 2005 in press).**

1.7 Research objectives

The pilot study was conducted for the Namakwa Sands Mine (Pty) Ltd, at their Mineral Separation Plant, with the following objectives:

1) A preliminary investigation of the surrounding vegetation to quantify the extent of potential effects of gaseous emissions from the Namakwa Sands Mineral Separation Plant.

2) Collect baseline information about the present abundance and species composition of plant communities as well as the condition of the vegetation around the Mineral Separation Plant.

3) Carry out an assessment to establish baseline details about the soil pH, plant foliar sulphur content, as well as the sulphate concentrations in mist and dust samples in a selected area east and south of the Mineral Separation Plant.

4) Identify potential bioindicator plant species that can be used to detect or monitor changes in the areas around the Mineral Separation Plant that may potentially be affected by emissions, from the Mineral Separation Plant.

5) To make recommendations that will provide Namakwa Sands Mine management with guidelines for further studies as well as possible measures for amelioration if the ecosystem is found to be negatively affected by the emissions.

The pilot study will endeavour to provide preliminary information to be used in monitoring the effects of the gaseous emissions from the Mineral Separation Plant, on the adjacent Succulent Karoo vegetation. The results from the analysis of the soil pH, plant foliar sulphur content, mist and dust sulphate concentration and the selection of potential bioindicator plant species will assist in setting goals for biodiversity conservation in the ecosystem around the Mineral Separation Plant. This is an open arid ecoregion punctuated by a rugged topography (Dean and Milton 1999). Such ecological conditions can lead to unexpected influences on plant responses to environmental stimuli. Small topographic changes in the ecosystem can lead to large differences in plant community productivity (Begon *et al.* 1996). Quadrats could yield varying mean densities either in original or in the transformed data. What is important is the significance of the differences in the parameters being measured (Goldsmith 1991). Data that are offered in support of explanations that are free of theories are unreliable, no matter how much data happens to support them. In the absence of a theory, one could be unaware of the variables that need to be measured (Rosenzweig 1995).

We assumed that the distance from the emission source was the independent variable on which plant abundance, soil pH, electrical conductivity and $SO_4^{=}$ concentrations depended. I tested the hypothesis that damage to plants decreases with an increase in distance from the smoke stacks. In order to infer that damage was caused by the gaseous emission pollutants, trends in pollutant concentrations were compared with trends in plant damage. Analysis of the correlation of pollutant concentrations with plant damage variables were used to draw conclusions about the effects of pollutants in the ecosystem.

CHAPTER 2

LITERATURE REVIEW OF ACIDIC GASEOUS EMISSIONS AND THEIR EFFECTS ON VEGETATION

2.1 Acidic gaseous emissions and their effects on vegetation

The major gaseous emission by Mineral Separation Plant is sulphuric acid fumes, estimated to be 7.2 $\mu g/m^3$ per second. The sulphuric acid fumes are having a negative effect on the surrounding vegetation. Evaluation of pollutants involves studying their source and the mechanism of their formation (Varney and McCormac 1971). The combustion of fossil fuels results in the emission of gaseous products, which are mainly nitrogen oxide (NO_X), carbon dioxide (CO_2) and water vapour (H_2O). The effects, if any, of these gaseous products are not considered to be harmful in terms of the present study. Other gaseous components that are produced during the combustion or oxidation of fuels are sulphur dioxide (SO_2) and oxides of nitrogen. These products emanate from the oxidation of sulphur and nitrogen that are contained in the fuels (Torvela 1994). Apparently, due to the oxidation of sulphur and nitrogen containing fuels, the gases that are produced can dissolve in water vapour present in the atmosphere to form acid rain (Brady 1990). Records of plants dying from acid rain are numerous throughout the world, especially in mountainous places where there are acid rocks and no soil buffering capacity to neutralise the acids (Ennos and Bailey 1995).

Chemical pollutants cause disturbance to the ecosystem in many ways, including deposition of acid particulate matter and acid rain (Pullin 2002). At the study area the mist blown by the westerly winds dissolves the sulphur oxides from the emissions, resulting in deposition of sulphuric acid in the ecosystem. Most sulphur oxide emissions that escape into the atmosphere from the high stacks at the Mineral Separation Plant are intended to drop about 1 km away from the source. The droplets could be in the form of acid rain, depending on the vapour content in the atmosphere. Acid rain is a broad term that is used to describe several ways by which acids fall from the atmosphere (Brady 1990). A more precise term is acid deposition, which has both a wet and a dry aspect. Wet deposition refers to rain, fog, mist and snow. As this acidic water flows over and through the ground it affects a variety of plants and animals. Dry deposition refers to acidic gases and particles. About half of the acidity in the atmosphere falls back to earth through dry deposition (USEPA 2004).

Air pollutants that come about through anthropogenic influences such as industrial emissions, have variations in their rate of deposition, depending on the activities at the source and meteorological factors (Varney and McCormac 1971). Atmospheric emissions from industrial activities are an important factor in air pollution, especially downwind of the source (Pumure *et al.* 2002) (Figure 2.1). A little shift in the wind direction for 5 degrees, is sufficient to cause the concentrations at the receptor area to increase from 10%, during turbulent wind conditions, to 50% and even 90% increase during moderate to constant wind conditions respectively (Boubel *et al.* 1996). Lyons and Scott (1990) indicated that the dynamics of atmospheric turbulence can constantly change the pollutant concentrations and duration of action on a single receptor.

Figure 2.1: **The release of acid emissions into the atmosphere from the stacks at the Mineral Separation Plant. The gaseous emissions are driven inland or east wards by the prevailing westerly winds.**

2.1.1 Sulphur dioxide as an air pollutant

Sulphur dioxide and its various compounds rank highly among air pollutants that impact on the environment. Sulphur oxides are a major reason for pollution problems in many cities, although it is a non-metallic element found in nature, either free or in combination with other elements, it is almost invariably present as an impurity in coal and fuel oils that are commonly used for combustion processes (Corman 1969). According to Navara *et al.* (2003) the relationship between the concentration of industrial pollutants in the air and the degree of injury to local vegetation is believed to be negatively influenced, by a conglomeration of substances of which sulphur dioxide, in most cases is an easily recognised pollutant. Despite the lower actual concentrations in comparison to other common pollutants, its toxicity to organisms, inconvenience to humans, annoyance (unpleasant smell as rotten eggs) and actual damage is tremendous. Sulphur dioxide dosages in the range of 0.05 to 0.5 ppm, for 8 hours or more can cause injury to plants (Manning and Feder 1980). Sulphur exists on earth in elemental form and as compounds, including part of more complex molecules such as proteins (Varney and McCormac 1971). It is essential to establish the type of pollutants supposedly impacting on the vegetation, because the effect of two or more pollutants impacting on the environment in unison is greater (synergism) or less (antagonism) than the effect predicted from two compounds individually (Otitoloju 2002). For instance the effect of sulphur dioxide combined with dust particles in smog, are far more serious than the effect of the two components separately (Reeves 1996). Studies have shown that sulphur dioxide and nitrogen dioxide reacting in combination are more toxic to plant growth than the sum of their individual predicted effects (Botha 1989, Ashedon 2003). According to Kupcinskiene *et al.* (1997) it is clear that the exposure of plants to a combination of SO_2 and NO_2 has significant adverse effects on plant growth as compared to the exposure to the two pollutants separately.

It is essential to recognize that sulphur goes through various stages both in the atmosphere and in the soil horizon. Sulphur dioxide combines with water in the atmosphere to form an acid (Pullin 2002). At times SO_2 in the atmosphere combines with moisture in the air, or with water present on the surface of a leaf, results in the formation of sulphuric acid (H_2SO_4). The most abundant acid commonly found in the atmosphere is sulphuric acid (Jacobson 2002). Injuries caused to plants by sulphuric acid are normally wide spread in an affected area and almost all plant species in the area are likely to show symptoms ranging from leaf scorch, spotting, defoliation, and even in the death of the entire plant community (Skelly and Lambe 1974, Botha 1989).

The response of plants to sulphur dioxide pollution is quite predictable (Manning and Feder 1980). It is feasible to recognise the injuries that sulphur dioxide causes to plants. Sulphur dioxide has been recorded to have toxic effects on the leaf stomatal functioning. The malfunction of the stomata not only affects the in-flow of the pollutants into the foliar tissues, but also affects evapo-transpiration. This results in disruption of the water relation in the plant (Keller 1982). A visible plant foliar injury symptom to acute sulphur dioxide exposure is severe interveinal chlorosis and necrosis (Krupa and Legge 1999). The plant leaves show interveinal discoloration, specifically white, bleached areas (Botha 1989).

Sulphate ($SO_4^{=}$) is a secondary airborne pollutant, and the conversion rates of SO_2 to sulphate are highly variable from day to day. This is because the sun energy and the wind turbulence play a role in the conversion of sulphur to sulphate. As sulphur dioxide leaves the smoke stack, it is usually diffused rapidly, however oxidation to sulphur trioxide (SO_3) takes place rather slowly. But with time sulphur trioxide can build up substantially, and it reacts quite rapidly with water to form sulphuric acid (Corman 1966). See the equation outlined below:

$$2\,SO_2 + O_2 \rightarrow 2\,SO_3 \xrightarrow{H_2O} H_2SO_4$$

Sulphur dioxide Sulphur trioxide Sulphuric acid

Source: Corman (1966)

2.1.2 Vegetation assessment

Maintenance of biological diversity has recently been recognized in many circles as the single highest conservation priority of our time. Biological diversity is fundamentally our living natural resource base (Meffe and Carroll 1997). Ecological assessment is the process of identifying, quantifying and evaluating the ecosystem processes and functions, so as to provide a scientifically defensible approach to their management and utilization (Treweek 1999). In vegetation and environmental gradient studies, care is required in the selection of the sites to obtain useful information about vegetation condition (Slingsby and Cook 1988). Ecological changes due to elevated contaminants in the ecosystem are investigated by comparing species abundance and plant conditions (Read and Pickering 1999). Such investigations require information about parameters of various ecosystem components, which may include the measurement of physiological characteristics of plants such as densities, soil chemical and physical characteristics and plant stress patterns (Blank and Lutz 1990). Determination of the appropriate level and scale of the parameters to be examined depends on the system being investigated and the assessment objectives (Stephanie *et al.* 2001).

Vegetation assessment focuses on the assemblage of plant species populations occurring together in space and time and their response to environmental perturbations (Begon *et al.* 1990). In the present study, most importantly, the assessment focuses on the gradient of plant species numbers and proportion of the dead plants along the transects as well as plant response to elevated levels of sulphurous compounds emitted into the atmosphere. Different environmental processes operate at varying spatial and temporal scales to influence the numbers and identity of plant species in communities (Morin 1999). The changes in plant community patterns in the ecosystem due to intrinsic dynamics, necessitates plant species identification and assessment of plant numbers, density and distribution. Assessment of interaction of ecological components such as elevation, erosion and slope, helps to know the ecological factors that could affect the outcome of the investigation into pollution effects on vegetation.

2.1.2.1 Selection of potential bioindicator plant species

The process of selecting potential plant bioindicator species for monitoring purposes involves observation of the ecological patterns and responses of plant species and communities to environmental stimuli such as pollution. The area around the Mineral Separation Plant provides a scenario where various plant species have probably had sufficient duration of exposure to the gaseous emissions to have suffered damage. Bioindication is best applied in ecosystems with various plant species that have been subjected to frequent pollution episodes (Manning 2002). The high level of exposure to pollutants provides clear recognition of the sensitive plant species in comparison to the tolerant species. Plant species that are suitable for use as bioindicators should have wide distribution ranges and be sensitive to particular external environmental stimuli (McGeoch 2002).

It is an advantage to apply plant bioindication in monitoring programmes, because it is non-destructive and the plant bioindicator species are always in-situ, making the whole approach efficient and inexpensive. Moreover, the plant bioindicator species react to the whole spectrum of the emission complex and not just to a selective pollutant (Dässler and Börtitz 1988). Noss (1990) indicated that species bioindication is vital, because detection and mensuration of ecosystem change is easy and can be appropriately quantified. Stringent rules for bioindicator selection will compromise their cost effectiveness in answering pressing conservation questions (McGeoch 1998). In the present study ecological bioindication approach will effectively and efficiently be applied in monitoring the effects of the acidic gaseous emissions from the Mineral Separation Plant on the surrounding vegetation.

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Integrated studies are essential to investigate bioindicators and bio-accumulators and not just the consideration of a single plant species in isolation (Knabe 1982). Certain plant species will react in a specific way towards environmental stimuli. For this reason the study of the interactive relations between plants and the environment should begin by characterizing plant responses to variations in the ecosystem and then to determine the implications and significance of the observed or measured reactions (Zonneveld 1982). Therefore, a suite of approaches may be used in combination to determine the trends in pollution effects. Observation of plant species responses to environmental disturbance provides a dependable bioindicator for monitoring pollution. The reliability of plant bioindication in monitoring programmes is due to the repeatability of the measurements of parameters involved in the investigation. While expected effects of pollutants on plant response may facilitate diagnosing the problem, it is essential to obtain background details about the ecology, herbivory, plant nutrition and physiology (Manning and Feder 1980). Such information enables one to select bioindicator plant species that respond to changes due to elevated concentrations of the suspected pollutants in the ecosystem.

2.2 Pollution effects on soil

The physical structure, physiochemical properties and biological activities of the soil are the driving variables controlling the structure and function of the ecosystem that the soil supports (Marrs 2002). The structure and nutrient content of the soil are important for plant growth. Intricate connections between climate, soil and vegetation make it hard to separate cause and effect in respect of plant distribution. The vegetation affects the soil in which it grows; the vegetation is determined by the soil in which it grows. Most plant species have a broad tolerance range for soil types; consequently, soil types are not a major limiting factor to plant distribution (Krebs 1985). Plants species respond to a collection of ecological factors that include competition among themselves, to form communities. Soils influence competitive interaction among plant species (Begon *et al.* 1996). Therefore, changes caused by pollutants to soil chemistry are likely to bring about changes in vegetation composition. Disturbances not only occur at varying intensities and frequencies, but they also affect ecosystem species composition and structure in many ways (Stephanie *et al.* 2001).

Procedures that are used to assess soil quality and determination of key soil properties are complex. A clear understanding of the real biogeochemical effects on vegetation change requires an integrated assessment (Carrasco-Letelier *et al.* 2004). This is due to the numerous physical, chemical and biological processes that regulate biogeochemical processes and their variation in space, time and intensity (Doran and Parkin 1994). The physical and chemical characteristics of any soil is a result of the variation in the underlying rock topography, coupled with the colonisation by the plant communities and input of nutrients via abiotic and biotic transfers in the ecosystem (Gann *et al.* 2005). In the study area the rock substrata of quartz and limestone patches gives rise to ecologically unique flora (Desmet and Helme 2003). Apart from the soil type water availability and evolutionary factors, could influence the colonising of the ecosystem niche by a specific plant species. Gully erosion and wind are some of the major factors that influence the soil characteristics in the study area. Disturbances such as erosion devastate the substrate while changing the soil chemistry, texture and drainage characteristics, all of which affects the ecosystem function (Stephanie *et al.* 2001). The eroded patches of quartz rock out-crops support shallow rooted and rich flora of miniature succulents within the Succulent Karoo (Schmiedel and Jürgen 1999). The colluvial soils support vegetation that is characteristically taller and denser without any dwarf and cryptic species (Desmet and Helm 2003). Wind as a major resource driver in this strandveld vegetation, facilitating the formation of sparse plant cover that is arranged as mixed species clumps, commonly referred to as fertile islands

(Milton 2001). Wind carries the sea mist that provides moisture in the drought prone environment and the dust that accumulate around obstacles to form plant habitats.

It is essential to consider the soil characteristics of the area under investigation for pollution effects on vegetation. Natural element concentrations in the soil may interfere with the study of the concentrations of anthropogenic contaminants such as industrial gaseous emissions (Gann *et al.* 2005). However, the topsoil is likely to yield more representative samples, when it comes to investigations of pollutant concentrations in the ecosystem. Most chemical compounds accumulate on the soil surface. According to Read and Pickering (1999) the topsoil is considered to be the most representative soil exposure source to the plant surface root system. In the present study the upper soil crust was sampled for the pH levels, ultimately used as a proxy for the effect of the gaseous emissions from the Mineral Separation Plant on the surrounding vegetation.

2.2.1 Soil acidity

Acidity of the soil is a major limitation in plant productivity in much of the world (McBride 1994). The soil pH is the most important single chemical soil characteristic required in determining the chemical environment of plants and soil microbes (Balon *et al.* 2003). Generally, we expect a plant species to be most abundant in an environment where conditions for its growth and reproduction are optimum. Outside this range biotic or abiotic conditions limit its distribution, growth and reproduction. Consequently, the ability of the plant to compete successfully with other plants of a better-adapted species decreases and so abundance declines (Begon *et al.* 1996). Distribution of many plants reflects environmental gradients of soil pH or moisture and a species with specific soil nutrient requirements will be abundant under optimum growth conditions (Beeby 1994).

There are many soil properties linked to the pH of the soil, including those of ion exchange capacity and nutrient availability. For instance, some ionic compounds decrease in solubility with increasing soil pH (soil alkalinity), which for example may cause iron deficiency in plants. In fact, in acidic conditions of pH 4.2 and below, concentrations of micronutrient cations aluminium is often sufficiently high to be toxic to most plants (Brady 1990). In acidic conditions ($pH < 5.0$) the solubility levels of Al^{3+} and Mn^{2+} may be high enough to the extent of being biologically toxic, whereas under alkaline conditions ($pH > 7.0$), there is low solubility of micronutrient cations such as

Zn^{2+} (McBride 1994). Soil pH is the 'master variable' that controls the ion exchange, dissolution/precipitation, reduction/oxidation, adsorption and other reactions. Acidification may be a natural process in many soil environments; however, it is accelerated by human activities such as agricultural practices, pollution from industries and mining (McBride 1994). In areas where rainfall exceeds evapo-transipiration and which are unaffected by industrial pollution, acidification is a continuous natural process that is caused by the release of protons (H^+) during the transformation and cycling of carbon, nitrogen and sulphur (Balon *et al.* 2003). For instance, the oxidation of primary sulphides in the soil is one of the natural pedogenic processes resulting in acidification (Néel *et al.* 2002). According to Treshow and Anderson (1991) acidification causes changes in the solubility of chemicals and enhances leaching out of essential plant nutrients, disrupting the ratio of critical elements in the soil. In the study area the natural acidification processes are obviously taking place. However, the concern is on detecting the patterns that point to the effects of the gaseous emissions from the Mineral Separation Plant on the surrounding.

Plants differ in their tolerance to variations in acidity levels. Strict pH requirements in a plant species could be related to soil nutrient status as influenced by pH rather than the direct effect of pH (Krebs 1985). Acidic soils are usually common in humid regions. In these soils the concentration of H^+ ions exceeds that of OH^- ions. These soils may contain large amounts of soluble aluminium (Al^{3+}), iron (Fe^{2+}; Fe^{3+}) and manganese (Mn^{2+}). Alkaline soils are found mainly in semiarid to arid regions. In these soils OH^- ions are dominant over the H^+ ions. Due to the alkaline reaction, the soil contains low quantities of soluble Al, Fe and Mn (Tan 1995).

Soils are a sink for atmospheric pollutants (McCormac and Varney 1971). The deposition of acidic pollutants from atmospheric emissions is usually in the form of particulate matter, fumes and aerosol. However, the solubility of the particulates increases as more acidic conditions arise. Under sufficiently alkaline conditions all transitional metal compounds will precipitate. Hence, deposition of high concentrations of salts may result in traces of accumulation of other metal ions, due to the chemical reactions of various elements. This is known as co-precipitation (Reeves 1996). Buffering capacity of the soil is the ability to resist change upon addition of acids or bases to the soil. The concept of buffering capacity is not limited to the soil's resistance to changes upon addition of acids or basis, it also affect microbial activity that determines the soil nutrient status. Other factors being equal, the higher the cation exchange capacity of the soil, the greater is its buffering capacity (Brady

1990). Buffering is the mechanism by which rapid lowering of the soil pH is prevented. The presence of aluminium in the cation exchange sites increases the buffering capacity of the soil. Soil colloidal particles (clays and humus) are the sites of most chemical, physical and biological properties of soil (Brady 1990). Soils that are rich in humus have a higher buffering capacity than the impoverished soils. Callaway and Walker (1997) indicated that soils directly beneath the canopies of perennials are highly fertile compared to those in the surrounding areas without perennial cover. This has been attributed to the addition of humus in areas underneath the shrubs that increases the buffering capacity of the soil, thus maintaining higher pH levels. The mineral elements in the leaves and stems of vegetation determine the characteristics of the soil that develops around them, especially in respect of its acidity (Brady 1990).

Soils vary in the landscape even within a very small distance. Tan (1995) noted that individual soil bodies in a given area occur side by side with other soils, fitting together like jigsaw puzzles. This variation was all the more reason to consider the characterisation of the soil in vegetation studies.

2.2.2 Electrical Conductivity

Electrical conductivity (EC) is the standard measure of salinity in soil or water. In arid and semi-arid environments, salts tend to accumulate in the soil resulting in saline conditions. The salts are mostly chlorides, sulphates of calcium, magnesium, sodium and potassium. The salts accumulate in the upper layers of the soil due to insufficient rain to flush them down to the lower layers (Brady 1990). EC is a measure of the accumulated salts in the soil (Boubel *et al.* 1996). Increase in salinity raised the concentrations of Mg^{2+}, Na^{+}, and Cl^{-}, whereas a decrease in Ca^{2+}, K^{+} and total-P causes increased salinity and a deficiency of essential plant nutrients (Carter *et al.* 2005). EC values are usually reported in terms of percentage, milligrams per kilogram, parts per million (ppm) and deci-siemens per meter (dS/m) or other suitable ratios (Brady 1990). Determination of the EC is important in the evaluation of the soil's toxicity due to accumulation of salt. Elevated salt concentrations result in decreased species richness and a change in species composition (Wait *et al.* 2005). According to Brady (1990) the accumulation of neutral soluble salts such as sodium chloride seriously interferes with the growth of most plants.

High concentration of salts can cause plant deaths. Hence the ability of some plants to survive under saline conditions is an important ecological adaptability and often influences the natural distribution of plant species (Flowers and Yeo 1996). In the arid Karoo salt tolerant plants such as the *Salsola* species and *Zygophyllum incrustalum* are a common feature (Roux and Opperman 1986). Mechanisms that plants use to survive in saline soils vary (stunted growth, fine root turnover, rapid root replacement etc). In certain circumstances plants growing under saline conditions tend to limit the transpiration rate for the purpose of reducing the translocation of toxic ions to the shoots. Consequently, the limiting of the transpiration rate results in stunted plant growth (Flowers and Yeo 1996).

The EC is highly influenced by the altitude and the drainage system of the sampling area (Boulding 1994). Climate is another factor that influences the soil EC. In warm and dry environments the negative effects are more pronounced than in cold humic regions. It should be remembered, during soil sampling for salinity analysis, that the distribution of salts may be uneven (Flagmann and George 1975).

2.3 Measurement of mist and dust deposition

In the present study, mist and dust samples were analysed as possible indicators of pollutant deposition from the Mineral Separation Plant and the effects on the surrounding vegetation. The relationship between wind and dust is an aerodynamic response, whose parameters can be measured. Knowledge of wind patterns provides accurate estimation of wind power potential (Pérez *et al.* 2005). The vertical wind motion, though minor in intensity, is essential for daily weather formation, pollution dispersion and transportation (Boubel *et al.* 1996). Wind erosion displaces sand and dust particles, and carries pollutants that are gathered on its path along with it. Particles are solids that are bigger than aerosols and dust fits the description of particles (McCormac and Varney 1971). Once the movement of the dust particles has begun, the mobile particles exert a drag effect on the flow of the wind, hence altering the velocity profile (Wilson and Cooke 1980). Wind carries various substances and deposits them along the direction of flow. Any obstruction along the flow pathway results in the deposition and accumulation of the dust and all the substances contained in it. Research indicates that most of the particles moved by wind are confined to levels close to the ground surface and much of the load becomes redistributed towards the leeward edges of depositional accumulations, or into damp hollows or on rough surfaces (Wilson and Cooke 1980). Pollutants originating from a point source such as the Mineral Separation Plant are likely to leave more deposition at the beginning of the transects and a reduction along the way as the wind passes through various vegetation obstacles. The emission stacks at the Mineral Separation Plant are above 100 m high, to allow the main pollution plume to be deposited beyond 1 km away from the point source.

Primary health based Particulate Matter (PM) standards revised by the Environmental Protection Agency of the United States of America (EPAUSA) in July 1997, set the threshold values for PM at 15 μg/m^3 and a new 24 hour PM standard at 65 μg/m^3 (Rodrigues 2002). These standards are set for the purpose of regulating the release of particulate matter into the atmosphere especially through industrial activities. The concentration of many particulate matter components in the external atmosphere differs over a 24-hour cycle. Diurnal influences and effects of the sunlight and factory emission rates have an effect on the concentrations. Hence, the measure of particulate concentration on average per 24-hour cycle is more appropriate (Reeves 1996). Diurnal variations of pollutant concentrations may exhibit bimodal distributions with high peaks in the morning or noon and another high peak in the evening, depending on the season and environmental factors (Ta *et al.* 2004). The measurements of the mist and dust deposition in the study area may have been affected by the undulating topography around the Mineral Separation Plant, resulting in differences in the total sulphur deposition along the three transects.

Considering that the South African National Environmental Management Act (NEMA, Act No 107 of 1998) emphasises the determination and control of all sources of airborne or air-carried pollutants and dust, it is imperative to develop simple, reliable pollution monitoring systems at minimal cost (Rodrigues 2002). Numerous experiments have been conducted to determine the most efficient and cost effective instruments for the measurement of dust and the substances contained therein. The Modified Wilson and Cooke (MWAC) instrument is a highly recommended dust sampler. It has been recommended not only for its high efficiency, compared to the state of the art instruments of high volume samplers, but also for the fact that its efficiency is independent of wind speed. This apparatus consists of a glass bottle, two glass pipes, a Styrofoam plug, a zip-lock plastic bag and ash-free filter paper (Figure 3.3 (a) and (b)). The installation procedure is easy and the small size and weight enables one to measure wind horizontal flux profiles effectively (Goossens *et al.* 2000). Ideally, all samplers should have isokinetic properties. This implies that the ambient wind speed at the equivalent height should be maintained through the orifice of the sampler (Zoebeck *et al*. 2003). The efficiency of the MWAC sampler is because the inlet and outlet tubes are of the same size, leading to minimum obstruction. This might also explain why the MWAC efficiency is independent of wind speed

(Goossens and Offer 1999). This apparatus is used in the present study to sample mist and dust at different distances for the determination of pollutant concentrations.

2.4 Foliar sulphur content

The uptake of air by the leaves is controlled by the chemical and physical properties and the gas to liquid diffusion pathway. Therefore, the entry of the air pollutants into the leaf depends on more than ambient concentration. The leaf stoma conductance regulating the ambient air passage is a critical factor. Our concern is about the concentrations of the pollutants in the plant and not the atmospheric concentrations (Treshow and Anderson 1991). This is because not all the pollutants in the atmosphere have an effect on the plant survival. According to Begon *et al.* (1996) there is a strong correlation between stomata water conductance and the photosynthetic rate even within short periods. Stomata conductance adjusts to coincide with the intrinsic photosynthetic capacity of the plant.

In photosynthesis and in the associated chemical synthesis, there are numerous steps that could be disrupted or blocked by outside interference by air pollutants and other agents. Apart from the interruption of chemical reaction, pollutants can destroy the chemical action sites such as cell and chloroplast membranes, grana, thylakoids, ribosomes, mitochondria and others (Treshow and Anderson 1991).

Direct quantitative indicators of plant response to environmental stimuli are uncommon; therefore proxies such as plant materials as accumulators of certain pollutants are used as indicators (Zonneveld 1982). In a chemical pollution scenario it is important to consider the effect of the pollutant on the organisms. Hence the available analytical data should be interpreted on the basis of the relationship between the pollutant concentrations and the impact on the organisms. This may not be an easy correlation to determine (Reeves 1996). There are a number of factors that influence the level of concentrations of the pollutant that can cause the plant to die. These may include individual genetic traits, metabolic pathway, water availability and the frequency of exposure to the pollutant. In the present study the plant material sulphur content was used to evaluate the effect of the gaseous emissions from the Mineral Separation Plant on the vegetation.

2.4.1 Sulphur metabolism

Sulphur is an essential plant nutrient and at the same time SO_2 (sulphur dioxide) and H_2S (hydrogen sulphide) are air pollutants that can cause severe foliar discoloration, in excessive concentrations in plants. SO_2 is more toxic in its effects on plant growth when it is in combination with NO_2 (Asheden 2003). Related consequences for adding sulphur and nitrogen oxides involve both the direct absorption of pollutants in the leaves and the indirect absorption from the soil through the root system (Treshow and Anderson 1991).

Different plant species and in some cases even different varieties or cultivars of a single species are known to vary in the severity of their response to air pollutants such as SO_2. Both acute and chronic SO_2 injury conditions are anticipated in the affected ecosystem (Manning and Feder 1980). In most cases the reason for this differential response is not understood, but it is believed to be due to differences in physiological tolerance to the pollutant gas as well as differential gas uptake by the plant tissues (Miller and Xerikos 2003). Plants that are relatively resistant to sulphite are known to convert and metabolize the compound rapidly to the non-toxic sulphate under conditions of severe sulphite stress. Moreover, the photosynthetic rate of leaves exposed to SO_2 and O_3 (ozone) at high humidity and intermediate light intensity is reduced significantly, with visible symptoms of injury occurring on leaves (Carlson 2003).

Sulphur enters the plant via the roots in the form of sulphate, which is an essential element to the production of some amino acids, some proteins and co-enzyme A, which is critical to the transfer of energy (Treshow and Anderson 1991). It is evident that sulphate or other forms of sulphur in the oxidation state greater than -2 must be reduced to sulphides to be used in the synthesis of amino acids. During metabolic process sulphur is oxidized from its organic forms of sulphides (S^{2-}) to sulphites (SO_3^{2-}) and sulphates (SO_4^{2-}). A molybdenum-containing enzyme, sulphite oxidase, oxidises the potentially toxic sulphite to sulphate. Unlike other organisms, including humans, plants are able to synthesize methionine, a sulphur-containing amino acid.

Hydrogen sulphate (H_2S) may completely replace pedospheric (SO_4^{2-}) as the source of sulphur and suppress SO_4^{2-} uptake by the plant roots. H_2S is taken up via the stomata, metabolised into cysteine, catalyzed by O-acetylserine (thiol)lyase, and subsequently into other S metabolites; hence H_2S

uptake shows saturation kinetics with respect to the atmospheric H_2S concentration (De Kok 1990). Despite being an essential element in protein syntheses sulphur as a toxic pollutant in its form as sulphur dioxide can induce one of the two responses in plants; it may have some sub-lethal effect, causing an impairment of growth, reproduction or metabolism. Alternatively, it may sooner or later cause the death of the individual. Both sub-lethal and lethal effects can be quantified and are the most direct methods of judging the biological impact of sulphur pollutants (Beeby 1994). Sub-lethal effects can be indicated by the percent discoloration of leaves, whereas lethal can be indicated by the number of plant deaths resulting from elevated concentrations of sulphur pollutants.

CHAPTER 3

METHODS USED TO ASSESS THE VEGETATION AND TO CONDUCT THE CHEMICAL ANALYSIS OF THE SOIL, PLANTS MATERIALS AND MIST AND DUST

3.1 Assessment methods

A number of techniques can be used to monitor and assess the hazards of toxic chemicals in the environment. One technique cannot provide all the answers; hence the need to use a suite of methods to derive the best possible and most comprehensive, appraisal (Connell *et al.*1999). In the present pilot study we depended mainly on biological monitoring tools. Such investigations require information about parameters of various ecosystem components, which may include biochemical and physiological measurements of plant densities and stress patterns, as well as determination of the chemical and physical characteristics of the soil (Blank and Lutz 1990).

3.1.1 Research approach

Considering that we are dealing with biological components in this ecosystem, it is imperative that observations are made on the environmental factors that may also have an influence on the response of the plants in the area. These will include weather conditions, topography, soil conditions, erosion aspects and the actual damage to the plant crowns. Dead plants and seedling regeneration were both recorded, to establish plant population responses to possible pollution effects. However, care has to be taken not to confuse the effect of drought or attack by insects with the effects of pollutants. Plant mortality rate in the Succulent Karoo can be altered by factors such as drought as well as by herbivory (Milton *et al*. 1997). The possibility that pollution and drought or disturbance can act in synergy, to result in defoliation should also be considered as discussed in the second paragraph of section 2.1.1. To ascertain the cause of the injuries on the selected plant species, an observation on the basic characteristics of the individual plant species and the seasonality of various plants in the ecosystem were made. Each of 27 sample plots was sampled to assess plant species composition, soil pH, concentration of sulphate in mist and dust samples, and the sulphur content of leaf samples of selected plant species. All the assessments were done in order to determine the environmental factors that could have a major impact on the plant community dynamics.

3.1.2 Vegetation assessments

The possible effects of the gaseous emissions on vegetation were assessed by soil pH measurements, ion chromatographic analysis of mist and dust samples, foliar sulphur content analysis and the evaluation of plant conditions. A preliminary assessment of the plant species abundance, composition and plant crown densities was also done. The methods used to survey the area are detailed as follows:

3.1.2.1 Field sampling methods

The sample plots were demarcated between 23rd and 26th June 2004 following verification of the wind data, from the Namakwa Sands Mine local weather station 3. This was to ascertain that the sample plots were mainly located downwind of the gaseous emission source at the Namakwa Sands Mineral Separation Plant. From the observations in the weather records and the available local information about the prevailing winds, it was concluded that the most strong and frequent winds were from the west and west north-west, hence the decision to set the permanent sample plots along east and south-east trajectories. The location of a control transect in the southern direction was selected for minimum effect of wind-blown fumes (leeward of the smoke stacks), but with environmental conditions similar to those of the downwind transects and representative of the surrounding vegetation. From the windrose charts (Figure 1.4) it is evident that windblown pollutants from the Mineral Separation Plant are likely to have much influence to the east of the plant. No transect could be set in the north western direction despite the typical Namaqualand Strandveld vegetation situated along this area, as it is a prohibited area due to the dumping of radio active waste material in the proximity. The south-western direction was rejected, because the vegetation was severely overgrazed and vegetation rehabilitation works were in progress. The rehabilitation of the area was done to reduce the impact of the adverse weather conditions such as wind erosion and to restore the Succulent Karoo to original status as discussed in the first paragraph of section 1.6.

One of the difficulties in the application of random sampling for parametric statistics in ecology, is the effect of the highly variable nature of the living systems, so fixed quadrats (systematic sampling) are frequently used in monitoring programmes (Goldsmith 1991).

Systematic random sampling involves random selection of the starting point and setting of the plots at pre-selected distances (Bechtold and Johnson 1989). Systematic random sampling was conducted along three transects radiating from the Mineral Separation Plant fume stacks. They were located in the eastern, south-eastern and southern directions. In the present study, the first sample plots along each transects were not set in their location because of any special features in the ecosystem, we simply happened to find the 400 m mark from the starting point of each transect that was near the fume stacks of the Mineral Separation Plant.

The permanent sample plots of 10 m x 10 m (0.01 ha) were located on three transects at the following distances from the Mineral Separation Plant: 400 m, 800 m and 1,200 m (Figure 3.1). The important consideration was the distance between each set of sample plots along each transect, where significant change of the pollution effects could be detected. Three replicate sample plots were demarcated at each of the three distances along each of the three transects, giving a total of 27 permanent sample plots, within a radius of 1,200 m from the supposed pollution source. The size of the permanent sample plots was determined to minimize variations in samples due to artefacts and to avoid compromising sufficient data capture in the study area. These quadrats were set in an area of approximately 1.12 km^2. Global Positioning System (GPS) grid references were taken for the permanent sample plots (Appendix 4).

All the plants in each permanent sample plot were examined and the height, crown diameter and density of the shrubs were determined (Appendix 5). All the plant species in the sample plot were recorded to obtain preliminary information about the species growing in the area around the Mineral Separation Plant (Appendix 6).

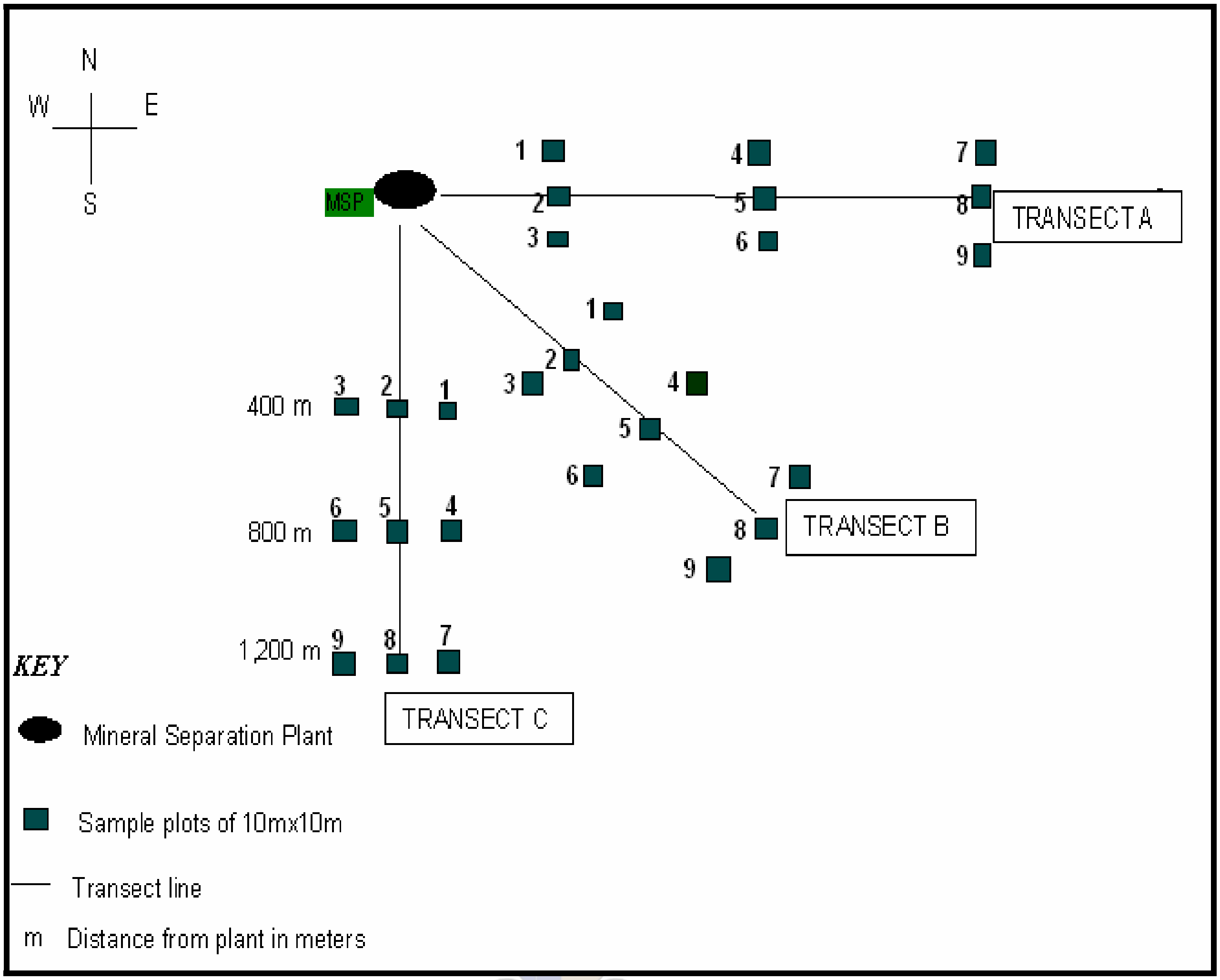


Figure 3.1: **Layout of sampling plots in the pilot study.**

The following variables were recorded in each plot:

- Shrub height (cm) for each plant in sample plot
- Crown diameter (cm) (Maximum diameter + Minimum diameter/ 2)
- Crown density (% of the canopy live or dead)
- Distance from point source (m)
- Projected cover (% of ground covered by plants. $\pi r^2 n / 100$)

The height and crown diameter of individual plants were measured. The crown diameter was used to determine the area of the horizontal spread of the total projected canopy cover. This is often indicated as the percentage of the sampling unit area (Coetzee and Gertenbach 1977).

Dead plants and plant species exhibiting loss of foliage or other peculiar signs of stress were recorded, taking into account that the crown defoliation could be due to natural deciduous characteristics of some plant species. The crown densities were assigned a score value from 1 to 5, depending on the state and health condition of the crown. The full crown density was assigned a score of 5, while the most damaged crown was given a score of 1. The tabular expressions of the scores in percentages are as follows: 1 = 0% - 20%, 2 = 21% - 40%, 3 = 41% - 60%, 4 = 61% - 80% and 5 ≥ 81%. This scoring method is used to classify visible injury symptoms (chlorosis) of leaves during assessment of damage in the vegetation (Moraes *et al.* 2002).

3.1.2.2 Scanning for potential bioindicator plant species

Plant species richness and abundance can provide suitable parameters for bioindication, when compared across sites, especially if morphological matching is not feasible to achieve in a monitoring programme (Rosch *et al.* 2001). In this study a number of plant species were selected as potential bioindicators (Table 4.3). A single species can best be applied as an indicator in an ecological homogenous ecosystem; otherwise a suit of indicator plants is more dependable (Zonneveld 1982). The criteria for the selection of potential bioindicator plant species, was based on the relative wide distribution through the study area and an apparent sensitivity to environmental disturbances, as indicated by proportion numbers of damaged or dead plants.

3.1.3 Statistical analysis

Histograms and linear regression analysis were used to establish the trend in the distribution of plants in the study area. This illustrated the total number of plants and the proportion of dead plants in the sample plots. The aim was to determine the effects of the pollutants along a vegetation gradient.

3.1.3.1 Canonical Correspondence Analysis (CANOCO)

Canonical Correspondence Analysis is a multivariate exploratory technique used to analyse ecological data. This procedure provides an illustration of multi-dimensional (Eigenvector analysis) interaction of various ecological components in the ecosystem (Hopker 1995). This procedure of data analysis was applied, to determine the relationship between the ecological variables and the vegetation in the study area. These observations were used to make conclusions about the environmental factors that have an impact on the various vegetation components, in relation to the acidic gaseous emissions. To utilize the CANOCO for Windows version 4.5 programme, the plant species data was prepared for analysis in combination with vegetation parameters and field environmental conditions data matrices (Appendix 7). The plant species data was checked thoroughly using the CANOPOST software, for structure and plant species spelling inconsistencies. The data was then stored for further analysis of the environmental variables correlations. A good model should have consistency so as to provide asymptotic behaviour of the phenomena under investigation. Consistency is an essential characteristic in a model if prediction and forecasting is to be accurate (Davidson 1995).

The importance of the Canonical Correspondence Analysis is that it provides the information on the relationship between the different environmental variables to each other and to elements in the vegetation. The output of the Canonical Correspondence Analysis is essential in the study of the effects of pollutants on the vegetation. The end point in interpreting the correlations established in the model depends on the level of necessity (Tabachnick and Fidell 1989).

3.1.3.2 Clustering analysis

Clustering is a multivariate exploratory technique that makes use of the amalgamation process. One assumption in using the clustering method is that the data were collected from randomly selected samples, to allow for statistical analysis (Davidson 1995). The program STATISTICA (StatSoft, Inc. 2003) was used to analyse the data. The purpose was to determine the clustering groups of the permanent sample plots with common parameters and ecological characteristics. The characteristic of most multivariate methods is to compress data and identify the structure of ecological variables interactions (Hopker 1995). The data being entered in numerical and ordinal values was standardized to Euclidean distance. The application of the log form in transformed data provides the variables that are close to normality (Davidson 1995). The minimum sum-of-squares clustering problem algorithm is applied to solve problems based on non-smooth optimization technique (Birgrov and Yearwood 2004).

The hierarchical classification used in this analysis was agglomerative. In this instance two of the most similar objects of the ecological components are joined together as a start point (Lepš and Šmilauer 2003). Complete linkage amalgamation procedure and Euclidean distance, were applied in the process with the dendrogram as the final product. Each group of clusters is internally homogenous and different from the other clusters. The longer the linkage distance from the other clusters the greater the difference between the characteristics of the object from the homogenous groups. The application of complete linkage algorithm procedure makes it easier to interpret the ecological variables and similarities of the objects (Lepš and Šmilauer 2003).

3.2 Soil sampling

3.2.1 Field methods

Soil sampling was conducted between the 24th and 26th June 2004. Samples were collected from each of the twenty seven permanent sample plots in Transects A, B and C. The purpose of the sampling was to determine whether there were any differences in pH levels between the areas near the Mineral Separation Plant (400 m), through the middle plots (800 m) compared to the furthest sample plots (1,200 m). The other criteria was to compare the soil pH in the soil samples collected from the open space between plants and from underneath the shrub canopy. The assumption is that the shrubs create micro-conditions underneath each plant that buffer the soil from acidification. The plant residues and other materials that accumulate underneath the shrubs decompose and add humus to the soil. It is these humus colloids, which adsorb the soil cations, thus positively influencing the soil chemical properties including the pH. The focus of the investigation was on the effect of the sulphur dioxide component of the gaseous emission, which had accumulated over time in the soil.

Soil composition may vary greatly within the same area due to local influences (Reeves 1996). Care was taken to collect representative soil samples. Soil crust samples 3 cm wide, 3 cm long and 2 mm thick were collected using a putty knife. Pollutants deposited from the atmospheric emissions are immobile and will remain in the surface layer of the soil profile (Reeves 1996).

Due to the drought conditions the soils were quite dry; hence there was little risk of biodegradation or chemical change to the stored samples. The preservation of the samples in their original condition and the maintenance of the properties and identity at all stages, are important factors in soil characteristics investigations (Tan 1995). The ultimate goal was to obtain results from the samples that reflect the true situation in the field.

To establish the pH gradient in the pilot study area, more soil samples were collected on the 30th and 31st August 2004 (Figure 3.2). The purpose was to plot the pH gradient (contours) of the study area.

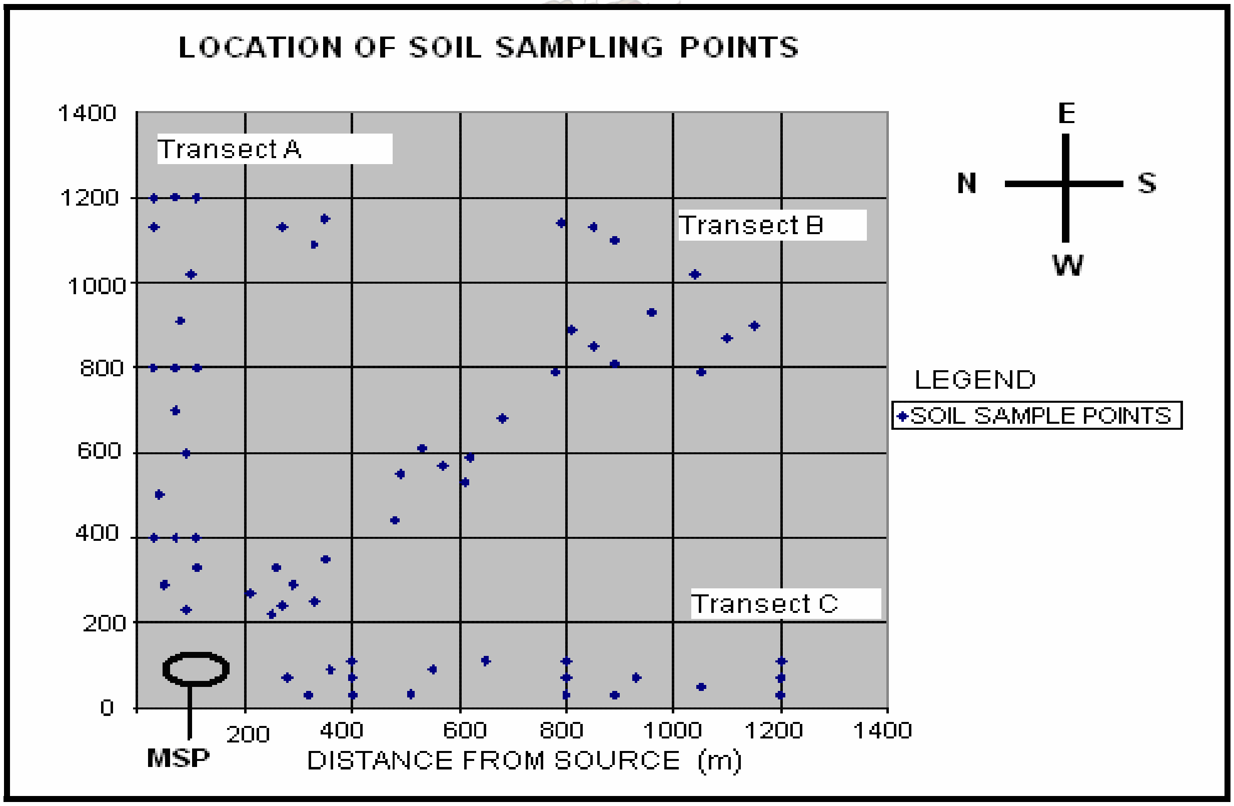


Figure 3.2: **The diagram to illustrate the positions of the soil sample points for the pH gradient mapping in the pilot study area.**

In this instance, samples were collected by uncapping the top crust, with dimensions of 5 cm width, 5 cm length and 2 mm depth. Samples were collected from five different spots at each sampling point. The soil crust from five spots at each sampling point, were combined to obtain representative samples for each particular sampling site.

3.2.2 Laboratory procedure for pH analysis

Soils have a tendency to form aggregates that contribute greatly to the heterogeneity of the soil within a given fraction (Tan 1995). To homogenise the soil samples, a mortar and pestle was used to grind it and break the hard crusts and to loosen the particles. The soil was then sieved to ensure homogeneity. Materials that did not pass through a 2 mm sieve were discarded, following internationally accepted soil chemical analysis standards (Tan 1995). The potentiometric method of determining soil pH depends on the use of electrodes to measure the H^+ ion concentration in the solution. When the electrode is placed in the solution, an electrical potential difference develops between the indicator and the solution. This gives the reading of the H^+ ion concentration in the solution in pH units (Tan 1995).

The soil solution was prepared in the ratio of 1:5 soil and distilled water. Five grams of the soil sample was weighed and put in a clean bottle. Then 25 ml of distilled water was added to the soil and mixed thoroughly by hand shaking the closed bottles for 15 minutes. The samples in the closed bottles were then placed on the shaker and left to mix for one hour. The idea was to obtain a thorough homogenous solution. The pH meter was calibrated to ensure that accurate measurements of the pH values were taken.

3.2.3 Statistical analysis

The paired t-test was used to analyse the pH data from between and beneath the shrubs. A comparison was made to see if there was any correlation and difference between sample means, of the soil pH from the samples taken in the open space and in the samples from beneath the shrubs. It is important to conduct statistical analysis, even though at times this does not imply that the accuracy of the results is in conformity with the scientific truth in the field (Tan 1995). Rank correlation was used to test for correlation between pH in the open space and that from beneath shrub canopies. We are interested in assessing the trend of pH values from the gaseous emission source at the Mineral Separation Plant, to the areas further away.

The Repeated Measures Analysis of Variance technique was used to determine the variability between two sets of variables and the distance. The Analysis of Variance (ANOVA) provides the relative variability accounted for by the inclusion of parameters with their corresponding covariates in the model (Davidson 1995). The ANOVA provided the insight to variability in the parameters that were tested. All monitoring methods that are capable of providing sufficient sensitivity and power in the statistical sense must consonant with the objectives (Hinds 1984). ANOVA tests for the differences in means between groups. This statistical method assumes normal distribution of the means of the variable of interest (Tabachnick and Fidell 1989). In the present study, differences in the pH means for the soil samples taken from the open spaces and underneath the shrubs were tested. Distance from the Mineral Separation Plant was used as the independent variable.

Contour analysis and three-dimensional plotting of the pH values and gradient in the study area, was made possible with the application of the *SURFER* program (Golden software Inc., version 1987).

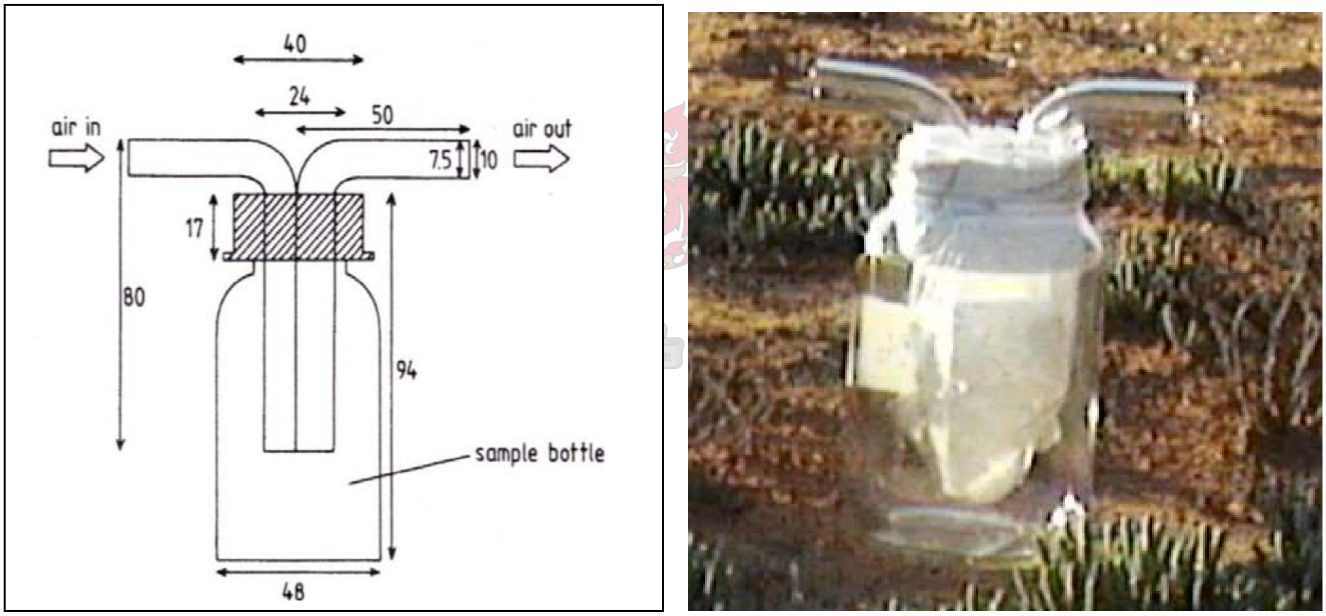
3.3 Mist and dust capture and chemical analysis

The aim of the pilot study was to assess the effect of gaseous emissions from the Mineral Separation Plant on the surrounding vegetation. Mist and dust samples were used to examine the sulphate concentration in the air, as distance increased from the gaseous emission source at the Mineral Separation Plant, to a practically acceptable distance, namely the furthest points in the pilot study area transects as illustrated in Figure 3.1. After due consideration a decision was made to use the Modified Wilson and Cooke (MWAC) sampler (Figure 3.3a) to obtain mist and dust samples. The MWAC apparatus used to capture mist and dust in the present study (Figure 3.3. (b)) has been used in other research studies to determine point source pollution in the ecosystem with success (de Clercq 2004 Pers.comm.). In the present study the MWAC apparatus was not tested prior to the commencement of the mist and dust capture.

de Clercq W (2004) Department of Soil Science, University of Stellenbosch. Stellenbosch.

3.3.1 Field methods

The MWAC samplers for dust and mist capture were set in each of the 27 permanent sample plots. The apparatus consists of a glass bottle of 16 cm height, 10 cm mid diameter and 7.5 cm top diameter. Figure 3.3 (a) shows the original sample of the Modified Wilson and Cooke dust sampler, with different specifications from the one used in the present study (Figure 3.3 (b)). A zip-lock plastic bag was placed in the bottle with an ash-free filter paper inside acting as a settling chamber. The bottle was then closed with a Styrofoam plug of 5 cm thickness, with two perforations for the insertion of two glass tubes. Finally, these inlet and outlet glass tubes of 2 cm diameter, bent at an angle of approximately 90^{o} as illustrated in Figure 3.3 (b), were set in the bottle through the Styrofoam plug. The positioning of the samplers on the ground were such that, the inlet tube was oriented toward the supposed pollution source (Figure 3.3 (b)).



(a) **(b)**

Figure 3.3 (a): **Construction scheme of the Modified Wilson and Cooke (MWAC) dust sampler and *(b)*: Picture of the MWAC mist and dust sampler as set out in the study area at the Mineral Separation Plant (Goosens and Offer 1999)**

The MWAC samplers were left in the field for 65 days, collecting mist and dust samples that accumulated on the filters in the zip-lock plastic bags. The aim was to determine the mist and dust samples sulphate concentration along three transects from the Mineral Separation Plant. Comparisons were made of the pH, electrical conductivity and sulphate concentrations of the mist and dust samples from the sample plots near the gaseous emission source (400 m), through the middle sample plots (800 m) to the furthest plots (1,200 m). Differences in the sulphate concentrations of these samples were to be taken as a measure to assess the potential of the gaseous emissions from the Mineral Separation Plant to have a negative influence on the adjacent vegetation. Another source of sulphur that may enter the MWAC samplers includes deposits from the soil surface.

The samplers were collected from the plots after 65 days and packed in boxes to ensure that there was no contamination of the mist and dust samples contained in the MWAC samplers during transportation and storage. To avoid possible changes to the pH and chemical composition of the mist and dust samples, laboratory analysis were done as soon as possible about 35 hours after collection of samples from the study area.

3.3.2 Laboratory methods

The filter papers were removed from the samplers and placed into clearly marked beakers. The contents of the zip-lock bags were washed out thoroughly, with distilled water using a laboratory wash bottle with attachment, to ensure that no solids were left inside. All solids were quantitatively brought into the beakers. Measurements were taken of the mass of the contents from each zip-lock bag using a laboratory Precisa 3610 CD-FR standard scale. Each beaker with the samples was filled with distilled water up to the weight of 100 g, to obtain a solution of mist and dust that had accumulated in each MWAC sampler. The mixture was left for an hour to ensure that all the solids were dissolved in the solute. The mist and dust pH, electrical conductivity and sulphate concentrations were determined from the solution. The Metrohm 744 pH meter was used to determine the pH levels of each sample, while the values of the electrical conductivity values were obtained using the Cyberscan CON 510 electrical conductivity meter (Appendix 8). Later the same samples were analysed for $SO_4^=$ concentrations and other soluble anions, using a Dionex DX-120 ion chromatograph (IC).

3.3.3 Ion chromatographic process

The Ion Chromatograph (IC) was applied to investigate the concentration profiles of emission ionic species likely to be present in the mist and dust samples. This procedure of analysing solutions for chemical concentrations is based on the principle of cation separation and conductivity detection. One obvious reason for the application of the IC method is that it has good sensitivity and has a stable baseline. Moreover, during the process it is possible to recognise the generation of undesirable, chromatographic effects resulting from the interference of sample matrix, which at times may shorten retention time during analysis (Tanikkul *et al.* 2004). The ion exchange separation was conducted in an aqueous solution. This separation process is referred to as chromatograph. The mechanism of adsorption occurs at the liquid-solid interface to facilitate the separation of ions. The process has non-linear adsorption isotherms, which can interfere with the separation efficiency (Miller 1975).

3.3.4 Statistical analysis

A histogram is used to show the increasing trend of pH along the transects, from the gaseous emission source at the Mineral Separation Plant outwards. A Pearson Correlation Analysis was done to determine whether there was any significant correlation between the pH in the mist and dust samples and the distance from the gaseous emission source. Data from each transect were considered for the pH and distance correlation. Pearson correlation has the advantage of providing easy calculation, fast and accurately the absolute and relative power and inter and intra correlation between sets of data (Guevara *et al.* 2002). In the final analysis data were pooled from the three transects on the basis of distance, to analyse the correlation between mist and dust samples pH against distance. In this instance, distance was the predictor (independent) variable, while pH was the dependent variable. Data were pooled for Transects A, B and C to provide the overall pH trend from the Mineral Separation Plant outwards.

A Two-way ANOVA was performed to determine whether the distance and transect direction had an effect on the $SO_4^{=}$ concentrations and the electrical conductivity. The least square means were applied to minimise the square differences between the observed correlation outputs. The purpose was to see if the mean differences in the variables of interest had only occurred by chance (Tabachnick and Fiddel 1989).

3.4 Plant foliar sulphur content

A reconnaissance survey was conducted in the potentially polluted area to assess the health of different plant species. I observed that some species, such as *Zygophyllum morgsana* (Zygophyllacea), *Ruschia* sp. (Aizoaceae) and *Othonna cylindrica* (Asteraceae) had a degree of foliar discoloration. However, this could not be taken as direct evidence of the effects of pollution from the Mineral Separation Plant. It was evident that the plants were being injured by both pollutants and by herbivores, with more severe damage occurring in the sample plots closer to the gaseous emission source at the Mineral Separation Plant (Figure 3.4). According to Begon *et al.* (1996) a three-way interaction between air pollutants, plants and herbivores is a complex phenomenon to assess. It was evident that herbivory may increase in the presence of pollutants. The appearance of ailments in shrubs within the same space of time signifies a linkage of some kind or some triggering factor to all the effects (Mellanby 1989). Obviously, the physiological and chemical composition of plants is negatively affected by pollution, whereby making them more susceptible to attacks (Figure 3.4). Plants growing in soils with low nutrition and faced with pest attack are more susceptible to pollution (Dässler and Börtitz 1988). It should be remembered that the mere presence of aphids in the area could not be taken at face value as an indication of the presence of pollutants. An investigation was required to determine the effect of the specific pollutants on the affected plant species to which the aphids are attracted for their feed. Such information in turn can be used to determine, whether there is an increase or decrease of the aphid abundance along the transect gradient. According to Hoplopainen and Oksanen (1995) the correlation of the mean aphid densities and the increase of free amino acids in plants can be influenced by pollution gradient.

Figure 3.4: **Pictures taken from the pilot study area to illustrate probable complex effects of pollutants and herbivory especially nearer to the emission source at the Mineral Separation Plant. (a) Illustrates an aphid attack on *Mesembryanthemum guerichianum.* (b) Shows the accumulation of supposed smog on plants, combined with herbivory on a *Ruschia* sp. (c) Shows some injuries on *Lampranthus suavissimus*. (d) Shows a caterpillar probably feeding on a *Ruschia* sp. (e) Shows the presence of the tent tortoise (*Psammobates tentorius*) probably feeding on *Salsola aphylla* and (f) Shows an observation of the presence of lichens which are often used as bioindicators of pollution levels in an environment.**

To determine whether there were any effects of sulphur on vegetation, plant materials were obtained for sulphur analysis. Sulphur dioxide is one of the chemical compounds that are released into the atmosphere from the Mineral Separation Plant. Hence, the necessity of determining the foliar sulphur content in the various plant species. Plant leaves are considered the most suitable component for routine chemical concentration analysis (Tan 1995). The analysis was done to obtain quantitative results on the foliar sulphur content. What matters most are the concentrations of the pollutants in the plant and not the ambient concentrations of the pollutant that can be avoided by the closing of the stomata (Zonneveld 1982). The other important consideration was the comparison of the plant foliar sulphur content, from the sample plots near the gaseous emission source (400 m) and further way (1,200 m).

3.4.1 Field methods

Observations were made to determine which plant species were widely distributed in the study area, with presence at 400 m, 800 m and 1,200 m distance of each transect. The following three plant species were chosen; *Othonna cylindrica*, *Zygophyllum morgsana,* and *Salsola arborea.* The differences in plant foliar sulphur content (percentage of dry mass) along the transects was an indication of the effect of the gaseous emission from the Mineral Separation Plant on the surrounding vegetation.

All the plant foliar samples were collected on the leeward side of the sample plants. Rather than just the exposure to the emitter, it is essential to consider the exposition to wind. Sulphur content in the plant foliar located on the windward versus the leeward of the sample plants differ considerably. In essence, streams of air get in contact with the leeward sides of the obstacle (Knabe 1982). Care was taken to pick only the leaves that were out of touch with the water splashes from the ground. This was to avoid double contamination of the foliar samples from the sulphur that could have accumulated on the soil surface. The basal and terminal leaves were avoided on picking plant material samples for sulphur analysis. This was to ensure that only leaves with the same exposure time were picked for investigation (Vike 1999).

For all the foliar samples, only the mature leaves of the same age category were picked. In this case, the foliar samples were collected from stems at 2-3 cm length from the tips of the shoots, to ensure uniform exposure to potential pollutants. Leaves covered with dust were avoided, to keep away from introducing external contaminants into the sulphur analysis samples. Pollutants deposited on the leaf surfaces could influence the results on the level of chemical concentrations by plant uptake. All the samples were stored in paper bags to avoid moisture build-up and possible chemical deterioration of the foliar samples.

3.4.2 Laboratory methods

In the laboratory, samples were cleaned by blowing off the dust, to ensure that they were free of any surface contaminants. Cleaning of foliar samples provides comparable results, since the variations in amounts of leaf surface pollutant particulates are eliminated (Vike 1999). Considering that the leaf samples were in the category of the succulents with high water content, washing them would have probably deteriorated the condition of the samples and interfered with the chemical analysis. The fresh weight of the samples was recorded before putting them in the oven that was pre-set at 45°C. The moderate heat drying rather than the high heat, rapid drying process was done for the purpose of maintaining the chemical balance in the leaves. To start with, samples were left in the oven for 24 hours and then weighed. Thereafter, they were weighed at various time intervals, until each sample attained a constant weight (Appendix 9). Drying the samples to a constant weight was used as an indication of attaining dry weight. The analysis of emission effects on plants is normally based on dry matter (Zonneveld 1982).

The *Salsola arborea* plant material samples dried within 30 hours, where as *Zygophyllum morgsana, Ruschia* sp. and *Othonna cylindrica* leaves took up to 52 hours, for the first samples to reach a constant weight (Appendix 9).

3.4.2.1 Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES)

The dry foliar samples were analysed for their sulphur content (%) using the plasma emission spectroscopy method. This process determined the concentrations of a specified element in a given sample. It involved measuring of the radiation intensity emitted by reactive atoms released from the sample at the wavelength specific for that element (Tan 1995). Only the free atoms are present in the reaction as all the molecular bonds are ruptured. Under this state the atoms can either emit or absorb light at the characteristic wavelength of the element's unique atomic electron orbital energies (Gauglitz and Vo-Dinh 2003). Subjecting the sample to a high temperature flame helps to break the chemical bonds, thus generating free atoms. This is the atomizing process (Torvela 1994).

The samples were ground before subjecting 1 g of each sample to analysis. Nitric/perchloric acid was then added to the samples and left to digest them overnight. The digest was then heated on a hotplate and each quantity made up to 1 g volume. The sulphur content was determined by Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES) using 181.972 wavelength, the certified standard for sulphur test. The sulphur content (%) for each sample was determined as illustrated in the results (Appendix 9).

3.4.3 Statistical analysis

From the compiled data of the plant foliar sulphur analysis the histogram was prepared, to visualise the effect of sulphur emission along the pilot study transects. Histograms have the advantage of providing a satisfactory way of identifying possible relations, whether positive or negative (Slingsby and Cook 1988). It was necessary to determine whether the foliar sulphur content (%) was increasing from the sample plots near the Mineral Separation Plant, at 400 m and the plots further away at 800 m and 1,200 m.

CHAPTER 4

RESULTS

4.1 Vegetation assessment

The vegetation included 64 plant species recorded from 27 permanent sample plots, set in the study area around Namakwa Sands Mineral Separation Plant. In total, 2,614 plants were recorded from the 27 permanent sample plots, with 551 dead plants and 657 seedlings. Means with shared superscripts do not differ significantly at $p<0.05$ (post hoc Tukey test). The proportion of the dead plants decreased with distance from the Mineral Separation Plant (Table 4.1 & Figure 4.1). At 400 m the recorded dead plants in the sample plots were a proportion of 28%, 19% at 800 m and only 10% at the furthest point of 1,200 m. There was a significant difference in the proportions of the dead plants per distance from the Mineral Separation Plant.

Table 4.1: **Summary of the total number of plants and the proportion of the dead plants with the mean values and standard error (Appendix 5)**

Distance from NSMSP	**Number of plants**		**Proportion of dead plants (%)**		**N**
	Mean	**Std error**	**Mean**	**Std error**	
400 m	118.65^{a}	4.18	28	5.78	**9**
800 m	79.11^{b}	13.86	19	4.06	**9**
1,200 m	91.55^{b}	9.42	10	2.40	**9**

The histogram shows the gradient of the total number of plants and the proportions of the dead plants (Figure 4.1). Data was pooled for all the three transects per distance (400 m, 800 m and 1,200 m) from the Mineral Separation Plant. The trend suggests that there is an effect of the gaseous emissions from Mineral Separation Plant, on the surrounding vegetation (Appendix 10).

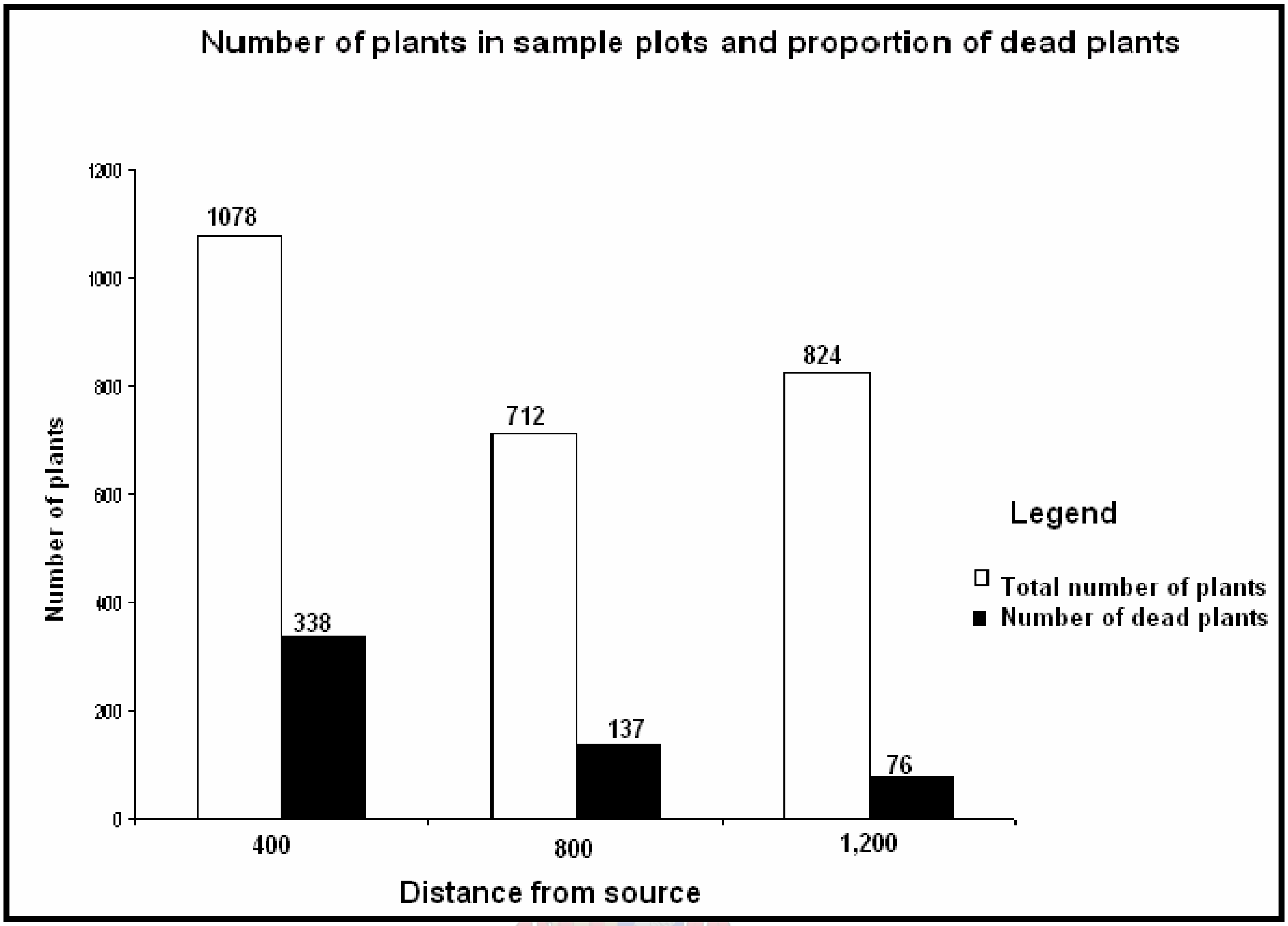


Figure 4.1: **The total number of plants found in the sample plots at various distances of Transect A, B and C with the total number of dead plants. The proportion (percentage) of the dead plants, are decreasing from the sample plots near the gaseous emission source (400 m), to the sample plots further away (1,200 m) (Appendix 5)**

Univariate test of significance

Plant density and proportions of dead plants were greater at 400 m from the Mineral Separation Plant than at 800 or 1,200 m away (ANOVA F$_{(2.24)}$ = 6.43, $P<0.05$). The computed F value is larger than the critical value, therefore it is evident that there was a significant difference in the means of the proportions of dead plants as distance increased from the Mineral Separation Plant (Table 4.2).

Table 4.2: **Univariate test of significance for total number of plants (Dead plants against distance) Sigma-restricted parameterization (Appendix 5)**

	Sum of Squares	**Degrees of freedom**	**Mean Sum of Squares**	**F**
Intercept	251141.3	1	251141.3	438.89
Distance	7363.6	2	3681.8	6.43
Error	13733.1	24	572.2	

Scatter plot for the proportion of dead plants

The proportion of dead plants in the sample plots decreased with distance from the gaseous emission source (n = 12, $r^2 = 0.206$, $P<0.05$). The trend suggested that the gaseous emissions from the Mineral Separation Plant had more detrimental effects nearer the point source than further away. The slanting regression line from 400 m down to 1,200 m shows the trend of reduction in the proportion of the dead plants. The sample plots adjacent to the Mineral Separation Plant may be highly affected by the emissions probably by the occasional wind mixing and churning of the fume plume, causing it to fall in the vicinity of the gaseous emission source. However, the high fume stacks at the processing plant are intended to deposit the main emission plume further away (beyond 1 km).

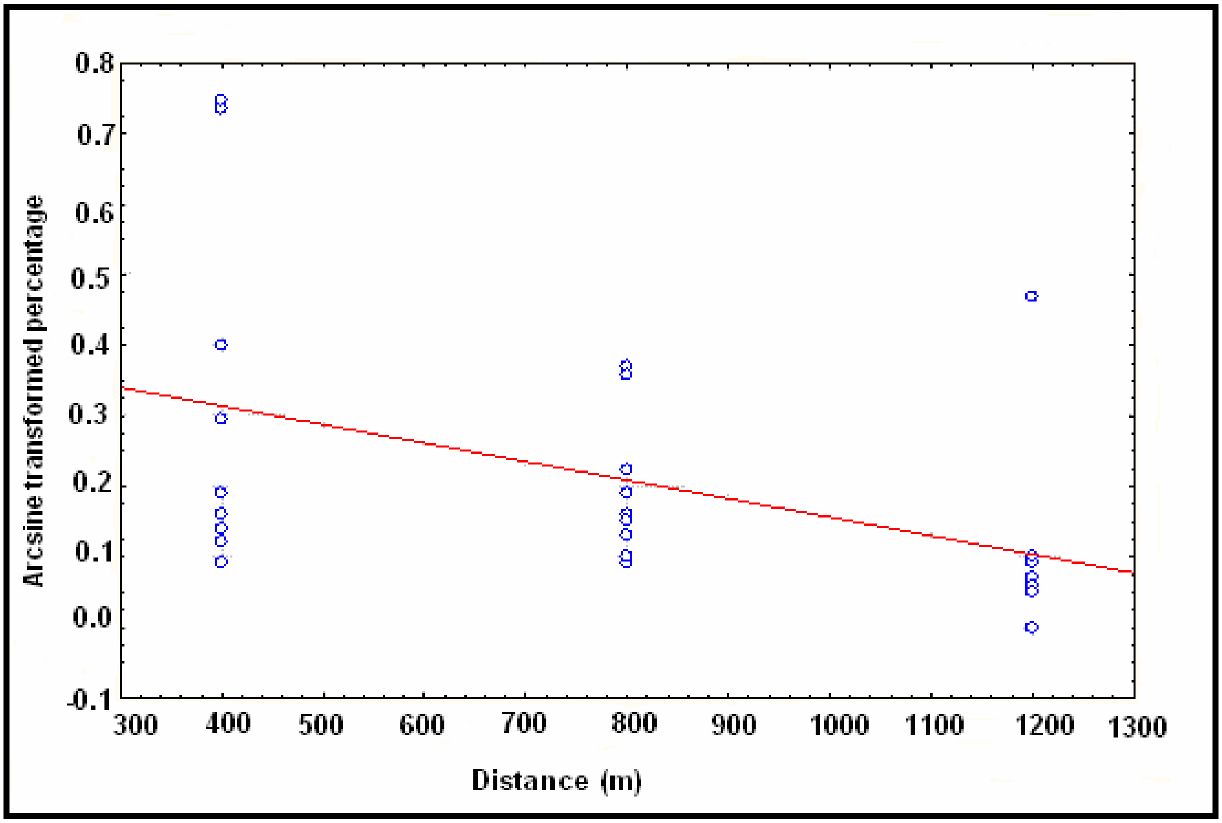


Figure 4.2: **The scatter plot shows the trend of dead plants distribution along the transects, from the gaseous emission source. With distance from the Mineral Separation Plant: $r^2 = 0.2061$; $r = -0.4539$, $p = 0.0174$; $Y = 0.419 - 0.0003*x$.**

4.1.1 Scanning for potential bioindicator plant species

A total of nine plant species (Table 4.3), were selected from the matrix of 64 plant species recorded in the permanent sample plots on the basis of their wide distribution and abundance (Appendix 5). The plant species selected included: *Asparagus fasciculatus* (Asparagaceae)*, Atriplex lindleyi* (Chenopodiaceae), *Galenia fruticosa* (Aizoaceae)*, Lampranthus suavissimus* (Aizoaceae), *Lycium ferocissimum* (Solanaceae), *Psilocaulon* sp. *(Brownanthus)* (Aizoaceae), *Ruschia fugitans* (Aizoaceae), *Ruschia* sp. (Aizoaceae. SP 9) and *Salsola arborea* (Chenopodiaceae). The apparent sensitivity of the plants was another important consideration in qualifying any plant species as a potential bioindicator plant species. Potential indicator plant species with higher proportions of dead individuals in the permanent sample plots nearer to the emission source were: *Galenia fruticosa, Lycium ferocissimum, Lampranthus suavissimus* and *Ruschia* sp. (SP 9) (Tables 4.3).

***Table 4.3*: Summary of transects and distances showing the distribution of the most abundant plant species with a wide distribution. The letter (T) stands for the total number of plants and the letter (D) denotes the number of dead plants for each of the selected plant species (Appendix 6)**

Transect /Distance	***PLANT SPECIES***																	
	Lycium ferocissimum		***Salsola arborea***		***Lampranthus suavissimus***		***Atriplex lindleyi***		***Galenia fruticosa***		***Ruschia*** sp. (SP 9)		***Ruschia fugitans***		***Asparagus fasciculatus***		***Psilocaulon*** sp.	
	(T)	(D)	(T)	(D)	(T)	(D)	(T)	(D)	(T)	(D)	(T)	(D)	(T)	(D)	(T)	(D)	(T)	(D)
A. 400m	26	16	32	0	71	17	8	0	20	0	63	54	77	0	0	0	0	0
A. 800m	13	3	27	9	87	27	0	0	0	0	3	2	73	22	1	0	0	0
A.1,200m	0	0	0	0	68	22	0	0	0	0	21	4	0	0	5	1	4	0
B. 400m	71	0	7	3	74	39	17	3	127	30	0	0	10	0	0	0	1	0
B. 800m	0	0	21	2	10	0	0	0	0	0	0	0	17	2	0	0	13	0
B. 1,200m	0	0	10	5	0	0	0	0	92	0	21	0	6	0	3	0	10	0
C. 400m	1	0	2	0	1	0	116	85	28	8	2	0	0	0	5	0	0	0
C. 800m	0	0	0	0	23	2	69	6	70	15	0	0	2	0	13	5	44	7
C. 1,200m	0	0	1	0	0	0	2	0	7	0	0	0	0	0	9	0	6	0
	111	19	100	19	334	107	212	94	344	53	110	60	185	24	36	6	78	7

4.1.2 Canonical Correspondence Analysis (CANOCO)

The ecological factors recorded in the study, contribute to the patterns and processes in the ecosystem giving the shape of the landscape. The overall outcome of the CANOCO multivariate data analysis indicated that the sample plots with similar characteristics are clustered together in the same grid and the variables with some element of correlation are grouped together (Figure 4.3). The ecological factors with distinctly different influence appear in opposite directions in the CANOCO output diagram. The ecological factors such as elevation and sulphate ($SO_4^=$) concentration are indicated by the long arrows in the graphs pointing in opposite directions, indicative of a negative correlation. All the ecological factors that are closer to the X and Y axis, denotes closer relation among themselves, in comparison to those factors with arrows further apart. The numbers of plants, plant density and number of dead plants are the parameters that are clear indicators of the ecosystem condition in the study area.

The number of plants increased with a decrease in crown density. Plant diameter and plant height decreases as Electrical Conductivity (EC) and $SO_4^=$ concentration increases and altitude decreases. Higher levels of EC and $SO_4^=$ concentrations are found at lower altitudes. The factors affecting plant distribution and composition in the ecosystem are diverse with complex interactions. Factors that seem unique to most sample plots in Transect A, are elevation, dominant plant height and crown diameter, in comparison to Transects B and C. The plant height could have interfered with the mist and dust capture in most sample plots on transect A, resulting in lower $SO_4^=$ concentrations along the transect.

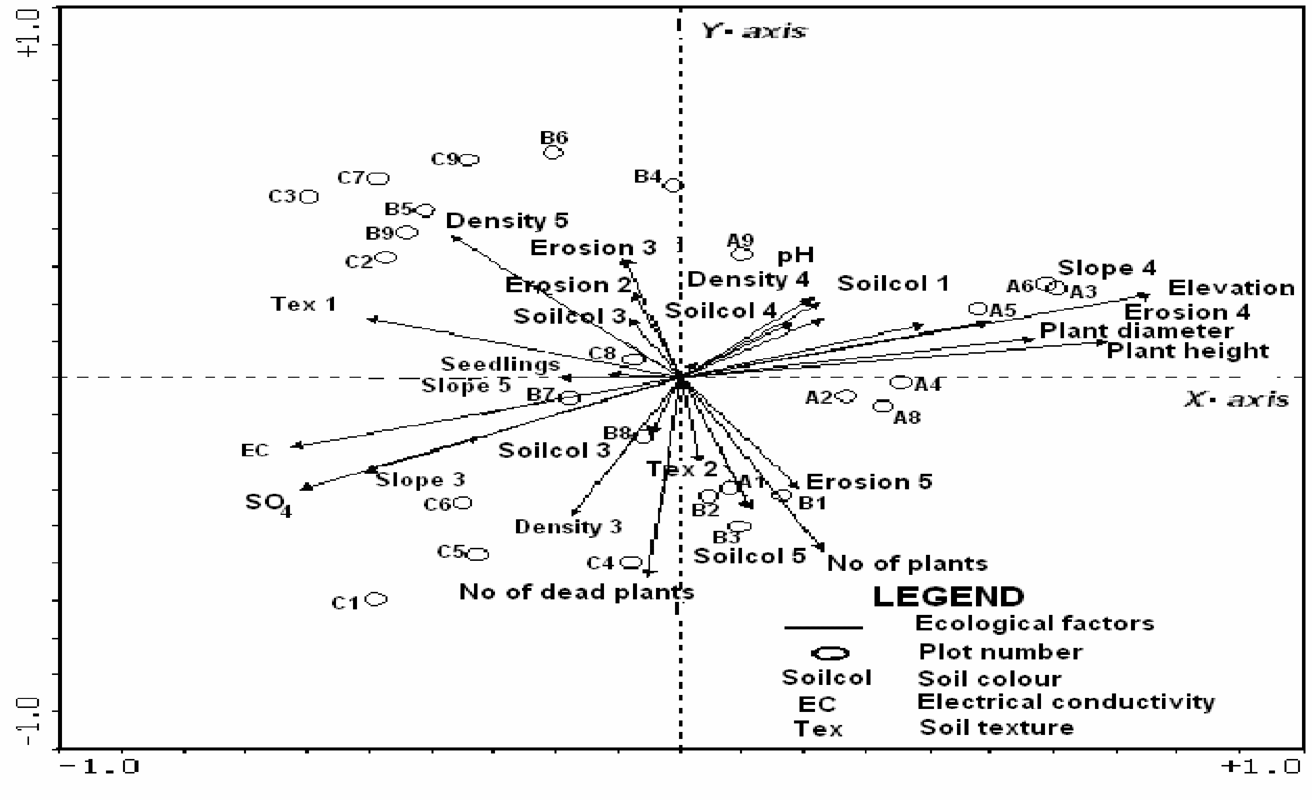


Figure 4.3: **The CANOCO program output, illustrating the correlations of the various ecological variables in the pilot study area. It also shows the environmental factors that have effects on the vegetation variables (Appendix 7)**

4.1.3 Clustering analysis

The clustering analysis provided a multidimensional observation of the similarity in the characteristics of the sample plots in the study area. In the dendrogram the linking and clustering of the sample plots that have some commonality in ecological elements within the area can be visualised. The shorter the linkage distance between clusters, the closer the relation among the sample plots. The longer the linkage distance the more pronounced the disparity among the sample plots (Figure 4.4). There is no overlap in this clustering system, every variable (relevé) has its own linkage in the hierarchy, with a chance to express the similarity or difference with other plots within the system. There are four distinct sample plot groupings in the dendrogram. Sample plots C5, C9, C6, C8, C4, C7, B9, B6 and B5 are highly impacted by the same environmental factors, most probably the sulphate from the Mineral Separation Plant. Sample plots A1, B4, C3 and C1 are impacted by various ecological factors, showing distinct disparities in the dendrogram. The ecological factors that have been used to characterise the sample plots include: soil pH, electrical conductivity, texture and colour, elevation, slope, soil erosion, mist and dust sulphate concentration (abiotic factors). Others are plant abundance, mortality, crown cover (%), and crown density (biotic factors) (Appendix 10).

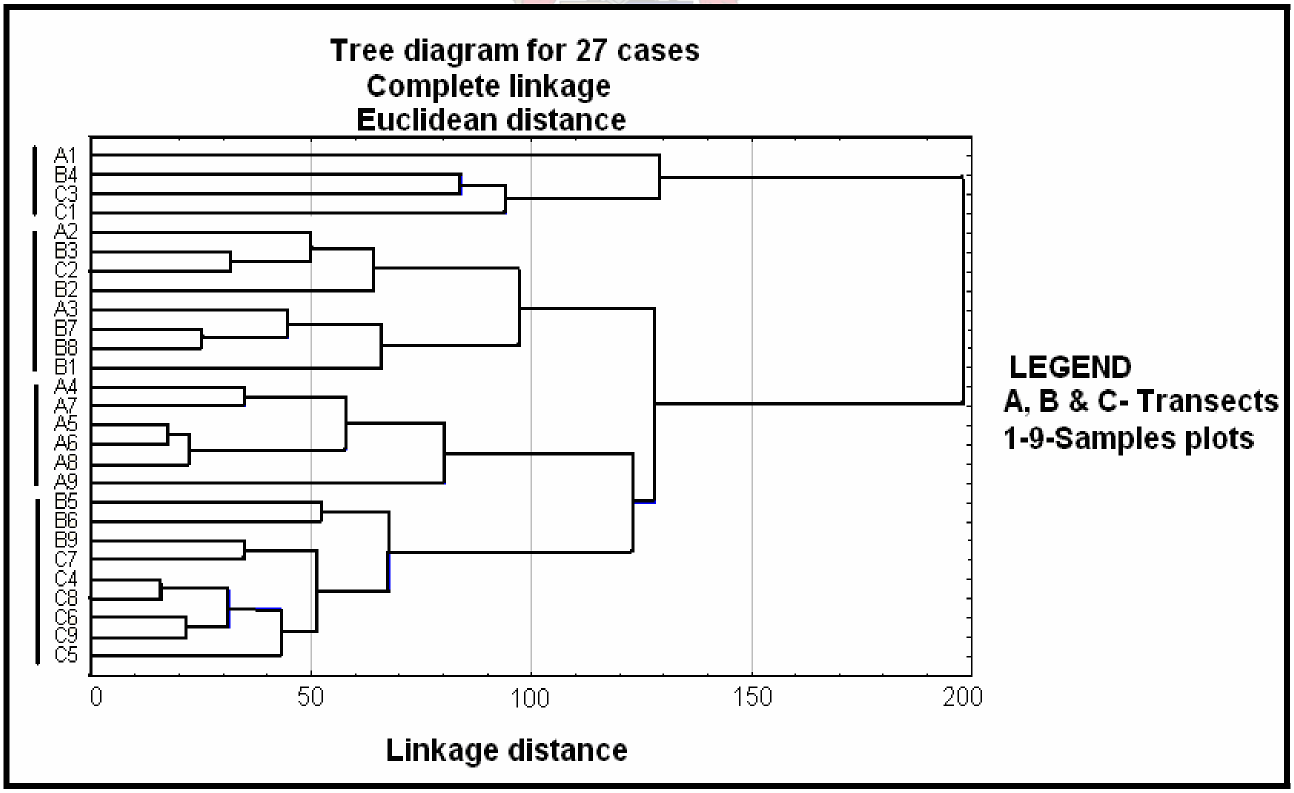


Figure 4.4: **The clustering dendrogram illustrates the groupings of the sample plots with similar ecological characteristics in clusters. All the sample plots from Transects A, B and C have been classified according to their abiotic and biotic similarities within the ecosystem (Appendix 7)**

4.2 Soil sampling and chemical analysis

The soil sampling was undertaken to test the hypothesis that soil pH increased with distance from the gaseous emission source and the hypothesis that soil pH would vary between open sites and under shrub sites.

4.2.1 Descriptive statistics

The average pH in the open space was lower (8.0), than that from underneath the shrubs (8.9). The maximum pH in the open space only reached 8.7 (less alkaline); whereas the maximum from underneath the shrubs was 10.54 (more alkaline). The pH in the open spaces had a gradient, which increased from the gaseous emission source (400 m) outwards (1,200 m). At 400 m the pH was 7.89 increasing to 7.95 at 800 m and 8.18 at 1,200 m. The pH gradient from underneath the shrubs had no specific pattern, the lowest being 8.83 at 400 m, with 8.97 as the highest at 800 m and 8.92 at 1,200 m (Table 4.4).

Table 4.4: **From the descriptive statistics, it is clear that pH in the open space (O) on average increases with distance from source. The pattern is not the same for pH from underneath the shrubs (S). The descriptive statistics also show that pH levels underneath the shrubs is higher (10.54 maximum) as compared to the open space (Appendix 11)**

Area	**Distance**	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
(s) pH	400	9	8.828	1.038	.346	8.030	9.626	7.89	10.54
	800	9	8.971	.769	.256	8.38	9.562	7.78	10.21
	1200	9	8.918	1.148	.383	8.035	9.800	7.17	10.37
	Total	27	8.906	.961	.185	8.526	9.286	7.17	10.54
(o) pH	400	9	7.891	.333	.111	7.635	8.147	7.51	8.53
	800	9	7.953	.522	.174	7.552	8.355	7.05	8.45
	1200	9	8.180	.491	.164	7.802	8.558	7.51	8.74
	Total	27	8.008	.457	.088	7.828	8.189	7.05	8.74

4.2.2 Paired t-test

The paired t-test was done on pooled data for Transects A, B and C to determine the relationship between the soil pH value means in the open space and from underneath the shrubs. The null hypothesis stated that the mean value of the pH in the open space is equal to the pH mean from underneath the shrub (HO: $\mu (O) = \mu (S)$). The alternative hypothesis stated that the pH mean value, from the open space samples was not equal to the pH mean from underneath the shrub canopy samples (H1: $\mu (O) \neq \mu(S)$).

The standard deviation for the pH from underneath the shrubs was higher (0.961) than that in the open space (0.457). This illustrates that the variables obtained from underneath shrub canopies are more varied than those of the open space. The correlation between the two sample areas is high (0.711), with a significance level of $p<0.01$. The result of the t-value of 6.547 at a two tailed significance level of $p<0.01$ (Table 4.5), was evident that the sample means for the open space was significantly different from that from underneath the shrubs. Therefore, the null hypothesis that H_0: $\mu (O) = \mu (S)$ was rejected. The alternative hypothesis that H_1: $\mu (O) \neq \mu (S)$ was accepted. This was to emphasise that there was an influencing factor controlling the soil pH levels between the two microsites. This suggests that there is an effect of the supposed sulphur pollutants on the soil, with the increase in the concentrations from the gaseous emission source at the Mineral Separation Plant outwards. The pollutants are deposited on the soil surface and tend to accumulate. There is an interception of the pollutants by the shrubs, reducing the quantity of the pollutants that reach the soil surface underneath the shrubs. The humus from the plant materials probably, neutralises the pollutants that reach the soils underneath the shrub canopies thus elevating the soil pH.

Table 4.5: **The paired sample test on pooled data for Transects A, B and C gives a positive correlation between the pH in the open space (O) and that of the sub-canopy (S). The paired sample test at 26 degrees of freedom gives a t-value of 6.547, at a two tailed significance level of $p < 0.01$. These figures show high significance levels, therefore providing evidence that the pH mean in the open space is different from that underneath the shrub canopies**

Paired Sample statistics				**SD**	**Mean**	**Standard error**
Pair	(S) pH	10.5 max	N = 27	0.961	8.906	0.185
	(O) pH	8.7 max	N = 27	0.457	8.008	0.088
Paired sample correlation						
		N	**Correlation**	**P**		
Pair	(S) pH & (O)pH	**27**	**0.711**	**< 0.01**		
Paired Sample test						
		Mean	**Sd**	**Std Error mean**	**95% Lower**	**95% upper**
Pair	(S)pH-(O)pH	0.897	0.712	0.137	0.615	1.179
		t	**Df**	**P**		
		6.547	**26**	**< 0.01**		

4.2.3. Repeated Measurements Analysis of Variance

This is a two group profile design analysis, which was used to see if there was any difference in the soil pH means between the open space (O) and from underneath the shrubs (S) (Figure 4.5). The other component of the analysis was to see if there were differences in soil pH mean values between distances from the sample plots near the gaseous emission source (400 m) through the middle plots (800 m) and further away (1,200 m). The observation was that the soil samples from underneath the shrubs had higher soil pH mean values compared to the open space (Figure 4.5). Generally, there was no overlap of the vertical bars between the two sample variable sets, denoting a significant difference in the soil pH means ($p<0.01$). Statistically there was no significant difference in the soil pH means between distances ($p = 0.842$) from samples taken underneath the shrubs, as can be seen from the graph below. The graph for the pH samples from the open space shows a slight increase in the pH, whereas the graph for the pH underneath the shrubs indicates an erratic trend from the 400 m, through the middle plots to the plots further away 1,200 m. There is no significant difference in the mean soil pH values between distances for samples from the open space and underneath the shrubs.

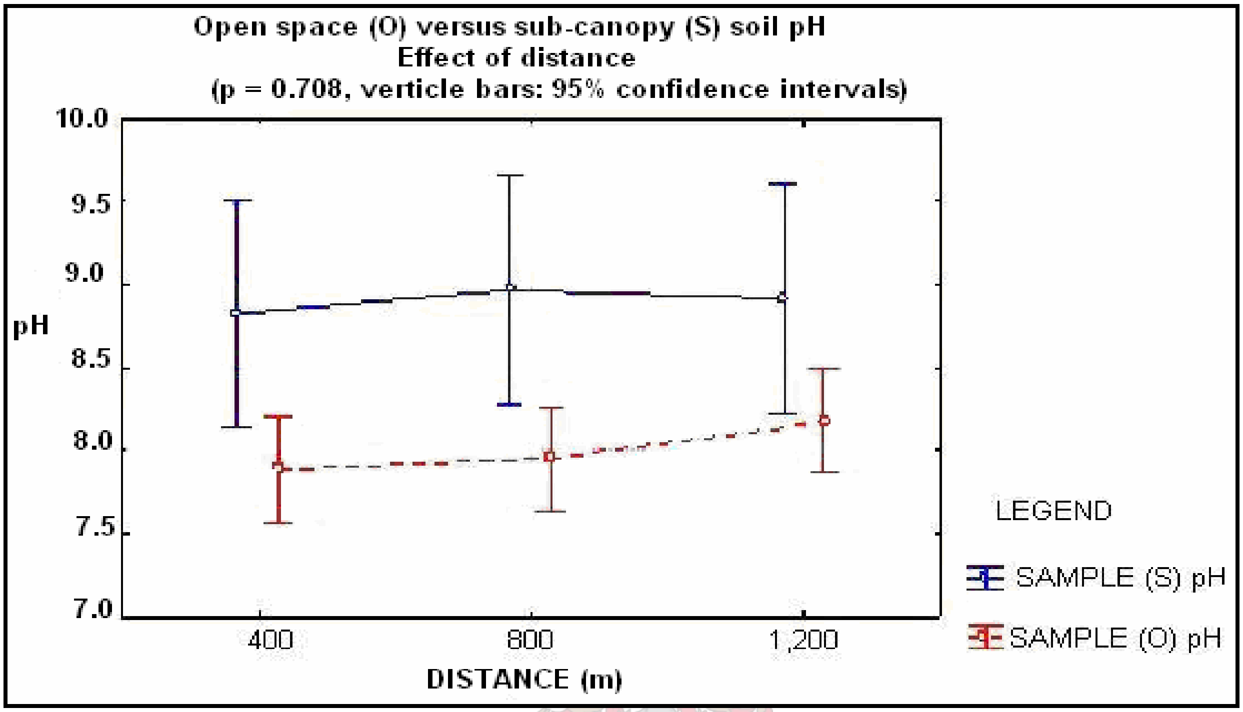


Figure 4.5: **A comparison of the soil pH means for the open space (O) and underneath the shrubs (S) with reference to the effect of distance. The vertical bars denote the 95% confidence interval (Appendix 11)**

The comparison of the soil pH mean values from pooled data for Transects A, B and C, between the open space and underneath shrubs (Figure 4.6), confirmed that there was a difference. This can be seen from just a slight overlap of the vertical bars for the two sets of variables. The $p < 0.01$ illustrates a highly significant difference. The soil pH mean value from the samples taken from underneath shrubs is higher as compared to that from the open space.

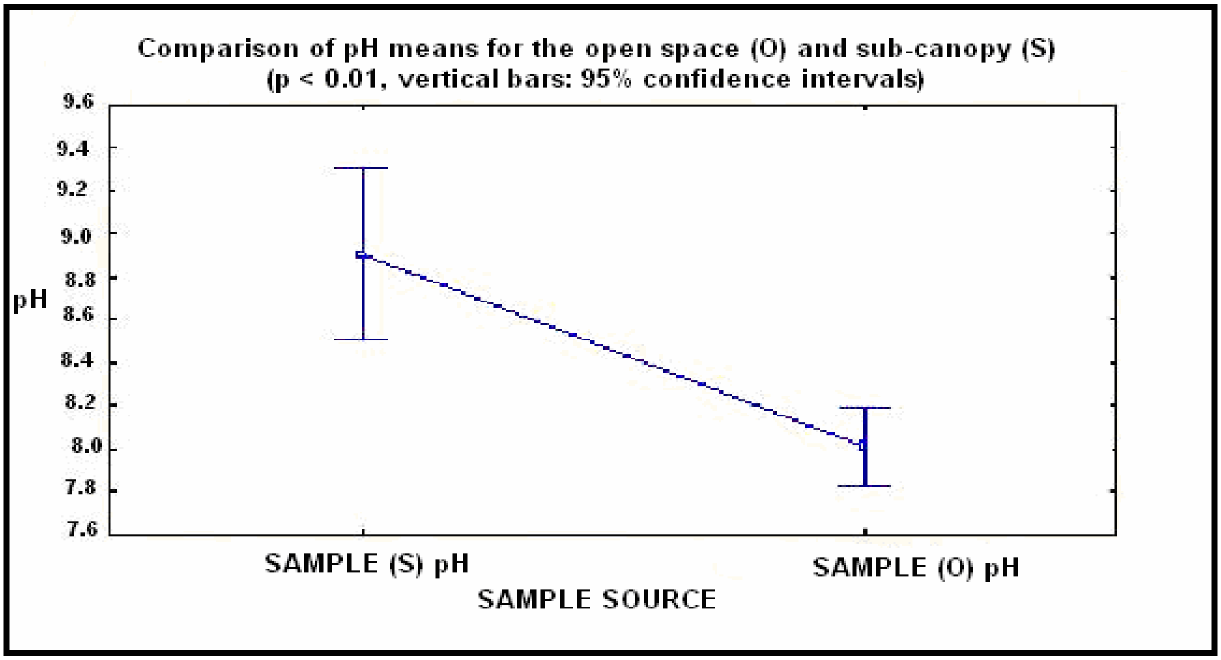


Figure 4.6: **Comparison of the pH means for the Open space (O) and from underneath the shrub canopy (S) (Appendix 11)**

4.2.4 Contour map for soil pH

Transect B has a pattern of the soil pH (8.35, 8.55 and 8.95) that is generally increasing away from the Mineral Separation Plant. Transects A and C had an erratic soil pH pattern, probably due to interactions of the ecological components. In addition to that the installation of the smoke stacks at a higher level (above 100 m) is for the purpose of preventing the immediate deposition of the main pollution plume within the range of 1 km away from the emission source.

There is a general increase in soil alkalinity in a southerly direction. This is not correlated directly to distance from the Mineral Separation Plant. It would be appropriate to test whether a geological gradient or deposition of acidic emissions by the prevailing wind is responsible for this gradient. Soil pH shows no consistent trend with distance from the emission source (Figure 4.7 and Figure 4.8). Soil pH in the study area was significantly lower on high altitude than on the lower altitude ($r^2 = 0.0933$; $r = -0.3054$, $p = 0.0134$). This can be seen from the scatter plot below (Figure 4.9).

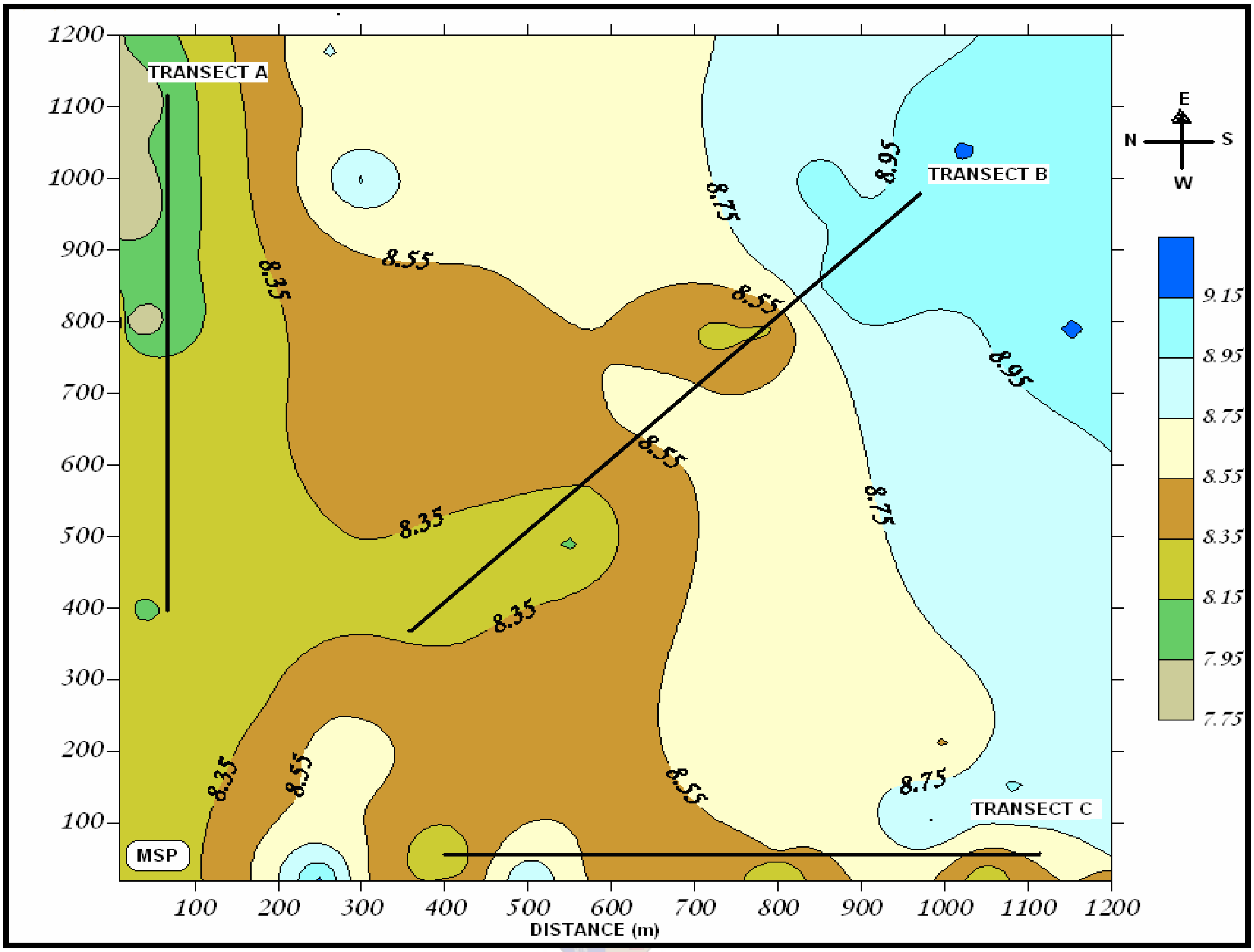


Figure 4.7: **The pH levels and gradient in the study area with the contours connecting areas of the same soil pH level, from the Mineral Separation Plant outwards (Appendix 12)**

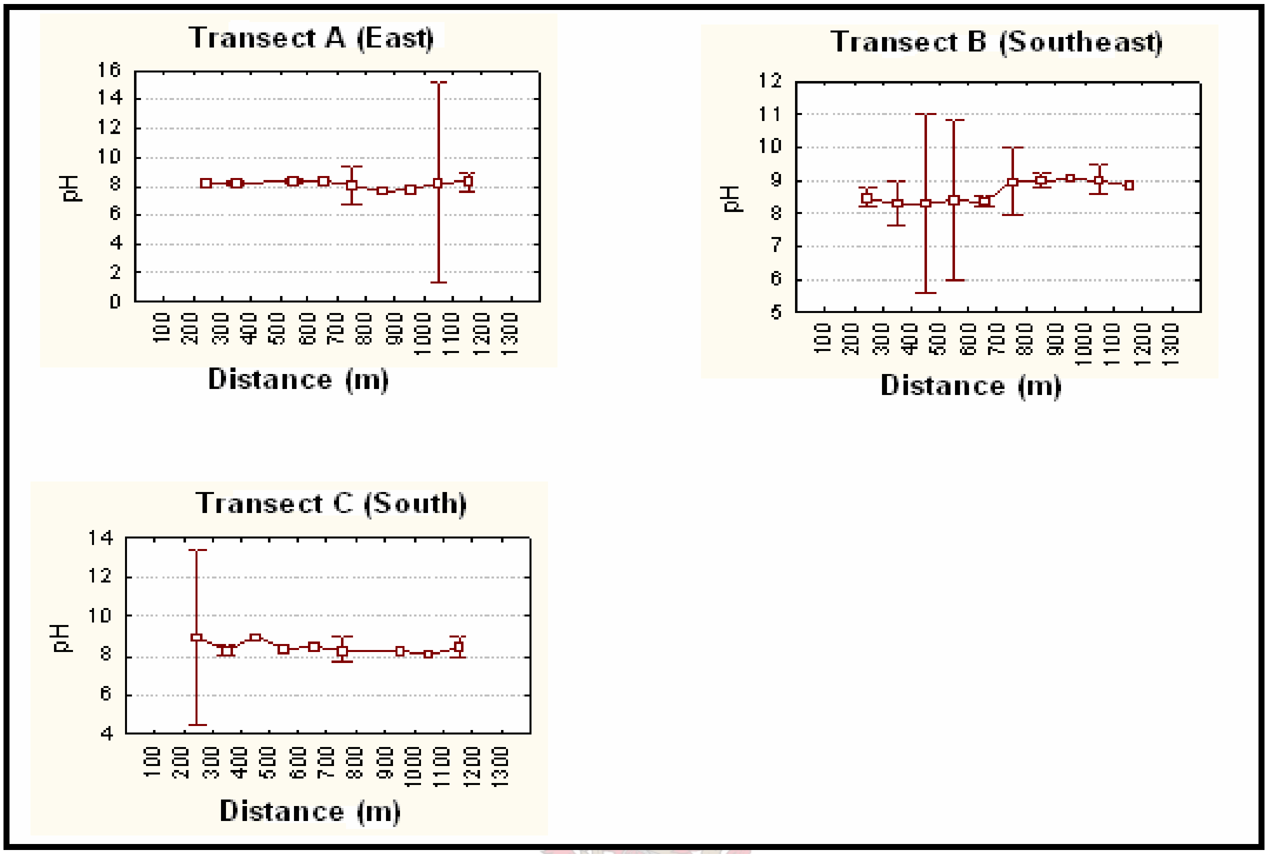


Figure 4.8: **The diagram shows the soil pH trend for Transects A, B and C, with distance from the gaseous emission source**

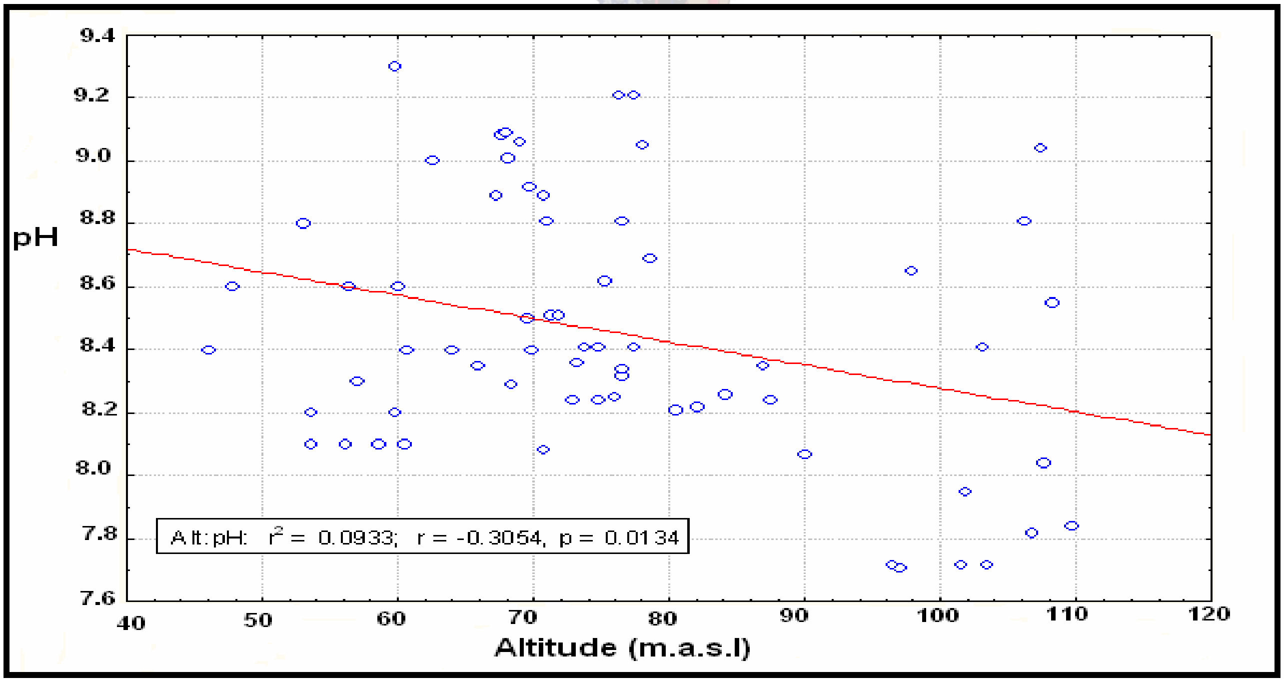


Figure 4.9: **The graph shows that soil pH is lower on the high altitude sites**

Altitude variation with distance from emission source

In the study area, altitude varies with distance from the gaseous emission source, along Transects A, B and C. As can be seen (Figure 4.10) there is a hill on Transect A. Transect A is on a higher altitude than Transects B and C. The altitude could possibly explain the lower soil pH on Transect A, in one of the two ways:

1. The hill may comprise acidic rocks.
2. The hill may have trapped acid emissions from the Mineral Separation Plant

Now, if we find that plant mortality and leaf sulphur was low towards the end of Transect A (on the hill), then we can discount the second explanation and accept option1. Along Transects A, B and C, the mist and dust pH increase with distance from the gaseous emission source (Figure 4.9). Along Transect A (on the hill) the proportion of the dead plants and the plant leaf sulphur content decrease with an increase in distance from the emission source (Appendix 10, Table 4.8), suggesting that the erratic soil pH pattern (Figure 4.7) is due to the acidic rocks within the hill.

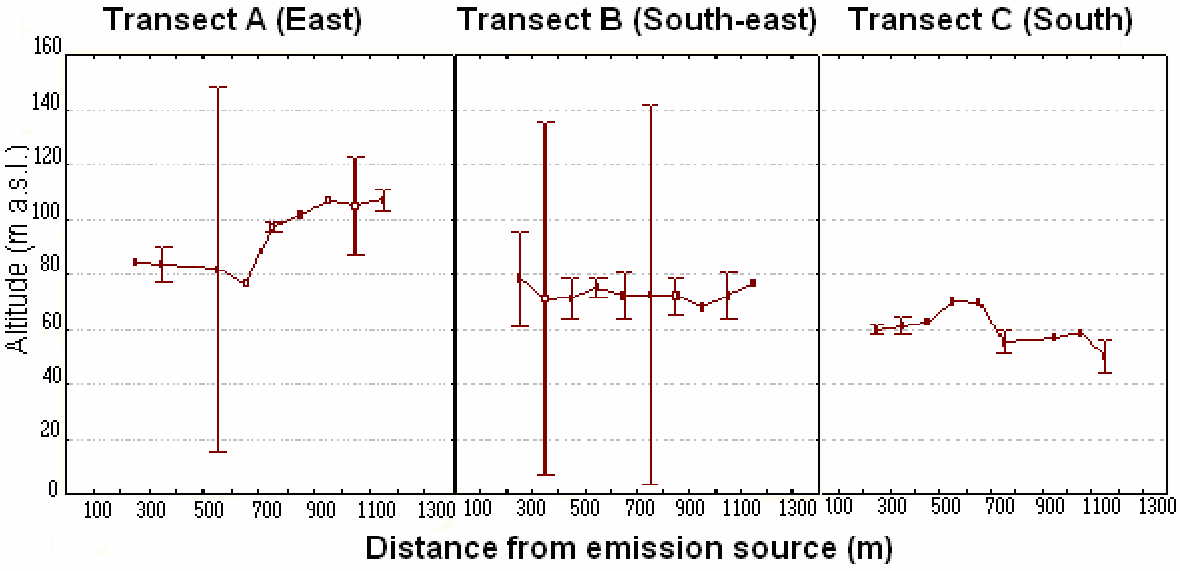


***Figure 4.10*: the graphs show how altitude varies with distance from the emission source along Transects A, B and C**

4.3 Mist and dust survey

The wind movement along the transects is likely to effect more deposition of pollutant particulate matter in a pattern that is decreasing in concentration from the gaseous emission source, to the areas further away. Hence the pH values and sulphate concentration from the mist and dust samples are expected to follow the same trend, if there was any effect from the acidic gaseous emissions on the mist and dust samples. Moreover, the construction of the smoke stacks above 100 m at the Mineral Separation Plant was intended to deposit the main pollution plume more than 1 km away from the gaseous emission source.

4.3.1 pH results

From the histogram Transects A, B and C had the pH values for the mist and dust samples increasing from the sample plots adjacent to the Mineral Separation Plant (400 m), through 800 m, outwards (1,200 m) (Figure 4.11). There was no significant difference between the pH values for Transects A ($p = 0.07$), B ($p = 0.67$) and C ($p = 0.17$). The lack of significance in the pH values per distance for all the three transects was attributed to the small sample sizes.

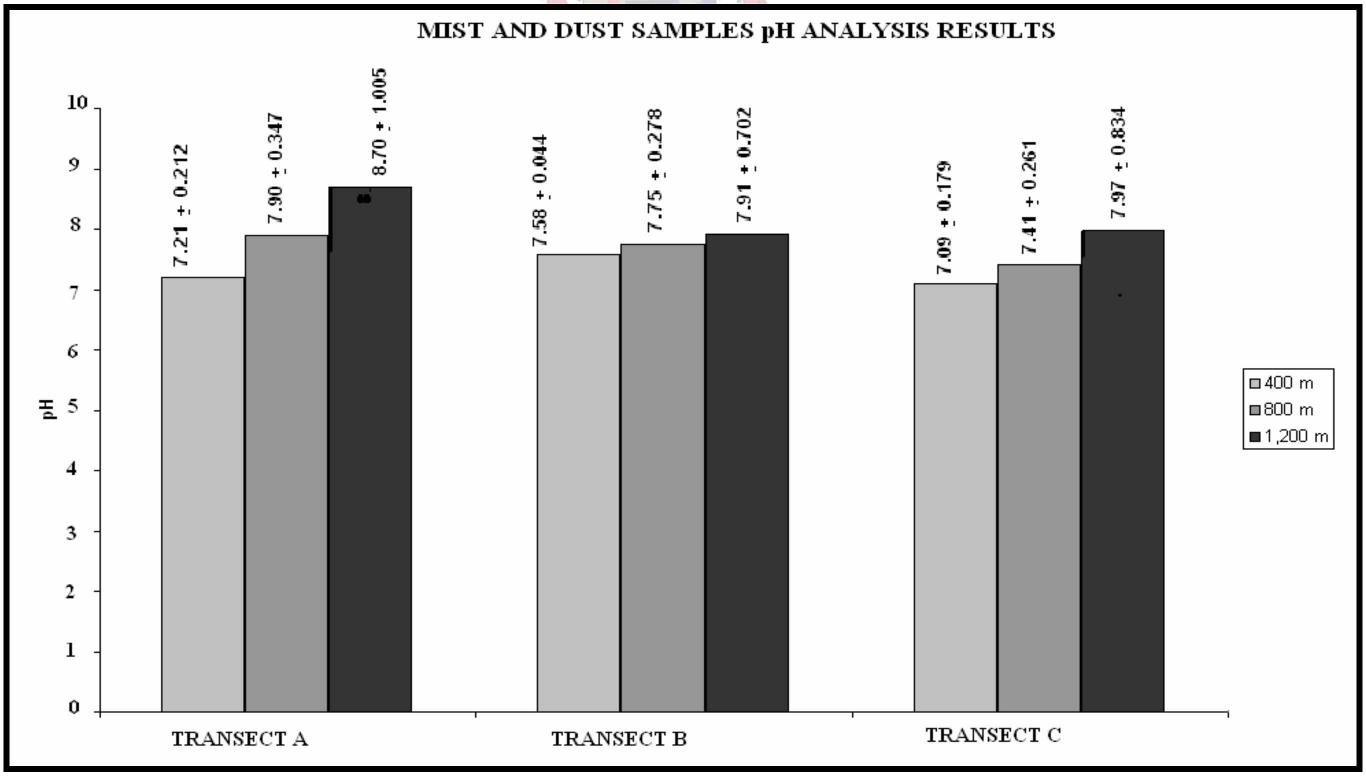


Figure 4.11: **The histogram illustrates the mean pH values from the mist and dust sample analysis. The trend is that the pH values for Transects A, B and C are increasing from source (400 m), through the middle sample plots (800 m) to the furthest sample plots (1,200 m) (Appendix 8)**

The laboratory analysis results for mist and dust, illustrates that the pH values on all three transects increased from the emission source outwards (Figure 4.11and Table 4.6). The average pH values for the various distances along the three transects (pooled data) were: 7.295 mean, with 0.260 standard deviation at 400 m, 7.684 mean, with 0.338 standard deviation at 800 m and 8.193 mean, with 0.833 standard deviation at 1,200 m. The sample size at each distance was 9. The gradient (pattern) of the pH levels consequently seems to suggest that there could be an influence of sulphate and other chemicals in the mist and dust samples, indicative of an effect of the gaseous emissions on the vegetation around the Mineral Separation Plant. The pH of the mist and dust samples at 400 m is significantly lower than at 1,200 m, but there is no significant difference between pH values at 400 m and 800 m and between 800 m and 1,200 m.

***Table 4.6:* Descriptive statistics for the mist and dust pH values for Transects A, B and C pooled on the basis of distance from the Mineral Separation Plant (Appendix 8)**

Distance	**Mean**	**Median**	**Standard deviation**	**Standard error**	**N**
400 m	7.295	7.25	0.260	0.087	9
800 m	7.684	7.60	0.338	0.113	9
1,200 m	8.193	8.28	0.833	0.278	9

The median being the middlemost value of the data sets was used as a predictor variable. Comparison of the mist and dust samples pH from the pooled data for Transects A, B and C showed a gradual increase of the median values from 400 m (7.25), through 800 m (7.60) to 1,200 m (8.28) (Figure 4.12). This suggests that there may be an effect of the acidic gaseous emissions from the Mineral Separation Plant on the surrounding vegetation.

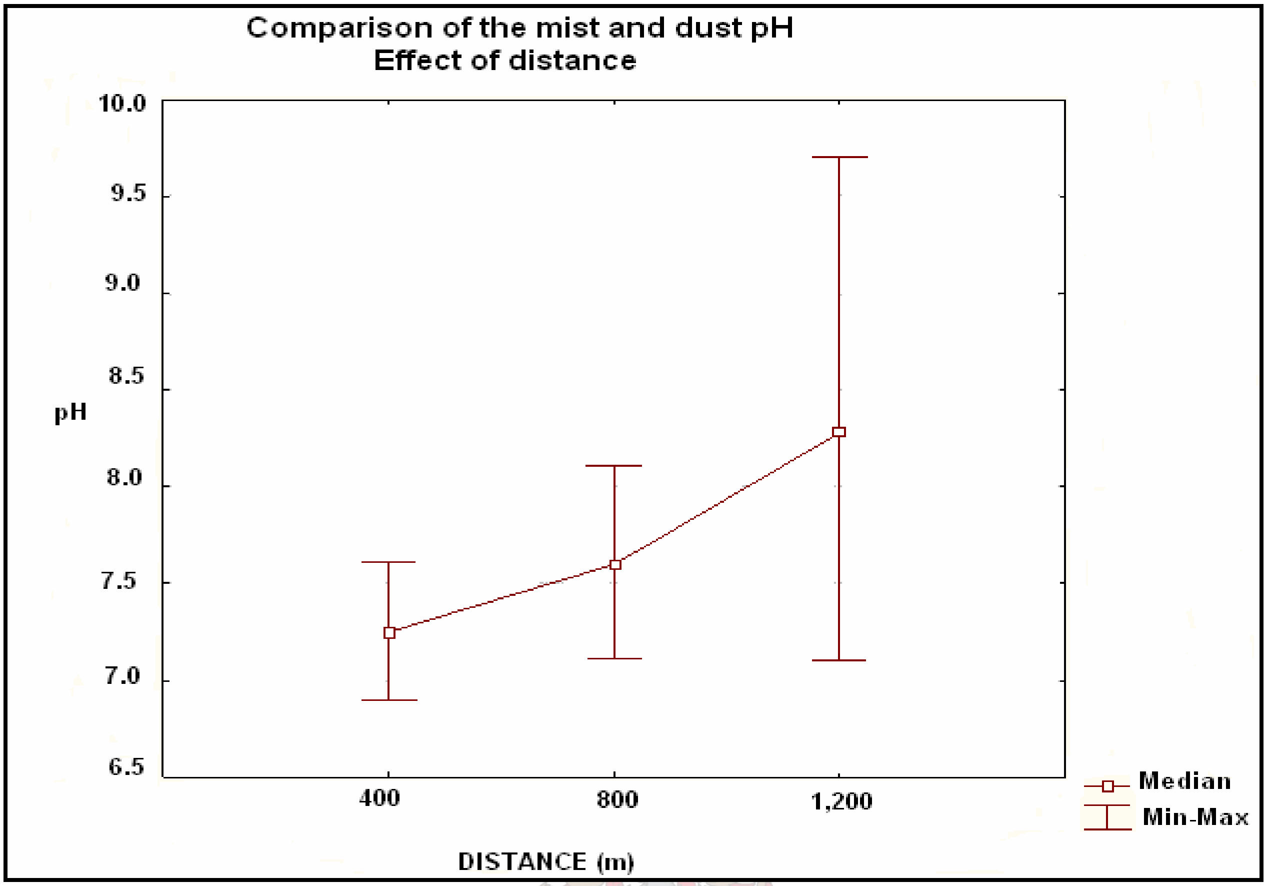


Figure 4.12: **Comparison of the mist and dust samples pH for the pooled data from Transects A, B and C on the basis of the distance from the Mineral Separation Plant, shows an increase in values from 400 m to 1,200 m (Appendix 8).**

4.4 Pearson correlation

The correlation between distance and pH on Transect A is 0.614. This level of correlation is not significant at 5%, but is significant at 10% (Table 4.6). This suggests that it is not by coincidence that the mist and dust pH on this transect increase with distance, from the emission source to the sample plots further away (1,200 m). The correlation analysis for Transect B between distance and pH is 0.353. This is not significant. This suggests that the increase in pH could be due to chance. The correlation between pH and distance for Transect C is 0.644 (Table 4.6). This is not significant at 5% but significant at 10%. The outcome suggested that there was a factor affecting the pH of the mist and dust samples. The pollutants are probably deposited in higher concentration nearer the Mineral Separation Plant (400 m), than in the areas further away (1,200 m).

From the pooled data of Transects A, B and C for the mist and dust pH values, a general correlation analysis was carried out without consideration of the transects and without consideration for wind influence. The pooled data was used to provide a representation of the mist and dust pH condition in the study area. The results are similar to those done on the basis of the transects. The statistics indicate that the Pearson Correlation Coefficient between distance from the gaseous emission source and pH is positive and significant at 10% (Table 4.7). The pH and number of plants (Appendix 10) are negatively correlated throughout the transects. The number of plants is not increasing with an increase in the mist and dust pH and distance from the Mineral Separation Plant.

***Table 4.7*: Distance: correlation coefficients and level of significance for pH of mist and dust samples plant abundance for Transects A, B and C, together with the pooled data for the different distances against pH of mist and dust (Appendix 10: Plant distribution trend for Transects A, B and C with distance from the emission source)**

Location	**Correlation**	**Distance**		**No. of plants**		**N**
Transect A	pH Pearson correlation	0.614	p = 0.079	-0.240	P = 0.534	9
Transect B	pH Pearson correlation	0.353	p = 0.351	-0.163	P = 0.676	9
Transect C	pH Pearson correlation	0.644	p = 0.061	-0.459	P = 0.214	9
Pooled data	pH Pearson correlation coefficient	0.531	p = 0.004	-0.177	P = 0.376	27

4.5 Electrical Conductivity (EC) of mist and dust samples

The electrical conductivity data of mist and dust samples were analysed to determine the effect of gaseous emissions from the Mineral Separation Plant, on the surrounding vegetation. However, from the statistical analysis outputs, no positive conclusions could be drawn regarding the effects of gaseous emissions on vegetation, using electrical conductivity as criteria (Figure 4.13). The electrical conductivity values for Transects A, B and C had appeared to have no relationship, neither decreasing nor increasing from the Mineral Separation Plant (400 m) outwards (1,200 m) (Figure 4.13). On average the electrical conductivity on Transect A (17.65 µs/m) is lower than that of Transects B (33.93 µs/m) and C (33.61 µs/m). The difference in electrical conductivity levels between Transect A and Transects B and C could be attributed to the high altitude on Transect A. The drainage system usually has an influence on the electrical conductivity.

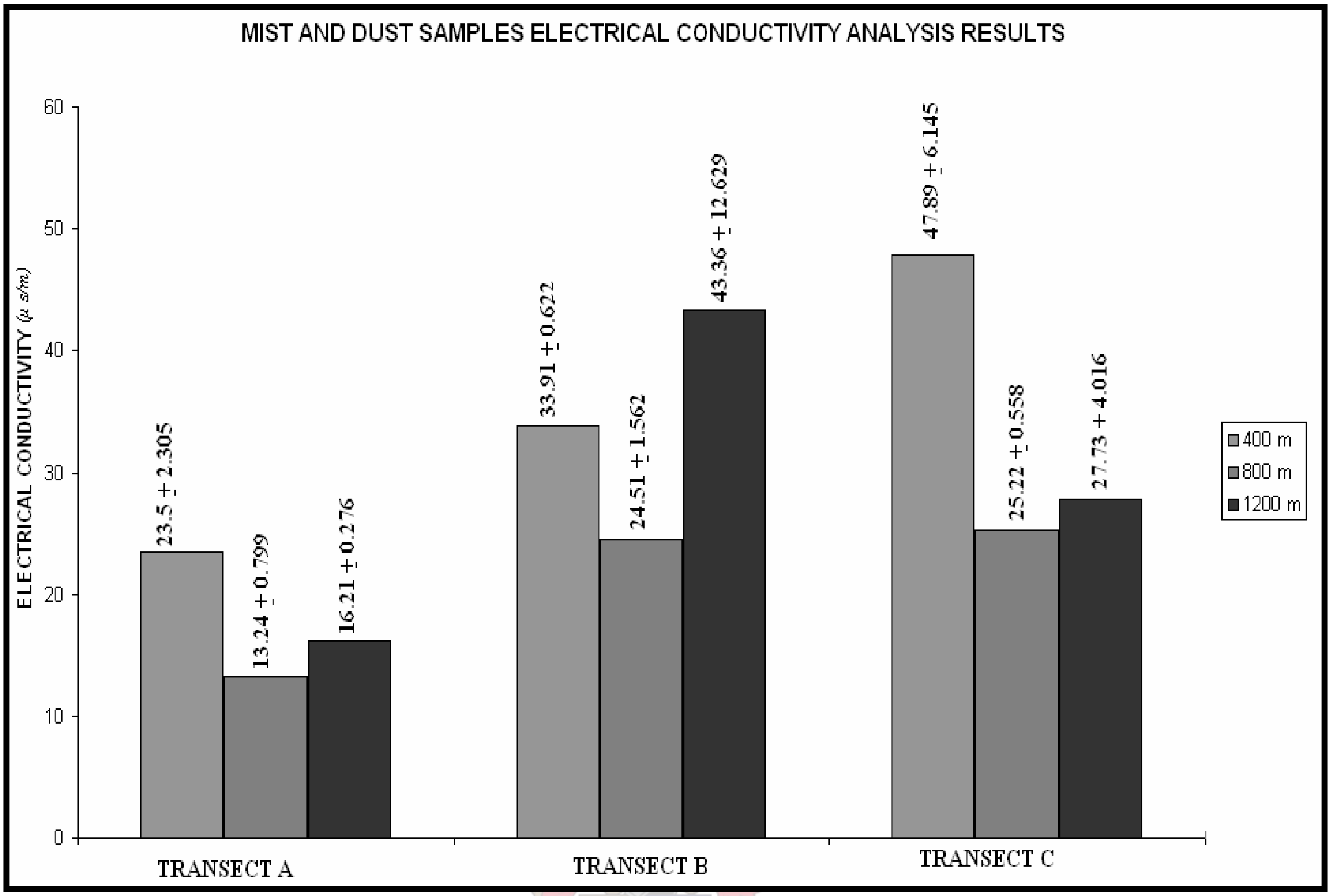


Figure 4.13: **The electrical conductivity values for mist and dust samples appear to have no relationship with distance along Transects A, B and C, from the sample plots adjacent to the Mineral Separation Plant (400 m) and further away (1,200 m) (Appendix 8)**

4.3.2.1 Two-way ANOVA mist and dust Electrical Conductivity (EC)

Two-way ANOVA was used to determine if there was any effect of electrical conductivity mean values against distance for Transects A, B and C. The analysis outcome showed a difference in the electrical conductivity mean values of mist and dust samples, especially with Transect A having the lowest values, but not significantly different from Transects B and C. The effect of both transects (direction) and distance on electrical conductivity indicated that the difference was not significant ($p = 0.411$) (Figure 4.14 & Appendix 8).

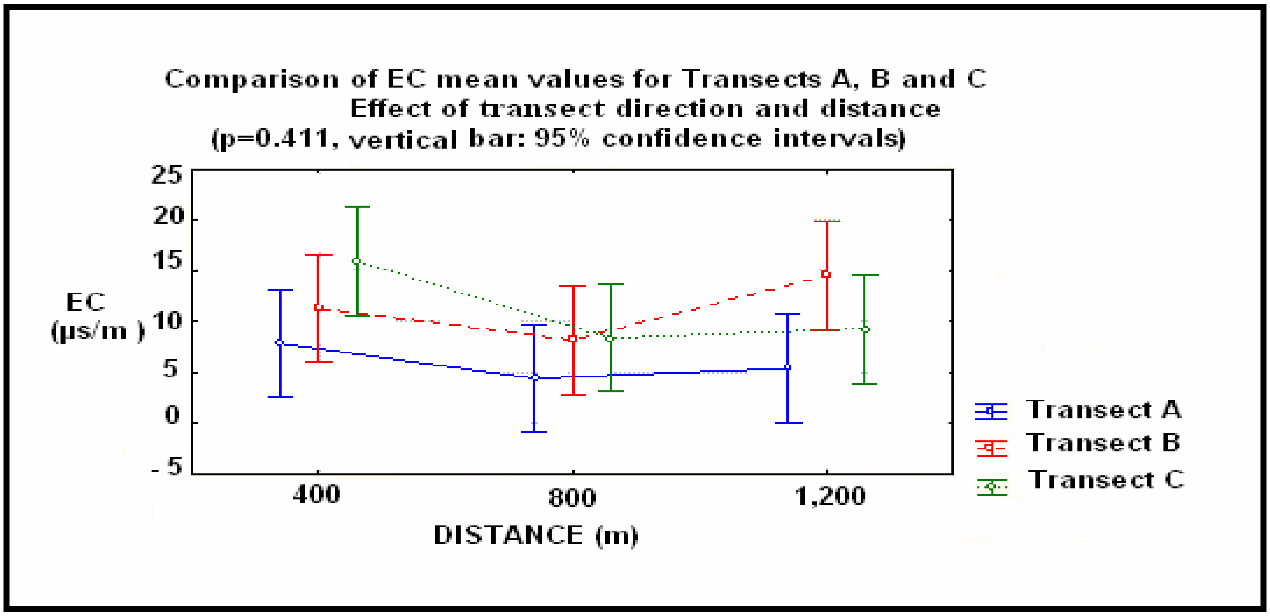


Figure 4.14: **Comparison of the electrical conductivity (EC) mean values to determine whether transect direction and distance of the sample plots from the emission source had an effect. The value of p = 0.411, at 95% confidence intervals**

The data for each transect were pooled on the basis of direction and the univariate statistical analysis performed relating to electrical conductivity. The outcome was that there was a p = 0.026 significant difference in the electrical conductivity mean values between transects (Figure 4.15 & Appendix 8). This is especially so with Transect A that had a much lower electrical conductivity mean value compared to Transects B and C, with no significant difference between them.

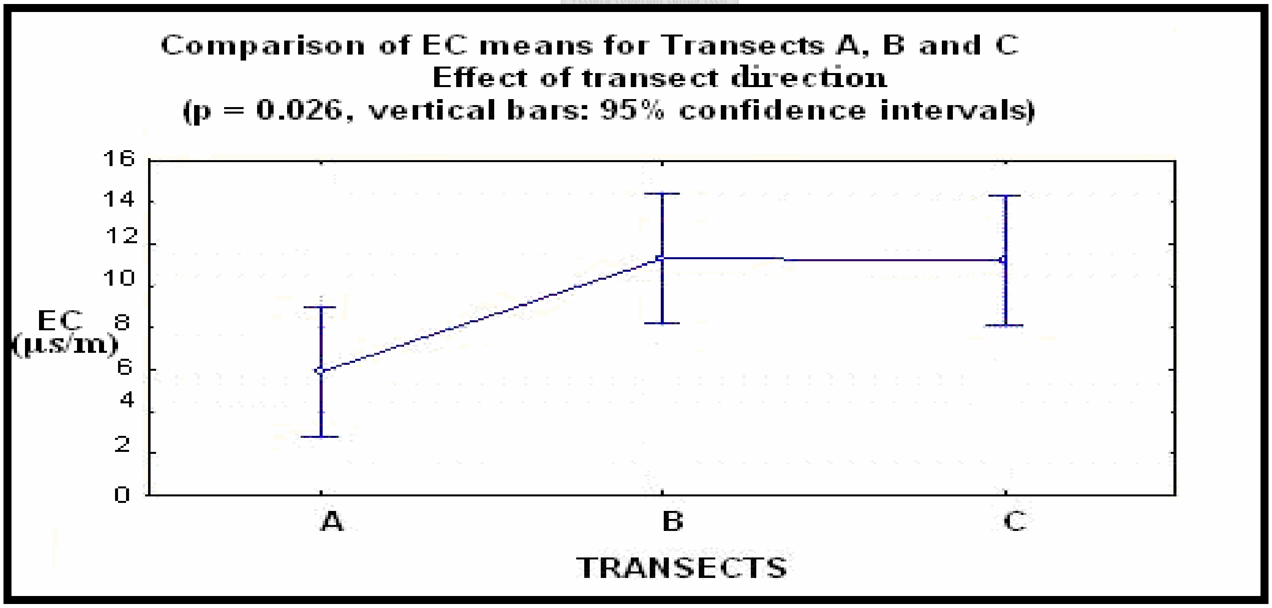


Figure 4.15: **Univariate statistical analysis to determine whether there was a significant difference between the mean electrical conductivity of the different mist and dust samples, data pooled for each transect. The vertical bars denote 95% confidence intervals, p = 0.026**

Comparison of the electrical conductivity mean values of mist and dust samples between distances, using the pooled data for Transect A, B and C, it can be seen that the difference was not significant (p = 0.101) (Figure 4.16). The electrical conductivity mean values were not significant (0.101) and the trend in the distribution showed no relationship.

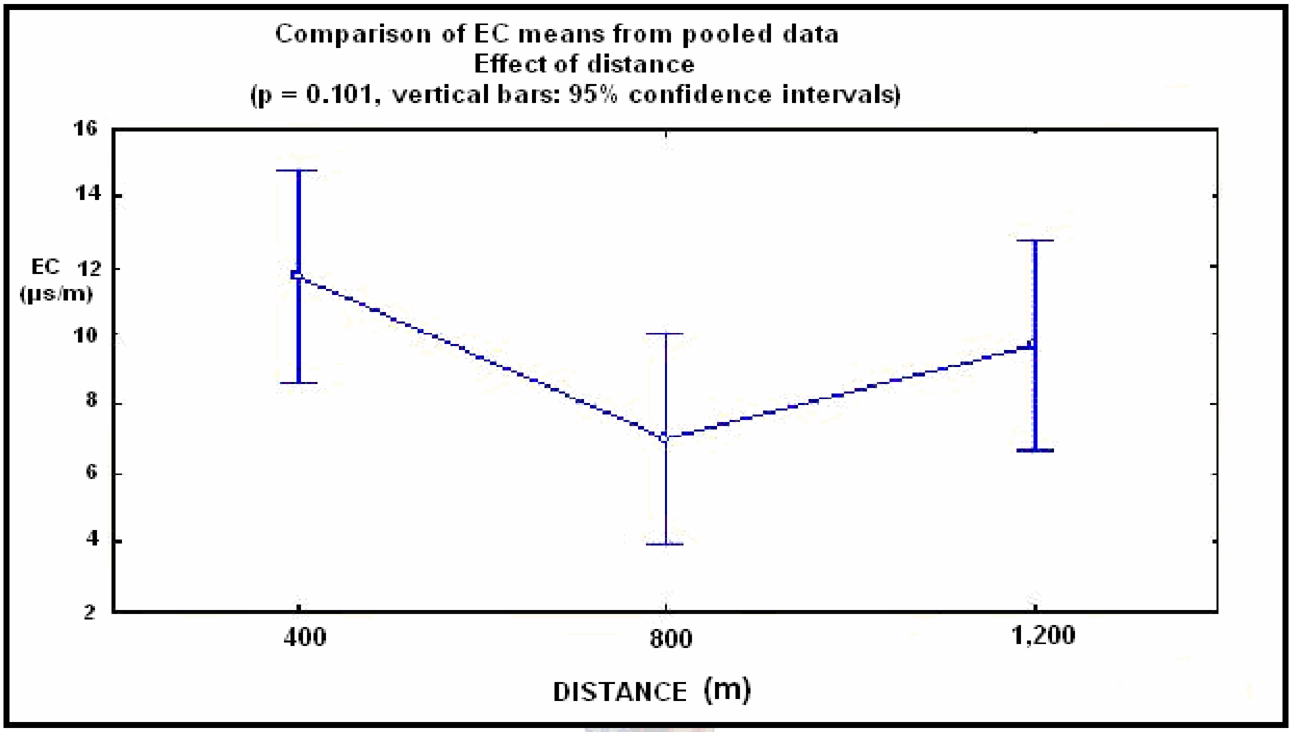


Figure 4.16: **A comparison of the electrical conductivity mean values from the pooled data of the mist and dust samples, against the distance from the gaseous emissions source. P = 0.101 and the vertical bars denotes the 95% confidence intervals**

4.3.3 Mist and dust sulphate concentration

The mist and dust sample analysis for sulphate concentrations was an indirect way of attempting to quantify the impact of the acidic gaseous emissions on the ecosystem. The results of the ion chromatography analysis of the mist and dust samples for sulphate (Table 4.8) revealed that the sulphate concentration values were decreasing away from the gaseous emission source at the Mineral Separation Plant. The wind movement along the transects, naturally effects the deposition of pollution particulate matter in a designated pattern, with higher concentrations expected nearer the emission source. The decreasing trend in the sulphate concentration of mist and dust samples suggests an effect of the gaseous emissions on the ecosystem. The trend may not be highly pronounced due to the high smoke stacks at the Mineral separation Plant that are intended to deposit the main pollution plume more than 1 km away from the emission source.

4.3.3.1 Descriptive statistics

On average Transect C had the highest soluble sulphate concentration in the mist and dust samples, whereas Transect B had the second highest and Transect A the lowest (Table 4.8 & Appendix 8). This trend could be attributed to the high plant abundance along Transect A that may have interfered with the pollutant particulate matter movement by the wind. Although, the large standard deviations denotes that the means for the mist and dust soluble sulphate concentrations may not be significantly different.

Table 4.8: **Descriptive data for soluble sulphate concentration in mist and dust samples, for Transects A, B and C**

	Mean (mg/litre)	**SD**	**SE**	**Minimum**	**Maximum**	**N**
Transect A	49.378	45.619	15.207	21.5	132.9	9
Transect B	81.067	31.423	10.474	37.8	120.8	9
Transect C	88.511	55.281	18.427	39.1	195.3	9

4.3.3.2 Two-way ANOVA mist and dust sulphate concentration

The aim was to determine if the differences in the sulphate concentration in the mist and dust samples per transect and distance from the Mineral Separation Plant had happened by chance or not. The mean values for all the three transects are higher at 400 m compared to the values at 800 m and 1,200 m (Figure 4.17). The vertical bars for Transects A and B have overlapped at 400 m, signifying similar mean sulphate concentration. Transect C had a higher mean value at 400 m, with a very small overlap in the vertical bar with Transects A and B. The whole trend of the mist and dust samples sulphate concentration had an abrupt drop from 400 m to 800 m, with a further gradual decrease from 800 m to 1,200 m. The differences in the mist and dust mean sulphate concentrations are not significant (Figure 4.17).

The statistical probability (p) for the possible interaction between transect direction and distance from emission source was (p= 0.143) which indicates a significance of approximately 15% (Figure 4.17). There was no significant difference in the mean values of mist and dust samples sulphate concentration at each distance for all the three transects at 5%, but significant at 15%. The statistical outcome suggested that there may be an effect of the gaseous emissions from the Mineral Separation Plant, on the surrounding vegetation.

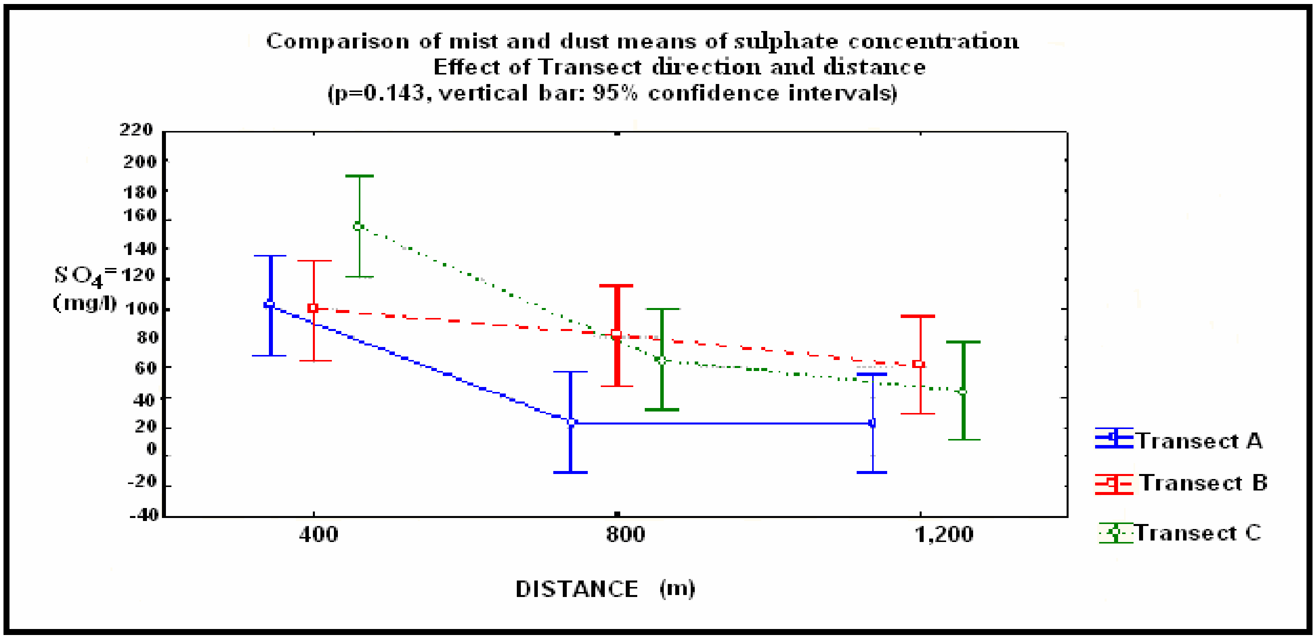


Figure 4.17: **The graphs show a comparison of the mean sulphate concentration between transects and distance. The vertical bars signify 95% confidence intervals (Appendix 8)**

Using the univariate test of significance on data pooled per transect, the outcome showed that there was a significant difference in mean sulphate concentration between transects A and C (p = 0.018) (Figure 4.18). Transect A had the lowest mist and dust sulphate concentration mean value despite being directly downwind (east) of the emission source.

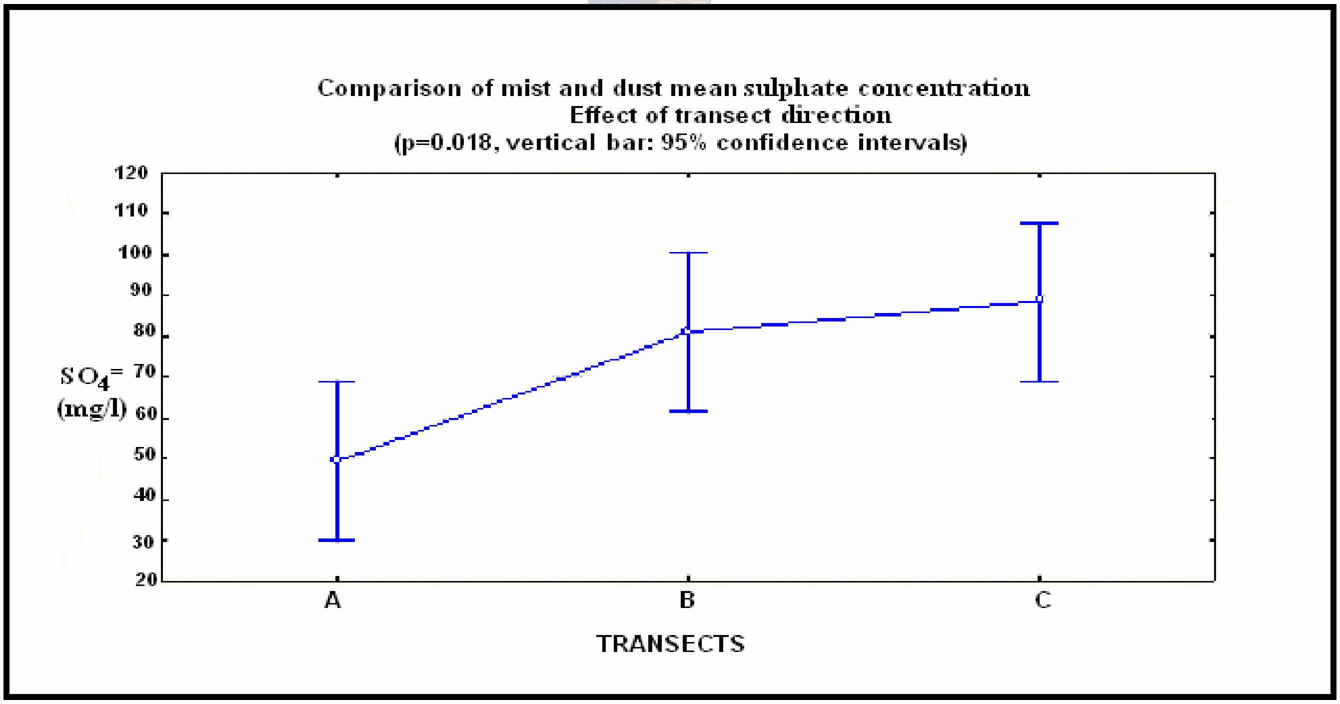


Figure 4.18: **Comparison of the sulphate concentration mean values between Transects A, B and C. The value of p=0.018, vertical bars denotes 95% confidence intervals**

A comparison of the mist and dust mean sulphate concentration between distances shows a decrease from 118.8 ± 31.6 mg/litre (400 m), to 57 ± 30.1 mg/litre (800 m), to 43.1 ± 19.6 mg/litre (1,200 m). The value of $p < 0.01$ denotes a significant difference in sulphate concentrations between 400 m and 1,200 m (Figure 4.19 & Appendix 8). The trend suggests potential effect of gaseous acidic emissions from the Mineral Separation Plant on the ecosystem

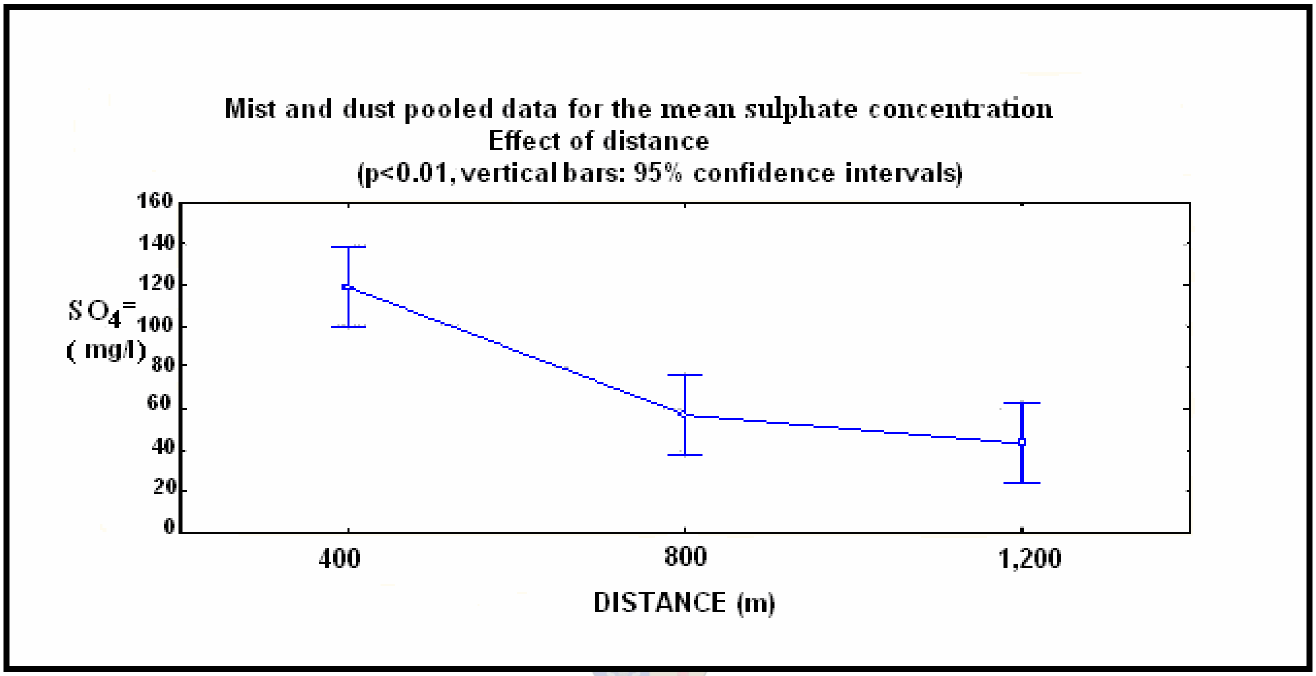


Figure 4.19: **Comparison of the mist and dust mean sulphate concentration between distances, from the gaseous emission source. The graph shows the value of p<0.01 and the vertical bars denote 95% confidence intervals**

4.6 Plant foliar sulphur content

The results from the determination of plant foliar of sulphur content (Table 4.9) demonstrated a weak trend of decrease in the sulphur content (%) of plant leaves, from the sample plots nearer the Mineral Separation Plant (400 m), through the middle sample plots (800 m) to those sample plots further from the emission source (1,200 m). There is no significant difference between the values of the plant foliar sulphur content from 400 m to the sample plots further away at 1,200 m. This trend was shown on Transects A and B for *Othonna cylindrical* and *Salsola arborea* respectively (Appendix 9). However, the pooled data on the plant foliar sulphur content on the basis of distance, for Transects A, B and C gives the average sulphur content as 0.290 % at 400m, 0.264% at 800 m and 0.232% at 1,200 m (Table 4.9). The data for the plant foliar sulphur content were pooled for Transects A, B and C in order to obtain a general trend of the foliar sulphur content in the study area. The trend showed that there was a gradient in the foliar sulphur content, with a decrease from the acidic gaseous emission source (400 m) outwards (1,200 m). The difference in the plant foliar sulphur content from 400 m through 800 m and further at 1,200 m was not significant.

Table 4.9: **Plant foliar determination of sulphur content (percentage of leaf sample dry matter) results, with reference to the Mineral Separation Plant gaseous emissions. Samples were taken at three different distances along Transects A, B and C. Only the plant species with samples at 400 m, 800m and 1,200 m distances from the Mineral Separation Plant were considered in the calculation of the mean values (Appendix 9)**

Transect	**Plant species**	**Sulphur content (%)**					
	Distance from source	**400 m**	**800 m**	**1,200 m**	**Mean**	**Standard deviation**	**Standard error**
A	*Othonna cylindrica*	**0.382**	**0.364**	**0.310**	**0.352**	**0.038**	**0.022**
A	*Roepera morgsana*	0.864	0.813	-	-	-	-
A	*Ruschia* sp.	0.186	-	-	-	-	-
B	*Salsola arborea*	**0.220**	**0.203**	**0.153**	**0.192**	**0.035**	**0.020**
B	*Othonna cylindrica*	0.464	-	-	-	-	-
C	*Salsola arborea*	**0.267**	**0.224**	**0.232**	**0.241**	**0.023**	**0.013**
Pooled data means		**0.290**	**0.264**	**0.232**	**0.262**	**0.029**	**0.017**
Standard Deviation		**0.091**	**0.086**	**0.079**			

Transect A

The individual plant foliar samples of *Othonna cylindrica* collected from Transect A sample plots showed a decrease in the percentage of foliar sulphur content, from the gaseous emission source at the Mineral Separation Plant (400 m) to the plots further away (1,200 m). At the distance of 400 m the sulphur content was 0.382 % with, 0.364% and 0.310% at 800 m and 1 200 m respectively. This trend in the foliar sulphur content (%) suggests that there was an influencing external factor in the ecosystem. The sulphur (pollutant) deposition pattern in this ecosystem suggests that the gaseous emission from the Mineral Separation Plant may have an effect on the surrounding vegetation, although the plant sulphur values from 400 m through 800 m and further away at 1,200 m are not significantly different.

Transect B

The foliar samples of *Salsola arborea* collected from Transect B indicateed a decrease in sulphur content (%), from the permanent sample plots near the gaseous emission source (400 m) outwards (1,200 m) (Table 4.9). At the distance of 400 m the sulphur content was 0.22% with, 0.203% and 0.153% at 800 m and 1,200 m respectively. This outcome suggested that there may be an influence of sulphur from the emission source at the Mineral Separation Plant to the adjacent vegetation.

Transect C

From the *Salsola arborea* foliar samples collected from the permanent sample plots along Transect C, the results were that the foliar sulphur content (%) was higher near the Mineral Separation Plant (400 m) as compared to the samples collected further away (1,200 m) (Appendix 9). At the sample plots at 400 m distance from the Mineral Separation Plant, the foliar sulphur content was 0.267%, at 800 m it was 0.224% and a rise to 0.232% further away at 1,200 m. This erratic trend does not clearly show any influence on leaf sulphur content (%) from the gaseous emission source along this transect.

CHAPTER 5

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion

Gaseous emissions have a negative effect on the quantity and quality of plant and the composition of the plant communities (Dässler and Börtitz 1988). According to Unsworth and Ormrod (1982) concentrations and spatial distribution of pollutants to which plants are exposed must be defined, to establish potential effects and possible environmental management controls. In the present study, various ecological components were assessed in order to characterize the impact of the gaseous emissions from the Namakwa Sands Mineral Separation Plant, on the surrounding vegetation. The outcome of the discussion has significant implications for decision making in an effort to contribute to conservation of the Succulent Karoo ecosystem. The installation of the high smoke stacks at the Mineral Separation Plant are intended to deposit the main pollution plume more than 1 km away from the emission source, such that the occasional deposition episodes are the only one that may be affecting the immediate surrounding.

The three transects (A, B and C) may have different pollution inputs from the Mineral Separation Plant, because of the prevailing wind conditions. The soil acidity, mist and dust samples sulphate concentrations and the plant material sulphur content decrease from the Mineral Separation Plant outwards on all the three transects. Soil pH measurements increases with distance from the emission source for the southeast and south transects, but decreases with distance on the east transect. Sampling in this pilot study was insufficient to determine whether this pattern was best explained by the prevailing westerly wind or by the presence of hilly topography 700-1,200 m from the emission source on this transect. The high smoke stacks at the Mineral Separation Plant (Figure 2.1and chapter 1, paragraph 2 of part 1.4) are intended to spread and dilute the pollution plume. The area affected by the pollutants is therefore likely to be much wider than the 1,200 m radius covered by the pilot study area.

5.1.1 Vegetation assessment

In the present study the focus was on the effect of the gaseous emissions from the Mineral Separation Plant on the adjacent vegetation. The relative abundance of plant species and the condition of the different species is a useful indicator of the extent and degree of environmental impact from elevated levels of pollutants in the ecosystem (Read and Pickering 1999). The best approach in understanding the structure of plant communities is by comparing them along environmental stress gradients (Callaway and Walker 1997). In this study, plant species abundance was compared along the radiating transects from the Mineral Separation Plant outwards. The area adjacent to the Mineral Separation Plant had more plants and a higher proportion of dead plants. Polluted environments tend to support a higher density of plants than may be possible in the absence of the pollutants (Begon *et al.* 1996). One possible reason for this is that recruitment of seedlings of weedy or short-lived plant species such as *Atriplex lindleyi* was greater in polluted areas, probably because of reduced competition caused by mortality of perennials or older plants. Pioneer species have a positive response to disturbance be it physical, chemical or biological ones, as compared to climax plant species (Zonneveld 1982). The percentage of plant deaths decreased from the pollution source at the Mineral Separation Plant, to the furthest distance in the study area. From the pooled data for all the three transects, the dead plants were 28% ± 5.03 at 400 m, 19% ± 6.11 at 800 m and 10% ± 4.36 further away at 1,200 m. There was no significant difference in the mean values of the proportion of dead plants per distance along all the three transects. However, the decreasing trend in the values of the proportion of dead plants along the transects, suggested that there was an effect of the acidic gaseous emissions from the Mineral Separation Plant, on the surrounding vegetation. According to Vike (1999) pollution dispersal pattern and distribution of damaged plants are determined by the dominant wind direction from emission source. In the present study the trend in the occurrence of the dead plants is following the wind direction (Figure 4.1). Despite the use of the pooled data from the three transects, the effect of the prevailing winds was noticed in the decrease of the number of dead plants from the emission source (400 m), outwards (1,200 m). In the study area, the higher number of dead plants adjacent to the Mineral Separation Plant (400 m) may possibly be due to the gaseous emissions from the processing plant. It is recommended that the release of the fumes in the atmosphere be minimised, to conserve the ecosystem around the Mineral Separation Plant.

According to Du Toit (1998) determination of the canopy-spread cover by perennial plant species provides a dependable botanical species composition parameter of the Karoo permanent vegetation.

The canopy-spread percentage of a specific area within the Karoo, gives an indication about the type of plant species likely to occur in the community. In this study the crown cover and composition varied with altitude, slope and aspect. However, one has to be mindful of the fact that other ecological factors such as soil pH, erosion and sample plot position in relation to the existing hills in the study area (Appendix 13), could have an influence on the vegetation characteristics. Transect A had a higher crown cover percentage (Appendix 7) and was dominated by plant species such as *Orthona cylindrica* and *Salsola arborea*. Transect C had a low crown cover percentage and was dominated by plant species such as *Atriplex lindleyi*. In plant communities, individual species do not occur at random at any scale, especially in the arid regions. According to Lamacraft *et al*. (1983) plant distribution follows a gradient of some major ecological factor in the ecosystem.

5.1.1.1 Potential bioindicator plant species

All the plant species in each permanent sample plot were counted and their physiological conditions assessed (live or dead). It was from these plant species that the potential bioindicator plant species were selected. The two important criteria for the potential bioindicator plant species selection were: wide distribution in the study area and the apparent sensitivity towards air pollutants based on the proportion of plant deaths. Plant bioindicator species must occur over a wide range of habitat, and their ecological and physiological characteristics, such as seasonal leaf shedding must be well known (Pullin 2002). The concept that the correlation of the plant bioindicator characteristics with the environmental factor must have at least an indirect cause (localised), must be accepted. It is not often easy to measure the direct effects of pollution, due to the complexity of the ecosystem dynamics (Zonneveld 1982). Moreover, the biological efficacy of the potential bioindicator plant species must be considered, which includes their reliability with respect to a predictable response towards ecological changes, representative distribution and sensitivity towards ecological disturbances (McGeoch 1998).

Plant species best suited as bioindicators are those whose reaction to stimuli can be correlated to the environmental factors, such as pollution, stress and site factors (Dässler and Börtitz 1988). As McGeoch (1998) indicated, the application of plant bioindication in monitoring programmes must be done cautiously, with the use of the most sensitive plants. This is because cumulative effects of pollution may only become more apparent after the thresholds are exceeded (Treweek 1999). Hence, the characteristics of good bioindicator plant species depend on their response to the environmental stress being investigated (McGeoch 1998). Some plants show obvious injury relatively far from the source; these are considered to be highly sensitive. The most tolerant plant species show no visible injuries, even when they are adjacent to the pollution point source (Weinstein and Davison 2003). However, in complex habitats or extensive sites, there is a requirement to find plant species whose behaviour and responses to environmental stimuli are indicative of the community as a whole. These species should be understood well enough to be used as ecological 'litmus-paper' (Goldsmith 1991).

Plant species such as *Atriplex lindleyi, Psilocaulon* sp. and *Asparagus* sp. were deselected from the list of potential bioindicator plant species, due to their concentration in ecologically disturbed zones. Although they were distributed at least in all the transects, their populations were higher in the areas with artefacts, which included patches of loose soil from excavated furrows and previous construction sites. Moreover, *Atriplex lindleyi* is a short-lived invasive alien plant species, which tend to be dominant only in unnatural environments. The following plant species were selected as bioindicators: *Galenia fruticosa, Lampranthus suavissimus, Lycium ferocissimum, Ruschia fugitans,* an unidentified *Ruschia* sp. and *Salsola arborea. Galenia fruticosa, Lampranthus suavissimus, Lycium ferocissimum* and the unidentified *Ruschia* sp. had high incidences of plant deaths in the sample plots nearer to the gaseous emission source (Table 4.3), suggesting a correlation with high sulphur content of the plant leaves. Tolerant plant species do not show any measurable change emanating from small or medium scale impacts from external stimuli such as pollutant inputs (Hilty and Merenlender 2000). Moreover, these bioindicator plant species are expected to be used in ecological monitoring, for repeated evaluation of the state or health of the plant community, in response to the external stimuli (Hinds 1984). In the present study the external stimuli of concern are the acidic gaseous emissions from the Mineral Separation Plant.

The bioindicator plant species selected in this study were effective, as the proportion of the dead plants in the area is decreasing from the sample plots nearer the emission source outward (Table 4.3). This suggests that the selected bioindicator plant species were responding to the decreasing gradient of pollution input from the Mineral Separation Plant outwards.

5.1.1.2 Integrated approach

Comprehensive field data, laboratory analysis and application of various statistical procedures make it possible to integrate data and determine the effects of gaseous emissions on the ecosystem. In essence, the outcome of the preliminary plant species composition assessment has provided information on the spatial distribution of the various plant species as well as the physiological response to the gaseous emissions and other environmental stimuli. Inputs of chemicals may be low at a given time; however, accumulation over the years may result in enhanced concentrations causing risk to the various plant species in the ecosystem (Stefan and Herman 2004). The present study brought out details about the major components of the ecosystem, such as soil, wind, mist and dust, and various plant species, the knowledge of which led to a better understanding of the possible effects of the gaseous emissions from the Mineral Separation Plant on the surrounding vegetation.

5.1.1.2.1 Canonical Correspondence Analysis (CANOCO)

The linear combination of variables into homogenous clusters in the CANOCO analysis is mathematically viable, making it a challenge to discern the ecological importance of the correlations (Tabachnick and Fidell 1989). The outcome of the CANOCO analysis illustrate that the natural systems respond to external stimuli and the influence of the surrounding ecological factors in specific ways (Treweek 1999). Therefore, we should take the opportunity to see the factors at play in the ecosystem; this will make it easier to understand the effects of the gaseous emissions on vegetation. It is quite vital to evaluate abiotic and biotic assemblages in the study area, before deducing whether pollution problems are at play in the ecosystem (Hinds 1984). The various ecological components evaluated have given an insight into some of the factors influencing ecosystem dynamics in the study area. These components were:

1. Elevation: the correlations of the various ecological factors demonstrated that elevation had an influence on the various components of the ecosystem, especially the most prominent vegetation parameters such as plant abundance and the proportion of dead plants (Figure 4.3). Topographic gradients have an effect on the groundcover arrangement in a landscape (Canton *et al.* 2003). In the present study Transect A is at a higher elevation and had higher plant abundance levels compared to the lower lying B and C transects. Landscape has a significant influence on soil physical properties and in turn affects plant growth (Rezaei and Gilkes 2005). Elevation has an influence on vegetation, apart from the external stress caused by the acidic gaseous emissions

from the Mineral Separation Plant. A change in altitude implies a hilly landscape and gradients in soil depth and soil chemistry. On Transect A the soil pH decreased with an increase in altitude.

2. Sulphur: Sulphate concentration in mist and dust samples was shown in the CANOCO output (Figure 4.3) as one of the influencing environmental factors on the umber of dead plants in the ecosystem. Evaluation of the potential effects of pollution requires an understanding of the pathways by which they enter and react with the ecosystem (Cape *et al.* 2003). Deposition of sulphur in the environment stresses ecosystems quite significantly through disruption of the plant metabolic pathways (Gbondo-Tugbawa and Driscoll 2002). In the present study, this is reflected in the high proportion of dead plants near the gaseous emission source and a decreasing trend further away from source.

3. Slope and erosion: these were moderately ranked in the CANOCO process. The medium sizes of their arrows (Figure 4.3) indicate that they are recognisable factors in the ecosystem, with a slight influence on vegetation in the ecosystem. A north-facing slope of the hill in the study area (Transect A) supported more plants than the other transects. North-facing slopes have higher soil nutrient pool and general fertility as compared to the south-facing slopes (Rezaei and Gilkes 2005). Erosion in the study area had a negative influence on the plant abundance in that some eroded areas had gullies and could not support plant growth. Plant species abundance increases towards the more favourable parts of the environmental gradients (Holmgren *et al.* 1997).

4. Soil acidity: the soil pH has been projected as having a moderate influence in the ecosystem. There is a gradient of pH values increasing from the areas near the gaseous emission source outwards. This is more pronounced on Transect B whereas along Transects A and C the pH trend does not show a strong relationship with distance from the Mineral Separation Plant, possibly because it is influenced more by soil type than by the emissions. Most reactions of the soil components or its biological inhabitants are sensitive to soil pH (Balon *et al.* 2003). According to Brady (1990) soil pH has a significant influence on plant and microbe nutrient availability.

5. Soil colour and texture: these had very short arrows in most areas of the CANOCO output, indicative of their low influence on vegetation in the ecosystem. Areas with coarse soil texture (pebbles) have fewer numbers of plants due to lack of the soil nutrients. According to Brady

(1990) soils with coarse grains have no water-holding capacity. In the study area, small quarzt pebbles overlying a thin topsoil layer, can be seen in the northwest of the Mineral Separation Plant, dominated by small succulent plants such as *Argyroderma congregatum* (Desmet and Helm 2003).

6. Plant parameters: these are prominently projected in the CANOCO output, indicative of their determinant effects in the ecosystem. These parameters included plant height, crown diameter and crown density. The plant characteristics in a community are influenced by the various environmental stimuli operating in the ecosystem, such as the gaseous emissions from the Mineral Separation Plant and the frequent wind episodes. Moreover, plant species do not colonise specific niches at random, they are influenced by the dynamics within the ecosystem (Silvertown and Wilson 1994).

5.1.1.2.2 Clustering Analysis

The clustering procedure provided an insight into the correlation of various ecological components of the ecosystem among each other. This is an excellent method of identifying observational units for site classification (Hinds 1984). The sample plots in the study area were grouped according to the common characteristics of the ecosystem, such as plant height, plant crown diameter and soil acidity. The clustering method was applied to provide preliminary information about the permanent sample plots with similar ecological characteristics. According to Yearwood and Bigirov (2004) clustering is the application of unsupervised classification of patterns into clusters based on their similarities. The effects of various abiotic factors such as soil acidity in plant communities are expressed in each permanent sample plot, in the assessed plant height, and crown cover (percentage) (biotic factors). Sample plots C5, C9, C6, C8 and C4 are grouped together with shorter dendrogram links (Figure 4.4) This denotes similarities in the ecological characteristics of these plots. Sample plots A1, B4, C3 and C1 are grouped together by long dendrogram links, suggesting that the underlying ecological factors linking them together such as plant height, sulphur concentrations, soil pH, slope and erosion may not be distinctly observable. Sample plots C1 and C5 are far apart, due to the differences in the overall ecological characteristics. Physically, the sample plots may be in the same wind direction, but the number of artefacts and eroded patches in the present study area could influence the soil pH, or any other component of the ecosystem, causing plants to respond in an unexpected pattern, compared to plants in the adjacent sample plots. The ecological factors influencing plant communities in various clusters, denotes a predictable association under particular sets of environmental conditions (Begon *et al.* 1990). This information is vital in explaining the response of various plant communities to measured ecological factors, such as sulphur accumulation, soil pH, slope and erosion (abiotic factors).

Moreover, changes in the ecosystem over time can easily be identified with the application of clustering methods. Plant communities tend to remain stable over a range of environmental conditions, but if threshold conditions are exceeded they rapidly change to a new steady state (Gosz 1992). The sample plots which appear in the same clusters may not do so during the monitoring period, due to the dynamics in the ecological components within the ecosystem. However, these correlations have specific ecological importance within the ecosystem. One needs to physically observe whether the clustered sample plots support similar plant communities. The information on plant species distribution patterns is vital in monitoring plant conditions and responses to the effects of the pollution from the Mineral Separation Plant. According to Laurence (1998) sufficient exposure of plants to pollutants retards growth of individual plants and modifies normal parasite-plant interactions, resulting in shifts in community plant composition, change in genetic structure, biodiversity and overall impaired ecosystem. Negative modification of plants community structure by pollutants is connected with wide distribution of sensitive species and a change in the plant succession processes (Alexeyev (1995).

5.1.2 Soil responses

The addition of plant materials underneath the shrub canopy enriches the humus component of the soil, thus influencing the pH levels. Moreover, the birds and other herbivorous animals are attracted to the shrubs and their frequent presence provides additional materials to the area through droppings and food litter. Hence, these materials provide more humus to the soil underneath the shrub canopy. Humus is composed of complex materials along with those that are synthesized by the soil micro-organisms. Humus together with the clays has an influence on the physical and chemical properties of the soil (Brady 1990). Humus is an important component of nutrients, which get released slowly by the decomposition process. It provides the water retention and cation exchange capacity of the soil (Slingsby and Cook 1988). Moreover, shrubs create a microclimate underneath the canopy, which in turn influences the physiological and chemical composition of soil. According to Belsky *et al.* (1989) shrubs affect the microclimate underneath by interception of solar radiation and reduced evaporation, hence soil microbial biomass are elevated as compared to the open space. Humus creates fertile soil conditions and improved soil moisture retention capacity (Brady 1990).

In the present study the implication of the pH values being lower in the open spaces and higher underneath the shrubs was that plants play a significant role in regulating the impacts of some abiotic environmental factors, such as pollution on the ecosystem. Microbial symbionts have a protective effect on plants, against soil abiotic stresses such as toxic molecules (Selosse *et al.* 2004). High level of sulphur deposition reduces microbial biomass and alters functional diversity of the soil micro-organisms (Klumpp *et al.* 2003). However, this is a complex situation in the sense that, despite this protective characteristic of plants, they also get negatively affected by elevated concentrations of pollutants in the environment. The high standard deviation (0.961) of the pH from underneath the shrub canopy could be attributed to the variation in the influence of the different plant species on soil. These differences are as a result of plant size, architecture, age, foliar chemical composition, root depth, productivity and other factors. The lower standard deviation (0.457) of the pH in the open space could be a result of the uniformity in the concentrations of pollutants that accumulate on the soil surface. Moreover, the open spaces have less buffering capacity, but accumulate the acidifying chemicals directly on the surface. Moreover, the soil pH in the open spaces had shown an increasing trend in the soil pH from the sample plots near the Mineral Separation Plant 400 m to the sample plots further away 1,200 m, were as the soil pH trend underneath the shrubs was erratic.

The pH gradient of the samples collected from the open space increased with distance from the gaseous emission source outwards. This could be attributed to the influence of the supposed high sulphur concentrations in the sample plots nearer the Mineral Separation Plant, as compared to the sample plots further away (1,200 m) from the emission source. In essence, industries that emit sulphur dioxide are among the most polluting sectors of the economy (Elbir and Muezzinoglu (2004).

The contour map (Figure 4.7) for the soil pH gradient suggested that there was an effect of the gaseous emissions from the Mineral Separation Plant on vegetation, using pH as a proxy. Generally, the pH increased from the sample plots nearer the Mineral Separation Plant, outwards. The trend may not be distinct, due to the high smoke stacks that have been installed at the Mineral Separation Plant to deposit the main pollution plume more than 1 km away from the emission source. The deposition of the pollutants in the immediate surrounding of the Plant may be from the occasional episodes.

5.1.3 Mist and dust responses

Without dependable mechanisms for monitoring pollution levels in the atmosphere and the ecosystems, it would be impossible to ascertain whether the pollution problem is improving or getting worse. The Modified Wilson and Cooke (MWAC) sampler provided a simple, but efficient mechanism to capture dust particles and mist, for analysis of chemical concentrations and composition. The advantage of using the MWAC apparatus is that it captures the particulate matter which is in transit, providing differences in the pollutants concentrations at various distances from the emission source as well as windblown dust from the soil. Considering that there are many factors that can influence the results of the soil chemistry in this environment, the mist and dust capture was expected to provide a more dependable result for the pH, and $SO_4^{=}$ concentrations along transects. Atmospheric particulate matter (PM), have considerable effect on vegetation and ecosystems by depositing the injurious chemical constituents (Grantz *et al*. 2003).

It should be noted that obstruction of the wind velocity results in deposition and subsequent accumulation of the substances contained in the mist and dust. As the vegetation intercepted the pollutants one may expect the deposition of the sulphate to be higher nearer the Mineral Separation Plant, compared to the areas further away (1,200 m) along the transects. This is because the particulate matter became reduced by deposition as the wind passed through the shrubs and other objects along the way. According to Goossens and Offer (1999) there is a direct proportional relation between the size of the particles deposited and the wind speed. This phenomenon is more pronounced in this environment, because much of the particle movement is confined to the lowest levels over the surface, as the particulate matter is transported mainly by the sea breeze. Hence the shrubs, even though they are short, provide obstructions along the wind path, resulting in a higher accumulation of particles at the beginning of the transects, near the Mineral Separation Plant. In more open areas where shrubs do not disrupt the wind movement, pollution effects are likely to be detected much further away from the gaseous emission source.

5.1.3.1 Mist and dust electrical conductivity (EC)

The electrical conductivity was evaluated in order to determine the effect of the gaseous emissions on the soil salinity. The neutral soluble ions such as sodium that cause soil salinity interfere seriously with the growth of certain plants (Brady 1990). However, due to the erratic outcome from the statistical analysis results, the electrical conductivity could not be used conclusively as criteria to determine the effects of gaseous emissions on vegetation.

The mist and dust samples chemical analysis did not show any sodium in the gaseous emissions. From the pooled data for Transects A, B and C there was no significant difference in the electrical conductivity mean values between distances from 400 m through 800 m to 1,200 m. The electrical conductivity mean value was lowest at 800 m as compared to 400 m and 1,200 m (Figure 4.16). This trend did not show any relation between the electrical conductivity and the deposition of gaseous emissions from the Mineral Separation Plant.

5.1.3.2 Mist and dust sulphate concentration

Long term absorption of sulphur dioxide by plants, at sub-lethal concentrations can cause chronic injury (Linzon 1971). The concentration of sulphate in the mist and dust samples demonstrated a clear trend of reduction with an increase in distance from the Mineral Separation Plant, to the area further away (1,200 m). The vegetation in the sample plots near the emission source was negatively affected by the high deposition of sulphate. This can be seen in the low pH values of the mist and dust samples and the proportion of the dead plants in the sample plots adjacent to the Mineral Separation Plant. The $SO_4^=$ concentrations were the least along transect A, due probably to the interference of the high plant height, during the mist and dust capture.

The sulphate concentration values for the mist and dust samples were higher at 400 m for each of the three transects (Figure 4.17). This suggests that there was an influence of the gaseous emissions from the Mineral Separation Plant along the three transects, as the sulphate deposition was high at 400 m, lower at 800 m and lowest at 1,200 m.

5.1.4 Foliar sulphur responses

Among other reasons the diversity and difference in physical and chemical properties of pollutants, are the factors for the unclear picture of the mechanism by which they damage processes in plants (Dässler and Börtitz 1988). Pollutants in an environment accumulate gradually; resident plant species may thus have been exposed to lower doses over a long period of time and adjusted to them. Hence, a measure of the concentration of pollutants in an individual or its habitat does not reveal the full impact of the pollutants. In any case the total pollutant concentration in the ecosystem may not be the dose to which the plants have been subjected (Beeby 1994).

In the present study, the foliar samples collected at distances of 400 m, 800 m and 1,200 m along each transect provided a comparison of the sulphur content in plant leaves from the Mineral Separation Plant, to the areas further away (1,200 m). This was undertaken to investigate the effects of the gaseous emissions from the Mineral Separation Plant, on adjacent vegetation. However, the results of the sulphur content from the Inductive Coupled Plasma Atomic Emission Spectrometer (ICP-AES) test, expressed in percentage cannot immediately convey the severity of the pollution problem on vegetation. This is because the thresholds for the critical concentrations that can cause death in the selected plant species, under the prevailing environmental conditions are not known. Such that, if this information was available it would be possible to predict that with these levels of sulphur content (%), specific plant species are likely to survive for a given length of time, with a predetermined additional uptake of sulphur. It may be interesting to know what levels of sulphur concentrations, triggers what reaction in the various plant species. This requires further study.

Foliar sulphur content in the samples collected from 400 m was 0.29% on average, which is higher than the 0.264% at 800 m and 0.232% at 1,200 m away from the Mineral Separation Plant. Although the foliar sulphur content mean values for all the transects were not significantly different, the gradual decrease (pattern) in foliar sulphur content with distance from the emission source revealed that the directional wind effects of the area had probably created a localized influence on vegetation. The impacts of some emissions can be restricted to the local environment (Field and Field 2002). Furthermore, ecological communities and plant characteristics are non-uniform (Begon *et al.* 1990). Hence, the uniform pattern and gradual decrease in the foliar sulphur content from the sample plots adjacent to the Mineral Separation Plant outwards, is attributed to external gaseous emission effects on the vegetation. The foliar sulphur content (%) gradient confirmed that there were point-source pollutants affecting the vegetation. This provides an opportunity for establishing a stringent monitoring system, to reduce the impacts of pollution in the ecosystem. In the present study there was no need to establish the sulphur content thresholds at which serious damage can occur on vegetation. Various ecological factors impinge on the concept of the threshold, which include plant species traits, metabolic pathways, soil conditions and moisture factors.

5.2 Conclusions

A number of issues and concepts have emerged from the results of this pilot study, regarding the various ecological processes in the ecosystem. This particular discussion considered the importance of these issues and concepts, in contributing to monitoring and managing of vegetation around the Namakwa Sands Mineral Separation Plant and probably elsewhere within the Succulent Karoo Biome. The intention of environmental management and monitoring is to ensure that ecosystem conservation is maintained along side the economic operations for which the mining industry was established. Limiting the release of gaseous emissions for the purpose of conserving the ecosystem is an essential consideration in sustainable development. There was evidence that emissions are damaging plants and depositing more sulphur in the sample plots at 400 m from the emission source as compared to the sample plots further away (1,200 m) along the transects. Patterns in soil pH were less clear especially on the outcome of the pH contour map and interpretation of soil survey and mist and dust results from Transect A, in comparison to the other transects was complicated by differences in geology, topography, soils and vegetation along the transects. It is problematic to specify the reasons for various statistical model outputs, because local scale environmental factors also exert profound influence on plant distribution and composition (Corney *et al.* 2004). In order to resolve the relationship between vegetation damage, altitude, geology and distance from the emission source, I recommend that a more intensive survey over a greater distance (at least 1 km onwards) be conducted to quantify vegetation damage and sulphur deposition to the east of the emission source. Moreover, the high smoke stacks (Figure 2.1) installed at the Mineral Separation Plant are intended to deposit the main pollution plume more than 1 km away from the emission source.

It is imperative to ensure that all the collective anthropogenic impacts on the ecosystem are regulated, so that organisms are not stressed beyond their ability to absorb impacts or recover from them (Treweek 1999). Therefore, monitoring will help to establish departures from the standards (baseline status) and enhance understanding of the natural components of the ecosystem around the Namakwa Sands Mineral Separation Plant. The ecosystem should be seen as a moving target changing due to the impacts of various ecological stimuli and anthropogenic effects (Jensen and Bourgeron 2001). In the present study distance from the pollution source at the Mineral Separation Plant gave a distinct assessment of the pollution effects on vegetation than the wind direction. Transect A (east) that is in the predominant wind direction appeared least polluted (Figure 4.16), probably due to the interference of the high vegetation during the capture of the mist and dust.

Hence, we can not conclude that Transect A is not polluted. It is essential to consider both the natural and induced biotic changes in relation to the impending major climatic change (Hewitt 2004).

Pollution as it affects vegetation should be a concern of all of us. This is because biodiversity conservation is directly linked to the survival of the human population. Therefore, bioindication monitoring of pollution effects on vegetation remains as an appropriate approach to ecosystem conservation. Treweek (1999) recommended that it was essential to consider options, whether these are policies, sites or processes as this is fundamental to conservation planning. Systems that preclude effective consideration of alternatives cannot be used pro-actively.

From the various factors considered and investigations performed which included: soil pH determination, mist and dust ion chromatographic analysis, foliar sulphur content analysis and assessment of plant conditions, the results suggest that the gaseous emissions from the Mineral Separation Plant have an effect on the ecosystem. The mist and dust sulphate concentration from the ion chromatographic analysis was more conclusive in showing the decrease of the sulphate concentrations away from the Mineral Separation Plant. Therefore, it is essential to follow up on this pilot study in order to further evaluate and confirm the observed effects apparently caused by sulphur emissions on the surrounding vegetation. The assessments should be used to elaborate mitigation strategies to minimise negative environmental impacts on the ecosystem (Carrasco-Letelier 2004).

5.3 Recommendations

1. Precision in measurement of weather and specifically wind factors such as wind speed records around the Mineral Separation Plant should be promoted. It is essential to model pollution deposition patterns under different wind conditions, to ensure that vital information about the cause and effects of air pollution are predicted. It is necessary to develop risk maps from time to time, for the gradient of the pollution effects, so as to provide information on ecosystem management.

2. It is essential to perpetuate and extend the bioindication or biomonitoring programme in the future, so as to develop and provide scientifically based principles on the effects of gaseous emissions on the surrounding vegetation. Research must be strengthened to improve knowledge in

plant response to various environmental stimuli especially pollution. The threshold of allowable emission output should not exceed the point where the apparently sensitive and widely distributed plant species, such as: *Galenia fruticosa, Lampranthus suavissimus*, *Lycium ferocissimum* and *Ruschia* sp (SP 9). are negatively affected. Plant distribution and proportion of plant deaths of these species has been used as an indicator of their sensitivity. These species should be used as a monitoring tool. However, their suitability could be tested further.

3. To limit the emission of sulphuric acid and other air pollutants as far as possible to prevent potential damage to the surrounding vegetation. Stringent purification methods should be introduced in the mineral processing system.

4. The application of the MWAC sampler to capture dust and mist is one procedure the Namakwa Sands Mine management can deploy to monitor the concentrations of pollutants in the ecosystem at various distances from the Mineral Separation Plant. The data can be used to evaluate trends of pollution effects in the area, for ecosystem conservation and for management purposes. The interception of the pollutants by the surrounding vegetation should not be a deterrent to using the MWAC sampler in an environment with similar features, as all the mist and dust capture points will be affected in the same way. Hence, usable results will be obtained.

5. The permanent sample plots established in the present study should be maintained for further investigations on the effect of the gaseous emissions from the Mineral Separation Plant, on the surrounding vegetation. The use of the same sample plots to monitor the effects of the gaseous emissions on vegetation will help to obtain results that are comparable and determine whether the pollution levels in this ecosystem are reducing or increasing.

6. The low soil pH result obtained in the sample plots located in the predominant wind direction (east) requires further investigation to teaze apart the suggested local rock influence and the deposition of the main pollution plume about 1 km away from the Mineral Separation Plant. There is a need to set the sample plots from 400 m to at least 2.0 km away from the emission source, if the terrain allows it.

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APPENDICES

Appendix 1: **Mist and dust samples ion chromatographic analysis results**

PLOT No	Cl^- (mg/l)	NO_3^- (mg/l)	$PO_4^{=}$ (mg/l)	$SO_4^{=}$ (mg/l)	Br^- (mg/l)	F^- (mg/l)
A1	65.2	2.6	3.1	132.9	0.0	0.2
A2	69.5	0.0	0.0	123.7	0.0	0.0
A3	55.0	2.4	3.0	49.2	0.0	0.0
A4	84.3	0.0	0.0	22.1	0.0	0.0
A5	57.6	3.7	0.0	24.4	0.0	0.0
A6	50.8	0.0	0.0	23.7	0.0	0.3
A7	49.3	0.0	0.0	23.8	0.0	0.0
A8	52.8	1.5	0.0	23.1	0.0	0.0
A9	45.3	0.8	0.0	21.5	0.0	0.0
B1	53.0	2.7	0.0	61.8	0.0	0.0
B2	185.8	0.0	0.0	116.3	0.0	0.2
B3	194.0	0.0	0.0	120.0	0.0	0.0
B4	145.7	5.0	0.0	120.8	0.9	0.0
B5	56.8	2.3	0.0	37.8	0.0	0.0
B6	86.9	1.8	0.0	87.2	0.0	0.0
B7	128.4	4.9	0.0	71.4	0.0	0.0
B8	75.3	5.8	0.0	52.4	0.0	0.0
B9	101.85	0.0	0.0	61.9	1.6	0.0
C1	175.9	0.0	29.9	155.3	0.0	0.0
C2	107.6	3.7	23.9	115.4	0.0	0.0
C3	244.2	0.0	11.9	195.3	1.0	0.0
C4	162.4	0.0	13.8	62.2	0.0	0.0
C5	78.3	0.0	28.7	79.7	0.0	0.0
C6	69.1	0.0	8.8	54.7	0.0	0.0
C7	158.2	0.0	16.5	39.1	0.0	0.0
C8	182.2	0.0	0.0	55.6	0.0	0.0
C9	77.2	0.0	0.0	39.3	0.0	0.0

Appendix 2: **Pictures taken from the eastern side of the Namakwa Sands Mineral Separation Plant, showing the influence of the predominant westerly winds transporting mist and dust. Pictures taken from same spot within 22 minutes of time difference.**

Appendix 3: **Plant abundance and mortality per species.**

VOUCHER COLLECTION ***No***	***SPECIES NAME***	***FAMILY NAME***	*AUTHOR*	***TOTAL NUMBER OF PLANTS***	***TOTAL NUMBER OF DEAD PLANTS***
SP 65	*Antimima sp.*	Aizoaceae	Goldblatt and Manning (2000)	6	0
SP 69	*Argyroderma congregatum*	Aizoaceae	Court (1981)	1	0
SP 62	*Aridaria brevicarpa*	Aizoaceae	Le Roux (1988)	21	0
SP 74	*Aridaria noctiflora*	Aizoaceae	Court (1981)	6	0
SP 50	*Aristida longifolia*	Aizoaceae	Goldblatt and Manning (2000)	13	0
SP 18	*Asparagus fasciculatus*	Aspragaceae	Goldblatt and Manning (2000)	36	6
SP 40	*Atriplex cinerea*	Amaranthaceae	Goldblatt and Manning (2000)	62	14
SP 6	*Atriplex lindleyi*	Amaranthaceae	Goldblatt and Manning (2000)	212	94
SP 21	*Atriplex semibaccata*	Amaranthaceae	Goldblatt and Manning (2000)	1	0
SP 45	*Augea capensis*	Zygophyllaceae	Goldblatt and Manning (2000)	2	0

VOUCHER COLLECTION ***No***	***SPECIES NAME***	***FAMILY NAME***	AUTHOR	***TOTAL NUMBER OF PLANTS***	***TOTAL NUMBER OF DEAD PLANTS***
SP 64	*Berkheya fruticosa*	Asteraceae	Goldblatt and Manning (2000)	3	2
SP 13	*Carpanthea pomeridiana*	Aizoaceae	Goldblatt and Manning (2000)	1	0
SP 76	*Cephalophyllum spongiosum*	Aizoaceae	Court (1981)	111	2
SP 50	*Cephalophyllum tetrastichum*	Aizoaceae	Van Jaarsveld *et al*. (2000)	13	0
SP 34	*Cheirodopsis rostrata*	Aizoaceae	Goldblatt and Manning (2000)	81	10
SP 19	*Crassula muscosa*	Crassulaceae	Goldblatt and Manning (2000)	2	0
SP 42	*Delosperma crassum*	Aizoaceae	Goldblatt and Manning (2000)	104	7
SP 73	*Didelta carnosa*	Asteraceae	Goldblatt and Manning (2000)	11	0
SP 81	*Dorotheanthus bellidiformis*	Aizoaceae	Goldblatt and Manning (2000)	1	0
SP 30	*Drosanthemum floribundum*	Aizoaceae	Goldblatt and Manning (2000)	5	0
SP 42	*Drosanthemum hispidum*	Aizoaceae	Goldblatt and Manning (2000)	104	7
SP 32	*Drosanthemum cf lique*	Aizoaceae	Goldblatt and Manning (2000)	62	1
SP 63	*Drosanthemum speciosum*	Aizoaceae	Court (1981)	3	0
SP 43	*Drosanthemum sp.*	Aizoaceae	Court (1981)	26	4
SP 25	*Euphorbia caterviflora*	Euphorbiaceae	Court (1981)	3	0
SP 3	*Galenia africana*	Aizoaceae	Goldblatt and Manning (2000)	62	6

VOUCHER *COLLECTION* ***No***	***SPECIES NAME***	***FAMILY NAME***	*AUTHOR*	***TOTAL NUMBER OF PLANTS***	***TOTAL NUMBER OF DEAD PLANTS***
SP 7	*Galenia fruticosa*	Aizoaceae	Goldblatt and Manning (2000)	344	53
SP 11	*Gazania krebsiana*	Asteraceae	Goldblatt and Manning (2000)	7	0
SP39	*Helichrysum hebelepis*	Astraceae	Goldblatt and Manning (2000)	2	0
SP 17	*Hermannia cuneifolia*	Malvaceae	Powrie (2004)	1	0
SP 38	*Hermannia filifolia*	Malvaceae	Powrie (2004)	30	5
SP 58	*Hoplophyllum spinosum*	Asteraceae	Goldblatt and Manning (2000)	6	0
SP 80	*Lachenalia unicola*	Liliaceae	Goldblatt and Manning (2000)	1	0
SP 49	*Lampranthus amoenus*	Aizoaceae	Goldblatt and Manning (2000)	12	0
SP 4	*Lampranthus suavissimus*	Aizoaceae	Germishuizen and Meyer (2003)	334	107
SP 16	*Lebeckia sericea*	Fabaceae	Goldblatt and Manning (2000)	4	0
SP 37	*Leipoldtia schultzei*	Aizoaceae	Goldblatt and Manning (2000)	1	0
SP 1	*Lycium ferocissimum*	Solanaceae	Goldblatt and Manning (2000)	111	19
SP 75	*Malephora crocea*	Aizoaceae	Goldblatt and Manning (2000)	4	0
SP 35	*Massonia crassicaule*	Geraniaceae	Goldblatt and Manning (2000)	8	4
SP 78	*Massonia grandiflora*	Hyacinthaceae	Goldblatt and Manning (2000)	1	0
SP 79	*Massonia depressa*	Hyacinthaceae	Goldblatt and Manning (2000)	1	0
SP 15	*Mesembryanthemum guerichianum*	Aizoaceae	Goldblatt and Manning (2000)	10	0
SP 70	*Monilaria moniliformis*	Aizoaceae	Goldblatt and Manning (2000)	1	0

VOUCHER *COLLECTION* ***No***	***SPECIES NAME***	***FAMILY NAME***	*AUTHOR*	***TOTAL NUMBER OF PLANTS***	***TOTAL NUMBER OF DEAD PLANTS***
SP 12	*Othonna cylindrica*	Asteraceae	Goldblatt and Manning (2000)	49	6
SP 41	*Pelargonium fulgidum*	Geraniaceae	Goldblatt and Manning (2000)	2	0
SP 61	*Pentaschistis* sp.	Poaceae	Goldblatt and Manning (2000)	1	0
SP 77	*Pentzia incana*	Asteraceae	Goldblatt and Manning (2000)	1	0
SP 28	*Psilocaulon* sp.	Aizoaceae	Court (1981)	78	7
SP 10	*Ruschia fugitans*	Aizoaceae	Germishuizen and Meyer (2003)	185	24
SP 36	*Ruschia paripetala*	Aizoaceae	Germishuizen and Meyer (2003)	93	6
SP 56	*Ruschia tumidula*	Aizoaceae	Goldblatt and Manning (2000)	6	0
SP 9	*Ruschia* sp.	Aizoaceae	Goldblatt and Manning (2000)	110	60
SP 33	*Salsola aphylla*	Amaranthaceae	Van Jaarsveld *et al*. (2000)	46	15
SP 2	*Salsola arborea*	Amaranthaceae	Van Jaarsveld *et al*. (2000)	110	19
SP 8	*Salsola kali*	Amaranthaceae	Powrie (2004)	29	11
SP 66	*Salsola* sp.	Amaranthaceae	Powrie (2004)	4	0
SP 24	*Stoeberia frutescens*	Aizoaceae	Court (1981)	27	8
SP 14	*Tetragonia fruticosa*	Aizoaceae	Goldblatt and Manning (2000)	32	0
SP 72	*Tripteris oppositifolia*	Asteraceae	Goldblatt and Manning (2000)	6	0
SP 26	*Tylecodon wallichii*	Crassulaceae	Goldblatt and Manning (2000)	13	6
SP 54	*Zygophyllum fulvum*	Zygophyllaceae	Goldblatt and Manning (2000)	21	0
SP 5	*Zygophyllum morgsana*	Zygophyllaceae	Goldblatt and Manning (2000)	33	11
SP 53	*Zygophyllum spinosum*	Zygophyllaceae	Goldblatt and Manning (2000)	16	0

Appendix 4: **Location of project sample plots at the Mineral Separation Plant- Transect A, B and C, direct from Namakwa Sands Mine Mineral Separation Plant**

SAMPLE PLOT No.	GPS READINGS	POINT 1	POINT 2	POINT 3	POINT 4
A1	**ELEVATION (m.a.s.l)**	87.3	87.3	88.7	88.7
	SOUTH	31°27.518'	31°27.524'	31°27.521'	31°27.517'
	EAST	18°17.404'	18°17.408'	18°17.411'	18°17.408'
A2	**ELEVATION (m.a.s.l)**	88.7	89.3	88.7	88.7
	SOUTH:	31°27.525'	31°27.528'	31°27.526'	31°27.524'
	EAST:	18°17.407'	18°17.409'	18°17.414'	18°17.418'
A3	**ELEVATION (m.a.s.l)**	77.0	77.0	76.6	77.4
	SOUTH:	31°27.585'	31°27.589'	31°27.566'	31°27.581'
	EAST:	18°17.410'	18°17.412'	18°17.418'	18°17.415'
A4	**ELEVATION (m.a.s.l)**	102.1	101.3	101.2	101.2
	SOUTH:	31°27.424'	31°27.429'	31°27.407'	31°27.407'
	EAST:	18°17.619'	18°17.627'	18°17.566'	18°17.666'
A5	**ELEVATION (m.a.s.l)**	103.3	103.3	104.4	104.8
	SOUTH:	31°27.407'	31°27.408'	31°27.408'	31°27.409'
	EAST:	18°17.656'	18°17.666'	18°17.665'	18°17.654'
A6	**ELEVATION (m.a.s.l)**	107.9	107.6	107.9	107.3
	SOUTH:	31°27.421'	31°27.409'	31°27.410'	31°27.411'

	EAST:	18°17.584'	18°17.619'	18°17.621'	18°17.619'
A7	**ELEVATION (m.a.s.l)**	109.7	109.2	110.0	110.6
	SOUTH:	31°27.325'	31°27.329'	31°27.324'	31°27.321'
	EAST:	18°17.814'	18°17.818'	18°17.822'	18°17.818'
A8	**ELEVATION (m.a.s.l)**	109.6	109.9	109.4	110.3
	SOUTH:	31°27.329'	31°27.333'	31°27.328'	31°27.325'
	EAST:	18°17.819'	18°17.825'	18°17.828'	18°17.823'
A9	**ELEVATION (m.a.s.l)**	109.9	109.6	109.1	110.3
	SOUTH:	31°27.333'	31°27.332'	31°27.333'	31°27.329'
	EAST:	18°17.826'	18°17.820'	18°17.834'	18°17.829'

TRANSECT B

SAMPLES PLOTS	**GPS READINGS**	**POINT 1**	**POINT 2**	**POINT 3**	**POINT 4**
B1	**ELEVATION (m.a.s.l)**	69.8	71.9	70.4	70.4
	SOUTH:	31°27.695'	31°27.700'	31°27.706'	31°27.699'
	EAST:	18°17.473'	18°17.471'	18°17.477'	18°17.477'
B2	**ELEVATION (m.a.s.l)**	69.9	69.2	69.2	70.4
	SOUTH:	31°27.702'	31°27.708'	31°27.713'	31°27.706'
	EAST:	18°17.472'	18°17.471'	18°17.478'	18°17.477'

B3	**ELEVATION (m.a.s.l)**	70.4	69.5	68.9	69.4
	SOUTH:	31°27.710'	31°27.75'	31°27.716'	31°27.716'
	EAST:	18°17.471'	18°17.471'	18°17.477'	18°17.480'
B4	**ELEVATION (m.a.s.l)**	64.9	63.7	63.7	63.1
	SOUTH:	31°27.721'	31°27.726'	31°27.725'	31°27.720'
	EAST:	18°17.704'	18°17.702'	18°17.709'	18°17.710'
B5	**ELEVATION (m.a.s.l)**	61.6	61.3	62.8	63.1
	SOUTH:	31°27.726'	31°27.731'	31°27.732'	31°27.726'
	EAST:	18°17.702'	18°17.701'	18°17.707'	18°17.708'
B6	**ELEVATION (m.a.s.l)**	61.3	61.3	61.9	62.5
	SOUTH:	31°27.732'	31°27.733'	31°27.733'	31°27.733'
	EAST:	18°17.701'	18°17.700'	18°17.706'	18°17.707'
B7	**ELEVATION (m.a.s.l)**	57.9	58.3	58.5	58.2
	SOUTH:	31º27.709'	31°27.747'	31°27.745'	31°27.739'
	EAST:	18°17.901'	18°17.899'	18°17.909'	18°17.908'
B8	**ELEVATION (m.a.s.l)**	61.4	61.9	61.3	60.4
	SOUTH:	31°27.750'	31°27.751'	31°27.753'	31°27.746'
	EAST:	18°17.897'	18°17.901'	18°17.908'	18°17.909'
B9	**ELEVATION (m.a.s.l)**	62.5	61.6	61.9	61.0

	SOUTH:	31°27.753'	31°27.758'	31°27.759'	31°27.755'
	EAST:	18°17.902'	18°17.900'	18°17.905'	18°17.907'

TRANSECT C

SAMPLES PLOTS	**GPS READINGS**	POINT 1	POINT 2	POINT 3	POINT 4
C1	**ELEVATION (m.a.s.l)**	59.7	59.4	59.1	59.4
	SOUTH:	31°27.822'	31°27.824'	31°27.830'	31°27.827'
	EAST:	18°17.400'	18°17.394'	18°17.396'	18°17.402'
C2	**ELEVATION (m.a.s.l)**	60.3	60.9	59.5	60.4
	SOUTH:	31°27.824'	31°27.828'	31°27.832'	31°27.830'
	EAST:	18°17.393'	18°17.386'	18°17.389'	18°17.395'
C3	**ELEVATION (m.a.s.l)**	57.6	57.0	57.9	57.3
	SOUTH:	31°27.828'	31°27.833'	31°27.835'	31°27.834'
	EAST:	18°17.385'	18°17.381'	18°17.382'	18°17.388'
C4	**ELEVATION (m.a.s.l)**	43.9	44.8	43.6	44.5
	SOUTH:	31°28.003'	31°28.003'	31°28.009'	31°28.008'
	EAST:	18°17.510'	18°17.508'	18°17.510'	18°17.511'
C5	**ELEVATION (m.a.s.l)**	46.3	46.4	46.0	46.0
	SOUTH:	31°28.003'	31°28.005'	31°28.017'	31°28.008'

	EAST:	18°17.506'	18°17.502'	18°17.501'	18°17.513'
C6	**ELEVATION (m.a.s.l)**	51.8	51.9	52.6	52.2
	SOUTH:	31°28.006'	31°28.011'	31°28.015'	31°28.013'
	EAST:	18°17.499'	18°17.491'	18°17.494'	18°17.500'
C7	**ELEVATION (m.a.s.l)**	46.7	46.1	47.2	47.2
	SOUTH:	31°28.231'	31°28.235'	31°28.233'	31°28.231'
	EAST:	18°17.659'	18°17.654'	18°17.657'	18°17.659'
C8	**ELEVATION (m.a.s.l)**	49.9	49.3	49.7	49.7
	SOUTH:	31°28.234'	31°28.233'	31°28.242'	31°28.239'
	EAST:	18°17.652'	18°17.647'	18°17.650'	18°17.656'
C9	**ELEVATION (m.a.s.l)**	48.1	48.8	49.0	49.4
	SOUTH:	31°28.233'	31°28.241'	31°28.246'	31°28.243'
	EAST:	18°17.646'	18°17.640'	18°17.644'	18°17.649'

Appendix 5: **Plant abundance, crown cover and proportion of dead plants per sample plot**

SERIAL No	*PLOT No*	*CROWN COVER (%)*	*TOTAL NUMBER OF PLANTS*	*TOTAL NUMBER OF DEAD PLANTS*	*PROPORTION (%)*
1	A1	13.0	110	74	67
2	A2	22.2	113	33	29
3	A3	15.6	145	13	9
4	A4	14.5	89	32	36
5	A5	26.6	94	15	16
6	A6	19.5	108	24	22
7	A7	9.2	58	26	45
8	A8	12.6	100	10	10
9	A9	12.7	125	6	5
10	B1	11.2	148	57	39
11	B2	10.4	129	25	19
12	B3	26.1	81	10	12
13	B4	25.0	57	11	19
14	B5	19.4	49	17	35
15	B6	20.6	43	4	9
16	B7	14.9	108	0	0
17	B8	22.0	127	12	9
18	B9	18.2	68	5	7
19	C1	12.5	142	96	68
20	C2	9.5	106	15	14

SERIAL No	*PLOT No*	*CROWN COVER (%)*	*TOTAL NUMBER OF PLANTS*	*TOTAL NUMBER OF DEAD PLANTS*	*PROPORTION (%)*
21	C3	6.0	94	15	16
22	C4	7.9	97	10	10
23	C5	5.6	87	11	13
24	C6	5.6	88	13	15
25	C7	9.6	80	8	10
26	C8	17.4	85	5	6
27	C9	10.1	73	4	5
TOTAL			**2, 614**	**551**	**21**

Appendix 6: **Plant species identification, location and the Author for the nomenclature used**

VOUCHER *COLLECTION* ***No***	*SPECIES NAME*	***FAMILY NAME***	*AUTHOR*	***GRID***	***ALTIT-UDE (m.a.s..l)***
SP 65	*Antimima* sp.	Aizoaceae	Goldblatt and Manning (2000)	S31º27.232', E18º17.654'	50.0
SP 69	*Argyroderma congregatum*	Aizoaceae	Court (1981)	S31º27.341', E18º17.644'	50.0
SP 62	*Aridaria brevicarpa*	Aizoaceae	Le Roux (1988)	S31º27.237', E18º17.659'	48.8
SP 74	*Aridaria noctiflora*	Aizoaceae	Court (1981)	S31º27.235', E18˚17.423'	51.5
SP 50	*Aristida longifolia*	Aizoaceae	Goldblatt and Manning (2000)	S31º27.744 ', 18º17.904'	68.3
SP 18	*Asparagus fasciculatus*	Aspragaceae	Goldblatt and Manning (2000)	S31º27.434', E18º17.626'	97.5
SP 40	*Atriplex cinerea*	Amaranthaceae	Goldblatt and Manning (2000)	S31º27.694 ', 18º17.469'	74.8
SP 6	*Atriplex lindleyi*	Amaranthaceae	Goldblatt and Manning (2000)	S31º27.528', E18˚17.408'	58.8
SP 21	*Atriplex semibaccata*	Amaranthaceae	Goldblatt and Manning (2000)	S31º28.433', E18º17.625'	71.6
SP 45	*Augea capensis*	Zygophyllaceae	Goldblatt and Manning (2000)	S31º27.011', E18º17.501'	48.8
SP 64	*Berkheya fruticosa*	Asteraceae	Goldblatt and Manning (2000)	S31º27.239', E18º17.644'	44.2
SP 13	*Carpanthea pomeridiana*	Aizoaceae	Goldblatt and Manning (2000)	S31º27.226', E18º17.541'	57.0
SP 76	*Cephalophyllum spongiosum*	Aizoaceae	Court (1981)	S31º27.328', E18˚17.445'	46.9
SP 50	*Cephalophyllum tetrastichum*	Aizoaceae	Van Jaarsveld *et al*. (2000)	S31º27.326', E18º17.819'	107.0
SP 34	*Cheirodopsis rostrata*	Aizoaceae	Goldblatt and Manning (2000)	S31º27.721', E18º17.703'	71.0
SP 19	*Crassula muscosa*	Crassulaceae	Goldblatt and Manning (2000)	S31º27.434', E18º17.626'	46.6
SP 42	*Delosperma crassum*	Aizoaceae	Goldblatt and Manning (2000)	S31º27.826', E18º17.392'	57.6
SP 73	*Didelta carnosa*	Asteraceae	Goldblatt and Manning (2000)	S31º27.253', E18˚17.830'	51.5

VOUCHER *COLLECTION* ***No***	*SPECIES NAME*	***FAMILY NAME***	*AUTHOR*	***GRID***	***ALTIT-UDE (m.a.s..l)***
SP 81	*Dorotheanthus bellidiformis*	Aizoaceae	Goldblatt and Manning (2000)	S31º27.264, E18˚17.451’	50.3
SP 30	*Drosanthemum floribundum*	Aizoaceae	Goldblatt and Manning (2000)	S31º27.239', E18º17.644'	44.2
SP 42	*Drosanthemum hispidum*	Aizoaceae	Goldblatt and Manning (2000)	S31º27.829', E18º17.398'	57.6
SP 32	*Drosanthemum cf lique*	Aizoaceae	Goldblatt and Manning (2000)	S31º27.720', E18º17.704'	64.2
SP 63	*Drosanthemum speciosum*	Aizoaceae	Court (1981)	S31º27.830', E18º17.395'	58.8
SP 43	*Drosanthemum* sp.	Aizoaceae	Court (1981)	S31º27.239', E18º17.644'	44.2
SP 25	*Euphorbia caterviflora*	Euphorbiaceae	Court (1981)	S31º27.704', E18º17.472'	64.9
SP 3	*Galenia africana*	Aizoaceae	Goldblatt and Manning (2000)	S31º27.529', E18º17.480'	65.8
SP 7	*Galenia fruticosa*	Aizoaceae	Goldblatt and Manning (2000)	S31º27.520', E18º17.407'	82.0
SP 11	*Gazania krebsiana*	Asteraceae	Goldblatt and Manning (2000)	S31º27.435', E18º17.622'	100.0
SP39	*Helichrysum hebelepis*	Asteraceae	Goldblatt and Manning (2000)	S31º27.829', E18º17.398'	57.6
SP 17	*Hermannia cuneifolia*	Malvaceae	Powrie (2004)	S31º27.436', E18º17.636'	77.1
SP 38	*Hermannia filifolia*	Malvaceae	Powrie (2004)	S31º27.839', E18º17.398'	57.6
SP 58	*Hoplophyllum spinosum*	Asteraceae	Goldblatt and Manning (2000)	S31º27.238', E18º17.659'	48.8
SP 80	*Lachenalia unicolar*	Liliaceae	Goldblatt and Manning (2000)	S31º27.232', E18˚17.459'	49.6
SP 49	*Lampranthus amoenus*	Aizoaceae	Goldblatt and Manning (2000)	S31º27.747', E18º17.904'	68.9
SP 4	*Lampranthus suavissimus*	Aizoaceae	Germishuizen and Meyer (2003)	S3º127.521', E18º17.408'	71.0
SP 16	*Lebeckia sericea*	Fabaceae	Goldblatt and Manning (2000)	S31º27.516', E18º17.49'	89.0
SP 37	*Leipoldtia schultzei*	Aizoaceae	Goldblatt and Manning (2000)	S31º27.728', E18º17.709'	66.2

VOUCHER *COLLECTION* ***No***	*SPECIES NAME*	***FAMILY NAME***	*AUTHOR*	***GRID***	***ALTIT-UDE (m.a.s..l)***
SP 1	*Lycium ferocissimum*	Solanaceae	Goldblatt and Manning (2000)	S31º27.317', E18º17.823'	104.5
SP 75	*Malephora crocea*	Aizoaceae	Goldblatt and Manning (2000)	S31º27.262', E18˚17.721'	48.5
SP 35	*Massonia crassicaule*	Geraniaceae	Goldblatt and Manning (2000)	S31º27.725', E18º17.709'	66.4
SP 78	*Massonia grandiflora*	Hyacinthaceae	Goldblatt and Manning (2000)	S31º27.266', E18˚17.455'	53.6
SP 79	*Massonia depressa*	Hyacinthaceae	Goldblatt and Manning (2000)	S31º27.661', E18'˚17.478	51.0
SP 15	*Mesembryanthemum guerichianum*	Aizoaceae	Goldblatt and Manning (2000)	S31º27.429', E18º17.622'	46.6
SP 70	*Monilaria moniliformis*	Aizoaceae	Goldblatt and Manning (2000)	S31º27.432', E18˚17.595'	51.0
SP 12	*Othonna cylindrica*	Asteraceae	Goldblatt and Manning (2000)	S31º27.424', E18º17.620'	91.0
SP 41	*Pelargonium fulgidum*	Geraniaceae	Goldblatt and Manning (2000)	S31º27.825', E18º17.388'	63.6
SP 61	*Pentaschistis* sp.	Poaceae	Goldblatt and Manning (2000)	S31º27.235', E18º17.652'	48.5
SP 77	*Pentzia pilulifera*	Asteraceae	Goldblatt and Manning (2000)	S31º27.269', E18˚17.649'	46.6
SP 28	*Psilocaulon* sp	Aizoaceae	Court (1981)	S31º27.709', E18º17.472'	77.4
SP 10	*Ruschia fugitans*	Aizoaceae	Germishuizen and Meyer (2003)	S31º27.525', E18º17.412'	100.0
SP 36	*Ruschia paripetala*	Aizoaceae	Germishuizen and Meyer (2003)	S31º27.728', E18º17.708'	66.1
SP 56	*Ruschia tumidula*	Aizoaceae	Goldblatt and Manning (2000)	S31º27.026', E18º17.513'	61.0
SP 9	*Ruschia* sp.	Aizoaceae	Goldblatt and Manning (2000)	S31º27.436', E18º17.633'	100.0
SP 33	*Salsola aphylla*	Amaranthaceae	Van Jaarsveld *et al*. (2000)	S31º27.720', E18º17.704'	64.3
SP 2	*Salsola arborea*	Amaranthaceae	Van Jaarsveld *et al*. (2000)	S31º27.524', E18º17.410'	68.9
SP 8	*Salsola kali*	Amaranthaceae	Powrie (2004)	S31º27.522', E18º17.407'	81.1

VOUCHER *COLLECTION* ***No***	*SPECIES NAME*	***FAMILY NAME***	*AUTHOR*	***GRID***	***ALTIT-UDE (m.a.s..l)***
SP 66	*Salsola* sp.	Amaranthaceae	Powrie (2004)	S31º27.324', E18º17.645'	52.1
SP 24	*Stoeberia frutescens*	Aizoaceae	Court (1981)	S31º27.669', E18º17.423'	69.3
SP 14	*Tetragonia fruticosa*	Aizoaceae	Goldblatt and Manning (2000)	S31º27.427', E18º17.619'	197.2
SP 72	*Tripteris oppositifolia*	Asteraceae	Goldblatt and Manning (2000)	S31º27.321', E18˚17.587'	52.0
SP 26	*Tylecodon wallichii*	Crassulaceae	Goldblatt and Manning (2000)	S31º27.701', E18º17.473'	70.4
SP 54	*Zygophyllum fulvum*	Zygophyllaceae	Goldblatt and Manning (2000)	S31º27.327', E18º17.819'	105.5
SP 5	*Zygophyllum morgsana*	Zygophyllaceae	Goldblatt and Manning (2000)	S31º27.528', E18º17.411'	82.6
SP 53	*Zygophyllum spinosum*	Zygophyllaceae	Goldblatt and Manning (2000)	S31º27.326', E18º17.819'	106.0

Appendix 7: Multivariate analysis data

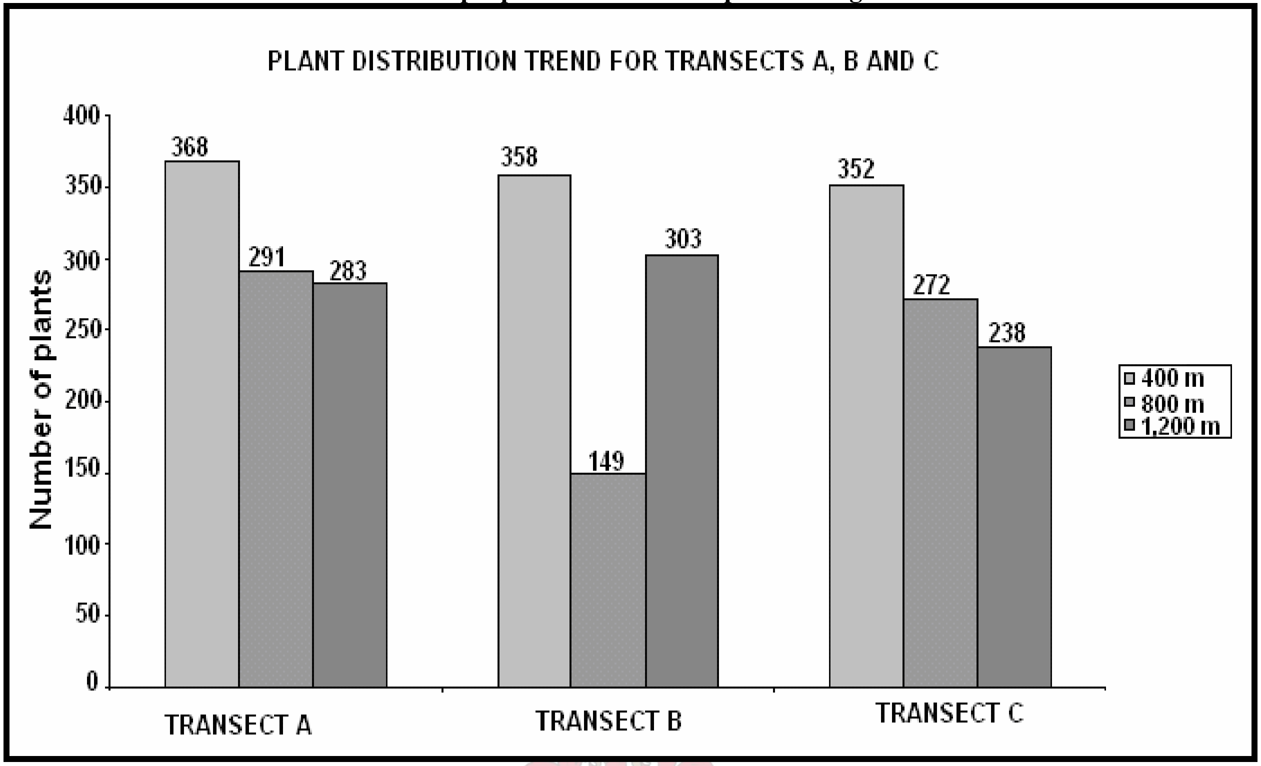
Appendix 8: **Mist and dust sample chemical analysis results. The Y and X coordinates were used to plot the pH gradient on the map**

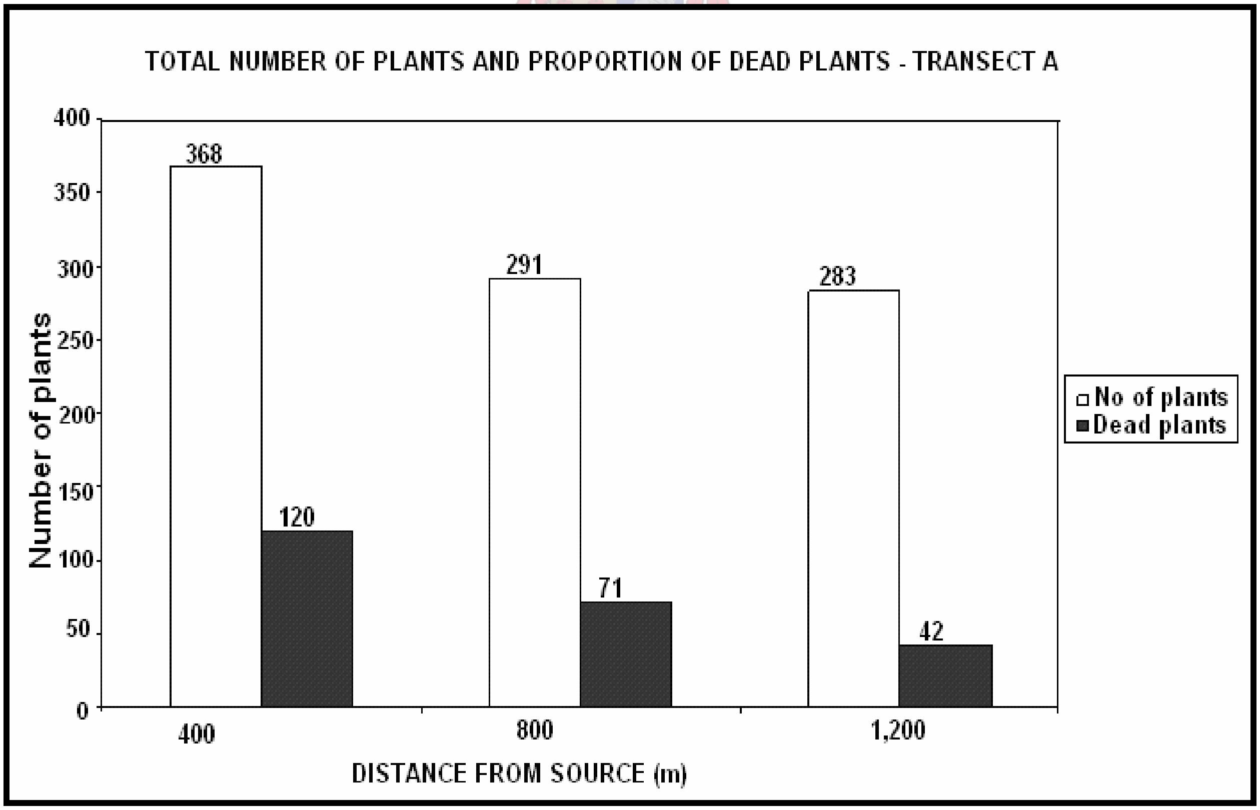
PLOT NUMBER	Y	X	Sample mass (g)	pH	*EC* *(μ s/m)*	SO_4 (mg/l)
A1	400	30	0.07	7.05	9.12	132.9
A2	400	70	0.07	7.13	8.82	123.7
A3	400	110	0.24	7.45	5.56	49.2
A4	800	30	0.01	8.09	3.01	22.1
A5	800	70	0.15	7.5	5.68	24.4
A6	800	110	0.09	8.11	4.55	23.7
A7	1200	30	0.11	8.7	5.4	23.8
A8	1200	70	0.05	9.7	5.21	23.1
A9	1200	110	0.24	7.69	5.6	21.5
B1	330	250	0.02	7.6	6.35	61.8
B2	290	290	0.21	7.61	14.22	116.3
B3	260	330	0.11	7.53	13.34	120.0
B4	530	610	0.01	7.43	10.92	120.8
B5	570	570	0.03	7.86	5.69	37.8
B6	610	530	0.17	7.95	7.9	87.2
B7	890	810	0.12	7.1	10.62	71.4
B8	850	850	0.01	8.28	7.44	52.4
B9	810	890	0.01	8.35	25.3	61.9
C1	110	400	0.04	7.14	20.8	155.3
C2	70	400	0.06	7.25	9.2	115.4
C3	30	400	0.14	6.9	17.89	195.3
C4	110	800	0.04	7.11	11.19	62.2
C5	70	800	0.18	7.51	7.41	79.7
C6	30	800	0.09	7.6	6.62	54.7
C7	110	1200	0.06	8.91	10.19	39.1
C8	70	1200	1.11	7.7	11.61	55.6
C9	30	1200	0.08	7.31	5.93	39.3

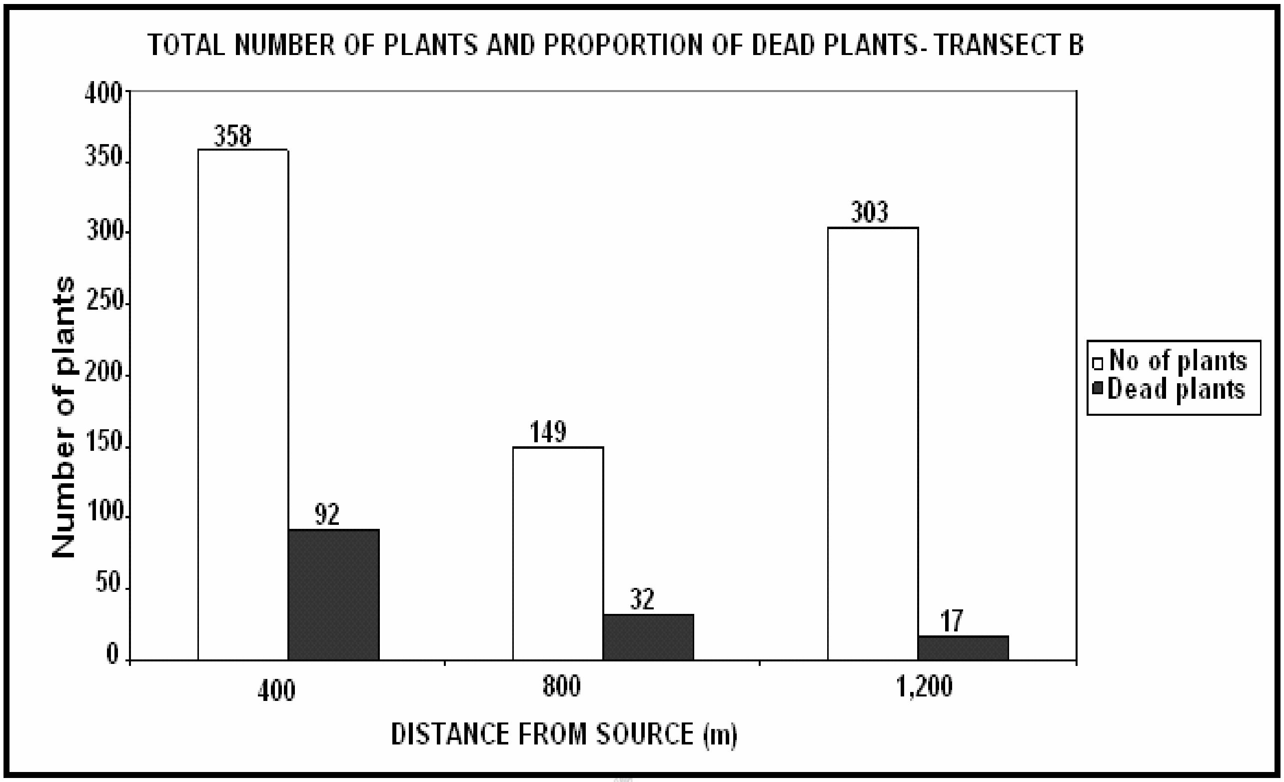
Appendix 9: **Plant foliar samples drying process data and the sulphur content results**

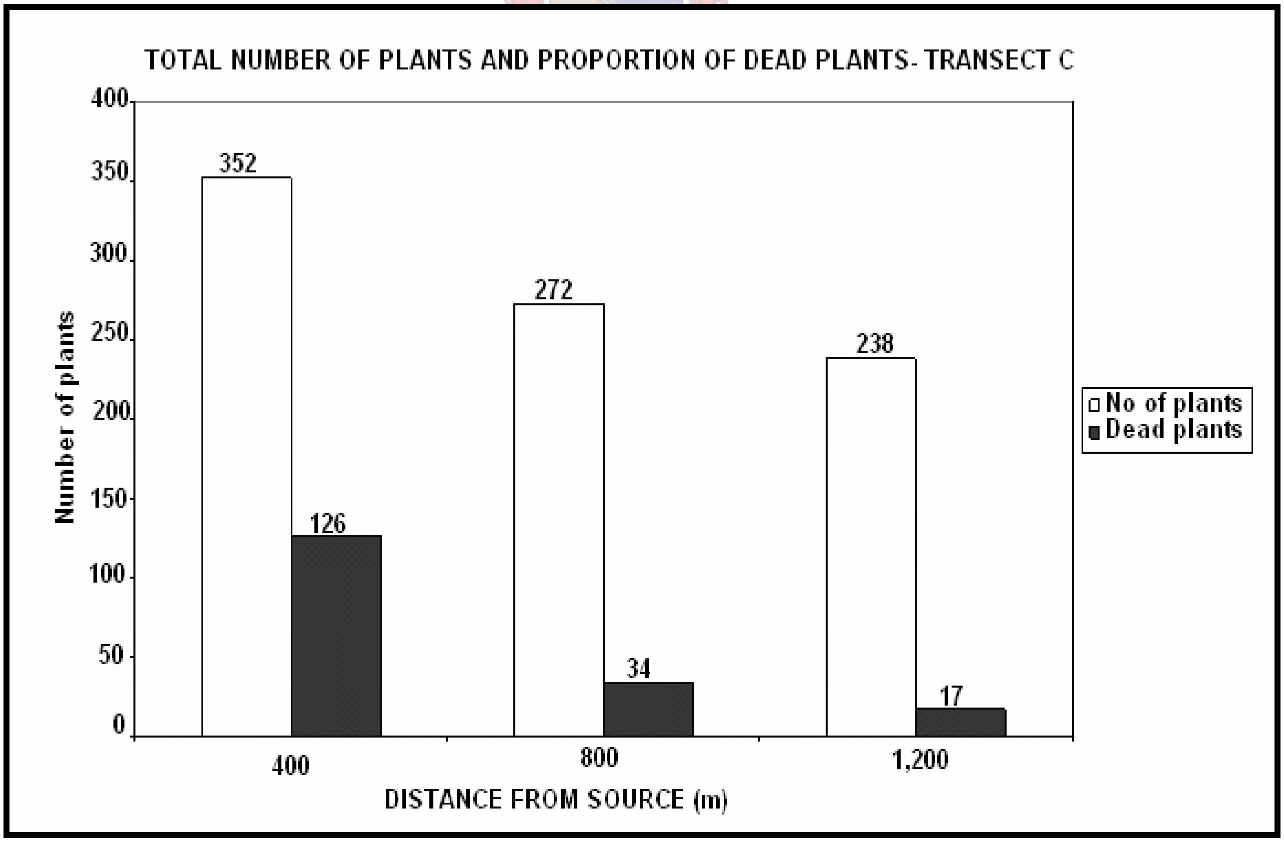
Serial No	TRANSECT No (Distance)	PLANT SPECIES	FRESH WEIGHT (g)	WEIGHT AFTER 24 HOURS (g)	WEIGHT AFTER 48 HOURS (g)	WEIGHT AFTER 52 HOURS (g)	WEIGHT AFTER 64 HOURS	DRY WEIGHT (g)	S (%)
1	A- 400 m	*Roepera morgsana*	113.34	80.1	28.38	26.64	20.22	20.22	0.864
2	A- 400 m	*Othonna cylindrica*	223.32	190.2	138.44	136.67	129.12	129.12	0.382
3	A- 400 m	*Ruschia tumidula*	169.75	151.45	81.81	81.56	80.07	80.07	0.186
4	A - 800 m	*Roepera morgsana*	121.03	97.81	60.61	58.76	50.98	50.98	0.813
5	A- 800 m	*Othonna cylindrica*	111.35	79.7	41.02	40.89	38.82	38.82	0.364
6	A- 1 200 m	*Othonna cylindrica*	150.1	134.29	105.43	103.63	96.82	96.19	0.310
7	B- 400 m	*Othonna cylindrica*	103.48	77.04	55.54	55.23	55.08	55.08	0.464
8	B- 400 m	*Salsola arborea*	185.44	154.29	113.34	110.55	-	108.97	0.220
9	B- 800 m	*Salsola arborea*	134.71	115.6	80.44	77.32	-	77.32	0.203
10	B- 1 200 m	*Salsola arborea*	88.38	73.05	45.51	44.8	-	44.8	0.153
11	C- 400 m	*Salsola arborea*	161.48	122.26	92.22	90.93	-	90.93	0.267
12	C – 800 m	*Salsola arborea*	67.7	56.31	35.76	35.68	-	35.68	0.224
13	C- 1 200 m	*Salsola arborea*	153.76	126.83	94.11	93.32	-	93.32	0.232

Appendix 10: **Plant distribution trend for Transects A, B and C with distance from the gaseous emission source and the trend of the proportion of the dead plants along the transects.**






TOTAL NUMBER OF PLANTS AND PROPORTION OF DEAD PLANTS- TRANSECT B
Number of plants
400
350
300
250
200
150
100
50
0
358
92
149
32
303
17
400
800
1,200
DISTANCE FROM SOURCE (m)
□ No of plants
■ Dead plants


TOTAL NUMBER OF PLANTS AND PROPORTION OF DEAD PLANTS- TRANSECT C
Number of plants
400
350
300
250
200
150
100
50
0
352
126
272
34
238
17
400
800
1,200
DISTANCE FROM SOURCE (m)
□ No of plants
■ Dead plants

Appendix 11: **Soil analysis data for open space (O) and shrub sub-canopy (S) samples**

TRANSECT	*PLOT No*	*SAMPLE (S) pH*	*SAMPLE (O) pH*	*SAMPLE (S) EC (µ s/m)*	*SAMPLE (O) EC (µ s/m)*
A	1	8.42	8.18	3.24	1.30
A	2	10.17	8.13	10.55	2.55
A	3	7.94	7.81	4.45	2.04
A	4	9.19	7.77	7.47	0.66
A	5	7.78	7.25	9.00	0.93
A	6	8.48	8.25	1.08	1.03
A	7	7.17	7.51	1.11	0.69
A	8	8.23	7.64	0.56	0.33
A	9	8.21	8.12	1.06	0.71
B	1	7.89	7.51	3.48	1.25
B	2	8.22	7.71	1.49	2.10
B	3	8.21	7.51	1.52	5.46
B	4	8.11	7.05	7.10	2.16
B	5	9.28	7.83	7.2	2.11
B	6	10.21	8.45	9.29	1.01
B	7	10.37	8.71	9.90	4.10
B	8	8.9	8.21	4.75	2.40
B	9	10.16	8.74	6.12	1.77
C	1	10.54	7.84	5.33	1.33

TRANSECT	***PLOT No***	***SAMPLE (S) pH***	***SAMPLE (O) pH***	***SAMPLE (S) EC (µ s/m)***	***SAMPLE (O) EC (µ s/m)***
C	2	9.81	8.53	5.06	0.87
C	3	8.25	7.8	5.10	5.20
C	4	9.31	8.11	2.71	0.91
C	5	9.66	8.44	3.41	2.02
C	6	8.72	8.43	7.05	7.01
C	7	7.97	7.61	1.85	1.47
C	8	8.93	8.47	2.14	1.59
C	9	10.32	8.61	4.20	2.71

KEY

S – Sample taken in shrub sub-canopy

O – Sample taken in the open space

EC - Electrical conductivity

Appendix 12: pH measurements of soil samples for contour map

TRANSECT	*SAMPLE No*	*ELEVATION (m.a.s.l)*	*GRID*		*pH*	*EC (µ s/m)*
A	1	84.1	280	70	8.26	20.10
A	2	82.0	320	30	8.22	16.14
A	3	87.5	360	90	8.24	9.61
A	4 (1)	77.4	400	30	8.41	9.22
A	5 (2)	80.5	400	70	8.21	11.24
A	6 (3)	90.0	400	110	8.07	7.61
A	7	86.9	510	30	8.35	9.79
A	8	76.5	550	90	8.32	10.21
A	9	76.5	650	110	8.34	14.71
A	10 (4)	97.8	800	30	8.65	13.01
A	11 (5)	96.9	800	70	7.71	5.11
A	12 (6)	96.3	800	110	7.72	10.41
A	13	101.4	890	30	7.72	13.14
A	14	106.7	930	70	7.82	11.74
A	15	103.3	1050	50	7.72	11.09
A	16 (7)	109.7	1200	30	7.84	2.47
A	17 (8)	107.6	1200	70	8.04	6.71
A	18 (9)	101.8	1200	110	7.95	8.35
A	19	106.1	1090	330	8.81	11.45
A	20	107.3	1130	270	9.04	12.09

TRANSECT	***SAMPLE No***	***ELEVATION (m.a.s.l)***	***GRID***		***pH***	***EC (µ s/m)***
A	21	108.2	1150	350	8.55	11.34
B	1	103.0	250	220	8.41	18.14
B	2	71.3	270	240	8.51	13.79
B	3	71.0	210	270	8.81	19.51
B	4 (1)	65.8	330	250	8.35	10.54
B	5 (2)	73.8	290	290	8.41	11.06
B	6 (3)	72.8	260	330	8.24	9.81
B	7	75.9	350	350	8.25	11.45
B	8	70.7	480	440	8.08	7.35
B	9	71.9	490	550	8.51	8.48
B	10 (4)	73.1	620	590	8.36	32.05
B	11 (5)	74.7	610	530	8.41	30.61
B	12	75.2	570	570	8.62	20.01
B	13	74.7	530	610	8.24	50.10
B	14	68.3	680	680	8.29	44.51
B	15	67.1	780	790	8.89	13.67
B	16 (7)	68.0	890	810	9.01	13.51
B	17 (8)	68.9	850	850	9.06	19.73
B	18 (9)	67.6	810	890	9.08	13.79
B	19	76.2	1040	1020	9.21	14.85

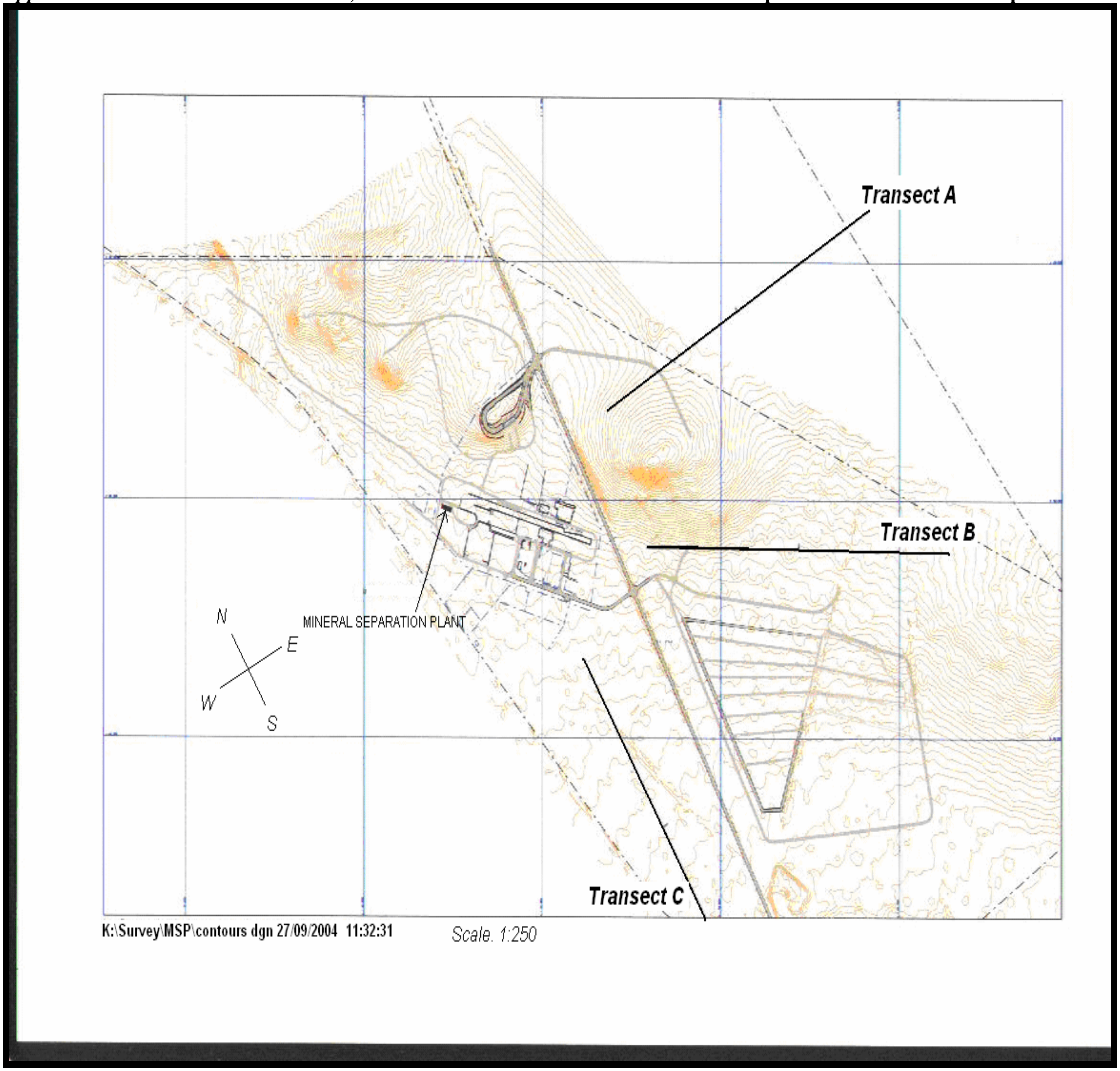
TRANSECT	*SAMPLE No*	*ELEVATION (m.a.s.l)*	*GRID*		*pH*	*EC (µ s/m)*
B	20	67.9	960	930	9.09	11.73
B	21	78.6	890	1100	8.96	14.28
B	22	77.4	850	1130	9.21	12.09
B	23	78.0	790	1140	9.05	9.66
B	24	70.7	1100	870	8.89	6.35
B	25	76.5	1150	900	8.81	7.56
B	26	69.7	1050	790	8.92	11.89
C	1	59.7	90	230	9.34	17.06
C	2	60.0	50	290	8.62	13.14
C	3	64.0	110	330	8.35	6.81
C	4 (1)	59.7	110	400	8.22	6.05
C	5 (2)	60.4	70	400	8.12	113.14
C	6 (3)	60.6	30	400	8.44	9.08
C	7	62.5	40	500	9.01	6.15
C	8	69.8	90	600	8.41	6.05
C	9	69.5	70	700	8.52	13.50
C	10 (4)	56.4	110	800	8.61	15.33
C	11 (5)	53.6	70	800	8.25	65.15
C	12 (6)	56.1	30	800	8.12	21.10

TRANSECT	*SAMPLE No*	*ELEVATION (m.a.s.l)*	*GRID*		*pH*	*EC (µ s/m)*
C	13	57.0	80	910	8.33	14.40
C	14	58.5	100	1020	8.14	23.02
C	15	53.6	30	1130	8.17	9.48
C	16 (7)	53.0	110	1200	8.83	7.15
C	17 (8)	47.8	70	1200	8.61	27.71
C	18 (9)	46.0	30	1200	8.42	48.60

KEY

( ) Permanent sample plots

Appendix 13: Location of Transects A, B and C on the Namakwa Sands Mineral Separation Plant contour map



Appendix 14: **Plant species found within the study area around Namakwa Sands Mineral Separation Plant**

1 *Mesembryanthemum gaucherianum* (Aizoaceae)

2 *Drosanthemum floribundum* (Aizoaceae)

3 *Psilocaulon sp*. (*Brownanthus*) (Aizoaceae)

4 *Tetragonia fruticosa (*Aizoaceae)

5 *Aridaria noctiflora* (Aizoaceae)

6 *Asparagus fasciculatus* (Asparagaceae)

8 *Zygophyllum morgsana* (Zygophyllaceae)

9 *Othonna cylindrica* (Asteraceae)

10 *Atriplex lindleyi* (Amaranthaceae)

12 *Salsola arborea* (Amaranthaceae)

13 *Cephalophyllum spongiosum* (Aizoaceae)

14 *Galenia africana* (Aizoaceae)

15 *Malephora crocea* (Aizoaceae)

16 *Tylecodon wallichii* (Crassulaceae)

17 *Massonia crassicaule* (Geraniaceae)

18 *Ruschia* sp. (Aizoaceae SP 9)

19 *Tripteris oppositifolia* (Asteraceae)

20 *Argyroderma congregatum* (Aizoaceae)

21 *Lampranthus amoenus* (Aizoaceae)

22 *Lampranthus suavissimus* (Aizoaceae)

Appendix 7: Multivariate analysis data matrix

	PLOTS																										
Transect	A	A	A	A	A	A	A	A	A	B	B	B	B	B	B	B	B	B	C	C	C	C	C	C	C	C	C
Plot number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Elevation (m.a.s.l)	88.7	88.7	77.4	101	105	107	111	110	110	70.4	70.4	67.4	63.1	63.1	62.5	58.2	60.4	61	59.4	60.4	57.3	44.4	46	52.4	47.2	49.7	49.4
No of plants	36	80	132	57	79	84	58	90	119	91	129	71	46	32	39	108	115	63	56	91	79	87	76	75	72	80	69
No of dead plants	74	33	13	32	15	24	26	10	6	57	25	10	11	17	4	0	12	5	96	15	15	10	11	13	8	5	4
No of seedlings	140	44	22	14	2	14	45	0	50	0	26	10	67	1	4	3	2	32	58	24	63	0	2	3	29	2	0
Plant height	36	31	24	46	32	32	38	31	23	20	19	17	20	20	16	25	27	19	14	21	15	30	15	16	29	32	24
Crown density	3	4	4	4	4	4	4	4	5	4	3	3	3	3	4	4	5	5	3	4	4	4	4	4	4	4	4
pH	7.05	7.13	7.45	8.09	7.5	8.11	8.7	9.7	7.69	7.6	7.61	7.53	7.43	7.86	7.95	7.1	8.28	8.35	7.14	7.25	6.9	7.11	7.51	7.6	8.91	7.7	7.31
Electrical conductivity (µ s/m)	9.12	8.82	5.56	3.01	5.68	4.55	5.4	5.21	5.6	6.35	14.2	13.3	10.9	5.69	7.9	10.6	7.44	25.3	20.8	9.2	17.9	11.2	7.41	6.62	10.2	11.6	5.93
Sulphur (mg/l)	133	124	49.2	22.1	24.4	23.7	23.8	23.1	21.5	61.8	116	120	121	37.8	87.2	71.4	52.4	61.9	155	115	195	62.2	79.7	54.7	39.1	55.6	39.3
Erosion	5	5	5	5	5	5	4	4	4	4	4	4	3	4	2	5	5	4	5	5	5	5	5	5	4	4	3
Slope	3	4	4	4	4	4	3	3	3	3	3	3	3	4	3	5	5	5	3	4	4	4	4	4	3	3	3
Soil colour	1	1	1	1	1	1	4	4	4	5	5	5	2	2	2	2	2	2	3	3	3	3	3	3	2	2	2
Soil texture	2	2	2	3	3	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1	1	1
Crown cover (%)	13	22.2	15.6	14.5	26.6	19.5	9.2	12.6	12.7	11.2	10.4	26.1	25	19	20.6	14.9	22	18.2	12.5	9.5	6	7.9	5.6	5.6	9.6	17.4	10.1

KEY

CROWN DENSITY

0	Dead plant
1	0 % - 20%
2	21% - 40%
3	41% - 60%
4	61% - 80%
5	>80%

SLOPE

1	Flat
2	Fairly flat
3	moderately steep
4	Steep
5	Very steep

SOIL TEXTURE

1	Coarse
2	Moderately coarse
3	Medium
4	Moderately fine
5	Fine

EROSION

1	Very extensive
2	Extensive
3	Moderate
4	Mild
5	None

SOIL COLOUR

1	5 YR 5/8 – 5YR 6/8
2	7.5 YR 6/2 – 7.5 YR 6/5
3	7.5 YR 6/8 – 7.5 YR 7.2
4	7.5 YR 7/5 - 7.5 YR 7/6
5	10 YR 6/8 – 10 YR 7/8

(Soil Colour Chart For Training)