NAMIBIA UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Assessment of Atmospheric Dispersion of Fly Ash within the Vicinity of Van Eck Coal-Fired Power Station, Windhoek, Namibia

Thesis Presented in Partial Fulfilment of the Requirements for The Degree of Master of Science in the Subject Environmental Engineering Under the Department of Civil and Environmental Engineering at The Namibia University of Science and Technology

By

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ABSTRACT

Increase in population led to the growth of industrialisation which has stimulated the development of alternatives to produce electricity, including the use of coal. Coal-fired power plants produce an abundant amount of electricity, addressing the ever-increasing electricity demand. Power plants produce fly ash as a result of coal combustion for electric power generation. The Van Eck Power Station is the oldest and only coal-fired plant in Namibia that is located at the outskirts of Windhoek. The power plant produces electricity from the combustion of coal. Its refurbishment began in 2013, to improve its efficiency and allow for longer operational period. Van Eck's rehabilitation included coal feeders which reduce emissions and new grates for boiler units which reduce ash emissions to ensure that the plant is a cleaner coal-fired power plant.

Fly ash is produced when coal is pulverised and blown with air into the boiler's combustion chamber where it directly burns and generates heat. Trace elements in coal deposits would not only contaminate the air, soil and underground water but also have an impact on human health. The thesis was aimed at assessing the possible pollutant elements found in fly ash and soil in areas surrounding the Van Eck Power Station. The thesis was also aimed at modelling the distribution and dispersion of those elements at a particular distance in areas around the Van Eck power plant using the Gaussian Plume Model. Soil samples were obtained from sites within the vicinity of Van Eck Power Station, and XRF Analysis was used to determine the concentration of elements in the soil. To obtain samples of fly ash, fall out buckets filled with distilled water were mounted on poles away from the main source of pollution. The deionised water was analysed using the Inductively Coupled Plasma (ICP-OES) Analysis method for the detection of elements. Gravimetric analysis was also applied to measure the weight of dust, which in the report is expressed as fly ash.

The study revealed more concentration of sulphur oxides specifically as sulphites and sulphates, as well as Zinc, while the rest of the elements of interest were detected significantly in low amount. Others were below the level of detection in both the fly ash and soil sampling. Also, soil sampled near the power plant was detected with a high amount of SOx and Zinc. Fly ash collected showed that areas near the power plant contain more pollutants than areas further from the power plant. Ash captured through the dust-fallout bucket method within the jurisdiction of the power plant was above the South African dust monitoring criteria. The model illustrated that elements during the day were more absorbed than reflected during the night.

Based on the research analysis, it was found that the power plant does not produce an abundant amount of pollution due to off-peak operations. However, comprehensive results may be obtained if this type of research is repeated on a different, specified timeframe. The station may require control efficiency compliance measures for noxious gases and particulate matter (PM) concentrations. These results will be important in the formulation of emission limits, air quality guidelines and control of emission of pollutants. Air quality modelling is essential in baseline reports of projects.

Keywords: *Fly ash, coal combustion, air pollution, concentration of elements*

DECLARATION

I, Ndeukumwa Ndashekwa Liliana Aushiku hereby declare that the work contained in the thesis, entitled Assessment of Atmospheric Dispersion of Fly Ash within the Vicinity of Van Eck Coal-Fired Power Station, Windhoek, Namibia is my own original work and that I have not previously in its entirety or in part submitted it at any university or other higher education institution for the award of a degree.

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LIST OF ABBREVIATIONS

AM:	After Meridian
ASTMS-D 1739:	American Society for Testing and Materials Standards
CA:	Course Ash
Cm:	Centimetre
DAM:	Day-Ahead Market
EDM:	Electricidade de Moçambique
ESKOM:	Electricity Supply Commission (ESCOM)
G:	Grams
ICP OES Analysis:	Inductively coupled Plasma - Optical Emission Spectrometry
IPP:	Independent Power Producers
M:	Meters
Mm:	Millimetres
MW:	Megawatts
NamPower:	Namibia Power Corporation
NaTIS:	Namibian Traffic Information System
NP:	NamPower
PM:	Particulate Matter
PM10:	Particulate with aerodynamic diameter of less than 10 µm
PM2.5:	Particulate with aerodynamic diameter of less than 2.5 µm
PV:	Photovoltaic
REFIT:	Renewable Energy Feed-in Tariff Programme
SAPP:	Southern Africa Power Pool
USEPA:	United States Environmental Protection Agency
VE:	Van Eck

Windhoek Met: Windhoek Meteorology Service

WT%: Weight percent

XRF Analysis: X-ray Fluorescence Analysis

ZESCO: Zambia Electricity Supply Corporation

ZPC: Zimbabwe Power Company

LIST OF SYMBOLS

Al:	Aluminium
As:	Arsenic
B:	Boron
Ba:	Barium
Ca:	Calcium
Cd:	Cadmium
Cl:	Chlorine
Co:	Cobalt
Cr:	Chromium
Cu:	Copper
Fe:	Iron
Hg:	Mercury
K:	Potassium
Mg:	Magnesium
Mn:	Manganese
Ni:	Nickel
P:	Phosphorus
Pb:	Lead
S:	Sulphur
Si:	Silica
Sr:	Strontium
Ti:	Titanium
V:	Vanadium
Zn:	Zinc

Zr: Zirconium

SiO_2: Silicon dioxide

SO_3: Sulphur trioxide or Sulphite

SO_4: Sulphate

MNO_2: Manganese dioxide

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CHAPTER 1

1. INTRODUCTION

Windhoek is the capital city of Namibia, located in the Khomas Region in the central part of the country. Windhoek, located on Latitude: -22.559, Longitude: 17.083 has a population of about 322,500 in 2011, with an area of 715.8 m^2 (City of Windhoek, 2018). Located in the Northern Industrial area of Windhoek, surrounded by numerous settlements and vegetation, the Van Eck Power Station is a 4 unit power plant, designed to produce 120 Mega Watts; however, it is currently generating only 80 Mega Watts (Nampower, 2017).

According to Baird, (1995), increase in population may lead to higher economic activities. Population growth improved and altered urbanisation therefore, prompted the development of alternatives to produce electricity, such as the use of coal, (Baird, 1995). Coal-fired power plants produce an abundant amount of electricity, addressing the ever-increasing electricity demand (Breeze, 2014). However, the accumulation of large amounts of ash from fossil fuel combustion for electric power generation has become a major environmental concern. The concentrations of trace elements in coal deposits are variable and depend on the composition of the original coal, conditions during combustion, and the effectiveness of emission control, storage and management of waste products.

Several years ago, Namibia's national power utility, NamPower, was opting for the reintegration of its Van Eck coal-fired power station since the old station was nearing the end of its lifespan. Refurbishment of Van Eck Power Station to improve efficiency began in 2013. The restoration was to allow for a longer operational period (Nampower, 2017). Upgrading the power plant implies that more atmospheric emissions are emitted for longer periods. However, although the power station has been refurbished, it is not fully operational as a baseload plant but rather operates as a peak load plant. Based on the aforesaid, the research was undertaken to assess whether it poses a threat to the environment after the its restoration.

The study was aimed at analysing trace elements found in fly ash and their composition and modelling air pollution by using Oliver Sutton's Gaussian Plume Model. Soil sampling techniques based on USEPA was adopted and ASTM Standard was used while capturing fly ash. Fly ash was collected in buckets filled with distilled water. The abundance of elements was determined by XRF Analysis for soil samples and ICP Analysis for liquid samples. Particulate Matter (PM) such as fly ash captured by buckets were analysed by using the

Gravimetric technique to determine the mass of the PM. Dutch permissible limits criteria were used to compare trace elements found in soil and fly ash. Air quality modelling using the Gaussian Plume Model was used to simulate the distribution of trace elements from its origin to areas near the power station. The model also assumed the concentration of elements specifically SOx at different distances at a specific location. It also analysed the possibility of trace elements found in the soil around the power plant. Regression analysis was used to deter the relationship between the dependent and independent variables. In this scenario, the concentration of elements in soil depends on the wind speed and temperature.

Regarding the data collection and statistical analysis made, sulphur oxides detected both in soil and distilled water were considerably high while Zinc and Chromium were among other trace elements detected with the highest values, although they were below the USEPA limits. PM collected at the warehouse located in the power plant was above the South African dust limits. Most of the trace elements in soil showed below Level of Detection (LOD). Similarly, water/liquid samples detected that most of the trace elements were <0.01%.

The importance of the study was to create responsiveness to decision-makers and commercial industries on the quantity of trace elements produced by the plant and the long-term impact on environmental wellness. This report describes the research work done mainly on-air pollution and monitoring, the methodologies adopted to answer all research questions and the presentation of results of dispersion model simulation of the impact of Van Eck Power Station on ambient air quality.

1.1. Objectives of the Study

The main objective of the study was to assess pollution emitted from the Van Eck Power Station focusing on fly ash to estimate the atmospheric distribution and evaluate the emissions spatially dispersed around the point source, and areas subject to emission, and was also to determine the quantity and the real magnitude of fly ash.

Specific Objectives

- To analyse trace elements found in soil in areas near and further from the plant.
- To compare the presence of heavy elements found in fly ash at Van Eck Power Station concerning distance from the station and its correlation with wind velocity and temperature.
- To model atmospheric dispersion to quantify the relationship between emissions and concentration dispersion.

Research Questions

- What is the concentration of trace elements found in fly ash and soil at Van Eck Power Station and areas further from the station?
- What is the mean concentration distribution and dispersion of trace elements?
- What is the relationship between wind speed and trace elements distribution?

1.2. Problem Statement

The 120-megawatt power plant was initially uneconomical, environmentally unsustainable and operating below capacity, with outdated equipment in need of replacement. However, with electricity demands exceeding domestic generation capacity, and insufficient alternative power generation capacity, decommissioning the plant would have resulted in power outages and lost economic productivity. Although Namibia was importing power from the Southern Africa Power Pool (SAPP), other SAPP members were facing electricity shortages of their own (Nampower, 2017), hence imports were not a failsafe solution to the country's power deficit. It was on this contextual that NamPower decided to embark on a project to rehabilitate the ageing 120 MW coal-fired Van Eck Power Station after a comprehensive feasibility study. The project was to restore three turbines, four generators and four boilers, resulting in increased local power generation capacity. In 2012 Marthinusen & Coutts, a division of ACTOM (Pty) (Ltd) company, commenced on a project on all three turbines with the aim of increasing and enhancing the reliability and efficiency of the station to meet its original design output of 120 MW. According to Coralynne and Associates' report, (2016), the first two units were already performing per their specifications. The last two units were completed by the end of November 2015 and the end of January 2016 (Coralynne and Associates, 2016).

The Van Eck power station is a peak-off-load plant that only operates intermittently. This was experienced during fieldwork. It was observed that the power plant operated for a limited period of time during the research time frame and operates mostly during the winter season. The peak-off-load circumstance is caused by technical failures, as a result of the station's near ending lifespan. At times it operates as a backup electrical function when the water level at Ruacana hydropower plant are very low (Nampower, 2017). Based on the aforesaid statement, the thesis was aimed at assessing Van Eck's impact on the environment by evaluating the intensity of pollution from the station, the possibility of the production of pollutant elements and fly ash and to compare the concentration of elements with regulatory standards.

There are unacceptable ambient pollutant concentrations emitted in industrial zones, containing quite many pollutant sources (Leelosy, Molnar, Havasi, & Lagzi, 2014). Hence, the Northern Industrial area at the outskirts of Windhoek might produce a considerable amount of pollutants. The City of Windhoek however, seems not to consider the plant as a point source of pollution and this may become a serious environmental issue if not addressed. In point of fact, there are no regulations on fuel burning, emission limits, ambient air quality guidelines, or smoke-controlled areas in existence for Windhoek. It is unknown if there are any regulations about dust control in Windhoek or anywhere in Namibia.

Concentration distribution depends on meteorological data. Highest ground level concentration is mostly associated with wind direction, the prevailing wind direction of Windhoek is Northern, with an approximate speed 2.5 m/s (Timeanddate.com, 2019). Henceforth ground concentration may likely to be detected on opposite direction. Similarly, wind speed plays a crucial role in the purification of the atmosphere. Average windspeed in Windhoek occurs frequently during afternoon hours and early mornings between April and June (Mendelsohn, Jarvis, Roberts, & Robertson, 2003). Hence, settlements downwind such as Katutura might be prone to pollution. Adoption of Gaussian Plume Model is significant in predicting the dispersal and distribution of pollutant elements and particulate matter at a specific area at a particular distance. Therefore, the model serves as a way to solve the issue of absence of data and information transparency and on the ecological aspects relating to the coal-fired power plant.

There are insufficient studies to evaluate ecological parameters based on Van Eck coal-fired power plant and unavailability of resources on the development of environmental impact analysis. These aforementioned limitations may generate difficulties in future research that is essential in the implementation of policies and modelling predictions on environmental events. Furthermore, studies based on atmospheric aspects encounter insufficient support and funding as the study of this nature requires complex software. Researchers are therefore left in limbo due to limited or absence of funds. Ultimately, the situation has been worsened by the country’s failure to formulate laws to regulate the emissions from factories and power stations. It is therefore ideal to model to identify which sources are contributing to the excessive concentrations. Air quality engineers can take appropriate action to solve the problem.

CHAPTER 2

2. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

Industrialisation associated with development has increasingly become a common norm and brought drastic changes into human livelihoods, which seem to become easier for mankind; however, it has negatively brought deviations in climatic conditions, ecosystems as well as to the well-being of humans. Power production is one of the main parts of industrialisation. It is significant for lighting, cooking, running medical facilities and industries, agriculture, and for motion, e.g. motor vehicles. There are several ways of electrical energy production, whereby the thesis largely focused on coal as the primary source of energy production (Stoch , 2015). The amount of air pollutants at a given location is a function of emission rate, the distance of the receptor from the source and the atmospheric conditions such as wind speed, wind direction, and the vertical temperature structure.

Most studies conducted assessed coal-fired thermal power plants by calculating the environmental impact index at the planning stage (Leelossy, Molnar, Havasi, & Lagzi, 2014). However, this study focuses on evaluating the effect of Van Eck Coal-fired power plant while it is in operation, focusing on fly ash and trace elements. The research study analysed the following elements which are categorised as toxic to the environment: Arsenic, Beryllium, Boron, Cadmium, Chromium, Cobalt, Lead, Manganese, and oxides such as Sulphur oxides in soil and fly ash using the XRF-analysis, and in water suspension using the ICP analysis. According to Nalbandian (2012), arsenic (As), boron (B), cadmium (Cd), and lead (Pb) are major environmental concerns.

Nalbandian (2012), explains that Arsenic, cadmium, and lead are highly toxic to most biological systems at concentrations above critical levels. Selenium is an essential element but is also toxic above certain levels. High levels of molybdenum and boron in plants are of concern. Molybdenum affects the lactation of cows and boron is phytotoxic. Phytotoxicity is a term used to describe the degree of toxic effect by a compound on plant growth (Nalbandian, 2012). Moderate concern classification includes chromium (Cr), vanadium (V), copper (Cu), zinc (Zn), nickel (Ni) and fluorine (F). These elements are potentially toxic and are present in coal combustion deposits at high levels. Bio-accumulation is of some concern. However, barium (Ba), strontium (Sr), sodium (Na), manganese (Mn), cobalt (Co), antimony (Sb), lithium (Li), chlorine (Cl), bromine (Br) and germanium (Ge) are minor concerns due to the fact that these elements are of little environmental concern. Out of the above-mentioned elements, only a few of them were selected for analysis, mainly due to financial constraint, as the researcher was self-funded for the project and machinery that were to be offered without cost was either not operational or there was an absence of a skilled technician.

Fly ash has a high amount of fixed carbon and has a relatively low percent of Sulphur. The harder the coal, the more energy is produced. The Van Eck Power Station uses bituminous coal which produces a high amount of fly ash (3.3 wt%-11.7 wt.%.) compared to lignite, (Nazarof & Alvarez-Cohen, 2001). During combustion, chemical bonds holding carbon atoms in place are broken, releasing energy. Through the process of carbon breakdown, several harmful elements are produced, such as SOx, NOx, heavy elements and PM.

2.1. Background of the Area of Study

The point source of pollution is located at the Van Eck Power Station in the Northern Industrial area of Windhoek, Namibia's Capital City. Windhoek is located in the centre of the West-central highland. The City is on an altitude of 2000m characterised with moderate temperatures and average rainfalls (Mendelsohn *et al*, 2003). Its day time average temperatures vary at 30°C in January to 20°C in July, while during the night between 17°C in January and 7°C in June at night. During winter overnight frost may occur and an annual average rainfall of the last 20 years for Windhoek is 370 mm (Mendelsohn *et al*, 2003). The Hottest month of Windhoek is December at an average of 25^{o}C, the coldest month is July on an average of 15^{o}C and the windiest month is October at an average speed of 2.5 m/s (Timeanddate.com, 2019).

Windhoek is mainly circulated by automobiles, from small motors to heavy-duty vehicles, caused by the busy industrialisation and the NATIS Centre which is opposite to the Power Station and next to the NamPower Training Centre. On the Northern part of the plant, the land is associated with agricultural activities, mainly livestock farming with Klein Windhoek River dividing the farm and the power plant. The area is dominated by vegetation, tall trees and grass. During morning hours, local people would roam around possibly in search of animal fodder for marketing and in search of employment. On the Eastern side of the plant, there are industrial buildings such as tanneries and milling companies. On the front side of the power plant, there is a road that divides it with Natis, NamPower Training Centre and China Town. Based on the observations obtained from the field, the road is frequently busy, specifically during weekdays, early mornings of 06:00 am and during knocking off hours of 04:30 pm. There is more traffic congestion during the aforementioned hours, therefore pollution from motor vehicles may exist.

Areas of Interest and their Characteristics

There are five main areas of interest on which fallout-dust capturing buckets were mounted and soil samples were obtained. These mainly include the Farm area, Van Eck Power Station, Natis, Lafrenz as well as residential areas of Katutura. There are several operations with the possible release of noxious and offensive gases into the atmosphere in the Northern Industrial area. Many of these minor industrial sources are likely to be low-level sources emitting at or near the surface. The list below categorises them into operation types:

- Metal works and engineering
- Construction (supply of bricks, cement, sand, aggregate and other building materials)
- Fuel Storage Depots
- Food and Beverage industries
- Incinerators
- Leather Tannery
- Chemical manufacture and storage

Figure 1: Van Eck Power Station, Northern Industrial, Windhoek

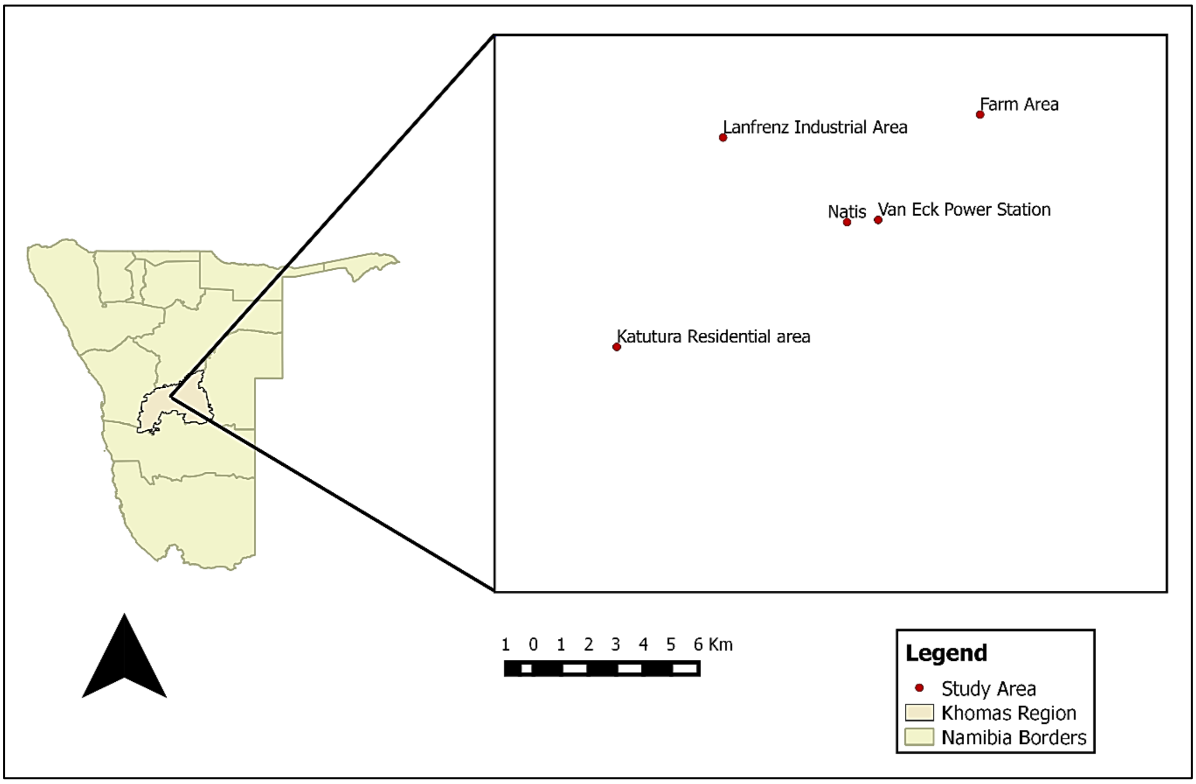

Figure 2: A map showing five main sampling areas of soil and fallout-dust.

<u>*Farm Area*</u>

The farm is situated behind Van Eck Power Station, just near Klein Windhoek River. The River which is upstream of the Swakoppoort Dam extends from Ludwigsdorf and it is 6km in length. There is thick vegetation ranging from tall trees to shrubs and grasses along the river bed. There is also a railway that is located between the power plant and the river. During fieldwork, some Guinea Fowls (*Numida meleagris*), were spotted along the Klein Windhoek River which was bloomed with blue-green algae.

<u>*Van Eck Power Station*</u>

The station comprises of operation buildings which include the operation belts, the two smokestacks and a warehouse. Coal is kept outside exposed by the air and as a result, oxidation occurs when coal burns and produces sulphur dioxide. The smell of sulphur becomes a nuisance to residents near the power plant. There are stockpiles of fly ash that produces a considerable amount of ash, and similarly, there is dust created behind the warehouse, on the conveyer belt where coal is transported.

<u>*Natis*</u>

Natis is situated in the Northern industrial area of Windhoek. The firm is responsible with the registration and clearance of cars, learner drivers' licence and drivers licence tests. Many cars are observed about the centre and pollutants from car exhaust fumes may occur in a significantly low amount. Along the centre, there is a water canal that was mostly dry. In this specific area, a bucket was mounted to capture air dust, and some few meters away, soil sampling was performed to obtain inclusive data collection.

Lafrenz Industrial Area

It is an Industrial park that is situated in Windhoek's Northern Industrial area. It is comprised of manufacturing, engineering and trade activities. Other services or business entities such as service stations for fuelling cars were spotted along the road. A soil sample was taken within this area, some few meters away from the road.

Katutura Residential Area

Soil samples were obtained from a residential area in Claudia Kandovasu Street, next to the Monte Christo Road and opposite to the Sam Nujoma Stadium. Another soil sampling was performed in Katutura suburb's known as Golgotha, near the road but further to an area with short dry yellow grass. The area is on an elevated height which gives a full view of the Lafrenz Industrial Park.

2.2. Operation of Van Eck Power Station

The Van Eck plant has a dry cooled station due to water constraints experienced in Windhoek. The coal used is imported mainly from Botswana and South Africa, usually transported by ship to Walvis Bay and then by rail or road to Windhoek. The plant is normally operated as a standby and peak-load power station. Moreover, it has been run at mid-merit to baseload. According to a report submitted by Hatch Consulting firm, (Carias & Lian, 2012), the power station has very limited equipment on emission control, hence it releases high levels of air pollutants. The station can only burn 3,500 tonnes of coal each week, although it may use emergency stockpiles if necessary (Carias & Lian, 2012). The plant is direct air-cooled with large fans reducing the maximum capacity by 2 MW/unit.

Characteristics	**Description**
Coal Fired Power Station	120 MW
Date Commissioned	Unit 1 and 2: 1972 Unit 3: 1973 Unit 4: 1979
Capacity	4 x 30 MW
Generator Type	Brown Boveri Orsal
	11.000 Volts

	1852 Amp 50Hz 3000 RPM
Boilers 1, 2and 3	Yarrow Africa
Boiler 4	Babcock and Wilcox
Coal Used per Mw/h Generated	650 kg 0.65kg/kWh
Coal cost per ton in 2017	N$ 1 955
Steam Generated per sec	37.79kg/sec 136.1 Tonnes/hr
Amount of steam needed to generate 1Mw/h	4.533 Tonnes

Table 1: Description of Van Eck Power Station. Source: https://www.nampower.com.na.

Environmental concerns regarding coal power plants have become a global concern and as a result, companies including NamPower are switching to more reliable and environmentally friendly technology, by utilising renewable resources for the production of power. Apart from Namibia, a small populated country with one single off-peak coal power plant, countries such as the United States of America produced approximately 130 million tons of coal ash in 2014 alone, one of the largest industrial waste generated, (Almeida, 2016). Coal ash causes health problems, such as its effects on the pulmonary system. To determine the permitted frequency of exceeding dust fall rate of Van Eck, the study adopted the South African National Dust Control Regulations in relation to ASTM 1739 standards which are indicated by the table below.

Restriction Areas	**Dust fall rate (D) (mg/m^2/day)-averaged over 30 days.**	**Permitted frequency of exceeding dust fall rate.**
Residential area	D < 600	Two within a year, not sequential months.
Non-residential area	600 < D <1200	Two within a year, not sequential months.

Table 2: Acceptable Dust Fall Rates-South African National Dust Control regulations, 2013.

2.3. Coal

Coal is a combustible organic sedimentary rock, a concentrated source of chemical energy called fossil fuel that is formed as a result of decomposition of animal and plant matter from millions of years ago. It is a non-renewable fuel with more than 50% of the weight of carbonaceous material (Stoch , 2015). The combustion of coal generates various by-products and among these, fly ashes are the most abundant, of which its distribution includes the fly ash and the bottom ash (Demirbas, 2008) . Fly ashes are mineral residues that are ejected through the furnace together with the flue gases. According to Stoch, (2015), the ash particles are captured by dust collection equipment, mainly electrostatic precipitators. Stoch also revealed that the world's largest fly ash is mainly produced by China with 600 million tonnes in 2017 (Ma, Xu, Qiqige, Wang, & Zhou, 2017).

The coal is mostly derived and composed of plant materials and transformed plant by-products. Mainly deposited as peat or mud, it is changed to coal by physical and chemical processes, (Demirbas, 2008). The process of transformation includes compaction and heating during long-term embedding in depths up to some kilometres and periods longer than a few hundred million years. The properties and composition of coal depend upon the original plant materials and their degree of decay (Stoch , 2015). Therefore, coal composition may vary significantly. Table 3 below illustrates typical ranges for fixed carbon, moisture, ash and sulphur contents for different types of coal. Stoch (2015) found that the most significant constituent of coal is fixed carbon which relative content increases from 30 wt.% in lignite coal to 85 wt.% in anthracite.

Type of Coal	**Fixed Carbon**	**Moisture**	**Ash**	**Sulphur**
Lignite	31.4	39	4.2	0.4
Bituminous	44.9-78.2	2.2-15.9	3.3-11.7	0.7-4.0
Anthracite	80.5-85.7	2.8-16.3	9.7-20.2	0.6-0.77

Table 3: Composition of various types of coal in wt.%. Source: Stoch, A, (2015). Energy Engineering and Management. KIC InnoEnergy.

Coal has a significantly high concentration of trace elements in comparison to other geological formations. Trace elements tend to accumulate in fly ash during condense volatilization process (Demirbas, 2008). Trace elements are easier filtered from acid ashes, causing soil pollution and resulting in ground water contamination. Fly ash produced from the Van Eck Power Station may pollute the streams of Klein Windhoek River and it may contaminate groundwater. Hence, this may cause a strain to the Windhoek municipality as the authority is experiencing water scarcity. It is therefore ideal for researching on water quality when opting for extracting underground water. It is thus important to come up with a reliable method of calculating the spreading of various substances that are constantly released into the atmosphere, especially during this era of massive air, water and land pollution.

Combustion of coal increases CO_2 in the atmosphere, which later contributes to the warming of the planet. Coal naturally encompasses sulphur, and when coal is burned, the sulphur combines with oxygen to form sulphur oxides (SOx). SOx reacts with molecules of water vapour thereby producing acid rain. Acid rain changes the pH level in rivers and streams as well as pH in the soil. Plants are mostly affected by acid rain, as it damages their physical structures such as leaves and roots. Acid rain causes damages to properties and monuments, and it causes health problems to humans and animals especially through its role in forming particulates. The main health effect of SO is impairment of the function of the upper respiratory system. High exposure to sulphur dioxide can alter breathing, cause respiratory illnesses, and worsen existing heart and lung diseases. Surprisingly, low exposure to sulphur dioxide can irritate the lungs and throat and bronchitis (Dwivedi & Jain, 2014). Due to the pollutants produced by combustion of coal, many coal power plants have smokestack scrubbers which trap sulphur emissions before they are discharged into the air and turn them into sludge and solid waste (Gibas & Glinicki, 2012). However, the technology is expensive, and the waste products require some means of disposal.

2.4. Weather Variations and Buoyancy of Fumes

Leelossy *et al*. (2014) argued that, pollutants released by stalks in the form of fumes are more or less likely to cause harm in an unstable atmosphere. This statement is inclined to temperature and wind. Pollutants in fly ash are vastly spread around and diffused when the area is windy, however, it is not the case with Windhoek based on the average wind speed recorded in the past by the Windhoek Meteorological Services. This implies that on any occasion when the plant is operational the environment becomes more in danger than before, thereby prone to pollution. Namibia is categorised as a semi-arid country. This implies that its evapotranspiration is greater than rainfall. According to Mendelsohn *et al.* (2003), Windhoek receives an average annual rainfall range between 300mm to 350mm per year, however in the recent years, a recorded rainfall was far less than its usual value. It suggests that rainfall is not sufficient enough to purify the troubled atmosphere. In addition, Windhoek's average wind speed, inefficiently cannot cleanse the atmosphere. It is therefore very crucial for the Municipality of Windhoek and other law-making institutions to be cautious with pollution and advocate for cleaner production through incentives and regulation of law.

2.5. Fly Ash Produced by Van Eck Power Plant

Fly ash produced at Van Eck Power Station is emitted through the stacks or discarded as stockpiles where it is blown by the wind and mixed with ordinary dust. Thus, the ash may enter the terrestrial or aquatic environment by wet or dry deposition or infiltrate the soil, thereby contaminating soil and water (Batkin & Keller, 1998). Fly ash can be deposited by the wind to areas within the vicinity of the (5-10 km) coal-fired power plants (Calder, 1948). Wind is an independent variable that influences the dispersion and deposition of fly ash (Dayal & Sinha, 2005). The higher the wind speed, the lower the pollutant concertation, hence wind acts as an atmospheric purifier. A study carried out by Calder (1948) showed that over downwind, the height of the plume increases with the distance under the adiabatic conditions. In addition, with assumptions, for further distance of travel, the height of the cloud increases linearly with the distance from the source of pollution (Calder, 1948). Apart from wind, temperature inversions play a crucial role in air quality, particularly during the winter season when inversions are the strongest. An inversion can prevent the dispersal of pollutants from the lower layers of the atmosphere and thus may cause localised air pollution.

A study done by Bradley (2014) on Coal Ash Ecological Risk assessment based on an incident of the Kingston Fossil Plant ash spill on 22 December 2008, Tennessee, United States, assessed and investigated the ecological impact on fly ash spill in riparian and aquatic biota, in which the investigation revealed that harmfulness occurred only in areas where the fly ash was greater than 40% of the sediment. The findings were primarily correlated with the presence of arsenic, which posed adverse impacts on aquatic life (Bradley, 2014). It is with this background that despite the fact that the study would be similar to that of Bradley, as they both focused on the same aspect- fly ash, the study was inclined to soil on dry land instead of the riparian or aquatic biome. However, the findings might be similar or slightly different, hence in this thesis, the null hypothesis states that the concentration of trace elements is not significantly different. It is however assumed that $\mu_1 = \mu_2$, at a confidence interval of 95%. Alternatively, the concentration of trace elements from fly ash found in areas subject to emission from the power plant is significantly higher. Hence, $\mu_1 \neq \mu_2$.

The study is a theoretical framework based and it is both qualitative and quantitative research based on analysing elements found in fly ash. Sampling method to be used is the probability random sampling (systematic random sample). The study adopted the Gaussian plume model, because it defines specific reference points such as the source of pollution, in a system that monitors atmospheric properties, including temperature, pressure, chemical concentration of tracers, over time. Due to the lack of air quality standards in Namibia, South

African National Air Quality Standards will be used to compare them with data obtained. South African NAQS was adopted because the country shares similar geographic and climatic features. (Van den Berg & Koep, 2017).

2.6. NamPower's Air Quality Monitoring

Namibia's state-owned company has engaged in environmental monitoring programme as part of the Airshed planning professionals at the end of Van Eck baseline air quality study, which recommends monitoring of Sulphur Dioxide (SO_2) and Particulate Matter (PM10 and PM2.5) concentrations be established downwind and directly west of the power station. However, the parastatal does not account monitoring of trace elements suspended in air and soil. Hence the study seeks to investigate the effect of pollutant trace elements emitted during combustion of coal through the stalks on the surrounding area. Although the power plant barely operates due to technical difficulties due to the old operates, it is significant to model air quality to monitor trace elements. This is not only essential in biodiversity protection but also to protect the health of residents living within the vicinity of Van Eck Power Station. The institution purchased apparatus for quality dust monitoring and it was fortunate that the researcher got access and was trained on how to operate it.

2.7. Importance of Air Quality Monitoring for Van Eck Power Station

There are unacceptably high ambient pollutant concentrations measured in industrial areas containing many large pollutant sources. Restoration of Van Eck Plant implies that efficiency is improved and longer operation times may influence ambient air quality in surrounding areas. Atmospheric air quality dispersion models are usually used to estimate just how much reduction has occurred during the transport of pollution from an industrial source, and consequently to project the pollution concentration at ground level (Abdel-Rahman, 2008). Monitoring of ambient air quality allows NamPower to determine the consequences of the past and future and determine the effectiveness of abatement strategies. Modelling is therefore significant to NamPower in identifying neighbouring sources of pollution to compare and quantify the amount of particulate matter (fly ash) and elements produced by the power plant. This is crucial in regulatory decisions that have to be made within certain frameworks inclined to air quality standards.

2.8. Namibia's Policy on Pollution and its Vison to Renewable Energy Production

Environmental policies in Namibia were planned to guide decisions and strategies that are essential in the protection of the air, land and water from pollution by focusing on the three pillars of sustainable development, which includes social and economic aspects (Ruppel & Ruppel-Schlichiting, 2016). Policies also include the Environmental Assessment guidelines which seek to assist in protecting biodiversity, maintain ecosystems and related ecological processes. The Namibian government through the Ministry of Environment and Tourism has done an immense influence in protecting Biodiversity (Flora and Fauna), which became a success story in Africa (Ruppel & Ruppel-Schlichiting, 2016). However, the state ignored one of the main and dangerous conditions that may cause massive destruction to ecosystems, and that is pollution by industries.

Air pollution may alter atmospheric conditions, and this can be exacerbated by the fact that the semi-arid country has more evapotranspiration than rainfall. Air quality is unfortunately not included in Namibian policies and regulations, however was included in the Atmospheric Pollution Prevention Ordinance No. 11 of 1976. The Ordinance does not include any ambient air standards with which to comply. It is implied in the Ordinance that air quality guidelines should be considered during the issuing of Registration Certificates (Republic of Namibia, 1976). The Ordinance also includes and outlines a range of pollutants as noxious and offensive gases but air pollution guidelines are primarily for criteria pollutants namely, sulphur dioxide (SO_2), oxides of nitrogen (NOX), carbon monoxide (CO), ozone (O_3), lead (Pb) and PM (Republic of Namibia, 1976).

In the Ordinance (No 11 of 1976), power plants are listed as a "Scheduled Process" which implies the processes in which:

(a) Combustion of solids or liquid fuels raise vapour for the generation of electricity for distribution to the public or purposes of public transport;

(b) Boilers burning solid or liquid fuels at a rate of not less than 150 megajoules per second (MJ/s) are used to raise steam for the supply of energy for purposes other than those mentioned in (a) above.

Per the Ordinance, the Executive Committee may declare any area a *controlled area* of the Ordinance by notice in the Official Gazette. Any planned development carried out in a *controlled area* must hold an existing registration certificate which is authorising an individual/company to carry on the process in or on the said premises. Most unfortunately, the Van Eck Power Station does not possess a registration certificate or a provisional certificate. This is similar to the Northern Industrial area of Windhoek, which has not been declared a controlled area, which prompts the condition for a registration certificate.

NamPower has embarked upon a journey to renewable energy technology to produce sustainably clean energy. Renewable energy production is the government's main aim as stipulated in the National Energy Policy which was previously known as the "Energy White Paper of 1998''. According to the NamPower Report, (2017), the parastatal has decided to invest in renewable energy although it might potentially disturb the National Grid Balance. However, the corporation has launched a study which will make recommendations for the NamPower grid to offer improved ancillary services and potentially implement storage facilities for all future renewable energy sources to supply during peak demand periods. NamPower has launched several projects such as the Renewable Energy Feed-In Tariff (REFIT) Programme which is aimed at increasing investment in renewable energy technology by offering incentives such as long-term contracts with attractive tariffs to Independent Power Producers (IPP). The company has successfully made some agreements with Diaz Power (44 MW wind power generation near Luderitz) and GreenNam (solar PV of 10 MW at Hardap and 10 MW at Kokerboom sites in the Southern part of Namibia), in purchasing and transmitting power. Additionally, the corporate has also awarded the Hardap Solar PV tender with a capacity of 37 MW, located opposite to Hardap Transmission Station few meters to Mariental, (NamPower, 2018). Renewable energy is the future and it will assist in eliminating Namibia's dependency on energy by external sources such as ESKOM, ZPC, ZESCO, EDM and DAM (Purchases).

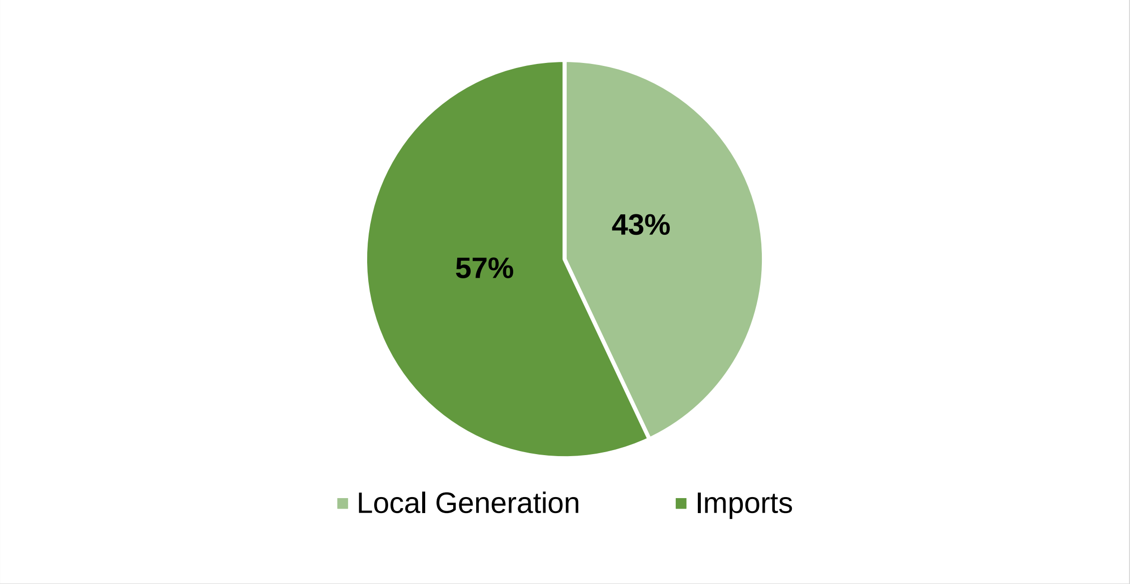

Figure 3: NamPower Energy trading of power produced locally and that imported. Source: NamPower Report (2017).

Nonetheless, according to a report by REEEI, (2012) in 2010 the water and electricity sector in Namibia has contributed with N$ 2,089 Million for the National GDP of N$ 81,509 Million, a contribution of 2,6% to the country's GDP. The energy sector has a significant impact on the economy in the sense that electricity plays an important role in the production of goods and services, (Renewable Energy and Energy Efficiency Institute , 2012).

2.9. Regulatory Requirements and Assessment Criteria

This thesis encompassed environmental regulations and guidelines used to govern the assessment of the emission limits and air quality impact resulting from the Van Eck Power Station. Air quality guidelines and standards are essential to effective air quality management, providing the link between the source of atmospheric emissions and the user of that air at the downstream receptor site. The guidelines are also built on standard concentrations that indicate safe exposure levels on a daily basis. Concentrations standards could, therefore, be based on health effects, whereby they may also be set based on irritational value, such as dust fallout. Air quality guidelines and standards are normally given for specific averaging or exposure periods and are evaluated as the observed air concentration expressed as a fraction of a benchmark concentration. Concentration standards provide limit values and a set of conditions to meet this limit values. Standards are usually legally implemented by the country's relevant authority or organisation such as the USEPA. This report used the USEPA, the South

African standards and guidelines on air quality monitoring, ASTM and the Dutch element permissible limits guidelines.

CHAPTER 3

3. METHODOLOGY

The research is a descriptive statistic based on quantitative data. Five main areas where sampling sites are located, were purposively identified, whereby soil samples and fly ash samples were obtained. This type of sampling can be referred to as “purposive samples” since they are based exclusively on the researcher’s choice of which units are to be collected or analysed (Mason, 1992). A total of 30 soil samples from thirty (30) sampling points were obtained and one sample of fly ash from the silo was obtained. Ten (10) samples of fly ash captured by using the dust fallout method of bucket capturing were also obtained for three consecutive months. This implies that ten (10) buckets were mounted to capture fly ash for 32 days and the process was repeated three times in three months. The preparation of sampling data is well explained in the experimental set-up.

Sampling Design

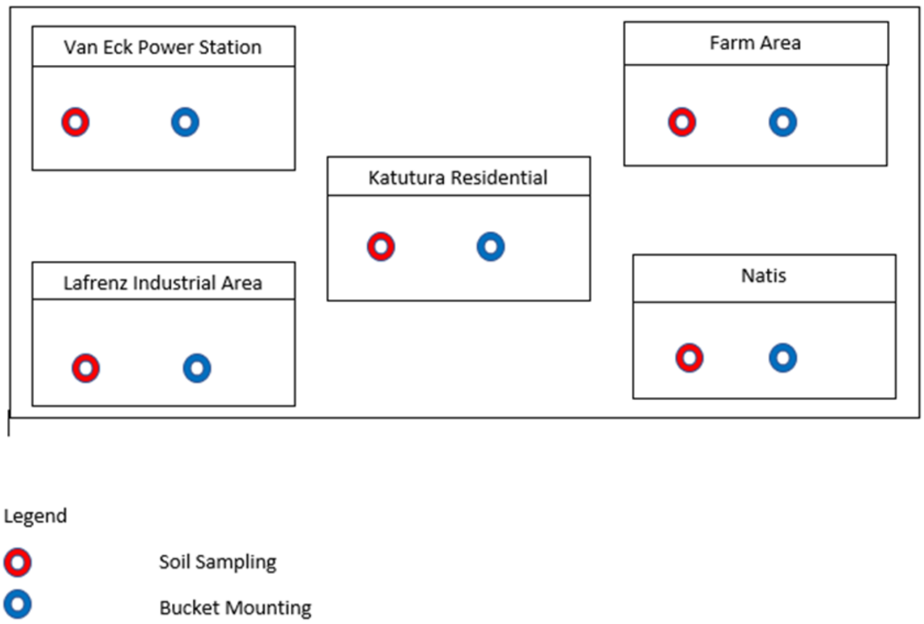

Figure 4: Sampling points at Van Eck Power Station and areas within the vicinity where soil, fly ash and dust was collected.

The fieldwork and lab work took four months and four days, whereby it started on 21 January 2019 until 25 May 2019. During the first day of observation, the researcher collected all the necessary parameters needed for the gaussian plume model, which started at the early hours of 06H00 AM and ended at 20H00 PM. Immediately after observation, the researcher, with the help of NamPower Employees mounted ten poles that were used for fallout-dust monitoring. In this situation, the student captured the fly ash assuming that it is dust and collected them in distilled water for analysis. The analysis of water was performed by Analytical Laboratories, while the remaining samples were analysed by Namibia Water Corporation (NamWater). This was done to reduce costs, as some of the analysis were either too expensive or could not be performed by the laboratory and alternatives had to be considered.

The study was conducted at the Northern Industry with its main target being the Van Eck Power Station, the farm area, NamPower training centre area and around Natis, Katutura residential area and the Lanfrenz Industrial area. The Five areas of interest were selected whereby the power plant was the central point, and other points were randomly selected from all four directions. Within the areas, dust monitoring was done whereby fly ash was captured by ten randomly posted buckets suspended on metal poles. The other method is the collection of approximately 30 soil samples and one fly ash sample from the silo.

3.1. Regression Analysis

Regression analysis was adopted to answer all the research questions by figuring the relationship between variables, meteorological data, and concentration of elements found in soil. Regression analysis is regarded by Mooi and Sarstedt, (2014) as one of the simplest forms, which analyse the relationship between a dependent variable and an independent variable. The advantages of using this analysis are that it indicates the relative strength of different independent variables' effect on a dependent variable, (Mooi & Sarstedt, 2014). Before undertaking regression analysis, sample size, varying variables, type of scale type of the dependent variable, and collinearity were put into consideration. In view, dispersion of elements found in soil and fly ash are variables that depend on wind speed, wind direction and temperature. Regression analysis was calculated by using Microsoft Excel software and results were presented in a table form.

3.2. Experiment Set-up

Soil Sampling

Based on the Environmental Protection Agency (EPA, 1997) soil sampling guidelines, every sample was systematically obtained from geographical points. At every sampling point, soil samples were obtained from a depth of 15-20cm, (United States Environmental Protection Agency, 1997). The soil sampled was obtained from the near-surface layer, whereby a precleaned stainless-steel trowel was used to remove and discard the thin layer which is mostly dominated by detritus. Meanwhile, the top layer of the desired sample depth which is the soil samples was obtained and samples were placed in zipper bags. The bags were labelled with identification names, the date and time when a specific soil was sampled. The zipper bags were sealed and transported to the Ministry of Mines and Energy for analysis of the concentration of elements. The tools were cleaned before and after use, with methanol and wrapped up in clean aluminium foil to prevent contamination. The sampler remained in the wrapping foil until it was needed, (US Environmental Protection Agency, 1997). The advantage of using a trowel is that it is easy to use, decontaminate and it is also easy to carry (portable).

Figure 5: Google Earth Map showing points where soil sampling was done in areas surrounding the power plant.

<u>Application of Portable XRF</u>

The Ministry of Mines and Energy under the Geochemistry Laboratory conducted the analysis using the handled XRF Thermo Scientific Niton XL3t 950 Goldd+. The analyser uses the energy dispersive x-ray fluorescence technique. The apparatus provided semi-quantitative scan of thirty soil samples and one fly ash sample submitted. The residues, soil, were scanned by using the X-ray fluorescence (XRF) apparatus to obtain traceable elements (Rezaee, Huggins, & Honaker, 2013). This process was done to all soil samples and data was recorded in Microsoft Excel for analysis. In a similar manner, fly ash was analysed to obtain concentration of heavy elements. The two results of soil and fly ash were compared Rezaee *et al*. (2013). A total of twenty-three elements were detected in soil samples, (Si, Al, Fe, K, Mg, Ca, S, Ti, P, Cl, Ba, Zr, Sr, Zn, Pb, As, Cu, Ni, Co, Cr, V, Mn, and Hg) and three Oxides which comprise of SiO_2, SO_3 and MnO_2.

Figure 6: Portable Hand-Held XRF Analyser used to detect trace elements in soil and in fly ash.

<u>Fallout Buckets</u>

Ten buckets were mounted on a pole to each and every sampling point. The buckets were filled with 5L of deionised water which collected the dust and Sodium Hypochlorite was added in each bucket to prevent algae or mould from forming. The buckets were exposed for plus or minus thirty-two days. The buckets were then removed and the process was repeated three times. In the first 32 days, fly ash was captured According to the STMS D 1739 standards, and each bucket's height should be twice more than their diameter. However, in a circumstance of scarce resources and unavailability of required material, four out of the ten buckets had a diameter of 20cm and their height was 20cm; these measurements are essential in the reduction of high evaporation.

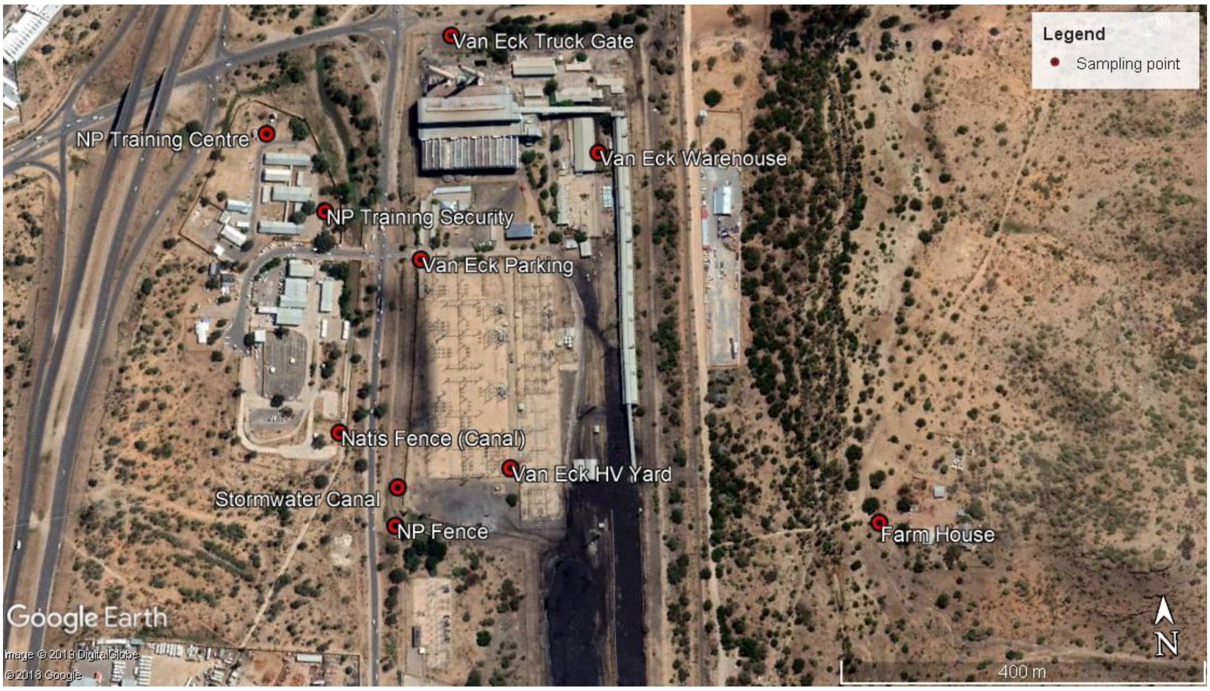

Figure 7: A Google Earth Map showing the areas where buckets where mounted in capturing fly ash and dust.

<u>Dust Fall Sampling Collector</u>

Every single pole was approximately 2.5m tall in height, whereby they were suspended 0.5m in the ground. The container is an open-topped cylinder not less than 150mm in diameter with height not less than twice its diameter. Containers are made of weatherproof plastic, so that they are capable of accepting legible, weatherproof, identification markings. They also contained tight-fitting lids in order to avoid spill out during handling and transportation. The stand, for the container, holds the top of the container at a height of 2 m above ground. The stand has a wind shield built to prevent debris from depositing in the bucket and to prevent birds and insects from accessing the water.

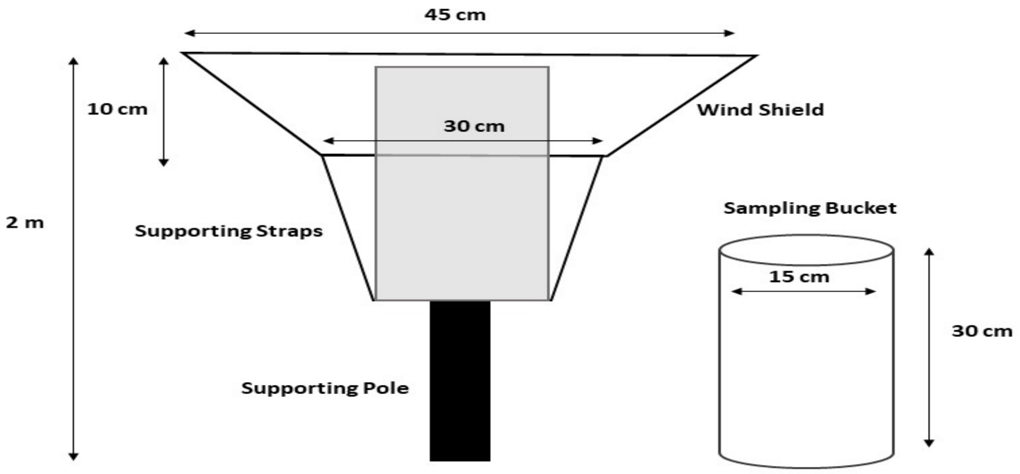

Figure 8: Dimensions for a dust fall sampling collector as per ASTM D1739.

<u>Significance of Dustfall-Monitoring Buckets</u>

This method is simple and it is basic and non-specific, but it is useful in the study of long-term trends. It requires minimum investment in equipment and can be carried out without a technically-skilled staff. This test method is useful for obtaining samples of settleable particulate matter for further chemical analysis such as fly ash.

Figure 9: Researcher replacing Fallout Dust Collector/bucket at a sampling point at Van Eck Security Gate.

Inductively Coupled Plasma - Optical Emission Spectrometry (ICP-OES) Analysis

The first ten buckets that stayed for the first 32 days were removed and the deionised water which contained fly ash samples were analysed by NamWater Co. and Analytical Laboratories Services by using ICP Analysis device. This ICP OES analysis is a Perking Elmer Optima 7000 DV that was used to detect the occurrence of trace elements in a sample. It is also capable of analysing aqueous solutions with high dissolved solid content and these solutions can be acidic, basic or neutral, (Ghosh, et al., 2013).

Figure 10: Picture of ICP-OES Perking Elmer Optima 7000 DV apparatus that was used to detect concentration of elements in fly ash suspended in deionised water.

Gravimetric Analysis

In the lab, filter papers were weighted (referred as pre-weight), using a scale and their mass was 0.015g, which was converted into 150 mg. After every pre-weight, each filter was placed sealed into transparent containers that were tagged with identification of a point where the sample was obtained.

Figure 11: A scale that was used to weigh filter papers and fly ash.

Distilled water with dust collected by the bucket was filtered using a filter paper through a sieve. Water drains down the Büchner in which the pressure was applied by using a pump, in order to assist water to drain through the filter paper. All filter papers shared the same characteristics. Every individual filter paper had an area of 84 g/m^2 and weighed 150 mg with a thickness of 47mm. The water was drained down the flask and disposed of in order to create room for another water sample. After filtration, dust was collected on the filter paper and its post weight was obtained.

Figure 12: Gravimetric Analysis apparatus suspended to pressure that drains water from the Büchner to the Vacuum flask.

Figure 13: (a). Büchner funnel and vacuum flask with filter Identified *(b). Fly Ash filtered from the Büchner samples*

<u>Calculated Fallout Dust</u>

Amount of fly ash, whereby in this report may be referred to as Dust was calculated by using the South African Dust Standards. The size of the bucket, the mass of the dust collected and the number of days the buckets were exposed in the open were considered in the equation. Calculations are shown below:

Mass of Dust (mg) = Weight of Filter paper (mg) - Weight of Filter Paper (mg) + filtrate (mg)

Calculated Fallout Dust (mg/m^2/day) = Mass of Dust (mg)/ (Cross sectional area of Bucket (m^2) x Days)

Cross-sectional Area of the Buckets is = πr^2

r = radius of the buckets

3.3. Meteorological Data

Weather data, specifically wind direction, wind speed, and temperature were obtained from the Windhoek Meteorological service. The concentration of elements and meteorological data, wind velocity and temperature were graphically plotted. Hourly average wind speed, wind direction and temperature are needed for the purposes of dispersion modelling.

3.4. Air Quality Modelling

In the field, the researcher collected all necessary data or parameters needed to calculate the Gaussian plume model. Daily average weather data was adopted from the Windhoek Weather Meteorological office starting from the first day of the research until the last day. In order to get the coefficients, incoming solar radiation during the day and cloud cover during the night was incorporated by using Pasquill's Stability Classification.

<u>Gaussian Plume Model</u>

Gaussian plume model uses a realistic description of distribution, where it signifies a logical solution to the diffusion equation for idealised circumstances (Abdel-Rahman, 2008). The Model was adopted by Oliver Sutton based on Eddy diffusivity theory on the motion of particles in the atmosphere. The model assumes that the atmospheric turbulence is both motionless and homogeneous (Sutton & Clarke, 1997). The study used meteorological data that is essential in predicting the dispersion of trace elements. The Gaussian plume model is explained below and all steps encountered in calculating the Model.

Equation:

$$C(x, y, z; H) = \frac{Q}{2\pi u_s \sigma_y \sigma_z} \left[\mathrm{Exp}\left(-\frac{y^2}{2\sigma_y^2} \right) \right] \left\{ \mathrm{Exp}\left[-\frac{(z-H)^2}{2\sigma_z^2} \right] + \mathrm{Exp}\left[-\frac{(z+H)^2}{2\sigma_z^2} \right] \right\}$$

Equation 1: Gaussian plume model equation.

whereby **C** is the concentration, **Q** is the emission rate of the pollutant from the source, **u** is the wind speed which defines the direction **x, y** is the horizontal distance perpendicular to the wind direction, **z** is the vertical direction, **H** is the effective height of the plume which is a summation of stack height and plume rise, and σ_y & σ_z are the parameters of the normal distributions in **y** and **z** directions, usually called the dispersion coefficients in y and z directions respectively (Sutton & Clarke, 1997).

Van Eck Stack Parameters

Parameters	**Unit**	**Value**
Stack diameter	M	5.40
Flue gas exit velocity	$m.s^{-1}$	7.77
Temperature of flue gas	^{0}C	150
Stack Height	M	103

Table 4: Characteristics of the boiler stack of the Van Eck Power Station.

Steps in Calculating Gaussian Plume Model

Step 1

Determination of Stability Class by Using Pasquill's Stability Classification:

The stability class was developed by Frank Pasquill, a method used for estimating the vertical and crosswind spread of PM and gases for distances up to 100 km downwind from the source. The method provides stability categories based on surface observations of wind speed, incoming solar radiation, and cloud cover (Priestley, McCormic, & Pasquil, 1958). Defining stability class was determined in the field by day and night observation. During the day, it was observed that, incoming solar radiation was strong and the average wind speed recorded was 2.7m/s. Hence, the stability class during the day is Class **A-B**, while that of the night was **F**, based on the wind speed of 2.7m/s and a clearer sky with cloud cover less than or equal to 3/8.

	Stability classes				
Surface wind at 10m, m/s	Day			Night	
	Incoming Solar Radiation			Cloud cover	
	Strong	Moderate	Slight	Thinly overcast (>or 50%, low cloud)	Mostly clear (< or = 3/8)
Range	1	2	3	4	5
<2	A	A-B	B	G	G
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

Table 5: Table 5: Pasquill's stability classification. Source: Ashrafi K, and. Hoshyaripour G A, (2008). A Model to Determine Atmospheric Stability and its Correlation with CO Concentration, https://waset.org/publications/9007/a-model-to-determine-atmospheric-stability-and-its-correlation-with-co-concentration. Accessed 28 March 2019.

Step 2

Calculation of Windspeed at Stack Height.

At normal instances, wind speed increases with height in the lower layers of the atmosphere. Wind speed measurements are taken at height above the surface by using a Cup Anemometer, whereby the Windhoek Meteorology Service measured at 9 meters. The wind speed and direction at stack height has an influence on the plume. Calculation was done by using the following formula adopted in Abdel-Rahman (2008).

$$u_s = u_{za}\left(\frac{Z_s}{Z_a}\right)^p$$

Equation 2: Windspeed at stack height.

Whereby $\mathbf{U_{za}}$ is the windspeed at $\mathbf{Z_s}$ as the stack height in meters (m), $\mathbf{Z_a}$ is the anemometer height in meters (m), and **p** is the exponent value based on the stability class. The table below shows the derivation of exponent value **'p'**.

Value of exponent p in formula		
Stability category	**Rural exponent**	**Urban exponent**
A	0.07	**0.15**
B	0.07	**0.15**
C	0.10	0.20
D	0.15	0.25
E	0.35	0.30
F	0.55	**0.30**

Table 6: Exponent value based on the stability class.

Based on table 6, the stability class for the day was A-B, and for the night was F. Since both stability category A and B have the same value, it does not seem to have an effect on the data, therefore the value of exponent p in Class A-B and F is 0.15 and 0.3 respectively.

Description	Values
Value of exponent, p	0.15
Anemometer height (z_a , m)	9.00
Stack height (z_s, m)	103
Wind speed at za (u_{za}, m/s)	2.10
Wind speed at zs (u_s, m/s)	3.03

Table 7: Values needed for the calculation of windspeed at stack height at Van Eck Power Plant.

Step 3

<u>Calculation of Plume Rise</u>

The values were obtained by the approval of NamPower. The parameters from table 6 and table 7 below were used to calculate the plume rise and Heat emission rate:

Formula:

$$\Delta h = 4.71 \frac{Q_h^{0.444}}{u_s^{0.694}} \qquad Q_h = \frac{\pi d_s^2 V_s}{4} \frac{P Mw}{R_u T_s} C_p (T_s - T_a)$$

Equation 3: Plume rise (Δh) and Heat emission rate (Q_h).

Parameters shown in Table 8 below were used to calculate Heat emission rate and Plume rise from equation 3.

Parameters	Value
Molecular weight of flue gas (M_w)	15.91
Stack diameter (d_s, m)	5.40
Flue gas exit velocity (V_s, m/s)	7.77
Temperature of flue gas (T_s, K)	413.50
Ambient Temperature (T_a, K)	301.25
Atmospheric Pressure (P, atm.)	0.82
Wind speed at stack height (u_s,m/s)	3.03
Heat emission rate (Q_h, kj/s)	7696.54
Plume rise (Δh,m)	116.07

Table 8: Parameters needed for the calculation of plume rise and heat emission rate – source: NamPower.

Step 4

<u>Calculation of **σ_y** and **σ_z**</u>

The variables, σ_y and σ_z are standard deviations which indicate the spreading of the plume in the **y** and **z** directions. These variables increase with the distance **x** from the source. The downwind distance (X, m) was fixed at 1000 m and based on the McElroy-Pooler's formula, the value of the aforesaid sigma is derived from the table below. Based on the first-class stability of urban areas, the formula deduced in table 9 below. On stability classes A-B, only one formula on each sigma can be chosen, since the formulas are the same anyway.

Formulae McElroy-Pooler (URBAN CONDITION)		
Stability	**σ_y**	**σ_z**
A	**$0.32X (1.0+0.0004 X)^{-1/2}$**	**$0.24X (1.0+0.001 X)^{1/2}$**
B	**$0.32X (1.0+0.0004 X)^{-1/2}$**	**$0.24X (1.0+0.001 X)^{1/2}$**
C	$0.22X (1.0+0.0004 X)^{-1/2}$	$0.20 X$
D	$0.16X (1.0+0.0004 X)^{-1/2}$	$0.14X (1.0+0.003 X)^{-1/2}$
E	$0.11X (1.0+0.0004 X)^{-1/2}$	$0.08X (1.0+0.015 X)^{-1/2}$
F	**$0.11X (1.0+0.0004 X)^{-1/2}$**	**$0.08X (1.0+0.015 X)^{-1/2}$**

Table 9: McElroy-Pooler for urban condition used in determining sigma values.

Hence, based on the formula deduced, table 10 below indicates the values of sigma in day (class A-B) and night (class F),

	A-B	**F**
σ_y (m)	270.45	92.967
σ_z (m)	339.41	20

Table 10: Calculated values of sigma y and z for day and night.

CHAPTER 4

4. RESULTS AND DISCUSSIONS

4.1. Temperature, Windspeed and Rainfall

The data collection period started 21 January 2019 until 17 April 2019 with a recorded windspeed, temperature and rainfall. According to the results obtained, January recorded the highest average temperature of 27.6 ^{o}C while April recorded the lowest with 21.7 ^{o}C. The highest wind velocity was recorded in April with a speed of 2.8 m/s. Stable atmospheric conditions frequently arise when warm air is above cool air and the mixing depth is meaningfully restricted. This condition is called temperature or thermal inversion. Temperature inversion can prevent the rise and dispersal of pollutants from the lower layers of the atmosphere and cause localised air pollution problem. The air near the earth's surface is warmer during the day time because of the absorption of the sun's energy. The warmer and lighter air from the surface rises and mixes with the cooler and heavier air in the upper atmosphere and this causes unstable conditions in the atmosphere. This constant turnover also results in dispersal of polluted air.

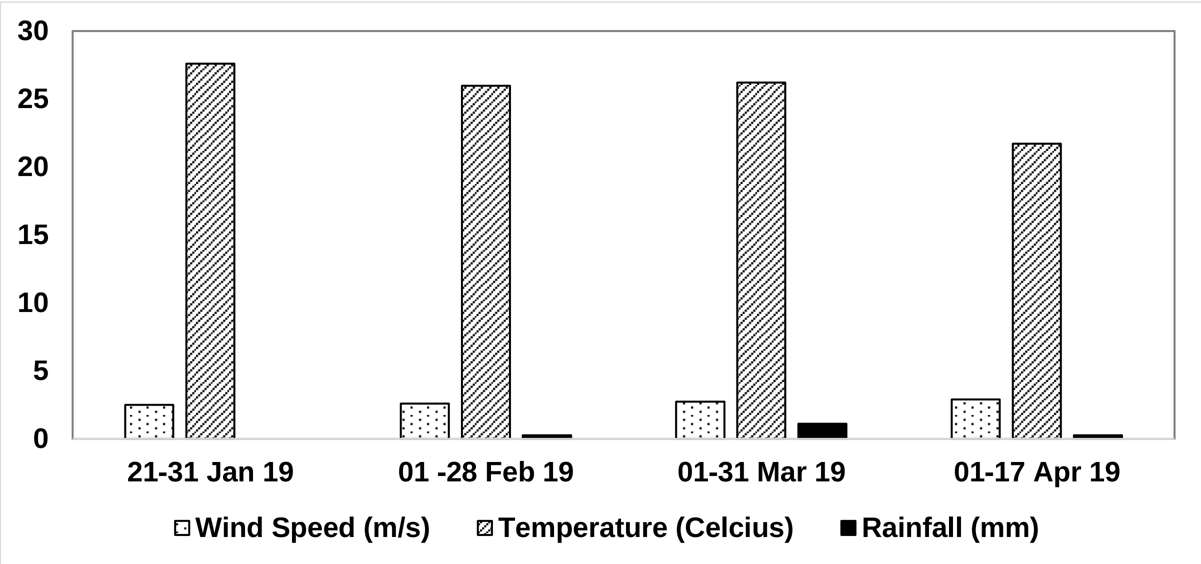

Figure 14: Graph showing Wind speed (m/s), Temperature (^{0}C) and Rainfall (mm) recorded during the research period.

4.2. Wind Direction

The wind rose gives information on frequency or number of events of wind speed and wind direction. In the wind rose, the extent of each arm is relative to the frequency at which the wind was observed (Enviroware, 2019). The Wind speed and direction presented in the wind rose, are typically distributed at a particular location over a period of time. Wind direction and wind speed was recorded on an hourly and daily basis by the Windhoek Meteorological Station, whereby the data was given by the researcher. The wind speed was recorded in meters per second (m/s) and the wind direction was recorded in compass degrees whereby it was converted into compass direction. Wind direction plays a major role in the dispersion of concentrates suspended in fly ash. In reference to the figure below (fig 15), the prevailing wind direction of Windhoek predominantly comes from the Southern direction. Most of the wind blows from SSW and SSE. In modelling, it may imply that concentrates may be found in areas in the Northern part, varying from NW, N and NE.

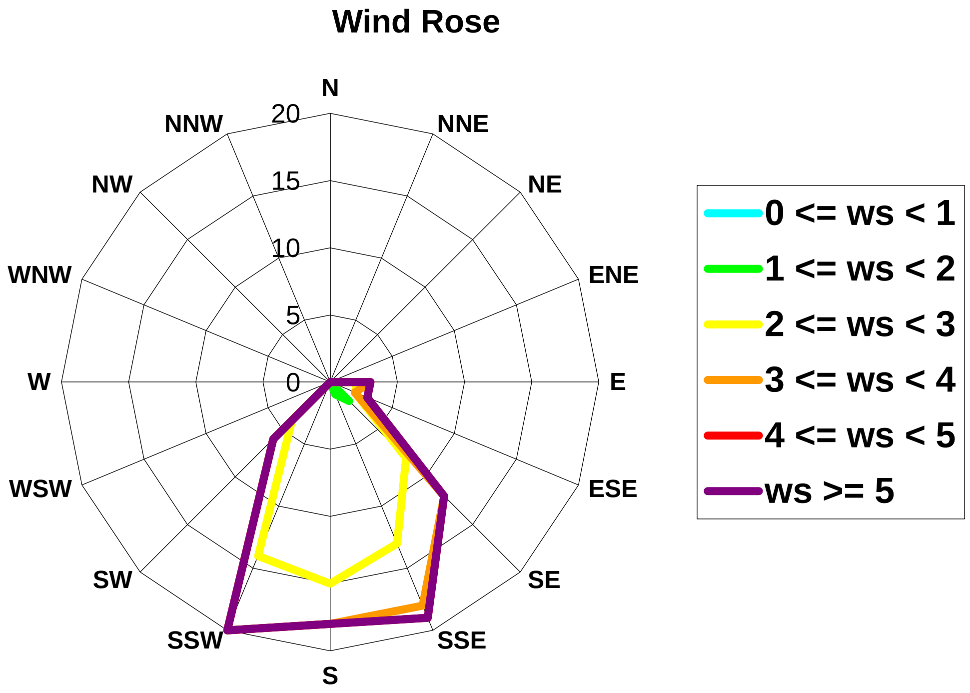

Figure 15: Wind Rose showing wind direction and number of wind speed (m/s) events occurring, recorded by the Windhoek Meteorological Service during the time of observation.

The results displayed by the Wind Rose may indicate that, there is a possibility of finding more trace elements in the Northern parts from the main point located near the smoke stalks, which is dominated by vegetation and anthropogenic activities, mainly motor garages (logistics). However, in situations whereby the wind speed at 4m/s occurs, air turbulence may cause the mixing of pollutant elements and particulate matter, hence there might be less deposition of elements in PM than expected. On the other hand, areas with less wind speed might experience more dust fall due to condition, however only in occurrences wherein the cloud from the stack is towards those specific areas. The cloud is designed according to the direction of the wind. In cases where there is limited wind, the cloud might be in a straight motion, on a vertical position, otherwise it changes directions due to wind speed and wind direction. The results obtained showed similar pattern in a study carried out by Maria Grundström which showed that at a speed more than 5m/s, less concentration of SOx was detected in the air. Composition of elements in the air increases with decreasing wind velocity and a certain wind direction (Grundström, 2015).

The figure 16 below, illustrates the distribution of wind speed, according to their classes. The class that recorded the highest wind speed is the Windspeed between 2m/s and 3m/s, followed by the windspeeds between 3m/s and 4m/s. No wind speed lower than 1m/s and higher than 5m/s was recorded during the period of data collection.

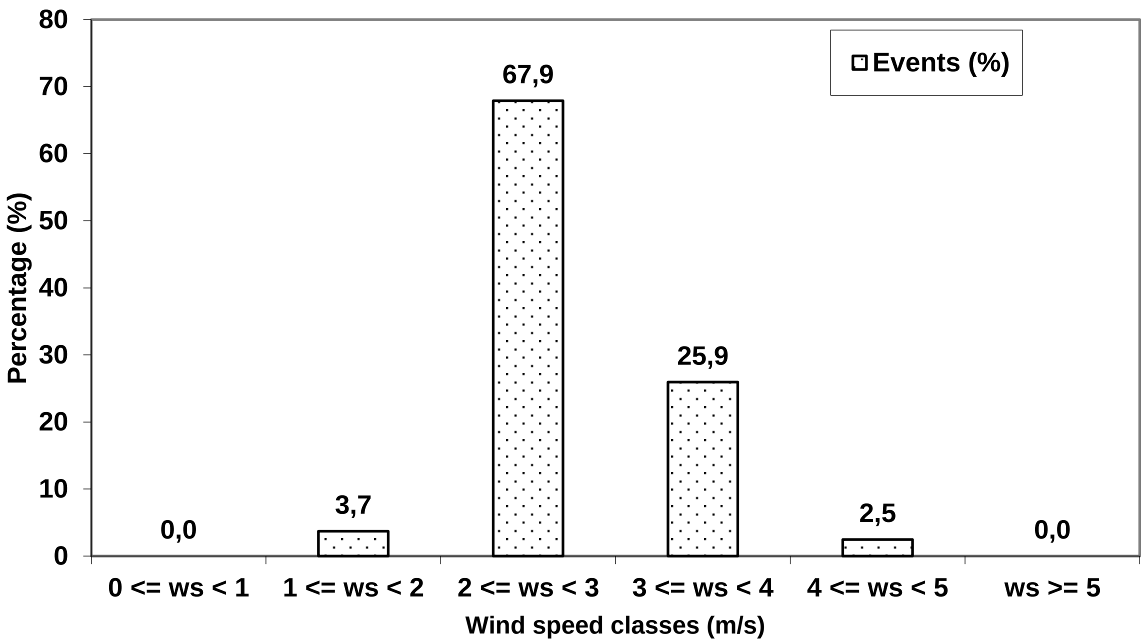

Figure 16: Distribution of wind speed classes (m/s) of Windhoek in percentages, data obtained by the Windhoek Meteorology Service.

According to Walcek (2001), in numerous early studies on transport and diffusion, the effects of wind shear on transport and dispersion were not quantitatively measured. Walcek (2001) further explained that analysis of several field studies of puff releases from stalks for distances more than 100 km, did not include the vertical wind shears. Higher wind speeds would more quickly transport a cloud of smoke downwind (Walcek, 2001). Based on the author, it is evident enough that wind speed plays a major role in the dispersion and diffusion of pollutant elements.

4.3. Concentration of Elements Found in Soil

Elements found in the soil were below level of detection, with the exemption of Zinc that was detected with a low composition of an average of 0.01030%. During the testing using Portable XRF, oxides were tested and high amount of Sulphite was detected in soil sampled *at al*l points with an average of 0.434848%. Sulphite was also detected highly at the main point where it is near the two stalks and subjected to the silo, and where ash exits and is transported for discarding. The figure below (fig 17) illustrates the composition of elements found in soil and different sampling points. Fly ash collected near the stacks detected with a high amount of Sulphite, as shown in figure.17 and similarly figure 20 shows high amount of Sulphate captured by the bucket system at points near the stacks of the power plant.

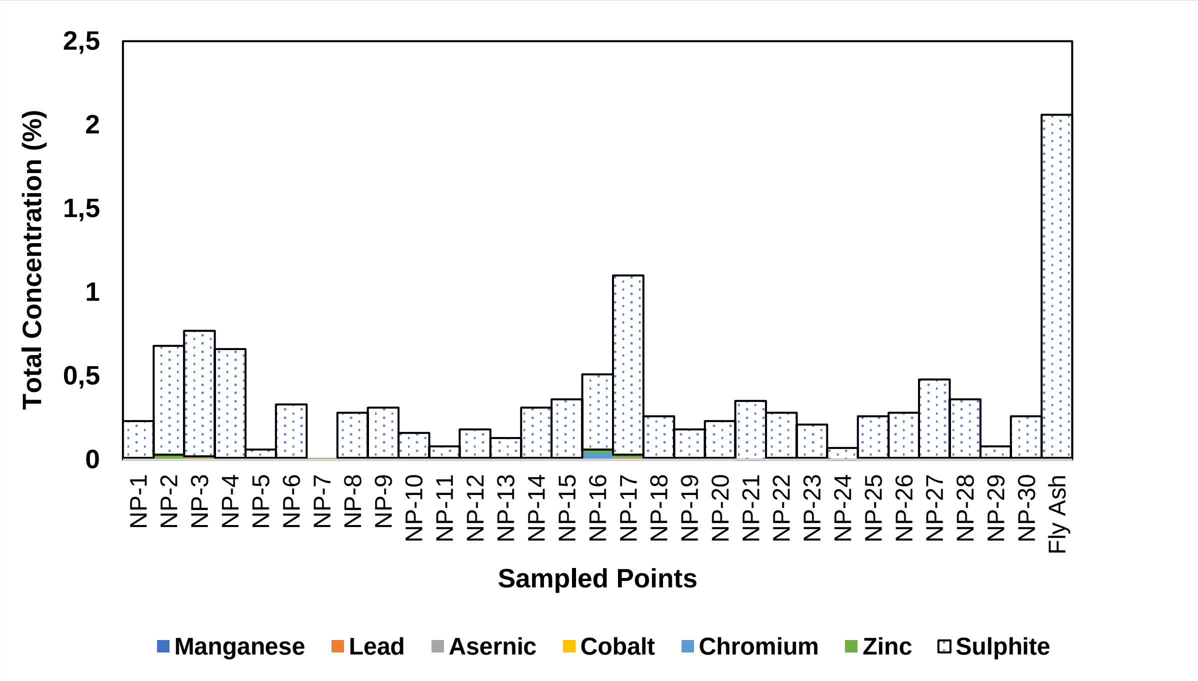

Figure 17: Concentration of elements (Sulphite, Zinc, Chromium, Cobalt, Arsenic, Lead and Manganese) in ppm, detected in soil and fly ash obtained from the Silo, by Portable XRF.

Metal/metalloid MPA	Maximal permissible addition MPA mg/kg
Zinc (Zn)	16
Chromium (Cr)	3.8
Cobalt (Co)	24
Arsenic (As)	4.5
Lead (Pb)	55

Table 11: Maximal permissible addition MPA of heavy metals and metalloids by the data of Dutch ecologists in mg/kg.y. Source: Vodyanitskii Y, N. (2016), Standards for the contents of heavy metals in soils of some states. Leninskie Gory, Moscow.

4.4. Mean Concentration of Elements Found in Soil

The concentration of elements found in soil where compared with the Dutch permissible limits, (Vodyanitskii, 2016). The values were converted from milligram per kilogram (mg/kg) to percentage (%). Manganese, Cobalt and Arsenic were below level of detection (LOD) on the XRF Analysis, although they are still available in the soil, only in small amounts; Zinc was beyond the permissible limits with 0.010645%, while the rest of the elements such as Chromium and Lead were below the permissible limits.

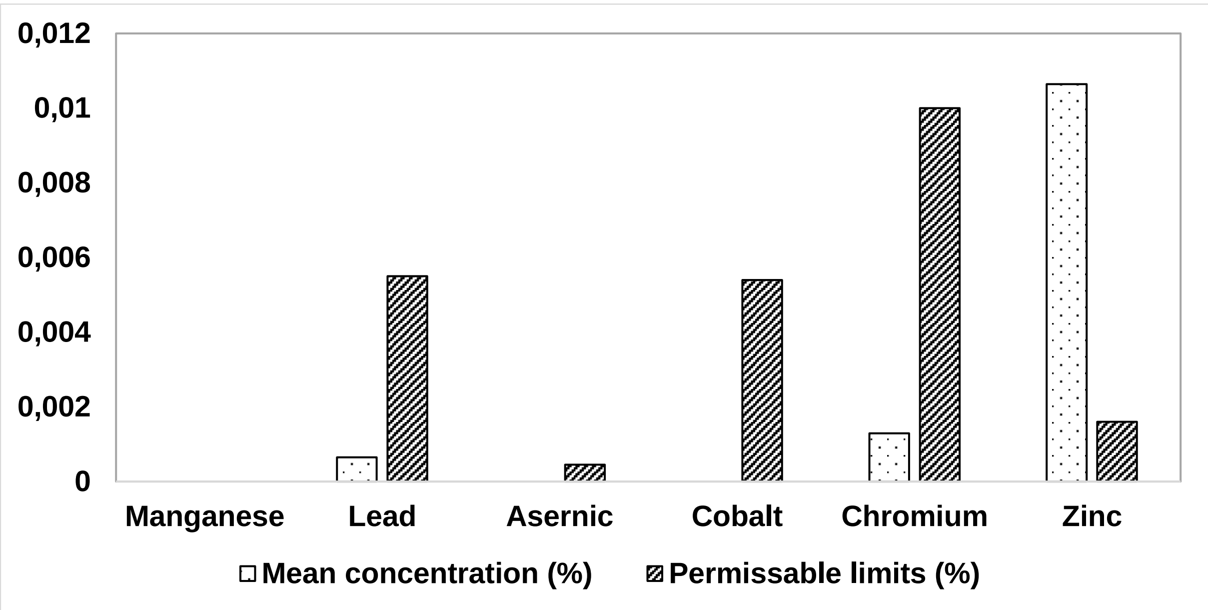

Figure 18: Mean concentration of elements (%) found in sampled soil compared to their permissible limits.

4.5. Elements Detected from Fly Ash Captured in Buckets

Manganese was highly found at NP Fence with 0.01% while other elements such as Cadmium, Arsenic, Boron and Cobalt were below 0.01%, Hence they were below the detection, which means that they are traced in small amounts. Lead was well represented in all the ten points whereby NP Training Security, Natis Fence (Canal), NP Training Centre, Van Eck Truck Gate and NP Fence have the same abundance of Lead with 0.02%. The Van Eck Parking, Van Eck Warehouse, Storm Water Canal, Farm House and Van Eck HV Yard have the same amount of Lead, (0.01%). The Van Eck Truck Gate detected with the highest abundant of Chromium with 0.04% and Zinc with 0.33%.

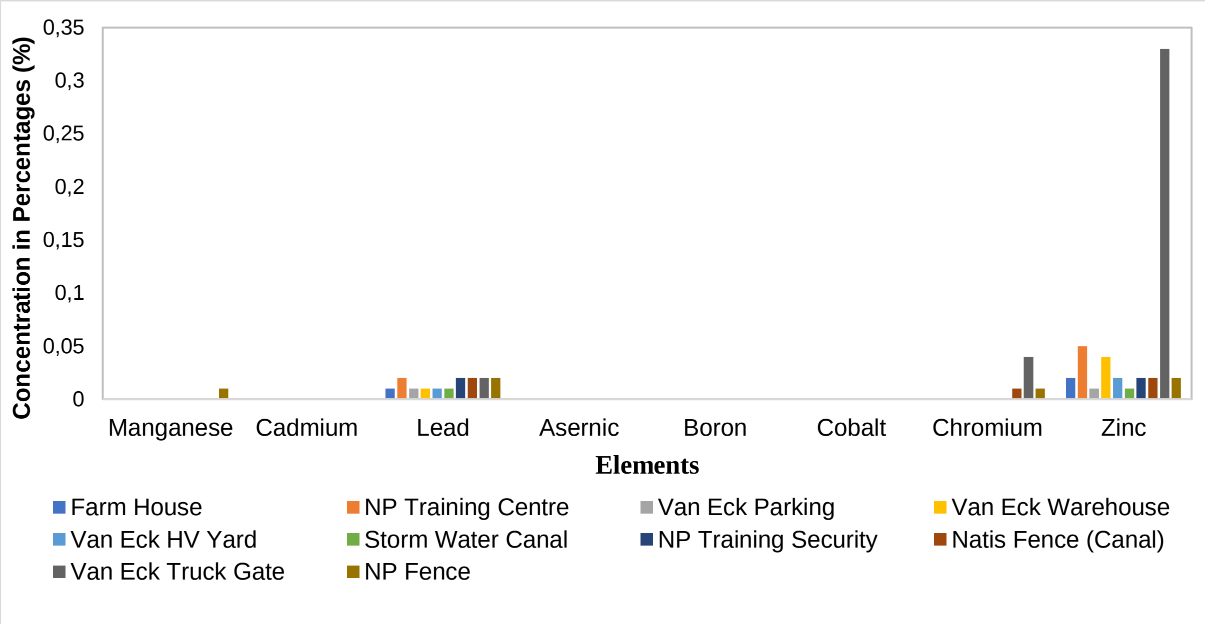

Figure 19: Concentration of elements detected in fly ash suspended in deionised water, captured by Buckets.

4.6. Sulphate Detected from Fly Ash Captured in Buckets

Data collected from deionised water with fly ash showed that of all the sampling points, the Van Eck Truck gate detected with the highest Sulphate exceeding the USEPA Sulphur limits with a percentage of 0.0099. This may be caused by the location of the Gate making it prone to deposits coming from the stalks. The Gate is located some few meters from the two smoke stalks and from an area where course ash is deposited for transportation. Another reason might be the wind direction and wind speed whereby the Truck Gate might be on the downwind. The Farm House detected the least concentration of Sulphate with 0.0001% and it is beyond the permissible limits. This might be a good indication that although the farm is within the area of the power plant, there is little harm to vegetation, human and animals. The Farmhouse is regarded as a residential area in terms of the South African Criteria, with concentration beyond limits, it is a positive result for the Van Eck Power Station.

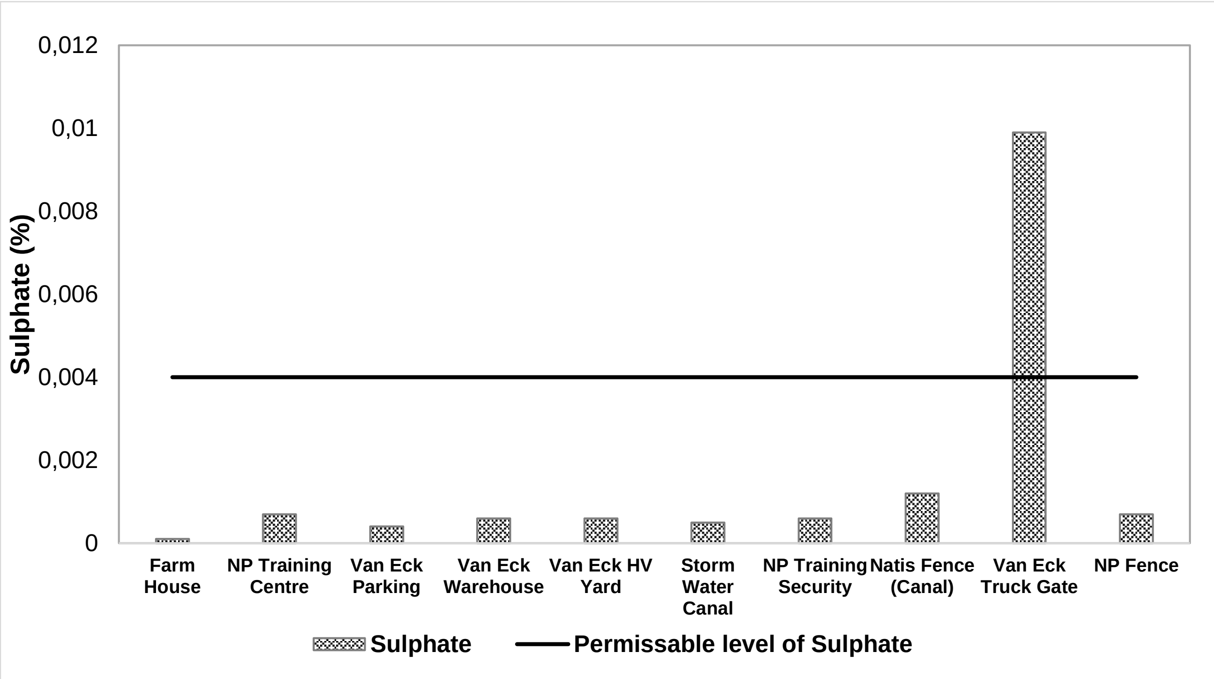

Figure 20: Comparison of Sulphate (%) detected from Fly Ash captured in Buckets with USEPA permissible level (0.004%)

4.7. Concentration of Elements Found in Captured Dust

The dust captured in water by the bucket method was analysed and was found to be similar to the results found in soil, Zinc and Sulphate dominated with averages of 0.054 mg/l and 15.3 mg/l respectively. Based on figure 21 below, more elements were detected in buckets near the power plant. In both maps presented below fig 21 and fig 22, there is a similar pattern on the distribution of Zinc and Sulphate, whereby fig 22 shows that Sulphate spread on a larger portion of land compared to Zinc.

Concentration of Zinc Found in Fly Ash

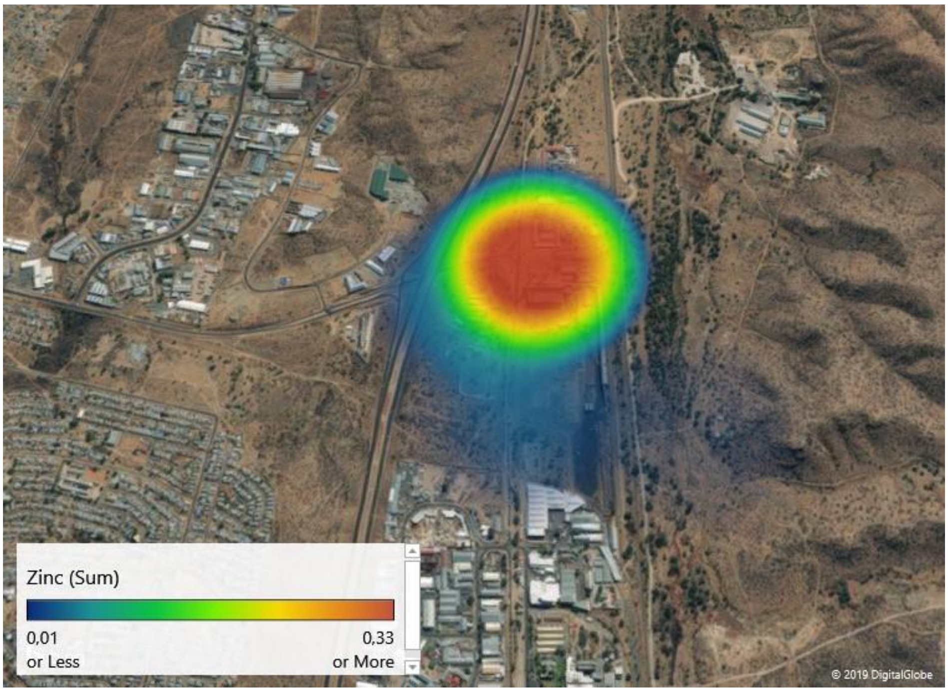

Figure 21: Aerial photo taken from Google earth showing distribution of Zinc (%) in fly ash from the main point of the Van Eck Power Station, Windhoek, Namibia.

Concentration of Sulphate Found in Fly Ash

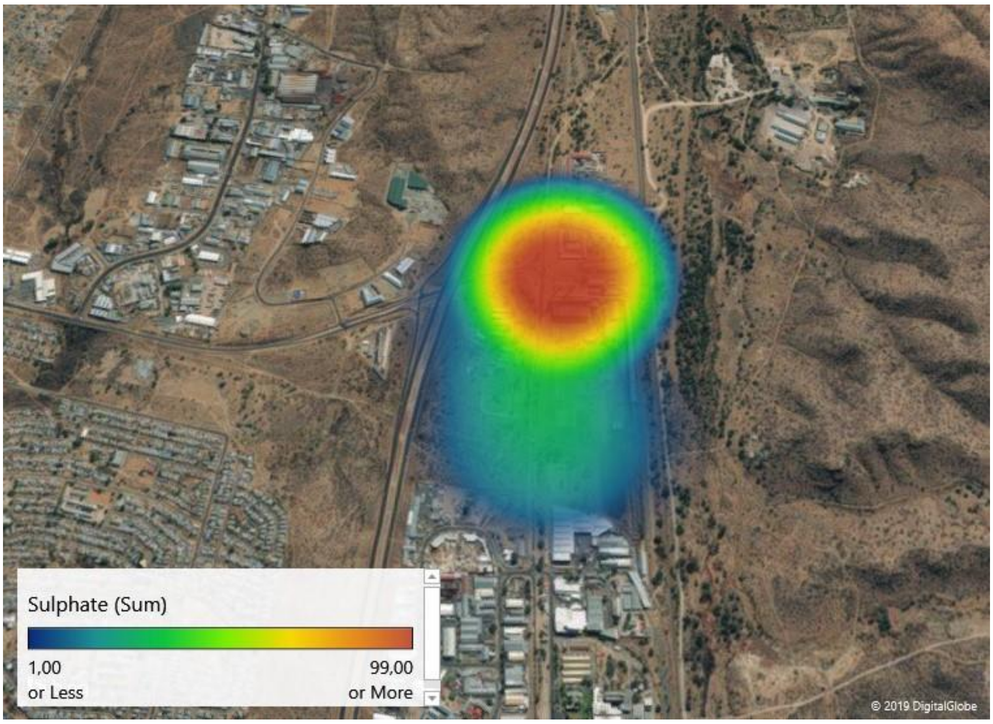

Figure 22: Aerial image showing distribution and concentration of Sulphate (%) in fly ash from the source of pollution, at the Van Eck Power Station.

4.8. Chemical Composition of Sulphate and Sulphite Obtained from Bucket and Soil

During data analysis, the initial plan was to obtain SO_2 in both soil and fly ash samples, however, the ICP Analyser was able to analyse Sulphate while the XRF Portable apparatus only detected Sulphite. According to Gutberlet, (1996), in both of the following reaction mechanisms:

- *$S05^{-}$ +$HS03^{-}$ → $SO42^{-}$+ $S04^{-}$+ H+*
- *$SO4^{-}$ +$HSO3^{-}$ → $SO42^{-}$+ $S03^{-}$+ H+*

both sulphate and sulphite free radicals are formed, in accordance with the following overall equation:

$S0_5^{-} + 2HS0_3^{-} \rightarrow 2SO_4^{2-} + S0^{3-} + 2H^{+}$

The author explains that, based on the above reactions, owing to a complete reaction, sulphite or hydrogen sulphite ions may no longer be available to maintain the chain reaction, hence the peroxomonosulphate free radicals react with heavy metal ions, such as Mn^{3+} or Fe^{2+}, and consequently regenerate the M^{3+} ions necessary for chain initiation. In this case, the peroxomonosulphate acts as an oxidant (Gutberlet, 1996). Subsequently, a situation in which a peroxosulphate free radical causes the formation of three M^{3+} ions is referred to as sulphite-induced autoxidation of the metal ions (Gutberlet, 1996).

4.9. Gaussian Plume Model

Based on parameters and weather data used in the equation, the model was calculated and the concentration can predict the emissions spatially around the source.

4.9.1. *Gaussian Plume Model During the Day*

During the day, based on the downwind ground-level concentration analysis, the stability class of the gaussian plume model during the day is A-B, hence according to Abdel-Rahman, (2008), it is regarded as an unstable condition. This implies that an unstable atmospheric condition produces the highest peak downwind concentration, as seen in figure 23. The turbulence in the unstable atmosphere shifts the plume to the ground very rapidly, resulting in high peak values near the stack. However, at father downwind, the concentrations drop off very quickly.

Concentration Distribution of Elements at Vertical Levels

Results :1

The Concentration C (mg/m^3) at different vertical levels (Z), cross wind Y and the downwind distance X of 1000m. The inputs in table 2 were calculated as shown in the Methodologies, the sigmas are the parameters of the normal distributions in y and z directions, usually called the dispersion coefficients in y and z directions respectively, (Abdel-Rahman, 2008). In this case it is assumed that the horizontal distance y, perpendicular to the wind direction is zero, and the emission rate Q is 168.30g/s at a distance of 2.70 m/s.

Inputs

X (m)	σ_y (m)	σ_z (m)	y (m)	H (m)	Q (g/s)	u_s (m/s)
1 000.00	270.45	339.41	0.00	219.07	168.30	2.70

Table 12: Table showing parameters needed to calculate concentration at different vertical levels, from a distance of X=1000m, when y=0 at an effective height H of 219.07m with a wind speed of 2.7m/s.

Trace elements are concentrated more at distance from 0m to 350m and as the distance increases, from the point source, the concentration of trace elements decreases. At a distance of 1000m or 1km, the concentration is 7,829806252 mg/m^3, less than the concentration at a distance of 50m with 174,39847 mg/m^3. In this equation, the ground is usually assumed to be a perfect reflector and its presence is represented by a mirror image source placed below ground.

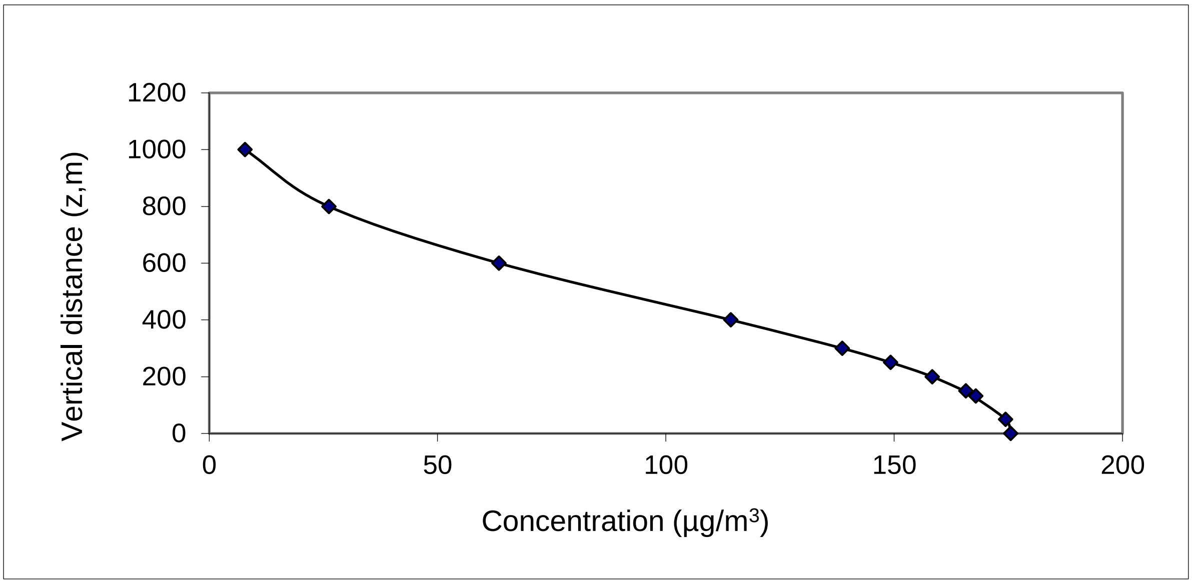

Figure 23: Concentration C (µg⁄m^3) at different vertical levels (Z) during the day.

Concentration Distribution of Elements at Crosswind

Results: 2

Ground level (Z=0) concentration C (µg/m^3) at different crosswind distances Y, at the downwind distance X of 1000m. The inputs in table 13 were calculated as shown in the methodologies, whereby the sigma represents the dispersion coefficients in y and z directions respectively. In this situation, it is assumed that the vertical direction, Z equals to zero and the emission rate Q is 168.30 g/s at a distance of 2.70 m/s.

Inputs

X (m)	σ_y (m)	σ_z (m)	z (m)	H (m)	Q (g/s)	u_s (m/s)
1 000.00	270.45	339.41	0.00	219.07	168.30	2.70

Table 13:Table showing parameters needed to calculate ground level concentration from a distance of X=1000m, when Z=0 at an effective height H of 219.07m with a wind speed of 2.7m/s

The concentration of the elements on the crosswind is highly significant at the origin (0m) at 175,5071724 ug/m^3 and lower at 6000m with 0 µg/m^3. In the diagram, it is shown that there is a negative crosswind distance with a significantly low concentration and rises as the distance increases. The ground is usually assumed to be a perfect reflector of pollutant particles and its presence is signified by a mirror image source placed below ground. Hence, the graph below shows a reflection of pollutants at a certain distance whereby the maximum concentration Cmax is at 372.61104$\mu g\ /\ m^3$.

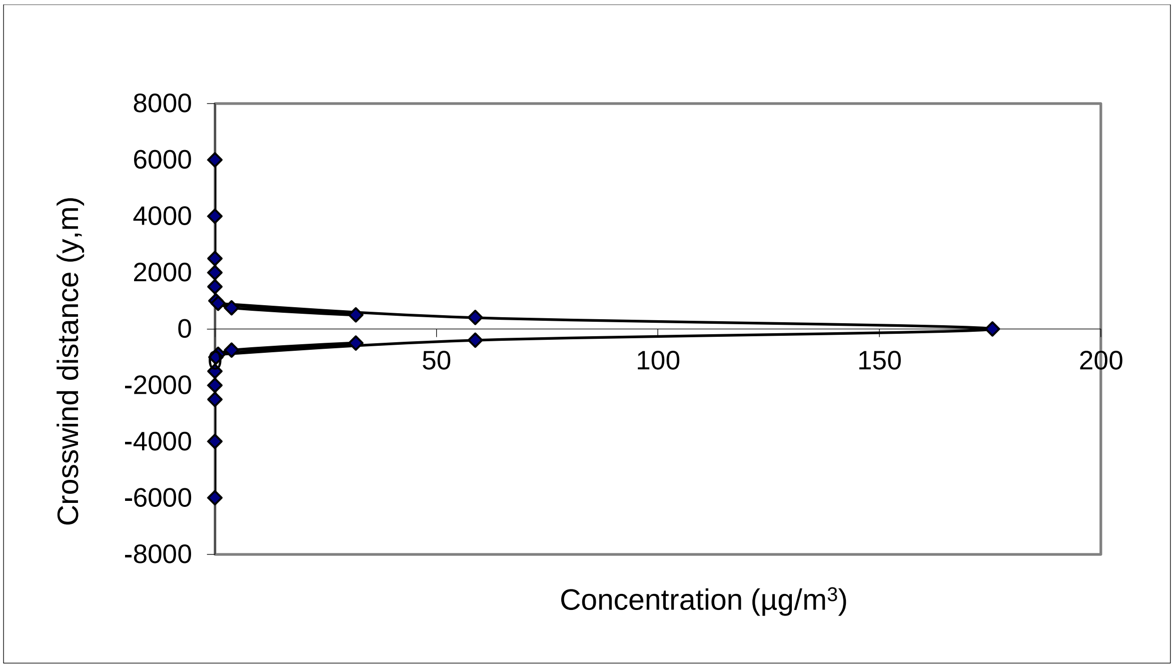

Figure 24: Ground level (Z=0) concentration C (µg/m^3) at different crosswind distances.

4.9.2. *Gaussian Plume Model During the Night*

The stability class for the gaussian plume model during the night analysed is class F, and is regarded by Abdel-Rahman, (2008), as a stable condition. This, however, causes a much lower peak of the downwind ground-level concentration. Beyond a considerable distance downwind, the concentration is more than that for the unstable atmosphere and continues to be estimated in the downwind direction. According to Abdel-Rahman, (2008), the atmospheric stability affects the plume rise (Δh). Hence the stable atmosphere is seen to produce the biggest plume rise.

Concentration Distribution of Elements at Vertical Levels

Results 1:

The Concentration C (µg⁄m^3) at different vertical levels (Z), cross wind Y and the downwind distance X of 1000m. The inputs in table 14 were calculated as shown in the Methodologies, the sigmas are the parameters of the normal distributions in y and z directions, usually called the dispersion coefficients in y and z directions respectively, (Abdel-Rahman, 2008). In this case it is assumed that the horizontal distance y, perpendicular to the wind direction is zero, and the emission rate Q is 168.30g/s at a distance of 2.70 m/s.

Inputs:

X (m)	**σ_y (m)**	**σ_z (m)**	**y (m)**	**H (m)**	**Q (g/s)**	**u_s (m/s)**
1 000.00	92.97	20.00	0.00	193.06	168.30	2.70

Table 14: Concentration (µg⁄m3) of pollutants during the night at different vertical levels (Z) when Y=0.

The figure below shows that there is a sharp graph with depicts the distribution of particles and elements at a maximum distance of 100m. At that particular distance, 1000m, the concentration of pollutants seems to be at 0 µg⁄m^3.

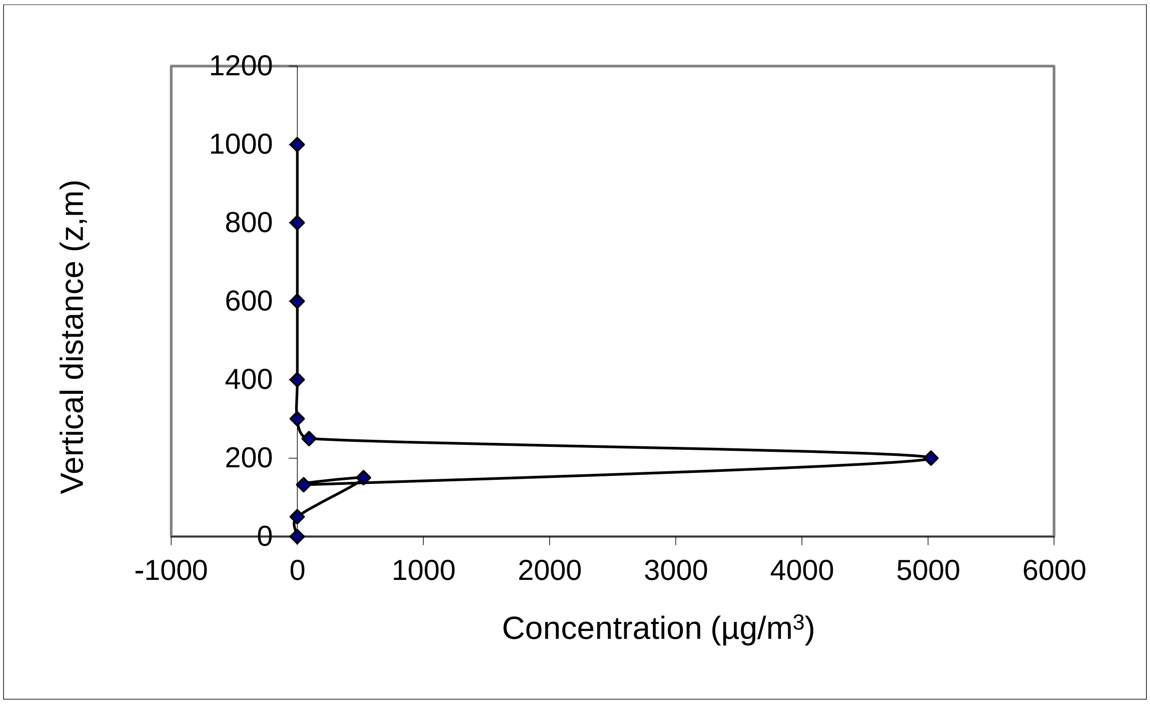

Figure 25: Vertical distribution of concentration C (µg⁄m^3) at different distances, when Y=0.

Concentration Distribution of Elements at Crosswind

Results: 2

Ground level (Z=0) concentration C (µg⁄m^3) at different crosswind distances Y, at the downwind distance X of 1000m. The inputs in table 3 were calculated as shown in the methodologies, whereby the sigma are the dispersion coefficients in y and z directions respectively. In this situation, it is assuming that the vertical direction, Z is equal to zero and the emission rate Q is 168.30g/s at a distance of 2.70 m/s.

Inputs

X (m)	σ_y (m)	σ_z (m)	z (m)	H (m)	Q (g/s)	u_s (m/s)
1 000.00	92.97	20.00	0.00	193.06	168.30	2.70

Table 15: Parameters of ground level concentration (µg⁄m3) at different crosswind distances when Z=0.

At a distance of 0 µg⁄m^3, the concentration was at its highest with a magnitude of 6E-17. This may be caused by very low wind speed whereby deposition of elements is localised, the lower the wind speed, the higher the pollutant concentration. The graph shows a reflection of ground and this is represented by a mirror image source placed below ground at 0 µg⁄m^3.

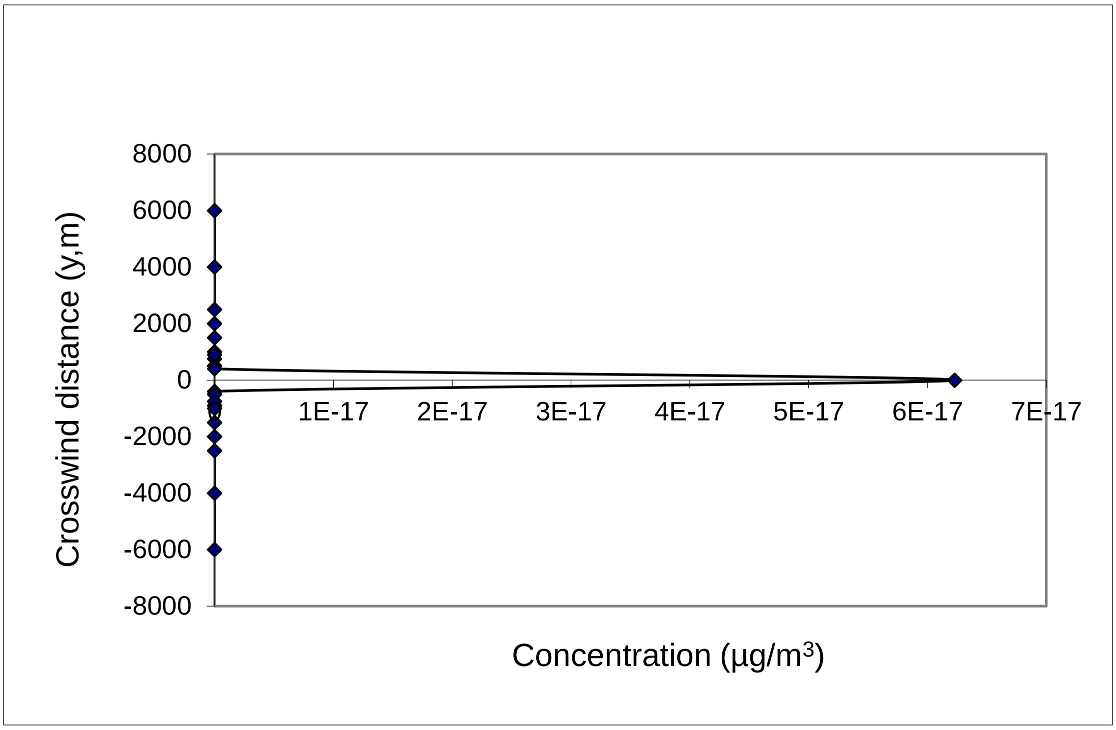

Figure 26: Ground level (Z=0) concentration C (µg⁄m^3) at different crosswind distances.

4.10. Dust-Fallout

The graph below illustrates the amount of Dust collected from the field during research work. According to the graph, in the first 32 days, abundant amounts of ash was collected from the Van Eck Warehouse with an amount of 1119 mg/m^2/day and it exceeded the residential and industrial limit. NamPower station fence was the second highest with 348 mg/m^2/day, while the Farm house weighted with the lowest dust of 136 mg/m^2/day. In the second 32 days, although the Van Eck Warehouse recorded with the highest mass of dust, it was beyond the industrial permissible limits (952 mg/m^2/day). The dust particles might come from the activities near the warehouse such as loading of coal from trucks to the conveyer belt. The Van Eck Storm Water Canal, Van Eck HV Yard, and Van Eck Parking recorded with 204mg/m^2/day. The three areas recorded the same amount of dust fallout on a possibility that they are in the same grid or the points are close to one another.

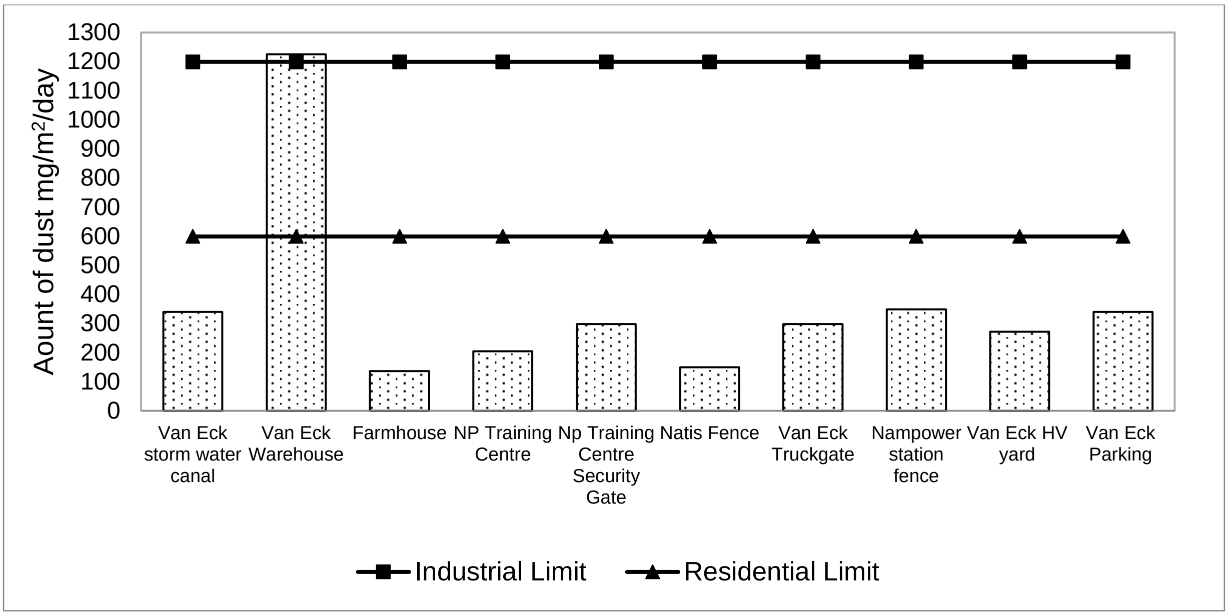

Figure 27: Amount of dust-fallout collected from the field in mg/m²/day in comparison to the dust fall rates according to the South African National Dust Control Regulations, 2013, from March-April.

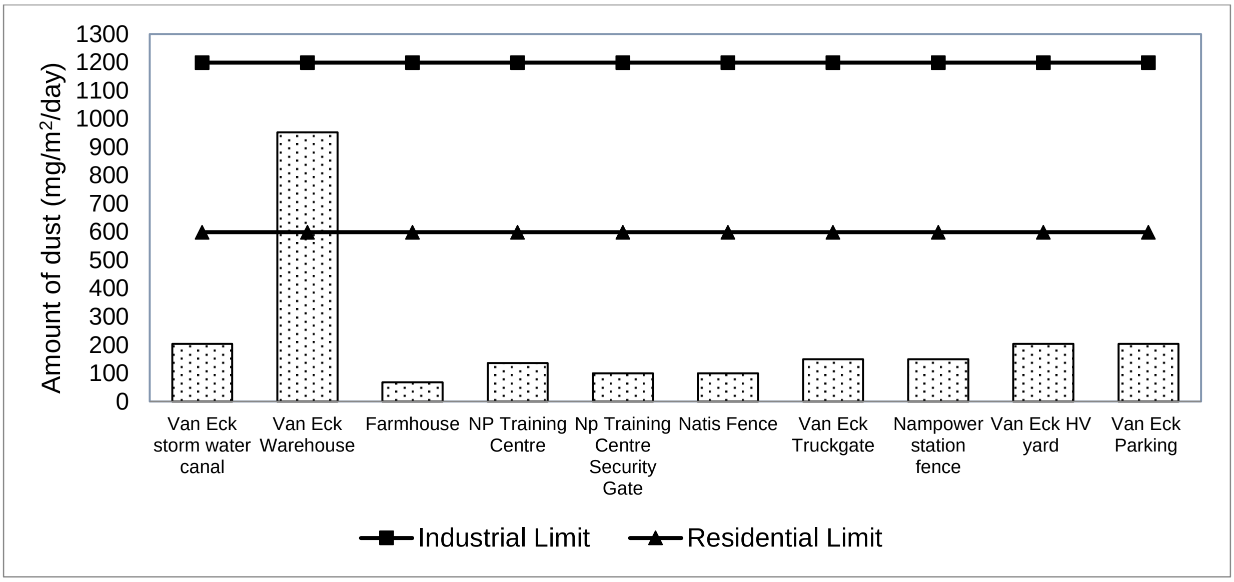

Figure 28: Amount of dust-fallout collected from the field in mg/m²/day in comparison to the dust fall rates according to the South African National Dust Control Regulations, 2013, from April-May.

4.11. Regression Analysis

In the table above, the p-value for wind speed and temperature with values 0,184843809 and 0,002600627 respectively are less than the significance level (0.95). This implies that the sample data provide enough evidence to reject the null hypothesis for the entire population, hence there is a correlation between meteorological data previously mentioned and the abundance of elements found in soil. Changes in the independent variable are associated with changes in the response at the population level. In simple terms, it implies that wind speed and temperature have an impact on element dispersion. Hence, the variables are statistically significant and were worthwhile in adding the regression model.

In statistics, the regression coefficient sign indicates whether there is a positive or negative correlation between the independent and dependent variable. A positive coefficient indicates that as the value of the independent variable increases, the mean of the dependent variable also increases, while a negative coefficient provides opposite description whereby as the independent variable increases, the dependent variable tends to decrease. Based on the analysis of data, the regression coefficients of wind speed and temperature showed negative, with -0,10712461 and -0,10837428 respectively. The coefficient value signifies how much the concentration of elements changes, given a one-unit shift in the wind speed and temperature while holding other variables in the model constant. Keeping other variables constant is crucial because it allows the assessment of the effect of each variable separate from the others.

4.11.1. Summary Output

Regression Statistics	
Multiple R	0,514414226
R Square	0,264621996
Adjusted R Square	0,215596796
Standard Error	0,433956192
Observations	33

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	2,032957683	1,016479	5,397672925	0,00994625
Residual	30	5,649539287	0,188318		
Total	32	7,68249697			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	4,52248208	1,306641408	3,46115	0,001636979	1,85396432	7,19099984	1,85396432	7,190999838
Wind speed (m/s)	-0,10712461	0,07893104	-1,35719	0,184843809	-0,2683233	0,05407407	-0,2683233	0,054074074
Temperature (ºC)	-0,10837428	0,032993325	-3,28473	0,002600627	-0,1757556	-0,0409929	-0,1757556	- 0,040992916

Table 16: Linear Regression Analysis of Independent variables (wind speed and temperature) and depended variable (Concentration in % of elements found in soil.

CHAPTER 5

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

In the results obtained, sulphur oxides were dominating in all sampling points in both soil and fly ash, however, fly ash sampled in the silo detected the highest level of concentration of all elements. This implies that based on the literature review, the burning of coal produces a considerable amount of sulphur oxides. The weather recorded by the Windhoek weather station during the period of data collection shows that there were dominant winds from the Southerly sectors, especially the South-east-Southerly and North-north-westerly directions. Pollutants emitted by the Van Eck Power Station include: Particulate Matter (Fly Ash), sulphur dioxide (SO_2), SiO^2 and SO^3 and trace elements. Emissions from the stacks are released approximately 105m above the ground surface.

The ICP-OES Analysis was used to determine the elemental composition in soil and fly ash and the mean concentration of the elements of concern ranged from 0.010ppm of Zn to 0.43ppm of Sulphite. The regression analysis shows that there is a relationship and association between windspeed and direction, and the composition of elements found in soil, thus, the variables are statistically significant. The gravimetric analysis shows that dust collected at Van Eck Warehouse was more than that obtained from the rest of the sampling areas. The dust may arise as a result of transportation and deposition of coal to the warehouse, and the conveyer belt.

In dispersion modelling, the model shows that at an unstable condition, more elements are concentrated at a distance nearer the smoke stalks, hence the further the distance, the wider the distribution of elements and the nearer the distance the more localised the elements would be. This, however, is dependent on temperature and wind speed/direction. The warmer the surface area, especially during the day, it results in vertical mixing thereby promoting dispersal of pollutants; however, at lower temperatures, a condition called thermal inversion, the pollutants are prevented from mixing and dispersing. Hence especially during cold nights, localised atmospheric pollution becomes a problem.

In addition, the model shows that pollutant elements are more concentrated at the source of pollution and thus elements and PM are distributed sparsely with increasing distance from the source of pollution. Also, it assumes that pollutant elements are either reflected by the ground and become part of the surface air, which causes air pollution, or they can be absorbed, which means pollutions of soil and underground water is at stake. It was observed that the dispersion of pollutants is mainly affected by the emission rate of the pollutant, the stack height, the exit velocity and exit temperature of the flue gas, and the stack diameter. Atmospheric conditions such as wind velocity, wind direction, ambient temperature as well as atmospheric stability also play a crucial role in the distribution of pollutants (Bhaskar & Mehta, 2010).

Nevertheless, it is likely that simulation of plume model using Microsoft Excel may not reflect the actual dispersion conditions, however, the inconsistencies are likely to be in direction of impact, while the relatively poor dispersion situations created by the Microsoft Excel software would result in conservative estimations of ground-level pollutant concentrations. It is therefore essential for NamPower to absorb and equip itself with applications/technology that is more accurate to build a comprehensive model that gives a true reflection of pollutants produced by the power plant, with little data errors.

5.2. Recommendations

During fieldwork, it was observed that there were other operations in the Northern Industrial area with the potential to discharge harmful and offensive gases into the atmosphere. Most of these small low-level industrial sources are likely to emit at or near the ground surface. It is therefore important to conduct a research project based on other industries' potential to emit pollution to justify the cause of pollution and implement strategical measures (Environmental Management Systems) on the reduction and prevention of pollution.

Trace elements are minimal in all the cases for now, because of the off-peak operation of the power plant. Based on the research analysis, it was examined that the power plant does not produce an abundant amount of pollution that may be harmful to the environment. This is entirely based on its operation, which does not work on a daily basis but rather depends on the season and the demand gap. If this type of research is repeated on a specified timeframe, then a substantial comprehensive data collection would be obtained and meaningful conclusions can be gained. These results will be important in the formulation of emission limits, air quality guidelines and control of emission of pollutants. Air quality modelling is essential in baseline reports of proposed projects and monitoring existing projects.

It was recommended from the study that the station may require control efficiency compliance measures for noxious gases and PM concentrations. The power plant may adopt and implement some abatement technologies to achieve compliance measures. Although Namibia's environmental policy does not have regulations related to the emission of pollution, it can utilise compliance measures from other countries or organisations. Thanks to the green paper, the Namibian Energy sector is in a process to divert into renewable energy production, by exploiting its abundant solar and wind sources.

The results obtained from the current work on fly ash from coal combustion are directed to several proposals, such as to search for additional precise information on elemental composition as well as morphological changes of fly ash particles, to perform extra comprehensive studies using modern quantitative techniques such as the Raman Spectroscopy that is used to obtain information on the structural and chemical composition of particulate matter.

There is little knowledge of how the climate system works and how its components and its interactions will respond to climate change. Due to uncertainties in predicted impacts and the future nature of when impacts will occur, not much is not known on how climate change will affect Namibia. It is thus important to consider executing climate change research which is properly coordinated and the benefits optimised to meet the needs of decision-makers in Namibia. Attention needs to be considerately inclined on projects that will support adaptation and mitigation measures to climate change and address specific areas of vulnerability.

5.3. Assumptions and Limitations

The following are assumptions and limitations that were observed during the research:

- The Van Eck Power Station does not run continuously, however, during dispersion model simulations, the emissions measured were presumed to be continuous and the results thereof may present a conservative estimate of ambient pollutant concentrations.

- Particulate matter emissions are infrequent in nature and depend on the utilisation of coal. There is likely to be some uncertainty of the estimation of emission rate; however, discharge quantities are low and not likely to be a cause for concern.

- There have been difficulties in obtaining meteorological data of Windhoek, on accessible website. Hence the Windhoek Meteorology Office was approached and assisted in providing data on a timeframe in which the study was conducted.

- Another limitation is that there are very localised meteorological conditions as a result of the topography around Windhoek. This may have affected the use of data set in the dispersion modelling simulations. Air dispersion models do not hold all the characteristics of a real environmental system; however, they contain features of interest for management issue or for solving a scientific problem. The Gaussian plume model that was adopted as part of the project, is generally regarded to have an uncertainty range between -50% to 200%. The model was selected over other models because others are complex and require applications that were too expensive for the researcher to purchase. Other dispersion models are the most difficult and are normally performed with more complicated dispersion models.

- During fieldwork, the initial plan was to mount 30 buckets within the vicinity of the station. However, due to the nature and topography of the area, that some randomly selected points ended up within the jurisdiction of the owners of the land, and that there were multiple obstructions, it became impossible.

- Lack of funds to cover costs was a difficult situation for the researcher. It was expensive to conduct data analysis and to purchase materials and apparatus.

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7. APPENDICES

Appendix A: Photos Taken from the Field

Figure 28: The High Voltage Yard at the Van Eck Power Station

Figure 29: The Van Eck Power Station in Operation

Figure 29: Fallout Bucket mounted at the Van Eck Power Station, near the HV Yard.

Figure 31: Vegetation next to the warehouse within the Van Eck Power Station.

Figure 32: Fly Ash taken from the power plant's silo.

Figure 33: Aluminium trowel used to sample soil and fly ash from the silo.

Figure 34: Soil samples taken at point NP-3 within the vicinity of the Van Eck Power Station.

Figure 35: Aluminium foil used in the field to wrap up the trowel.

APPENDICES

Appendix B: Permission Letter from NamPower

NamPower

NamPower Centre, 15 Luther Street, P.O. Box 2864, Windhoek, Namibia, Tel +264-61-2054111, Fax +264-61-232805, E-mail registar@nampower.com.na

Ms Ndeukumwa Aushiku
NUST
WINDHOEK

Enquiries: CN Shatona

Tel No : 061 – 205 2457

Date : 13 February 2018

Dear Ms Aushiku

RE: PERMISSION TO CARRY OUT ACADEMIC RESEARCH WORK

We acknowledge receipt of your request and a letter by Prof. Mashauri dated 30 November 2017 seeking approval to conduct an academic research study entitled:

"Pollutant Trace Elements in Fly Ash at Van Eck Power Station".

We are pleased to grant you approval for your request and kindly take note that you are allowed to contact NamPower employees to participate in your study. We advise you to arrange a meeting with Mr Laban Ndjendja, the Manager of the Van Eck Power Station and Mr Danie Louw, the Manager of Safety, Health, Environment and Wellness to discuss the details of your study plans and schedules.

Kindly note that the information from any NamPower document will only be used for the study mentioned above, and will under no circumstances be used for other purposes without prior written consent from NamPower.

For further enquiries, kindly feel free to contact the Human Resources Division.

Recommended by:

CN Shatona
Manager: Organisation & Human Resources Development

Approved / Not Approved

Kahenge S Haulofu
MD OF NAMPOWER

13/02/2018
Date

K. Ndiluta (Chairperson), K.S. Haulofu (Managing Director), D. Molinga (Deputy Chairperson), A. B. Matebele, A. Konine, S. N. M. Kalili, Dr. O. W. Von Oertzen
Namibia Power Corporation (Pty) Ltd Co. Reg. No. 2051

APPENDICES

Appendix C: Coordinates of Fallout Bucket System

Sampling Point	Longitude	Latitude
Farm House	17,079233	-22,512368
Van Eck Warehouse	17,07901598	-22,5127191
Van Eck HV Yard	17,07983786	-22,5126344
Stormwater Canal	17,07905991	-22,5123004
Van Eck Truck Gate	17,0783353	-22,5120647
NP Fence	17,07833241	-22,5120004
Natis Fence (Canal)	17,07777132	-22,5157545
NP Training Security	17,08263816	-22,5164577
NP Training Centre	17,07811609	-22,5157446
Van Eck Parking	17,07777529	-22,5135006

Appendix D: Coordinates of Soil Sampling Areas

Sampling Point	Longitude	Latitude
NP1	17,08005166	-22,51279516
NP3	17,08006681	-22,51271117
NP2	17,08005166	-22,51275316
NP4	17,08005166	-22,51275316
NP5	17,07047892	-22,51319618
NP6	17,08005166	-22,51275316
NP7	17,08005166	-22,51275316
NP8	17,08005166	-22,51275316
NP9	17,08005166	-22,51275316
NP10	17,08005166	-22,51275316
NP11	17,08005166	-22,51275316
NP12	17,08005166	-22,51275316
NP13	17,07822056	-22,51317121
NP14	17,07847004	-22,51233776
NP15	17,07788001	-22,51101745

NP16	17,07788001	-22,51101745
NP17	17,07862232	-22,51202361
NP18	17,0784328	-22,51255047
NP19	17,07783325	-22,51106424
NP20	17,07783325	-22,51106424
NP21	17,07917847	-22,51244882
NP22	17,07782095	-22,5131068
NP23	17,07764507	-22,51101287
NP24	17,07887323	-22,51043757
NP25	17,08075045	-22,51357646
NP26	17,08222645	-22,5158881
NP27	17,08006916	-22,51661241
NP28	17,07736726	-22,51663897
NP29	17,06187651	-22,51413743
NP30	17,0722713	-22,51848538

Appendix E: Gaussian Plume Model Results

Concentration of Pollutants Modelled During the Day

Results: 1

At Vertical Distance Z, when Y=0

	Z		A1	A2	A3	A4	Conc mg/m^3
1	**z_0=**	0,00	108,07565	1	0,81196447	0,8119645	**175,50717**
2	**z_1=**	50,00	108,07565	1	0,88332127	0,7303491	**174,39847**
3	**z_2=**	150,00	108,07565	1	0,97950674	0,5536596	**165,69795**
4	**z_3=**	132,00	108,07565	1	0,96763078	0,5857022	**167,87747**
5	**z_4=**	200,00	108,07565	1	0,99842283	0,4666183	**158,33527**
6	**z_5=**	250,00	108,07565	1	0,99585639	0,3848183	**149,21732**
7	**z_6=**	300,00	108,07565	1	0,97197269	0,3105453	**138,60896**
8	**z_7=**	400,00	108,07565	1	0,86754931	0,189491	**114,24032**
9	**z_8=**	600,00	108,07565	1	0,53269181	0,0543773	**63,447876**
10	**z_9=**	800,00	108,07565	1	0,231132	0,0110268	**26,171467**
11	**z_{10}=**	1000,00	108,07565	1	0,07086737	0,0015801	**7,8298063**

Results: 2

At Horizontal Distance Y, when Z=0

	y (m)		A1	A2	A3	A4	Conc, ug/m³
1	**y_0=**	0,00	108,07565	1	0,8119645	0,8119645	**175,50717**
2	**y_1=**	400,00	108,07565	0,33495977	0,8119645	0,8119645	**58,787843**
3	**y_2=**	900,00	108,07565	0,003938	0,8119645	0,8119645	**0,6911466**
4	**y_3=**	500,00	108,07565	0,18105104	0,8119645	0,8119645	**31,775756**
5	**y_4=**	750,00	108,07565	0,0213822	0,8119645	0,8119645	**3,7527287**
6	**y_5=**	1000,00	108,07565	0,00107449	0,8119645	0,8119645	**0,1885814**
7	**y_6=**	1500,00	108,07565	2,0903E-07	0,8119645	0,8119645	**3,669E-05**
8	**y_7=**	2000,00	108,07565	1,333E-12	0,8119645	0,8119645	**2,339E-10**
9	**y_8=**	2500,00	108,07565	2,7863E-19	0,8119645	0,8119645	**4,89E-17**
10	**y_9=**	4000,00	108,07565	3,1569E-48	0,8119645	0,8119645	**5,541E-46**
11	**y_{10}=**	6000,00	108,07565	1,328E-107	0,8119645	0,8119645	**2,33E-105**

Concentration of Pollutants Modelled During the Night

Results 1:

At Vertical Distance Z, when Y=0

	Z		A1	A2	A3	A4	Conc. ug/m3
1	**z_0=**	0,00	5335,568	1	5,8362E-21	5,836E-21	**6,228E-17**
2	**z_1=**	50,00	5335,568	1	7,7548E-12	8,479E-33	**4,138E-08**
3	**z_2=**	150,00	5335,568	1	0,09849943	1,288E-64	**525,55041**
4	**z_3=**	132,00	5335,568	1	0,00946263	4,349E-58	**50,488527**
5	**z_4=**	200,00	5335,568	1	0,94157196	1,346E-84	**5023,8212**
6	**z_5=**	250,00	5335,568	1	0,01737532	2,72E-107	**92,707198**
7	**z_6=**	300,00	5335,568	1	6,1897E-07	1,06E-132	**0,0033026**
8	**z_7=**	400,00	5335,568	1	5,651E-24	1,15E-191	**3,015E-20**
9	**z_8=**	600,00	5335,568	1	1,2617E-90	0	**6,732E-87**
10	**z_9=**	800,00	5335,568	1	1,048E-200	0	**5,59E-197**
11	**z_{10}=**	1000,00	5335,568	1	0	0	**0**

Results 2:

At Horizontal Distance Y, when Z=0

	Y		A1	A2	A3	A4	Conc, ug/m^3
1	**y_0=**	0,00	5335,568	1	5,836E-21	5,836E-21	**6,228E-17**
2	**y_1=**	400,00	5335,568	9,5518E-05	5,836E-21	5,836E-21	**5,949E-21**
3	**y_2=**	900,00	5335,568	4,4585E-21	5,836E-21	5,836E-21	**2,777E-37**
4	**y_3=**	500,00	5335,568	5,2346E-07	5,836E-21	5,836E-21	**3,26E-23**
5	**y_4=**	750,00	5335,568	7,3704E-15	5,836E-21	5,836E-21	**4,59E-31**
6	**y_5=**	1000,00	5335,568	7,5083E-26	5,836E-21	5,836E-21	**4,676E-42**
7	**y_6=**	1500,00	5335,568	2,951E-57	5,836E-21	5,836E-21	**1,838E-73**
8	**y_7=**	2000,00	5335,568	3,178E-101	5,836E-21	5,836E-21	**1,98E-117**
9	**y_8=**	2500,00	5335,568	9,379E-158	5,836E-21	5,836E-21	**5,84E-174**
10	**y_9=**	4000,00	5335,568	0	5,836E-21	5,836E-21	**0**
11	**y_{10}=**	6000,00	5335,568	0	5,836E-21	5,836E-21	**0**

Appendix F: Oxides and Elements Found in Soil and Fly Ash

Oxides Table (%)			
Sample ID	**SiO2**	**SO3**	**MnO2**
NP-1	48,58	0,022	<LOD
NP-2	43	0,65	<LOD
NP-3	45,54	0,75	<LOD
NP-4	62,06	0,65	<LOD
NP-5	47,11	0,05	<LOD
NP-6	51,4	0,32	<LOD
NP-7	0,45	<LOD	<LOD
NP-8	47,49	0,27	<LOD
NP-9	47,38	0,3	<LOD
NP-10	46,21	0,15	<LOD
NP-11	47,55	0,07	<LOD
NP-12	45,39	0,17	<LOD
NP-13	46,74	0,12	<LOD
NP-14	42,08	0,3	<LOD
NP-15	53,63	0,35	<LOD
NP-16	42,21	0,45	<LOD
NP-17	38,36	1,07	<LOD
NP-18	51,45	0,25	<LOD
NP-19	54,49	0,17	<LOD
NP-20	70,59	0,22	<LOD
NP-21	45,31	0,35	<LOD
NP-22	48,58	0,27	<LOD
NP-23	56,22	0,2	<LOD
NP-24	49,33	0,07	<LOD
NP-25	47,49	0,25	<LOD
NP-26	48,15	0,27	<LOD
NP-27	44,56	0,47	<LOD
NP-28	54,64	0,35	<LOD
NP-29	50,85	0,07	<LOD
NP-30	45,16	0,25	<LOD
NP-CA	38,31	1,27	<LOD

Fly Ash	36,90	2,05	<LOD
Main Point	40,02	1,95	<LOD

Concentration of Trace Elements Found in Soil and Fly Ash																							
Sample ID	**Si**	**Al**	**Fe**	**K**	**Mg**	**Ca**	**S**	**Ti**	**P**	**Cl**	**Ba**	**Zr**	**Sr**	**Zn**	**Pb**	**As**	**Cu**	**Ni**	**Co**	**Cr**	**V**	**Mn**	**Hg (ppm)**
NP-1	22,7	8,52	3,8	3,21	2,36	0,74	0,09	0,6	0,15	0,04	0,02	0,02	0,01	0,01	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-2	20,1	12,3	4,27	2,51	2,04	2,35	0,26	0,7	0,58	0,07	0,03	0,02	0,08	0,03	0,1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-3	21,29	9,38	3,82	2,35	1,87	1,28	0,3	0,63	0,33	0,07	0,01	0,02	0,01	0,1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-4	29,01	5,92	1,92	1,89	1,89	1,22	0,26	0,51	0,22	0,08	<LOD	0,03	0,01	0,1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-5	22,02	11,62	4,98	3,34	1,55	1,3	0,02	0,7	0,27	0,04	0,03	0,02	0,01	0,1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-6	24,03	8,69	3,15	3,29	2,75	0,66	0,13	0,68	0,19	0,05	0,01	0,02	0,01	0,1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-7	0,21	<LOD	4,1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0,02	0,01	0,1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-8	22,2	9,68	4,41	3,74	2,57	0,86	0,11	0,75	0,24	0,06	0,01	0,02	0,01	0,1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-9	22,15	8,14	3,3	3,17	2,02	1,04	0,12	0,65	0,25	0,06	0,02	0,02	0,01	0,1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-10	21,6	11,2	4,85	4,09	2,71	0,67	0,06	0,79	0,26	0,04	0,02	0,02	0,01	0,1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-11	22,23	9,16	3,95	3,49	2,7	0,76	0,03	0,83	0,14	0,04	0,01	0,02	0,01	0,1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-12	21,22	8,95	4,17	3,79	3,37	0,81	0,07	0,87	0,18	0,05	0,02	0,02	0,01	0,1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-13	21,85	8,66	4,32	3,73	2,45	0,78	0,05	0,91	0,18	0,05	0,01	0,02	0,01	0,1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-14	19,67	9,1	4,55	3,91	2,29	1,16	0,12	0,63	0,23	0,05	0,02	0,02	0,01	0,1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-15	25,07	7,39	2,92	2,28	1,96	0,65	0,14	0,56	0,2	0,04	0,01	0,02	0,01	0,1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-16	19,73	10,47	4,43	4,31	3,77	1,21	0,18	0,57	0,24	0,05	0,02	0,01	0,02	0,02	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-17	17,39	7,55	3,3	2,51	2,27	1,17	0,43	0,53	0,23	0,05	0,01	0,02	0,02	0,02	0,01	<LOD	<LOD	<LOD	<LOD	0,04	<LOD	<LOD	<LOD
NP-18	24,05	8,69	3,69	2,86	2,14	0,77	0,1	0,87	0,18	0,05	0,01	0,03	0,01	0,01	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-19	25,47	9,48	3,58	3,24	1,94	0,83	0,07	0,86	0,15	0,04	0,01	0,02	0,01	0,01	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-20	33	3,01	1,66	0,93	1,22	0,79	0,09	0,24	0,13	0,05	<LOD	0,01	<LOD	0,01	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-21	21,18	9,61	4,02	3,26	3,11	1,17	0,14	0,6	0,25	0,06	0,01	0,02	0,02	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-22	22,71	7,42	2,89	2,85	2,09	0,6	0,11	0,6	0,17	0,04	0,01	0,02	0,01	0,01	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-23	26,28	5,96	2,24	2,38	1,73	0,15	0,08	0,54	0,17	0,06	<LOD	0,02	0,01	0,01	0,01	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-24	23,06	8,61	4,1	3,94	2,78	0,77	0,03	0,74	0,17	0,05	0,01	0,02	0,01	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-25	22,2	8,41	4,02	4,01	1,89	1	0,1	0,79	0,24	0,05	0,01	0,02	0,01	0,01	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-26	22,51	8,53	4,84	2,77	2,57	1,35	0,11	0,92	0,3	0,05	0,02	0,02	0,01	0,01	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-27	20,83	8,23	3,74	3,43	3,11	0,89	0,19	0,65	0,21	0,05	0,01	0,01	0,01	0,01	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-28	25,54	8,86	3,42	3,47	3,83	0,78	0,14	0,77	0,21	0,06	0,01	0,01	0,01	0,01	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD

NP-29	23,77	7,65	4,16	3,04	2,05	0,52	0,03	0,62	0,17	0,04	0,01	0,01	<LOD	0,01	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-30	21,11	7,8	3,83	3,33	2,95	1,31	0,1	0,77	0,32	0,06	0,01	0,01	0,01	0,01	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
NP-CA	17,91	18,51	1,99	0,51	1,73	3,55	0,51	1,21	0,16	0,1	0,03	0,03	0,06	<LOD	<LOD	<LOD	0,01	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Fly Ash	17,25	15,17	2,27	0,6	<LOD	3,08	0,82	1,24	0,29	0,05	0,02	0,03	0,07	0,01	0,01	<LOD	0,02	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Main Point	18,71	15,6	2,84	0,71	1,33	3,05	0,78	0,9	0,24	0,15	0,05	0,03	0,07	0,01	0,01	<LOD	0,01	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD