AN ASSESSMENT OF SOUTH AFRICA'S COAL MINING SECTOR RESPONSE TO CLIMATE CHANGE ADAPTATION DEMANDS

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DECLARATION

I, the undersigned BONGANI CHAVALALA, student number 46513078 hereby declare that this thesis is my own original work with the exception of quotations and references which are attributed to their sources. This thesis has not been previously submitted to any other university and will not be presented at any other university for similar or other degree award.

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Date: 5 June 2017

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DEDICATION

I dedicate this work to my grandmother and my two sons, Celestial and Willow. I pass my sincere gratitude to Masha Mthiyane for the encouragement, support and inspiration. You were always there when I needed you.

ABSTRACT:

Climate change adaptation has received limited attention compared to mitigation across all spatial levels. This is besides the documented adverse impacts of climate change in different sectors of societies including mining in general and coal mining specifically. Against this background, the study set three objectives. The first objective was to identify current and possible future climate change impacts that may affect selected coal mines in South Africa. The second objective was to establish the nature and extent to which these mines were ready to address and implement adaptation measures. The last objective was to determine and document existing climate change adaptation practices in selected mines. Employing the mixed methods approach, the research engaged five coal mines located in Mpumalanga, Free State and Kwa Zulu-Natal, gathering both the qualitative and quantitative data. This data was analysed thematically. The research made three major findings. The first finding was that the climatic conditions in the research areas have been changing over the observed period. In general, rainfall has been declining and temperatures have been increasing, leading to increased cases of extreme fog, mist and heatwaves. The second finding was that there has been an increase in frequency and intensity of extreme weather events, most notably, floods and droughts. These changes in the climate and associated weather events have frequently affected mine operations particularly at the production sub-chain of the coal mining value chain. The third major finding was that despite this evidence of adverse impact of climate change on the production sub-chain of the South African coal mining value chain, adaption responses in all the studied mines showed reactive adaptation to extreme events instead of proactive adaptation planning and implementation. South Africa depends on coal-derived energy, electricity in particular and the coal mines are implicitly exposed and vulnerable to the adverse impacts of climate change. Reducing this exposure and vulnerability dictates the urgent need to implement anticipatory adaptation measures in all the sub-chains of the coal mining value chain.

Key Words: Climate change, Adaptation, Mitigation, Coal mining, extreme events, South Africa, vulnerability, exposure.

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LIST OF ACRONYMS AND ABBREVIATIONS

AMD	Acid Mine Drainage
BECSA	BHP Billiton's Energy Coal South Africa
CSP	Climate Service Partnership
CSIRO	Commonwealth Scientific and Industrial Research Organisation
COP 20	The twentieth session of the Conference of the Parties
CSIR	Centre for Scientific and Industrial Research
DEA	Department of Environmental Affairs
EIA	Energy Information Administration
GHG	Greenhouse Gas emissions
GCM	Global Climate Models
GIS	Geographic Information System
GFCS	Global Framework for Climate Services
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
IPCC	Intergovernmental Panel on Climate Change
ICMM	International Council on Mining and Metals
LTMS	Long Term Mitigation Scenarios
M & E	Monitoring and Evaluation
NOAA	National Oceanic and Atmospheric Administration
NASA	National Aeronautics and Space Administration
NAPAs	National Adaptation Programmes of Action
NDP	National Development Plan

NMHSs	National Meteorological and Hydrological Services
PCD	Pollution Control Dams
PV	Photovoltaic
PGMs	Platinum group metals
SHEQ	Safety, Health, the Environment and Quality
SDM	Side Demand Management
SARS	South African Revenue Services
SBSTA	Subsidiary Body for Scientific and Technological Advice
SPSS	Statistical Package for Social Scientists SDM Side Demand Management
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile Organic Compounds
WoF	Working On Fire

CHAPTER ONE: INTRODUCTION AND BACKGROUND

1.1 INTRODUCTION

The coal mining industry has been an integral aspect of all South Africans' lives for many years and may well continue to be so for a long while (Van der Zwaan 2005). My earliest memory of the coal mining industry was when I was five years old living with my aunt in Seshego, a township in the city of Polokwane in the Limpopo Province of South Africa. Every Saturday morning, a big truck carrying very dirty men and bags of coal would come careening down the road. Firstly, I was scared of the loud truck, and then the men were aware that I was scared of them too. One of them would jump off the truck with a bag full of coal and chase me back to the house. He would give my aunt the bag in exchange for money and my aunt would start stuffing the coal into the four-plate coal stove in the far corner of our small kitchen. I would get excited knowing that it was time to eat. The dirty old truck, the dirty and scary man and the bag full of coal presented two conflicting realities to the then five-year-old me; one was that of fear, the other was excitement because I knew that once the man and their truck had delivered their bag, my aunt would finally start cooking and we would get to eat.

Today, the coal mining industry is still an important aspect of all South Africans' socio-economic life and can cause the same fear and excitement. On one hand, the industry provides energy needed in all households, industries, and it creates thousands of jobs for people in South Africa and beyond (South African Chamber of Mines 2011). On the other hand, the world has woken up to the reality that the coal mining industry is one of the major contributors of greenhouse gas (GHG) emissions that include carbon dioxide, methane, nitrous oxide, and ozone which are responsible for global warming which in turn leads to climate change. Climate change is arguably the most debated and negotiated agenda in the world to date. Such debates and negotiations became prominent during the 1992 Rio de Janeiro Earth Summit, and continued to the most recent 21st United Nations Climate Change Conference, of Parties (COP21) that took place in Paris in 2015. These polarised debates are centred on who is causing climate change, how are they causing it, and how climate change impacts can be mitigated, and most recently how can humans adapt.

The energy sector has been and continues to be the focus and target of this debate. This is because of the role of fossil fuels in causing climate change (Olah *et al* 2006). Climate change is compelling the world governments to find solutions that will help manage problems associated with climate change. Although there have been debates about the role of human activity in causing climate change, there is no dispute that the climate is changing in a way that the human race has not experienced in its recent history. Evidence presented by the National Oceanic and Atmospheric Administration (NOAA) shows that natural and human activities (anthropogenic) have resulted in increased global average temperatures of 1.4 degrees Fahrenheit (0.8 degree Celsius) since 1880 (NOAA 2010). This evidence indicates that much of this increase has occurred in the last two decades of the 20th century which has been the hottest in 400 years and possibly the warmest for several millennia National (Aeronautics and Space Administration, 2011; NOAA, 2010). The Intergovernmental Panel on Climate Change, IPCC (2007) corroborates this evidence by stating that 11 of the past 12 years are among the warmest years since 1850. The acknowledgement of the presence of climate change is driving the world's leading governments and their counterparts to seek immediate and long term lasting solutions.

Having formally accepted climate change as a reality in 1990 when the IPCC presented its First Assessment Report to the world governments, world leaders have since been gathering regularly to negotiate climate change interventions. As stated above, the earliest of these gatherings was at the 1992's Earth Summit in Rio de Janeiro which led to the development of the Kyoto Protocol that was adopted in Kyoto, Japan, in 1997 and came to effect in 2005, to the latest COP 22 held in Marrakesh, Morocco in 2016 (United Nations Framework Conversation on Climate Change, UNFCCC 2011). These negotiations have been largely about how to manage climate change, mainly through reducing human-induced GHG emissions. To this end, less attention and effort was paid on how to live with the effect of climate change (Centre for Climate Energy Solutions, 2010).

What emerges is that climate change management generally comes in two categories; climate change mitigation and climate change adaptation. Change mitigation refers to efforts aimed at reducing and/or preventing GHG emissions. As such mitigation includes using new and cleaner technologies, bringing on board renewable energy, increasing the energy efficiency of older equipment, changing production processes to be resource efficient, changing management practices and/or changing consumer behaviour (United Nations Environmental Programme, 2007). Since the beginning of climate change discussions at the Earth Summit in

Rio de Janeiro in 1992, climate change mitigation has been more dominant compared to adaptation (Pearce *et al*, 2011; Centre for Climate and Energy Solutions, 2010). While it is understood and acknowledged that economic sectors need to reduce their carbon emissions in order to minimise their contributions to climate change, the world also has to start thinking about how it will cope with the changing climate that is already causing problems in many sectors, such as agriculture, construction, transportation and mining among others (Fussel, 2007). This is the essence of climate change adaptation described "as the process of adjustment to actual or expected climate change and its effects, in order to moderate harm or exploit beneficial opportunities" (IPCC, 2007:3).

Climate change adaptation has received less attention in comparison with climate change mitigation in many sectors including the mining sector. However, adaptation has been taken more seriously in sectors such as agriculture and transportation (Howden *et al*, 2007). It was only in 2001, at COP7 in Marrakesh where parties established the Least Developed Countries (LDC) work programme to develop national climate change mechanisms and build capacity, including National Adaptation Programmes of Action (NAPAs). In 2006, at COP12 in Nairobi, the Subsidiary Body for Scientific and Technological Advice (SBSTA) was mandated to undertake a five-year project to address the impacts, vulnerability and adaptation in relation to climate change. This project has been popularised as the Nairobi Work Programme. In 2010, the Adaptation Framework was established at COP16 held in Cancun. Activities under the Cancun Adaptation Framework related to including a process to enable LDC parties to formulate and implement National Adaptation Plans (NAPs), and a work programme to consider approaches to address loss and damage; support; institutions, including the establishment of an Adaptation Committee at a global level, as well as regional and national level arrangements; principles; and stakeholder engagement (Howden *et al.,* 2007). Climate change adaptation also features strongly in the Paris Agreement (UNFCCC, 2015).

While climate change adaptation has started to gain traction and measure of importance at the international climate negotiation platforms, the adaptation agenda and practice seem to remain behind compared to climate change mitigation especially at the sectoral level. For example, the National Development Plan (NDP), which is a blueprint for South Africa's development path signals this bias towards mitigation. The section dealing with climate change (Chapter 5) carries a mitigation theme, including emission reduction targets, monitoring and evaluation and reporting, mitigation policy alignment and measures, and the state's role and financing of climate change mitigation efforts. In this thirteen-page chapter, only two abstract paragraphs are dedicated to climate change adaptation. The NDP's proposed industrialisation and infrastructure development is an element that will require increased and stable energy supply, mostly coming from coal mining and supplies.

One factor that is certain is that the world and South Africa will not immediately move away from coal as a source of energy. The move will be gradual as renewable energy technologies gain traction. In the meantime and at least for the next 50 years, according to South Africa's Department of Environmental Affairs (2013), the country will still be dependent on coal for energy production. In South Africa, coal is used to generate more than 70% of the country's electricity and approximately 30% of the liquid fuels (Fossil Fuel Foundation, 2013). In addition, the coal sector contributes to employment. In 2010 alone, the coal sector employed 73,618 people and paid R14 billion in wages. This accounted for 14.4% of the total wages in the mining sector and contributed 1.8% of the country's Gross Domestic Product (GDP) (South African Chamber of Mines, 2011). Furthermore, coal is one of the country's prominent export products. In 2011 the country exported 67.6 million metric tonnes (Mt) to neighbouring countries that include Botswana and Mozambique. The country still holds an estimated 66.7 billion tonnes of unexploited coal (Council for Geosciences, 2012). More than 80% of South African coal is produced by five mining companies, BHP Billiton's Energy Coal South Africa (BECSA), Anglo American Thermal Coal, Xstrata Coal, Exxaro Resources and Sasol Mining (Chamber of Mines, 2011). The bulk of these reserves (about 70%) are found in the Mpumalanga Province mainly around the mining towns of Witbank and Ermelo, in the Limpopo Province mainly in Waterberg and Springbok Flats, the Free State Province mainly Highveld, and other smaller fields (Fossil Fuel Foundation, 2013).

These reserves are estimated to guarantee another 150 years of coal supplies. Similar to mining and non-mining sectors and sub-sectors, the coal value chain is vulnerable to climate change impacts. Given the importance of the coal sector to the South African economy against a background of identified adverse climate change impacts on the coal value chain and slow technological progress on alternative energy sources, there is a dire need for the coal mining sector to learn to adapt to climate change. The highly localised nature of climate change impacts mean that adaptation practices have to be appropriately contextualized to respond to specific and unique mine vulnerabilities and exposure assessments (Steel and Patrick, 2001). Although the exact nature of climate change impacts are location–specific and dependent on regional characteristics and ecosystems, in principle, there are broad climate related risks that are relevant to the entire South African coal mining industry (Steel and Patrick, 2001). Lodged in this assertion, this research explores current and potential climate changes impacts and adaptation practices in South Africa's coal mines.

1.1 PROBLEM STATEMENT

Globally, climate change adaptation has received relatively less and delayed attention from global climate negotiations. From the earliest global climate change negotiations and conferences such as the 1992's Earth Summit in Rio de Janeiro and the Kyoto Protocol in 1997, the UNFCCC major goal has been "to stabilise greenhouse gas concentrations at a level that would prevent dangerous anthropogenic (human-induced) interference with the climate system" (UNFCCC 2011). A serious move towards addressing climate change adaptation at the global negotiations level was only realised in 2010 during the Cancun climate change conference where an Adaptation Committee was formed, followed by the development of the Adaptation Framework. The South African government response to climate change has reflected the international climate mitigation bias. The country has been proactive in planning and implementing emission reduction targets as a response to climate change. In Copenhagen, the Presidency pledged that South Africa would undertake mitigation actions, which will reduce carbon emissions to below a business-as-usual trajectory by 34% by 2020 and by 42% by 2025 (IPCC, 2011). The NDP lays out details of climate change mitigation plans and mildly mentions adaptation (National Planning Commission, 2012).

The Department of Environmental Affairs (DEA) is leading the country's climate change policy response with a National Climate Change Response White Paper (DEA, 2010). Although the White Paper makes it clear that the nation will address mitigation and adaptation on an equal footing, subsequent policies and practice shows bias towards mitigation. For example, the National Treasury introduced the carbon tax paper in 2010 (National Treasury, 2010), which has developed over time and by the time of completing this thesis, a Draft Carbon Tax Bill had been published for public comment (National Treasury, 2015). In 2007, the Department of Environmental Affairs (2010) developed the Long Term Mitigation Scenarios (LTMS), which paid extensive attention to carbon reduction and the associated plans. With respect to adaptation, only water is argued to be the "primary medium whereby climate change impacts will be felt by people, ecosystems and economies" (DEA, 2010).

As a result of this bias, climate change mitigation and associated strategies are becoming standard practices and are well understood across a number of industries including the coal mining industries. In an effort to bring climate change adaptation on par with climate change mitigation, the DEA concluded the country's Long Term Adaptation Scenarios (LTAS) in 2013, seven years after the LTMS (DEA, 2013). While it is acknowledged that the development of the LTAS is a positive step towards climate change adaptation discourse, adaptation is still an area that is relatively poorly understood in general and more specifically by industries.

From the international level, there have been some case studies published in Canada for the mining sector broadly, although none for coal (Pearce *et al*., 2011). The Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia has established a climate adaptation "flagship" which has produced a limited number of general publications relating to adaptation in the mining sector (CSIRO, 2011). Within the South African mining industry, specifically in the coal mining sector, key players in the coal value chain are surprisingly investing very little in exploring adaptation needs and measures as suggested by the South African Coal Road Map (2011). Although there is growing interest on climate change adaptation at the global climate negation arena and some recognition of its importance at a country level, key economic industries are still far behind in understanding, planning and implementing climate change adaptation actions, more so in the coal mining sector. Ready or not, the coal mining sector will be and is affected by climate change, and this may result in disruptions or mine closures that will affect production if appropriate adaptation measures are not instituted. In South Africa, lost production in coal mines have and in the future will result in reduced coal supply to the main power utility Eskom, which in turn has and will compromise the country's electricity generation and supply leading to negative effects on economic growth and social development.

1.2 RESEARCH QUESTIONS AND OBJECTIVES

Cognisant of the established facts on the adverse impacts of climate change on the coal mining sector, and South Africa's reliance on coal as a dominant source of energy, the study poses two fundamental questions:

(i) What are the current and possible climate change impacts that may affect selected South African coal mines?
(ii) What is the extent and nature of climate change adaptation readiness in selected coal mines in South Africa?

The questions seek to meet the following objectives:

(i) To identify current and possible future climate change impacts that may affect selected coal mines in South Africa.
(ii) To establish the nature and extent to which the selected coal mines in South Africa are ready to address and implement climate change adaptation measures.
(iii)To determine and document existing climate change adaptation practices in selected mines in South Africa.

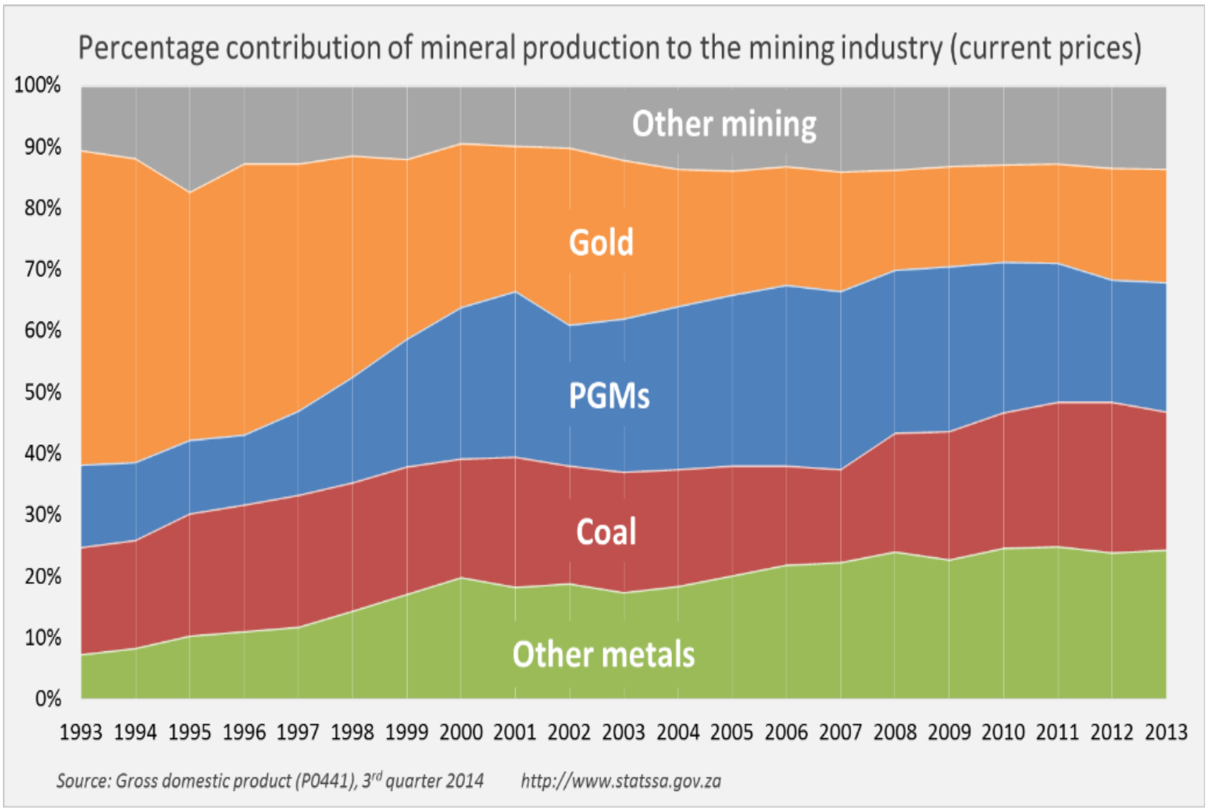
1.3 JUSTIFICATION AND SIGNIFICANCE OF THE STUDY

Steel and Patrick (2011), state that the continued use of coal for energy generation disregards the growing concern about its role in causing climate change. The increased use of coal as an energy source has been driven by the decline of oil and natural gas reserves (Steel and Patrick, 2011). Van der Zwaan (2005) predicts that coal will dominate world power production during the 21st century, irrespective of its contribution to regional pollution and global warming. This prediction is corroborated by the recent construction of a number of coal-fired power stations in both the developed and developing countries. Among the developed countries, Germany commissioned six coal-fired power stations with a combined capacity of 5,800MW in 2009. These plants account for 7% of the country's electricity needs (Homewood, 2013). In addition to the plants commissioned in 2013, the country is planning to commission 12 more coal-fired power stations by 2020. These will supply Germany with 19% of its annual power needs. As a developing country, South Africa is expanding its coal based-power supply. The country is building two more supercritical coal plants; the Medupi and the Kusile power stations respectively, and plans are at advanced stages to commission independent coal-powered electricity production. Lok (2011) notes that projected economic growth in South Africa will need additional power supplies and most likely additional coal-power electricity generating plants.

The German and South African cases illustrate a world that is locked into coal as a key energy source. Van der Zwaan (2005) advances four reasons why reliance and investment in coal exploitation for energy production is likely to continue in the medium to long term. Firstly, the resource base of coal is large, allowing for continued consumption even at levels substantially higher than the current levels. Secondly, the improving efficiency and competitiveness of coal technologies designed to reduce GHG emissions at coal power stations makes coal an attractive energy source. Thirdly, the employability of new coal technologies in conjunction with carbon capture and storage systems is to an extent, reducing negative perceptions attached to the burning of coal to generate electricity. Fourth and lastly, the improving economics of advanced clean coal technologies result in good financial return for investment. In addition to these four reasons, the coal industry's economic contribution to the South African economy is significant as it is the most profitable resource in the country (Statistics South Africa, 2015).

Figure 1.1 provides a comparison of coal mining economic contribution to the mining industry alongside other major minerals including gold and platinum for the period 1993 to 2013. From 1998 when gold mining output started to decline, coal mining output started to increase while other metals remained steady. The coal mining industry contributed approximately R37 billion to the economy in 1993, with gold contributing R115 billion (value added at constant 2010 prices). In 2013, coal contributed R51 billion to South Africa's economy, compared with gold's R31 billion (South African Chamber of Mines, 2011). The mineral's contribution to overall mining value rose to 22.5% in 2013 from 17.4% in 1993. Platinum group metals (PGMs) came close second in 2013, at 21.0% (South African Chamber of Mines, 2011). Gold's contribution fell to 18.5% in 2013 from 51.1% in 1993 (South African Chamber of Mines, 2011). It is expected that coal mining will continue to increase both in terms of mining activities and in terms of economic contribution to the South African economy, especially given that South Africa's plans for industrialisation and infrastructure development (Nationa PaC, 2011). Both these plans will require increased energy from reliable source(s), which for now and the foreseeable future will come largely from coal.

Figure 1.1 Percentage contribution of mineral production to the South African mineral industry



Source: South African Chamber of Mines (2011:13)

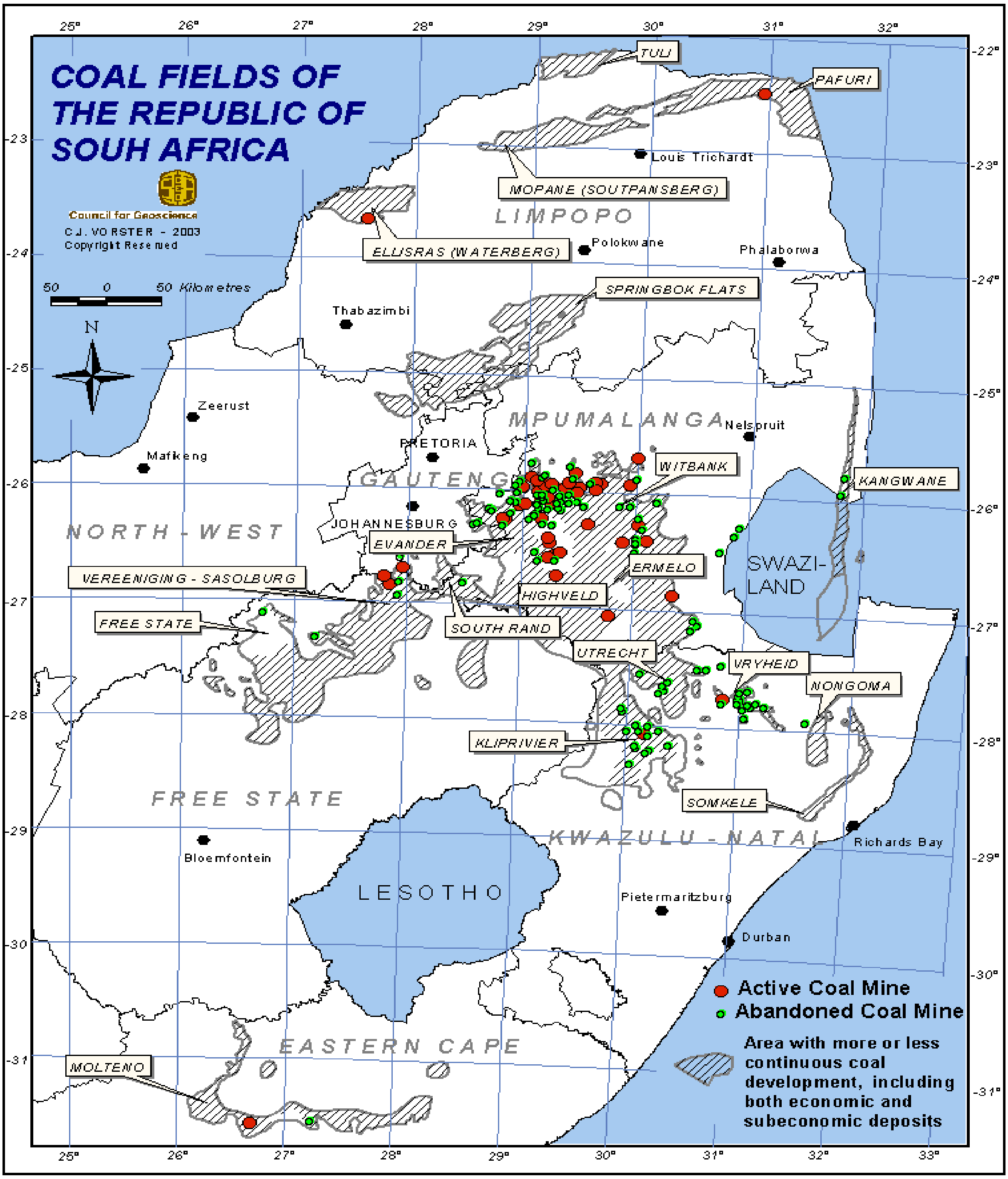
This demonstrated contribution of coal mining and use to South Africa's economy militates against calls to abandon the use of this abundant energy resource. Instead, it buttresses the need to build cleaner coal mining and power stations. However, the sustainability of the coal mining industry will depend not only on its ability to reduce its carbon footprint but also, and perhaps to a greater extent, on its ability to adapt to and exploit the adverse (and positive) impacts of climate change. Solutions to this challenge are not simple because climate change impacts are localized and thus tend to vary based on the characteristics and profile of the location of a mine. This implicitly means that coal mines have to develop and implement location specific climate change adaptation policies and implementation strategies. These strategies can only be developed and implemented if climate change impacts are acknowledged, studied, quantified and understood. While it is understood that climate change will affect all areas of the coal mining value chain, this study's focus is restricted to the policy and physical impacts of climate change of the coal mining value chain. Against a background of the current and possible future dominance of coal in South Africa's energy mix, reducing the adverse impacts of climate change on the coal mining sector is critical. As such, an understanding of the current and future climate change impacts and an understanding of the policies and strategies that inform climate change adaptation practices is likely to contribute to a South Africa which has a reliable and adequate (electricity) energy supply. Such a scenario is critical to the country's efforts of seeking to address economic, social as well as environmental challenges.

1.4 SELECTED STUDY AREAS

South Africa's coal deposits are largely concentrated in the Karoo Supergroup, which is a thick sequence of sandy rocks (South African Coal Road Map, 2011). Although rocks of the Ecca Subgroup are widespread around the country, conditions suitable for the formation of coal did not occur everywhere. As such the country's coal deposits are fairly restricted, occurring in the main Karoo basin in an arc from Welkom in the Free State province to Nongoma in the KwaZulu-Natal Province, and in several smaller outlying remnants of the Karoo Supergroup Sea (McCarthy and Pretorius, 2009).

This study will focus on the Highveld (Mpumalanga) Sasolburg (Vereeniging) and Vryheid (Kwa Zulu-Natal). These coalfields contain an estimated 90% of South Africa's recoverable coal reserves (McCarthy and Pretorius, 2009). Figure 1.2 shows that South Africa's coal fields are mostly located in the Mpumalanga Province, in the towns of Ermelo, Witbank and Evander. Some coal is in the Limpopo Province, in the Waterberg area, while some deposits are found in the Vereeniging/Free State Province in the Sasolburg area. Kwazulu-Natal coalfields are based in the Vryheid and Kliprivier area.

Figure 1.2 South African coal fields



Source: Council for Geosciences, 2016

1.4.2 Highveld Coalfield

The Highveld Coalfield is located in the Witbank town of south-eastern Mpumalanga. The width of the coalfield is +- 95km, stretching from Nigel in the west to Davel in the east which is 90km from other coal rich towns of Kriel and Standerton. The Highveld Coalfield is the second largest producing coalfield in South Africa after the Witbank coalfields. The coalfield hosts to up to five coal seams within the middle Ecca Group sediments of the Karoo Supergroup. The Karoo Supergroup comprises sediments ascribed to deposition in glacial to fluvio-glacial, and from shallow marine to fluvio-deltaic environments. The depth of the coal seams increases in a southerly direction. For example, the No.4 Seam can be mined by opencast in the Kriel (northern) district, while it occurs at a depth of around 200m in the Standerton (southern) district. The coal seams are generally flat-lying to gently undulating with a slight regional dip to the south (Forbes Coal, 2013).

1.4.5 Sasolburg-Vereeniging Coalfield

The Sasolburg-Vereeniging- Coalfield is mainly characterized by mudstone and sandstone of the overlying Beaufort Group (Adelaide Subgroup). These are underlain by the Volksrust formation of the Permian Ecca Group, a formation with a thickness of approximately 100m in the Heilbronn area. It consists mostly of argillaceous rocks which are found on the surface. The Volksrust Formation consists predominantly of grey to black silty shale, whereas thin siltstone and sandstone lenses/beds, that are frequently bioturbated, generally occur near the upper and lower boundaries of the succession (South African Chamber of Mines, 2011).

1.4.6 Vryheid Coalfield

The Vryheid Coalfield is based in the Kwa Zulu-Natal Province and lies to the east of the Utrecht Coalfield and covers an area of approximately 2,500km. This coalfield has produced some of the best coking coal, anthracite and thermal coal over a number of years (South African Chamber of Mines 2011). The Dwyka Formation covers most of the area lying on the Pre-Karoo sediments. It is composed of diamictites and associated fluvio-glacial sandstones and black shales. It averages 150m in thickness, but is thicker in Pre-Karoo glacial valleys and thinner or absent over Pre-Karoo highs. Nine coal seams have been identified within the main coal zone of the Vryheid Coalfield and several of these have been mined over the last century.

1.5 THESIS OUTLINE

Chapter One:

This chapter provides the background and introduction to the study. The main sections covered include: the research problem, the questions, the objectives, justification for the study and study site locations.

Chapter Two:

Chapter Two interrogates climate change and climate change adaptation as a theoretical concept. In addition the chapter interrogates literature related to South African coal mining in the context of climate change impacts and adaptation opportunities. This is done through the use of a general adaptation framework and a general mining coal mining value chain.

Chapter Three:

Presents the methodologies and outlines the process and the theoretical principles that informed the research approach, the data gathering approach, the data analysis, approach, challenges and limitations of the selected research approach. The chapter further discusses all the necessary ethical issues considered for this study.

Chapter Four:

Presents results, analysis, discussion and findings at Kriel Colliery, New Denmark Coal Mine and Mine X based in Mpumalanga. The chapter analyses climate change vulnerability and exposure that is inherent to the locations of these mines, mine designs as well as their adaptation plans and shortcomings.

Chapter Five:

This chapter presents analyses and discusses the research findings focusing on the vulnerability and exposure of Anglo American’s New Vaal open cast and underground coal mines which are located in the Free State.

Chapter Six:

This chapter presents analyses and discusses the research findings on climate change vulnerability and management with a specific focus on adaptation policies and practices at the Spring Lake coal mine located in the town of Dundee in KwaZulu-Natal.

Chapter Seven:

The chapter provides a summary of major findings, conclusions and suggestions for further research affecting all five mines in the three provinces. Based on the mines' exposure and vulnerability to climate change impacts, the chapter provides an adaptation framework using the coal mining value chain that highlights the key adaptation interventions undertaken, and further identifies areas in the mining value chain where adaptation actions are absent. This leads to a conclusion on the state of South African coal mining vulnerability and exposure to climate change, and their state of readiness with regard to climate change adaptation. In addition, suggestions for further research are provided.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents the theoretical literature that informed the research. The chapter is divided into three sections. The first section presents theoretical discussions on the phenomenon of Climate Change, paying attention to rainfall and temperature variations and extremes that are induced by Climate Change and their impact on different aspects of societal activities. The second section provides generic Climate Change Adaptation literature in the mining sector. The last section pays specific attention to Climate Change Adaption in the coal mining value chain and draws on literature from international and local coal mines as a basis for analysis of both Climate Change Impacts and Adaptation opportunities.

2.2 CLIMATE CHANGE

"The only constant in life is change" - Heraclitus (c. 500 BCE). These words ring very true in many respects including the context of climate. The saying implies that nothing is ever static, and in the context of Climate Change, there is no disputing that the climate has been changing since long before human existence on earth (Chiotti and Lavender, 2008; Auld and MacIver, 2006). However, it is the rate at which it is changing, the nature of the change, and the role of human (anthropogenic) activity on earth that has become a global problem. In fact, Climate Change and its impact on human life has arguably become one of the 21st century's thematic discourses among other global issues (Cooper *et al*, 2008). Within this discourse is an effort by different organisations to define the Climate Change phenomenon.

The Intergovernmental Panel on Climate Change (IPCC, 2012) defines Climate Change as "a change in the state of the climate that can be identified (e.g., using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer" (IPCC, 2012:3). The report attributes Climate Change to internal natural processes or external forces, or to persistent anthropogenic effects to changes in the gaseous composition of the atmosphere or in land use. This definition differs slightly from that of the United Nations Framework Convention on Climate Change (UNFCCC, 2001) which defines Climate Change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over a comparable time period" (UNFCCC, 2001: 18). The UNFCCC makes a distinction between Climate Change and Climate Variability.

Given the interchangeable manner in which the concepts of Climate Change and Climate Variability are used in these definitions, it is important to clarify the difference between the two concepts. Climate Change is attributable to human activity, and how it alters the atmospheric composition, while Climate Variability is attributable to natural causes (IPCCC, 2011). In this section, the two terms will be used interchangeably to differentiate among the different causes of climate impacts.

The phenomenon of Climate Change can be perceived in the context of planetary change from which all that lives on it must either adapt or become extinct (Climate and Development Knowledge Network 2012). However, for human beings, acknowledgement and acceptance of change - whether it is a family that has to move from one town to another, or a job candidate who has to move to a different company branch, - has always been difficult. Brug *et al*, (2005) states that it is human nature to resist change, and eventually people adjust to change, not by learning to like what is taking place, but by forming new expectations that can lead to success under the new conditions. The process of learning to live with new conditions involves three steps: (i) Mental - to figure out what is happening and how to respond. (ii) Emotional - to deal with various feelings like loss, anxiety, threat, relief, joy, optimism, etc. (iii) Physical - to accommodate the bodily implications of stress, excitement, etc.

When it comes to Climate Change and organisational adaptation, individuals form corporations. Although corporations appear to have a life of their own, they are governed and led by a collective of individual's mental tolerance for change, and this ability to adapt plays a role in how the organisation ultimately tolerates change and whether it adapts or not. As such, the individual's capacity to accommodate change, and the tolerance for adaptation, will influence the overall organisational culture in this regard. In the context of Climate Change, this means that depending on the leadership's philosophy and perceptions of the Climate Change phenomenon, the leadership may proactively develop Climate Change Adaptation Policies, backed by planning and financial budgets based on scientific analysis of the organisation's vulnerability and exposure assessments (Berkhout *et al*, 2006). However, it is common that regardless of whether leadership sees Climate Change as a reality and a threat to their organisations, they often develop Climate Change management policies and strategies due to stakeholder and investor pressure. In this case adaptation actions are often reactionary if they are ever carried through.

Often, change evokes emotion. Humans are creatures of habit. If something suddenly changes and they are forced to adapt, often people resist, preferring "business as usual" and desiring the comfort of familiarity. Climate Change provokes similar if not worse emotions. On January 2nd 2016, a 34-year-old farmer in the KwaZulu-Natal Province of South Africa committed suicide due to a lack of rain that has resulted in drought in the province. Unable to deal with the loss of this livelihood and overcome by emotions, he decided to take his own life (Chabalala, 2016). The actual physical impact of Climate Change is the one that gives Governments and sectors such as agriculture and mining no choice but to adapt or perish. Some of Climate Change physical impacts include flooding and drought, severe heatwaves, extreme cold, storms, extensive mist and smog (Ford and Pearce, 2007; McGeehin & Mirabelli, 2001). These impacts affect human economic activities such as agriculture which may affect food supply and increase costs. As such, Climate Change presents risks to humans' pursuit of improved social and economic well-being (Prowse, *et al*, 2009).

2.2.1 Climate Change vulnerability, exposure and impacts

Vulnerability to Climate Impact refers to the degree to which a natural or social system is susceptible, and its inability to cope with the adverse effects of Climate Change (IPCC, 2007). The purpose of assessing vulnerability is to identify the nature and extent to which Climate Change may harm a sector. In principle, this assessment enables the designing and implementation of measures and policies that can help reduce climate impacts. Although the concept of vulnerability and exposure are mistakenly used as if they mean the same thing, in principle and in practice, they are different. "Exposure" refers to the inventory of elements in an area in which hazardous events may occur (Cardona *et al,* 2012). As such, it is possible for a mine to be exposed to flooding due to its location, i.e. next to a river but not vulnerable if it has sufficient flood defence mechanisms in place.

However, to be vulnerable to an extreme event, it is necessary to also be exposed. The IPCC (2007), states that the character and severity of Climate Change Impacts are not solely dependent on the extremity of a weather event. Instead, they are also determined by the level of exposure and vulnerability of infrastructure and the surrounding ecosystem (Fussel, 2007). Reducing the intensity and severity of exposure and vulnerability depends on the availability of appropriate and effective specific and well-defined response strategies (Furgal and Prowse, 2008). Effective response strategies require well defined indicators that can detect statistically significant changes in the climate.

The well-known indicators of Climate Change are rainfall and temperature changes. Typically, the changes are observed through decades of historical precipitation and temperature data (Hulme *et al*, 2001). In South Africa, Hulme *et al*, (2001) note that although there is uncertainty with regard to future Climate Change scenarios - especially at regional level - national projections show that rainfall is likely to be on the decrease. However, extreme rainfall events will be realised in certain parts of the country - especially in the coastal areas. Similarly, global and national temperatures are projected to rise. Globally, the past 100 years have seen increases in global temperatures of approximately 0.6 °C - which is the highest increase ever recorded. The 1990s were recorded as the warmest decade, with 1998 standing out as the warmest year since instrumentational records began (Houghton *et al*, 2001). The Third IPCC report predicts that global average surface temperature will increase further by 1.4–5.8 °C by 2100.

2.2.2 Climate change and rainfall variability

One of the major impacts of Climate Change is the extreme decline of rainfall in some regions - causing drought - while there could be an extreme increase of rainfall in other regions of the same country, which in turn causes flooding (Bernard, *et al,* 2001). In south eastern Australia, Murphy and Timbal (2008) noted that there had been 10 years of below-average rainfall from 1997 to 2006. A similar dry spell was recorded only once during the 20th century. The authors note that the current drought conditions are exacerbated by increasing temperatures. The declines are mostly (61%) between the months of March and May (Murphy and Timbal, 2008). In other parts of the world, the US Department of Energy (2014) investigated the impacts of Climate Change on the US energy sector and found that increased frequencies of Climate Change-induced droughts are causing water shortages that have resulted in frequent power plant disruptions, the closure of coal mines, natural gas and nuclear power plants. Climate Change-induced severe storms have also caused disruptions in fuel supply.

2.2.3 Drought impacts

Certain parts of South Africa - including those that are subject to this study in KwaZulu-Natal and the Free State Province - have been hit by drought. The South African Weather Service (2015) stated that South African rainfall has one of the highest variabilities in the world. Furthermore, since 1960 rainfall variation has been fluctuating more than the long-term average, and it is in this context that large rainfall deficits must be assessed. Between July of 1960 and June of 2004, rainfall for all seasons was less than 80% of normal average (South African Weather Service, 2015). The South African Weather Service considers that a 25% and 50% deviation from the normal rainfall pattern signals severe and extreme meteorological changes, however it can be safely assumed that a shortfall of 20% from the normal rainfall pattern will cause water shortages in many regions. This is typically followed by social and economic hardship (South African Weather Service, 2015).

All but the south-western and southern regions of South Africa rely on summer rainfall, which normally occurs between October and March, the summer season. The South African water supply relies heavily on direct rainfall. The Department of Water and Sanitation (2014) stated that currently 77% of South Africa's water comes from surface water rivers; 14% comes from water that returned from treatment plants, and nine percent comes from ground water. High dependency on surface water rivers leaves the country vulnerable to evapotranspiration and evaporation. Drought is not the only problem; flooding, mainly due to increased intensity of extreme rainfall also causes problems. Wilby and Keenan (2012) stated that flooding is the most common natural hazard and the third most damaging climate phenomenon globally after storms and earthquakes. Climate Change-induced flooding is characterized by frequent heavy precipitation, increased catchment wetness and sea level rise. Wilby and Keenan (2012) also note that human population growth and occupation of flood-exposed places, such as low lying areas, increase the risk of flooding.

Between the 1970s and 2000s - the proportion of the world's annual gross domestic product (GDP) that is exposed to tropical cyclones rose from 3.6% (US$525.7 billion) to 4.3 % (US$1.6 trillion). The economic loss rose fastest in high-income countries (UNISDR, 2011). The 2011 floods in Australia, China, Germany and the United States demonstrate that even high and middle-income countries struggle to cope with weather extremes (Wilby and Keenan 2012). While developed countries are equally exposed to flooding, developing countries are more vulnerable. This is mainly due to poor infrastructure (Douglas *et al*, 2016).

2.2.4 Flooding impacts

Developing countries like South Africa are more vulnerable to flooding due to poor infrastructure design or lack thereof. Douglas, *et al*, (2016) states that increased storm frequency and intensity related to Climate Change are exacerbated by local factors such as growing occupation of floodplains, increased runoff from hard surfaces, inadequate waste management and silted-up drainage. The author further distinguishes four types of flooding in the urban areas of developing countries: localized flooding due to inadequate drainage; flooding from small streams within built-up areas; flooding from major rivers; and coastal flooding. In South Africa specifically, the provinces that have been severely affected by flooding are KwaZulu-Natal and Gauteng.

In KZN, Roberts (2008) states that based on the analysis of Global Sea Level Observing System (GLOSS) data, a number of economic and tourist areas may be affected by sea-level rise. Infrastructure, together with coastal vegetation, may be damaged. In Gauteng, Dyson (2012) noted that extreme rains that often result in flooding take place over most of the province and last for days, resulting in widespread flooding and disruption of infrastructure and even loss of life. The author cites the January and February 1996 flooding as an example of events. However, heavy rainfall may also occur in isolated areas over the Gauteng Province from so-called "Mesoscale Weather Systems", resulting in flash flooding. In these instances, the heavy rainfall may be for a short duration (but intense), and is often associated with strong winds and hail (Viviers and Chapman, 2004; Ngubo *et al*, 2008). Rainfall variabilities, especially extreme rainfall – have the potential to affect mining operations negatively.

Storms, hurricanes and wildfires have caused physical damage to the electricity distribution systems by damaging power lines and transformers among other system infrastructure. Traditional flood design methods are increasingly supplemented or replaced by risk-oriented methods which are based on comprehensive risk analyses. Besides meteorological, hydrological and hydraulic investigations, such analyses require the estimation of flood impacts. These assessments mainly focus on direct economic losses such as damage related to property and related factors. Although the flood damage to a building is influenced by many factors, usually only inundation depth and building use are considered as damage-causing factors (Merz *et al*, 2004).

2.2.5 Climate change and temperatures variability

One climatic aspect that is indicative of Climate Change is extreme temperature variations (McGeehin, & Mirabelli, 2001). The global temperature has been unstable, and in areas such as the Himalayas in Asia, temperatures have been rising and gradually melting the glacier (Groisman, 2003). Results for Europe and North America shows that future heatwaves in these areas will become more intense, frequent and longer-lasting in the second half of the 21st century. Couture *et al*, (2003) state that present-day heatwaves over Europe and North America coincide with a specific atmospheric circulation pattern that is intensified by ongoing increases in greenhouse gases. The model also indicates that more severe heatwaves will be produced in those regions in the future (IPCC, 2007a). Even if the atmospheric concentrations of greenhouse gases were stabilized today, mean global temperatures would continue to raise due to the unrealized effect of past climate conditions, thus causing increases (Meehl *et al*, 2005). Future increases in greenhouse gas concentrations, from future emissions, will add to the committed warming, thus leading to even higher mean global temperatures. Extremes of climate are also likely to change in the future, as there is an increased risk of more intense, more frequent and longer-lasting heatwaves. This is due to the possibility of a warmer future climate which would result in extreme events such as the European heatwave of 2003, becoming more frequent (Meehl *et al*, 2007; Stott et al. 2004; Beniston and Diaz 2004).

2.2.6 Climate change-induced high temperatures

In South Africa, different places are experiencing different effects of Climate Change, and this trend is going to continue into the future (South African Weather Service, 2015). The recent droughts in South Africa have been attributed to the El Niño effects, Climate Change and global warming. An El Niño is a climate cycle in the Pacific Ocean with a global impact on weather patterns worldwide. The phenomenon is a natural one - however the presence of greenhouse gas emissions in the atmosphere worsens its intensity and duration (Leary *et al*, 2008). A given the current rate of carbon dioxide emissions into the atmosphere, and some unique features of South Africa's climate system, such as our location in the subtropics and the important role that high pressure systems play in controlling the system, temperatures in Southern Africa are likely to increase by at least 1.5 times the global average rate (Leary et al, 2008).

In South Africa, the provinces that were most affected by heatwaves in the last few years are Mpumalanga, Free State, Limpopo, Northern Cape and KwaZulu-Natal. The South African Weather Service, (2015) noted that the provinces, especially KwaZulu-Natal and Northern Cape, reached highs of 42 degrees Celsius. These levels can be fatal mainly for the elderly, children and mine workers if precautionary action is not taken. Kovats, and Kristie, (2006) also notes that additional to heatwaves affecting children and the elderly, crops are also affected. Luber, and McGeehin (2008) state that from 1999 to 2003, a total of 3,442 heat-related deaths were reported in the United States of America. The U.S. previously reported an annual average of of 688 deaths. Extreme heatwaves, such as those witnessed across Europe in 2003, can result in a significantly higher mortality rate. Furthermore, heatwaves are more fatal in areas that have bad air quality. These are typically urban areas with many vehicles and power stations. In South Africa, such areas would be Mpumalanga, KwaZulu-Natal and Gauteng Provinces. The extent of the effect of heatwaves depends on the adaptation plans that a city or sector has in place (Kovats, and Kristie, 2006). Heatwaves and dry conditions provide a fertile environment for veld fires, especially if seconded by heavy winds.

In KwaZulu-Natal, a combination of unusually strong winds and very dry conditions saw large areas of grazing and timber destroyed. Six people reportedly died. In Mpumalanga, four people died when fires destroyed 24,000 ha of pasture. This specific incident also resulted in damages amounting to more than R32 million (South African Weather Service, 2015). As a response to increasing veld fire breakouts in KwaZulu-Natal, the South African Department of Environmental Affairs established and funded "Working on Fire" – an organisation that employs young people mainly from previously disadvantaged backgrounds to focus on mitigating and fighting fire breakouts. They are tasked with focussing specifically on KwaZulu-Natal and other provinces if need be (Department of Environmental Affairs, 2013). In other parts of the country, Climate Change-induced effects are different. Comparatively, more research has been done about Climate Change and high temperatures and their consequences, such as drought and the resultant water scarcity.

2.2.7 Climate change-induced low temperatures

In Mpumalanga and the Free State for example, the most common problems are mist and smog. These are typically present and naturally expected in winter and on cold days in summer. However, extremely low temperatures result in extremely dense mist and smog that also becomes prolonged beyond expected dispersion time. Mist is defined by the South African Weather Service, (2012) as a cloud of tiny water droplets suspended in the atmosphere at, or near the earth's surface, that limits visibility. Visibility is typically restricted to few metres. In Mpumalanga, mainly on the N1 and N4 highways that lead in and out of Witbank, Kriel and Standerton, various vehicle accidents have been reported and the single largest cause of those accidents is poor visibility caused by mist. For mining companies, poor visibility means limited or no access to mining sites (Tamenti, 2007). This restricts mine employees and contractors from entering or leaving the mine. This can result in loss of operation time for the mine (Prono 2008; Ford and Pearce 2007). Smog has similar effects as mist when it comes to causing poor visibility.

Smog is a result of fog and smoke or other atmospheric pollutants. Smog-forming pollutants come from automobile exhausts, power plants and factories (Rosenfeld, *et al*, 1998). In urban areas, at least half of the smog precursors come from cars, buses, trucks and boats (McKee, 2006). With regard to mining in general and coal mining particularly, smog levels are higher and more dangerous in areas where the coal-fired power stations are present. A prime example of this is found in Mpumalanga and the Free State Province. The major problem with smog, aside from causing poor visibility, is its contribution to air pollution that affects nearby communities, plants and animals. Responding to Climate Change impacts requires two broad strategies which are Climate Change Mitigation and Climate Change Adaptation. Climate Change Adaptation, which is the focus of this study, will be defined and discussed in detail in the next section.

2.3 CLIMATE CHANGE ADAPTATION

Before an in-depth analysis of what Climate Change Adaptation pertains to, it is perhaps important to understand the difference between Climate Change Adaptation and Climate Change Mitigation. Grothmann and Patt (2004) state that one of the central differences between "adaptation" and "mitigation" as a response to climate change, is the scale at which the response might take place. As Adger (2006) notes, mitigation should take place on a global scale in order to be effective. Adaptation on the other hand, should take place on a number of scales, from local to global, addressing climate-related problems unique to that specific environment, while making use of capacities available to that group of factors (Adger, 2001). Mitigation can refer to using new technologies, renewable energies, and making older equipment more energy-efficient. It can also mean changing management practices or consumer behaviour. The United Nations (2012:1), states that adaptation refers to the adjustments in ecological, social or economic systems in response to actual or expected climatic stimuli and their effects or impacts.

Climate Change Adaptation - the focus of this research - is described by the United Nations (2012:3) as "the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities". In some cases, Climate Change Adaptation falls within the scope of Disaster Risk Management which traditionally responds to natural and human-induced disasters. Recently however, the focus has been on reducing exposure and vulnerability, and increasing resilience to the potentially adverse impacts of climate extremes. In natural systems, the process of adjustment to the actual climate and its effects may require human intervention. Climate Change poses varying degrees of impact on mining, depending on different factors such as the mine's exposure and vulnerability. In the context of mining, these events may pose different impacts on all of the sub-chains of the mining value chain (United Nations 2012). For example, mines may require increased cooling in the case of underground mining, due to extensive and prolonged heatwaves (McGeehin and Mirabelli, 2001; Bernard, *et al*, 2001). Extremely high rainfall may cause flooding, while extremely low rainfall may result in drought and water shortages.

From the above definitions and identified potential impacts, one may conclude that adaptation includes: using scarce water and other natural resources more efficiently; adapting building codes to future climate conditions and extreme weather events; building flood defences and raising the levels of dykes to avoid flooding and using climate resilient material. All these efforts, if implemented correctly, should result in Climate Change-resilient mines. According to the United Nations Framework Convention on Climate Change (2011), Climate Change Adaptation practices can be separated into four components: (i) Climate Observation, Projection and Forecasting. (ii) Assessment of Climate Impacts and Vulnerability. (iii) Planning and Implementation. (iv) Monitoring and Evaluation of Adaptation Actions. These components are discussed in detail in the following subsections.

2.3.1 Climate observation, projection and forecasting for anticipatory adaptation

Climate Observation involves gathering of climatic data from oceans, the atmosphere and land, using a variety of techniques and technologies that include remote sensing, atmospheric observation, and land-based observations over a long period (Berry *et al*, 2006 and Auld *et al*, 2006). This data is stored and analysed over periods that extend up to and over 10 years (Lube and McGeehin, 2008). Data analysis involves trend and pattern analysis, which are used for climate modelling and the development of possible/likely future climate scenarios. These projections enable anticipatory adaptation practices. However, anticipatory adaptation is often riddled with uncertainty (Lube and McGeehin, 2008). The degree of uncertainty is determined by the quality input data used to make future projections. Consequently, the reliability of data is arguably the foundation of appropriate and effective anticipatory adaptation action.

Planning to adapt to Climate Change demands researchers, policy makers and practitioners to determine what the adaptation actions will pertain to (United Nations Framework Convention on Climate Change 2011). Decision-makers require reliable information, explained in the context and language of their business. This then requires the researcher to acquire reliable data that he can turn into useful information that can enable the preparation of appropriate adaptation policies and strategies (Leary *et al,* 2008 and Lemmen, 2008). An additional challenge is the source and the means to gather appropriate and relevant data. For policy makers to implement adaptation planning, the relevant data has to be presented in a manner which the policymakers can interpret and understand in order to devise appropriate and effective responses (IPCC, 2007).

In response to the poor quality of climate data and projections, there has recently been increased development of global and regional climate information centres and research institutes. Prominent centres and institutes include the National Meteorological and Hydrological Services (NMHSs) based in Geneva, Switzerland, the Climate Service Partnership (CSP), based in New York, USA, and the Global Framework for Climate Services (GFCS) which is a UN-led organisation aimed at developing climate information services (Lube *et al,* 2008). South Africa has the University of Cape Town's Climate Information Portal, which gathers and presents simplified historic, current and future climate projection data and analysis from different weather stations throughout the country. Technological advances and related process innovations have led to the developments that have seen the gathering of more accurate data, which in turn has given rise to more accurate climate models leading to improved climate change scenario planning (Lube *et al*, 2008).

In the absence of these technological advances in climate projections, traditionally, humans have been able to predict changing seasons using bio-indicators such as migration patterns or mating seasons of animals or blossoming periods of specific plants (Lobell *et al*, 2008). This knowledge has allowed humans to adapt effectively to changing seasons and weather. However, due to anthropogenically-induced Climate Change, this knowledge is no longer sufficient as the climate is changing more sporadically, with uncharacteristic variations rendering the traditional observations less effective (Lobell *et al,* 2008). Lately, there has been the development of climate projection and forecasting models, also known as Global Climate Models (GCM), that are aimed at customising climate information and targeting it to specific users based on their practices and information needs (weADAPT, 2011).

Global Climate Models also simulate future climate and attribute observed Climate Change to anthropogenic emissions of greenhouse gases (Lube *et al,* 2008). Such models include the

Atmospheric General Circulation Models (AGCMs) and Ocean General Circulation Model (OGCM) that simulate the circulation of the oceans. The challenges that are inherent in the GCMs are their accuracy, reliability and the uncertainty of their futuristic projections. Different models often produce different results, although there are often clear trends and matching patterns. For example, all models project a warming of the climate in nearly all parts of the world (Preston, 2011). It is important to note that although climate models can provide seasonal and decadal climate probabilistic assessments of specific weather events and climate conditions over a period of time, however they cannot forecast weather events or conditions for a specific day, month or year (weADAPT, 2011). Irrespective of which models are used to observe historic data or project future climatic trends, decision-makers want to know with a fair level of certainty of possible climate impacts on operations, their intensity and longevity. As such, climate impact vulnerability assessments become a critical aspect of Climate Change adaptation strategies.

2.3.2 Assessment of climate impacts and vulnerability

Impact assessment involves understanding the entire social and scientific objective, evaluating and analysing data, and turning it into information that is designed to meet user needs and to support decision-making (Paavola, 2008). Assessment of climate impacts and vulnerability requires scientific knowledge which provides credible answers to policy-relevant questions. Climate Change vulnerability assessment is critical, and especially needed at company level, because it is through understanding and the anticipation of the adverse impacts of Climate Change that a firm can prepare appropriate and adequate adaptation strategies and plans (Sauchyn and Kulshthreshtha, 2008). As such, vulnerability assessment provides information that defines adaptation and also informs the mode of adaptation (Fussel and Klein, 2006). There are three types of vulnerability assessment approaches: top down approach, bottom up approach and an integrated approach (United Nations Framework on Climate Change, 2012). The choice of approach is determined by the purposes of assessment which vary from social, economic and health, to environmental reasons. Table 2.1 presents a framework that can enable mining companies to assess their vulnerability to climate risks within their operations (ICMM, 2013).

Table 2.1: Vulnerability assessment framework for evaluating climate change policy and physical impacts

Impact areas	Impact evaluation	Business implication
Inputs	Description: What is the impact?	Financial: Higher operating expenditure or unplanned capital expenditure
Supply chains	Timeframe: When will the impact occur? Any action necessary?	Uncertain coal delivery to the energy sector
Markets	Time frame: When will it happen?	When is action necessary?
Exploration	Stakeholders: Who is impacted?	Is it financially viable to proceed to mine construction?
Construction	Primary/Secondary: Does the impact directly affect the activities or does it trigger other impacts?	Reputational: Increased risk of litigation, regulatory non-compliance, inability to operate
Operation	Primary/Secondary: Do the impacts directly affect activities or does it trigger other impacts?	Sustainability: Effect on capital expenditure and operational cost.
Closure and post closure	Likelihood: How certain is the impact? How much more often is it likely to occur?	Will the mining company be granted operating licences for future mining activities elsewhere in the future?

Source: Adapted from ICCM (2013)

The framework consists of three components which are relevant to the mining sector. The first component (Impact areas) identifies the most vulnerable components of the mining value chain. Furthermore, the framework was established using a general mining cycle, taking into account investor information, stakeholder considerations and environmental impact assessments. These specifically relate to Climate Change impacts on inputs to mining operations. These include energy and water supplies, the transportation of materials to and from the mine sites and end-user markets for mining outputs. The second component concerns impact evaluation. This involves assessing the possible impacts of changing climate in terms of who is affected, the time frame over which impacts are expected to occur; whether the impact could directly affect mining activities or are expected to trigger other secondary impacts, and the likelihood that the impact will occur (ICCM, 2013). The third component is concerned with the business implication. This relates to the financial consequences of Climate Change impacts on issues that include capital expenditure, operating costs, reputational costs from litigation, regulatory non-compliance and negative public perception that may come with climate change management (ICCM, 2013). This component also presents the possibility of positive spin-offs related to planning for Climate Change Adaptation, such as an opportunity to engage with host communities to achieve broader sustainable development agendas (ICCM, 2013).

Although the framework is not entirely new, it is informed by existing methods of assessing and reporting risks and opportunities in the mining and metals sector, it also draws its insights from the Carbon Disclosure Project (CDP). Within this project, mining companies report the location-specific Climate Change risks and opportunities, both in the policy and physical contexts. The importance of this framework in the context of this study is that coal mines can use it to identify the specific impacts on their operations, based on their locations and mine design. Vulnerability assessments enable private and public policymakers to plan appropriate and adequate responses. Effective responses require officially accepted and documented approval and commitment. This allows for effective adaptation planning and implementation (Fossil Fuel Foundation, 2013).

2.3.3 Planning and Implementation of adaptation

Planning involves the collection of useful information regarding how institutions are framing issues of adaptation, and the range of processes that are recognised as being part of adaptation responses. Planned adaptation to Climate Change would mitigate the risks and take advantage of climate change (Fussel, 2007). Depending on the specific issue under consideration, adaptation to Climate Change may have close links with natural resource management, water management, disaster preparedness, urban planning, sustainable development, poverty reduction etc. Efficient adaptation requires consideration of other factors that are important for current decisions. Some examples include current climatic risks, key non-climatic challenges and economic development plans (Adgar *et al*, 2006). In regions and sectors which face significant threats, it is particularly important to coordinate adaptation plans that take into account current and future climate risks, jointly (Fussel, 2007).

Implementation of adaptation plans typically start with the development of climate change management policies and making provision for funding as well as the transfer of technology to meet the specific needs and concerns of a mining company. Some adaptations are being triggered by Climate Change, and those adaptations are often purposeful and directed - as can be seen in the UK Government's creation of a UK Climate Impacts Programme and the widespread implementation of that programme (Adgar *et al*, 2006). Developing adaptation policies and implementing them are two different things. The former is easier and depends on the outlook of the organisation and its determination of its vulnerability. (Adgar *et al*, 2006). The latter will often be constrained and influenced by a higher-level adaptation framework as well as the institutions that define all aspects of activity in that organisation. Both dimensions of adaptation can be implemented in preparation for, or in response to, impacts generated by a changing climate.

" *Hence, adaptation is a continuous stream of activities, actions, decisions and attitudes that informs pronouncements on all aspects of life, and that reflects existing social norms and processes"* (Fussel, 2007).

It can therefore be difficult to separate Climate Change Adaptation decisions or actions from actions triggered by other social or economic events.

2.3.4 Monitoring and evaluation of adaptation actions

The development of Climate Change Adaptation frameworks has resulted in the inclusion of a monitoring and evaluation (M&E) component. This component consists of a system of measurements consisting of a unit and a scale that serve as a 'guide post' with built-in flexibility, rather than a rigid column and row evaluation sheet (Preston *et al*, 2011). The M&E frameworks capture overlaps between different domains of decision-making such as adaptation, development and disaster risk reduction (Preston *et al*, 2011; UNFCCC, 2011, International Institute for Environment and Development, 2011). Climate Change Adaptation efforts need to be monitored and their effectiveness need constant evaluation to assess whether they are meeting their intended outcomes, and whether resources are being used effectively and efficiently. As such, monitoring and evaluation (M&E) of Climate Change Adaptation is an ongoing process. The GIZ (2013), states that M&E can ensure accountability - which is a critical factor in Climate Finance. In addition, M&E provides a platform for project and programme management, thus help planners to assess what works, what does not and why.

Since Climate Change Adaptation is a relatively new practice in many industries, M&E can assist in identifying additional benefits brought about specifically by adaptation strategies from older, well-developed strategies such as Disaster Risk Management (GIZ 2013). Once adaptation plans have been implemented, it is important to answer whether adaptation did take place, whether vulnerabilities have been reduced, and whether adaptive capacity has been increased. As such, Monitoring and Evaluation in Climate Change Adaptation can be used for a variety of reasons - including assessing the effectiveness of an adaptation measure, or the implantation of an adaptation strategy (Stringer, *et al,* 2009). The purpose of M&E must be defined; indicators must be developed and decisions on how the results of adaptation strategies will be used; support for the further adaptation process must be made so that a proper approach and method for M&E can be undertaken (Schröter, *et al*. 2005).

Climate Change Adaptation M&E must address inherent Climate Change challenges that include uncertainty associated with climate projections and climate impacts particularly at local level. The success of Climate Change Adaptation is difficult to quantify, and often cannot be directly compared across different locations (Sauchyn and Kulshthreshtha, 2008). In addition, there is a lack of a universal metric which should be able to measure the reduction of Greenhouse Gas Emissions (GHG), or the reduction of impacts due to adaptation interventions. Another challenge that adaptation M&E should overcome is the separation of Climate Change Impacts and Non-Climatic Impacts. For example, the increased risk of bushfires in Mozambique is the result not only of aridity, but also of the spread of slash-and-burn clearing in response to population growth, and the decline in traditional governance of natural resources (Sauchyn and Kulshthreshtha, 2008). Adaptation success can only be predicted, sometimes far into the future, but requires urgent investment and planning. As such, it is difficult to build M&E into adaptation interventions whose effect and success cannot be immediately measured.

2.4 CLIMATE CHANGE ADAPTATION IN THE COAL MINING SECTOR

Although the Climate Change Projections have weaknesses, the impacts of Climate Change on mining are well documented. The South African Coal Road Map (2011) has noted some of the impacts of Climate Change such as increased temperature in the western, north-west and southern regions of the country. Although no well-defined trends on rainfall variability have been recorded, there is evidence of drying in the north-west, and wetting in the north-east (weADAPT, 2011). Furthermore, there have been significant increases in rainfall intensity and extreme rainfall over more than two-thirds of the country. All these pose direct physical impacts on mines.

Formal Climate Change Adaptation Practice in mining has only recently gained traction. Development of Climate Change Adaptation strategies to plan for and cope with current and expected impacts of Climate Change have been suggested to ensure the sustainability of a mine and safeguard the environment and community in which the mine operates (Pearce *et al* 2011). Linnenluecke, *et al*, (2013) note that studies on firm and industry's adaptation to Climate Change impacts are also beginning to emerge, although still sparse. In instances where firms seem to consider Climate Change Adaptation, they do so mainly for competitive purposes or due to pressure from changing political, economic and legal conditions. Often they disregard the dynamics of a changing environment (Dennis Consultants 2008; Brown Dart and Quesnel 2006). Nonetheless, firms, including those in the mining industry, are beginning to elevate the importance of Climate Change Adaptation.

The ICMM (2013) notes that although the mining and metal industry has vast experience in dealing with risk, Climate Change may pose unfamiliar risks that may be beyond the capacity of the current arsenal of experience within the industries. The South African Coal Road Map (2011), states that Climate Change Adaptation has been a significant aspect of coal mining since 2008. It categorises Climate Change Adaptation into two categories; the "resilient type", which addresses the potentially damaging effects of changing climate extremes, and the 'acclimation type', which addresses strategies to cope with gradual changes such as slow rates of warming and reduced water availability due to chronic droughts (The South African Coal Road Map, 2011). Climate Change Adaptation in mining is broadly driven by two major forces; Climate Change Policies and Legislation and bio-geo-physical impacts.

2.4.1 The impact of climate change policies on the coal mining industry

The international discourse on policies related to the coal industry addresses a number of issues. Among these is an acknowledgement that Climate Change is a critical issue for the coal mining sub-sector (Scales 2006; Pearce, *et al*, 2011). As a result, Climate Change Management is currently receiving increased attention. In the coal mining industry, Climate Change Management discussions are centred on achieving a balance between adequate coal supply for socioeconomic objectives, and the reduction of GHG emissions for environmental preservation. The discourse clearly shows bias towards mitigations and pays limited attention to Climate Change Adaptation as a critical component of Climate Change Management. Some of the Climate Change Mitigation policies include: the Renewable Energy Feed-in Tariff, The Energy Efficiency White Paper (2005), The 2.5c/kWh tax on electricity generated from non-renewable sources (SARS, 2008), Energy efficiency incentives in the Income Tax Act, The Clean Development Mechanism and the imminent Carbon Tax (Newman, *et al*, 2009).

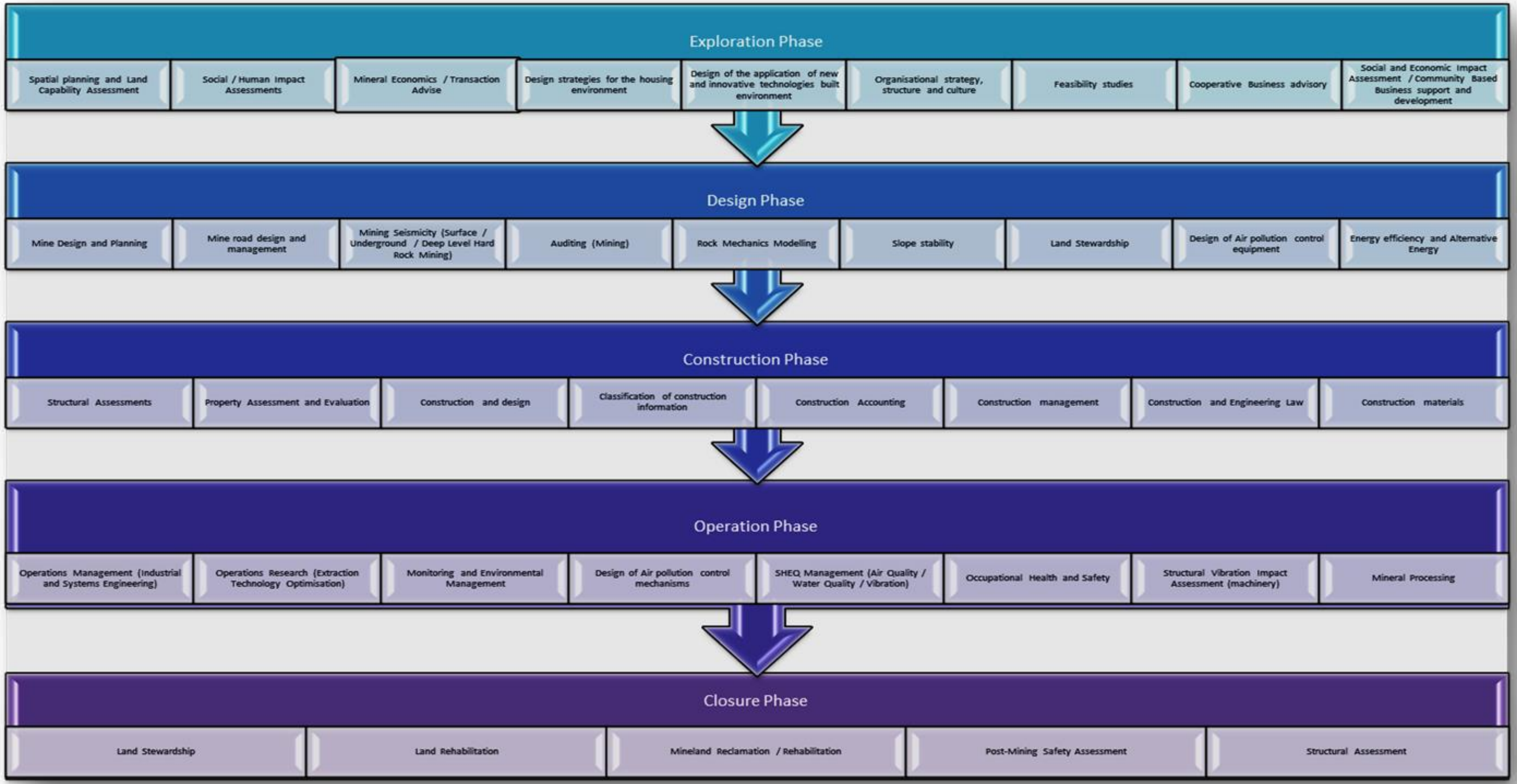
However, the Climate Change Adaptation agenda is also gaining momentum as Climate Change is already influencing investment patterns and the uncertainty relating to international climate policy is damaging for the industry Coal Industry Advisory Board (CIAB, 2009). This uncertainty is worse in sectors that are more prone to adverse Climate Change-induced impacts, and where there is no enforcement of Climate Change Adaptation policies (Coal Industry Advisory Board – CIAB, 2009). The Energy Information Administration's (EIA) scenarios for the coal market to the year 2035 suggest that government policies, particularly those related to Climate Change, are expected to play a critical role in shaping the global coal market in the future (World Energy Outlook, 2013).

The South Africa Road Map (2011) notes that the country's coal policy and regulations are limited to individual parts of the coal value chain, with no overarching policy or national strategy for the coal mining sector as a whole. This is because in the past, the South African Government has had a 'hands-off approach' toward the industry. However, the South African Government has since taken an active approach in the sector. Government involvement includes financial investments, thus any threat to the sector - including that which is posed by Climate Change - is a threat to that investment and the country's economic growth (Sebitosi & Pillay, 2008). While Government policy intervention in the coal sector is crucial, the actual development of a mine, along with the interpretation and implementation of Climate Change policy and strategies remain the responsibility of mining houses in general and their individual mines in particular (Berry *et al*, 2008). A key challenge in this regard is gaining insight into what are and/or will be Climate Change Adaptation-related measures in the industry. The value chain concept provides a framework for understanding how adaptation strategies can be framed and implemented in each of the industry's value chain sub-chains. A critical issue in this regard is to understand the activities in each sub-chain, so as to identify and possibly quantify potential risks based on mine site-specific data and dynamics.

2.4.2 Bio-geo-physical impacts of climate change on the coal mining value chain

The bio-geo-physical impacts of Climate Change on mining are characterised by uncertainties associated with unreliable data from scientific climate modelling technologies and methods (Groisman, 2003). For example, different models often produce different results on geographical profiling (Lube *et al*, 2008). However, having established the historical projected impacts of Climate Change in the mining sector, and having acknowledged that coal will be part of the South African energy source for the foreseeable future, it is important to understand the current and possible empirical cases of Climate Change Impacts in various stages of the coal mining value chain. Figure 2.1 is a simplified schematic representation of the coal mining value chain. The value chain comprises five sub-chains, namely: the exploration sub-chain, the mine design sub-chain, the mine construction sub-chain, the operation (production) sub-chain and the mine closure sub-chain (Mintek 2012). The sub-chains differ in the nature, level and intensity of vulnerability to the adverse impacts of Climate Change. Similarly, there is a difference in the nature of Climate Change Adaptation responses between the chains. The following sub-sections outline the activities and Climate Change risks in each sub-chain.

Figure 2.1 Coal mine value-chain



Source: Mintek technical-divisions, 2015

2.4.3 Exploration

The mine lifecycle begins with the search for financially viable and exploitable mineral reserves. Exploration is typically done through mapping and modelling, and also in the field through rock and soil sampling. Not all exploration efforts result in the development of an operational mine (ICMM, 2013). In fact, the majority of the exploration projects do not proceed beyond the exploration phase. One major problem which can result in discontinuation from mine exploration to mine design is the lack of water due to Climate Change-induced drought (El Idrysy and Connelly, 2012). However, mines tend to assess the underground water resources to see if they are sufficient to sustain mine operations.

Traditionally such assessment excluded historical data on local rainfall patterns. This is problematic because even if the current resources prove to be sufficient, without normal rainfall they may dry out before the end-of-mine lifespan, thus forcing early closure which may be costly and inconvenient for the mine employees. Furthermore, Climate Change will create both opportunities and threats to the mineral exploration business. One of the examples of opportunity is that the melting of Arctic ice will allow access to previously inaccessible exploration sites (The International Council on Mining and Metals [ICMM], 2013). However, the exploitation of mineral deposits in such a fragile environment presents environmental degradation risks because the environment there is delicate. Mining activities in such environments will require careful mine design features that will be able to take future climate risks into consideration.

2.4.4 Mine design and construction

If the data generated during the exploration phase indicates the presence of economically-viable mineral deposits, and the water resource is sufficient to sustain a mining project, the mine may design the mining activities and move on to the development phase. This phase involves studies that help mining companies. The design also determines the safety of the project, taking into consideration the environment and local population. At this stage, developers decide if the project is economically viable and socially responsible, while meeting or exceeding regulatory requirements. Mine design and construction includes the design and building of mining infrastructure. According to ICMM (2013), current Environmental Impact Assessments in mine design are conceived under the assumption that the climate is static, and tends to use historical observations of climatic and environmental conditions as a baseline. The advent of Climate Change dictates a paradigm shift in planning to consider current and future Climate Change Impacts. For example, basing mine site water balances on current or historic conditions might not be inadequate for future Climate Change-induced variations in water supplies, diversion ditches, water storage ponds, treatment facilities and other water management structures. As a result, engineering standards and guidelines now need to incorporate area-specific Climate Change Impact scenarios in developing the infrastructure that will directly and indirectly support the exploitation of the targeted mineral. Such designs will need to take into account possible flooding due to the frequency and intensity of extremely high rains. Based on these projections, levee dams may need to be raised above the normal standards.

2.4.5 Mine operation and processing

Once construction is complete and systems have been tested, mineral production begins. The production phases involve extracting the ore and processing and transporting the minerals. A coal mine extracts coal and associated products like methane gas from the ground. Coal is then processed into various products that include lignite, sub-bituminous and bituminous and anthracite. These products are then directly transported to downstream industries, or transformed through gasification or liquefaction before being transported. Downstream industries and plants process the intermediate coal products for the end users. The end-use may be in the form of steel and cement which are used in construction, electricity generation, fertilizers, petrochemical products, diesel, gasoline, liquefied petroleum gas and cooking briquettes (Daniel, 2013).

At the mine site, coal operations are dependent on a substantial amount of fixed assets and infrastructure, some of which are vulnerable to damage as a result of extreme weather events and environmental degradation, particularly through flooding, subsidence, erosion and storms. Climate extremes such as elevated temperatures may affect the efficiency of major equipment and cooling abilities of water treatment processes (ICMM, 2013). Some operations can be affected by changing precipitation patterns that result in landslides, soil erosion, changing ground water levels as well as permafrost instability. An example of such an occurrence is the 2010 floods in Australia. The floods limited access to coal mines, resulting in a rapid decline of coal export stocks at the port, leading to financial losses of about US$1 billion for the country’s coal industry (ICMM 2013). Reduced rainfall may result in water shortages which may pose water scarcity problems in mines which are located in areas already experiencing water shortage.

Furthermore, coal mining is highly reliant on water and energy; the two are interdependent as water is used for thermal and hydroelectricity generation (ICMM, 2013). As such, any interruption in water availability will have direct consequences on energy supply. The cumulative effect of these impacts may result in serious operational disruptions or complete shutdown of the mine. In coal mining, water is also used for cooling, crushing, grinding, slurry transportation, and tailing and storage. As such, Climate Change-induced drought will definitely affect water availability and mine production. In coastal areas, if sea levels rise simultaneously with the increased drawdown of wells, there is a possibility of saltwater intrusions, which may contaminate fresh water supplies.

2.4.6 Closure/post closure

Every mine has a finite lifespan. Environmental prudence dictates the need for environmental management during and post-mine operation periods. Often, such plans are developed and agreed upon by the mining companies, government and the community, before mining commences. This is meant to ensure that the land in and around mining sites is restored and/or remains fairly productive. Another reason is to ensure that the ecosystems in those lands are minimally disrupted during and after mining has ceased. Mining affects the environment in different ways that include catalysing the breakout of wildfires, and adverse impacts on soil and water quality. It is necessary to minimise the likelihood of such impacts by taking appropriate action. Reclamation and environmental protection efforts need to be consistent when closing operations. Measures must be taken to address environmental impacts related to a closed mine. These include flooding of unused shafts, planting of vegetation, and avoiding extensive soil erosion. In terms of water management, if Climate Change events contribute to the increased frequency and intensity of rains resulting in flooding, coal mines will need to ensure that their long-term closure plans incorporate additional water storage to contain excess precipitation and prevent pollutant-carrying run-offs from contaminating the environment (ICMM, 2013). These risks and possibilities need to be better understood and quantified for effective Climate Change Adaptation planning and implementation.

2.5 CONCLUSION

Based on the reviewed literature, there is sufficient scientific evidence to show that the climate is changing. This is seen by changes in rainfall and temperature variance, as well as the extremity of such events. These events have resulted in documented impacts on different aspects of society, including agriculture and mining. These impacts require countries, cities, industries and companies to respond. Although there is the realisation that Climate Change Response has largely been focusing on mitigation efforts both in terms of policy and practice, Climate Change Adaptation - the focus of this study - is still lagging behind in terms of policy, financing, and implementation in many sectors, including mining and the coal mining sector more specifically. This is besides documented evidence of infrastructure damage and disruption caused by Climate Change-induced events in different areas of the mining value chain.

A closer look at the coal mining value chain in the context of Climate Change Biophysical Impacts shows that mines need to develop a holistic but location-specific Climate Change Adaptation framework that takes into consideration all the sub-chains in order to develop a climate-resilient sector. However, as the literature has revealed, uncertainty related to accuracy of climate data and the projection of future events makes it difficult for mining companies to invest and plan. Be that as it may, market pressures, as well as costs incurred by not proactively planning for adverse Climate Change Impacts, will result in mine closures and a shift towards less vulnerable energy sources.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 INTRODUCTION

The study sought to assess South Africa's coal mining sector response to Climate Change Adaptation demands. This was achieved by identifying current and future Climate Change Impacts on selected South African coal mines, and by establishing the extent and nature of Climate Change Adaptation readiness in those coal mines. To achieve these goals, the following objectives were set out: (i) to identify current and possible future Climate Change Impacts that may affect selected coal mines in South Africa. (ii) To establish the nature and extent to which the selected coal mines in South Africa are ready to address and implement adaptation measures. (iii) To determine and document existing Climate Change Adaptation practices in selected coal mines in South Africa.

To address the above research objectives and goals, an appropriate mix of research methods was selected. These methods were suitable to gather and analyse the quantitative data related to historical and current climate trends and patterns and the qualitative data that is related to climate observations and experiences by mine employees and local community members. Both these methods were aimed at establishing the biophysical impacts of Climate Change and the responses in the form of Climate Change Adaptation strategies being employed by the mines.

3.2 METHODOLOGY

This study adopted a mixed-method research strategy. Mixed-method research is formally defined as "the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study" (Johnson *et al,* 2005: 82). Mixed-method research makes use of the practical method and its logic of inquiry includes the use of identification of patterns, the testing of theories and hypotheses, and abduction (de Waal, 2001). Both qualitative and quantitative methods are crucial for this study to meet its objectives. This study is not aligned to this philosophical outlook only, given the complexity associated with its pluralistic nature. As such, a qualitative approach was considered as part of a useful method in conjunction with the quantitative method.

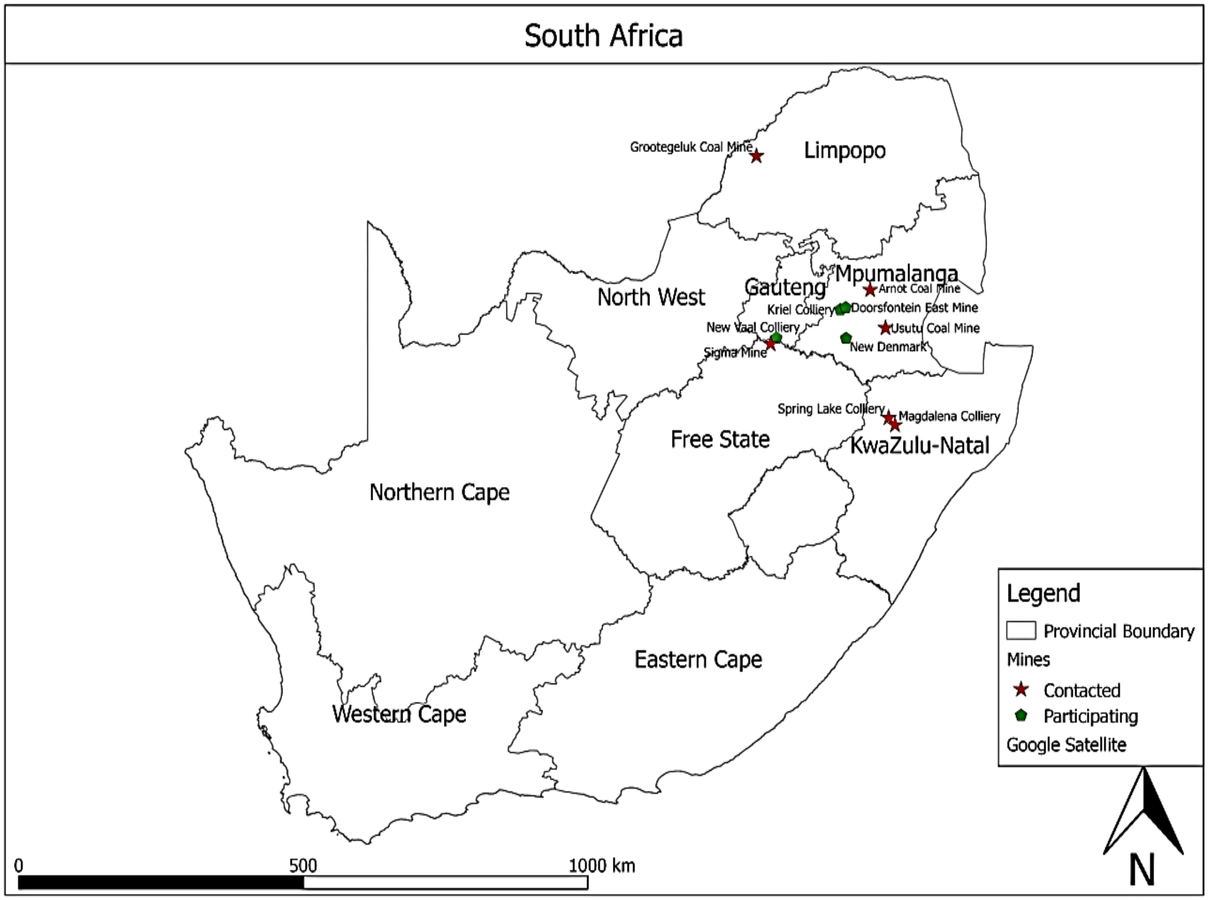
The debate on what causes Climate Change, what impact it can have in the social, environmental and economic context, and how humans respond should call for a combination of methods of enquiry that will take into account the scientific and social perspective. Perspectives, theories, philosophies, and observations must be drawn from both qualitative and quantitative methods for a balanced reflection. As such, the goal of mixed-methods research is not to replace either of these approaches but rather to draw from the strengths and minimize the weaknesses of both in single research studies and across studies. Using only qualitative or quantitative methods would have risked exposing the study to the weaknesses inherent in both of the methods, and missing an opportunity to draw strength from each other. Mixed-methods research as the third research paradigm can also help bridge the divide between quantitative and qualitative research (Onwuegbuzie & Leech, 2004).

Since this study is multi-faceted, trying to understand meteorological patterns and their impacts on the mining business - which consequently affect the social and economic life of communities where these mines are located - the mixed-method approach allows for the use of multiple data collection methods. The mixed method also allows for the expression of different ideologies by different mining role players, as well as differing forms of data analysis. The mixed-method approach was carefully chosen and aligned with the research objectives and the questions posed to meet these objectives. For instance, data related to the perception and responses to Climate Change in coal mining could not be gathered and analysed using quantitative methods, as much as historic and current climate data could not be gathered only through qualitative methods. Only a mixture of these methods could address the study's objectives and research questions.

3.3 RESEARCH STRATEGY: MULTIPLE CASE STUDY APPROACH

As a research strategy, a multiple case study and historically-descriptive approach were used as research designs. A multiple case study design allowed for exploring the differences within and between each case, and for making comparisons so as to develop an encompassing understanding of the Climate Change demands in the South African coal mining sector. Figure 3.1 shows the multiple cases (coal mines) that participated in the study. These are marked in green point indicators, and the mines marked with red point indicators were asked to participate but declined for reasons that will be discussed in detail in the data presentation chapters.

Figure 3.1: Participating and non-participating coal mines



Source: Author, 2016

The advantage of using multiple cases for this study is that each case provided unique data, rich in context. As a result, the product of this research is an in-depth description of cases. As is typically the case with case study research, a mix of data collection tools was used. These included: questionnaires, key informants' interviews and field observations - which in this case included mine design - document analysis, and infrastructure design and adjustments. Details relating to the strengths and weaknesses of these tools and how each complements another will be discussed in detail in the following sections. However, a point worth noting is the difficulty of generalising the findings of each case to other coal mines, including those that did not form part of this study. Yin (2013) notes that findings of case studies are often context-specific and so in many instances may not be generalised. However, this study will assume a degree of generalisation based on provisions made by Greene and David (1984) - who argue that generalizing from a sample of cases can be justified only to the extent that relevant characteristics of the sample are representative of the same characteristics of the target population. Therefore, the way in which the cases are selected is critical to the ultimate utility of the multiple case study design approach.

Learning from the Greene and David (1984) argument, it is safe to argue that a degree of generalisation can be made in this study, precisely because all coal mines exist within limited coal fields in the country, with 70% of them situated in Mpumalanga as stated above. Mine designs are also limited to either open-cast or underground. Moreover, 90% of South African coal mines are owned by five major mining companies. This means that Climate Change policies, plans and actions can be traced and compared within these major players. Lastly, the climate does not vary much within the areas where the coal fields and mines are located, meaning exposure and vulnerability is similar, but the impacts intensity and response are different. This presents an opportunity to generalise the findings.

However, this study does not assume that all South African coal mines, based on selected mines, face the same issues and respond in the same manner to the Climate Change challenge. To this end, the research selected mines in all major South African coal fields that represent the majority of coal mines in the country, in order to examine their exposure and vulnerability to Climate Change, and thus to document their adaptation plans and actions. From these mines, Climate Change demands and adaptation preparedness in South African coal mines generally, could be better understood and improved. According to Greene and David (1984), the four main features of a multiple case study design are: (a) a conceptual framework which provides the superordinate structure, (b) a sampling plan that ensures representativeness of the target population in the case samples, (c) procedures for the conduct of individual case studies that ensure sufficient comparability across cases, and (d) a cross-site analysis strategy that tests the limiting conditions of the findings. The goal was to replicate findings across cases, so as to understand the different and common Climate Change impacts in each case and to record and understand adaptation strategies (if any) in each case as well as compare these to other cases. This would give an indication of the effectiveness of each adaptation action, and thus broader adaptation readiness within the South African coal mining sector.

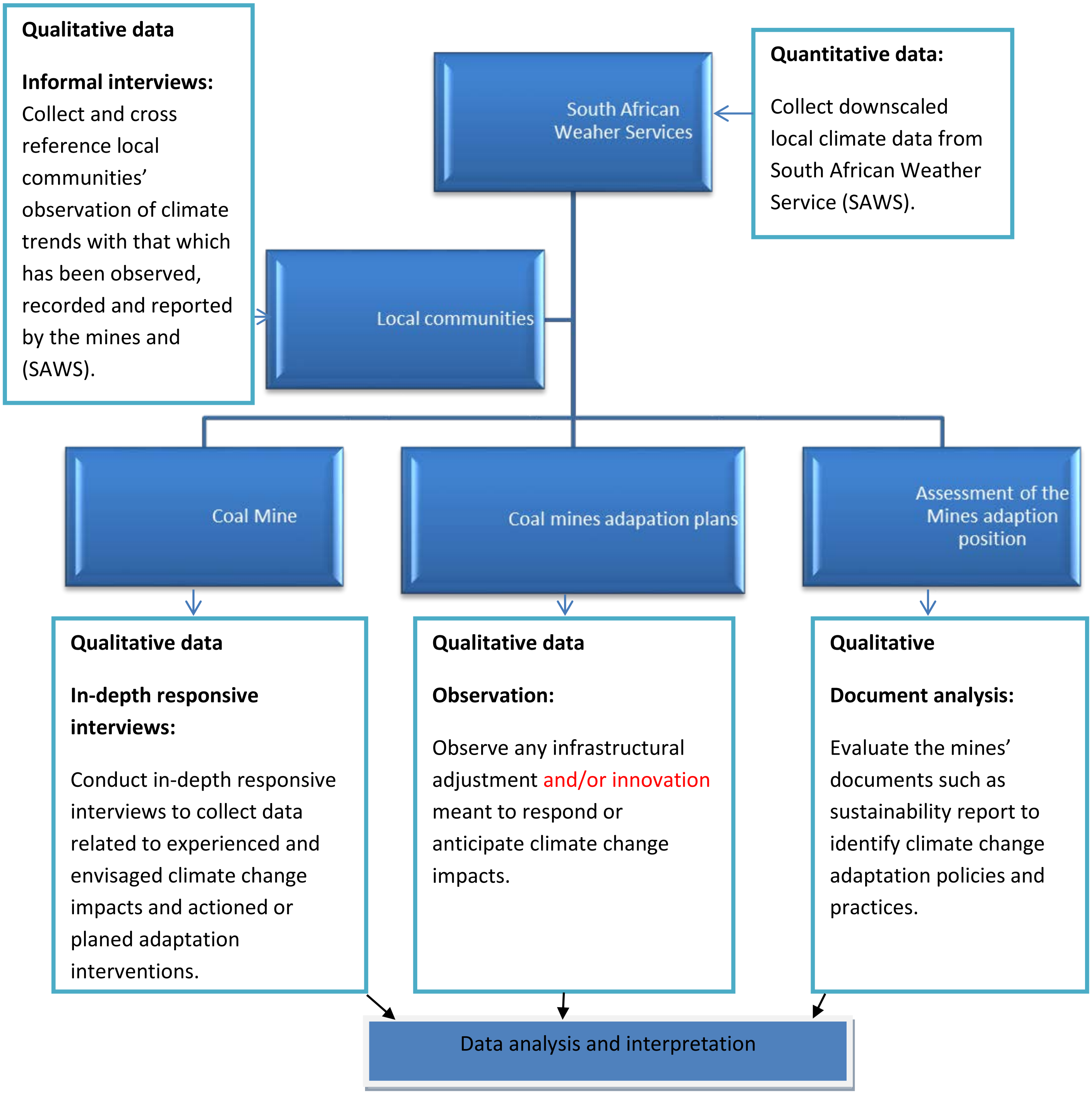
3.3.1 The conceptual framework

According to Greene and David (1984), the purpose of the conceptual framework is to structure data collection in a way that provides comparability across cases. The search for site-specific explanations is not overly constrained, as having some idea of what one is looking for is an important part of preparing for any kind of case study work (Smith, 1978). In a multiple case study design however, there is an even greater need for the definition of boundaries and focus prior to data collection. This is due to the need for comparability across cases, hence the conceptual framework must be relatively elaborate and explicit (Gartner, 1985).

Quantitative data from the South African Weather Service was critical in this study. The South African Weather Service provided available data for the four selected provinces where major coal fields and mine operations are based. For the purpose of this study, maximum and minimum temperatures, and precipitation, mainly annual, monthly and seasonal rainfall data was sought and provided. The data was tabulated on Excel spreadsheets. The received data had to be rearranged and coded according to the specific needs of the research. The major challenge with the data was that in some instances, such as in the town of Kriel in Mpumalanga, some data, i.e. temperature data was not available because the concerned weather station was not recording this.

Furthermore, in some cases, the data sets had gaps with no records on some days either because of technological problems or human error. In such cases, if the gaps for the specific month(s) were significant (more than two weeks), that month was excluded from the data set gathered for analysis. If the gaps were not that significant (less than two weeks), the gap(s) were filled in with an average value, taking into consideration previous and post two months' data sets. Lastly, in the case of Standerton, rainfall data was available up to 2006; thereafter that particular station did not keep rainfall records. In the data analysis sections, it is argued that poor data quality compromises the understanding of Climate Change and Adaptation Planning. Figure 3.2 provides a graphic presentation of the research methods and design.

Figure 3.2 Data collection process



Source: Author, 2015

Qualitative data was collected through structured interviews with mine environmental officers, engineers and mine managers as well as members of the surrounding communities. Rubin and Rubin (2011) note that a structured interview approaches a problem in its natural setting, explores related and contradictory themes and concepts, and points out the missing and the subtle, as well as the explicit and the obvious. Qualitative research is especially effective in describing how and why things change, and how people and systems respond to the change. According to Vanderstoep and Johnston (2009), qualitative research produces a narrative and textual in-depth description of the study at hand. This approach is appropriate for this research because the study sought to provide an in-depth narrative of how Climate Change may/is affect (ing) South African coal mines, how they perceive Climate Change, and what they are doing or not doing about it. It was also imperative to interview Climate Change experts who had insights into mining, specifically into coal mining, in the context of Climate Change Impacts and Adaptation. These were researchers in other universities and organisations with an interest in Climate Change and/or mining. The qualitative data was compared and augmented with quantitative data.

In addition, site observations were carried out in all participating coal mines. Observations largely focused on mining infrastructure, mine design and mining methods. Creswell (2009) states that, in field observations, the researcher takes field notes, often recorded in an unstructured or semi-structured way, using some prior questions that the enquirer wanted to know. Site Observation was a useful data-gathering method because it allowed for gathering data that the research informants may have been uncomfortable to discuss (Cresswell, 2009). Further information was collected via literature review and document analysis. As Babbie (2001) correctly points out, one has to enter the fieldwork with a good knowledge of the literature. This research was guided by existing Climate Change Adaptation theories and frameworks.

As such, these theories and frameworks guided the study in an exploratory way where collected data relating to Climate Change Impacts and Adaptation frameworks in each case, were compared and contrasted with developed and existing Climate Change vulnerability, exposure and adaptation models. These comparisons were aimed at measuring adaptation effectiveness across cases to identify common Climate Change Impacts and Adaptation strategies. From this understanding, generalisations regarding Climate Change Impacts in South African coal mining were made. The literature reviews in the previous chapter (Chapter Two) provided insights and background on the issue of Climate Change broadly from a policy and practice perspective within the mining sector. This background produced sufficient information from which to draft data gathering tools and relevant questions. As such, this chapter and the pilot study section in particular, were highly influenced by the reviewed literature. Document analysis refers to the analysis of any formal written material that contains information about the phenomenon being researched (Strydom and Venter, 2002). The reviewed documents are listed in Table 3.1.

Table 3.1 Reviewed documents

Document	Purpose
Environmental impact assessment reports	Data related to air, water, soil, socio-economic, impacts and how these may be affected by climate change while being in the care of the mine and how the mine intends to deal with the impact.
Environmental management programme reports	Data related to management of scarce natural resources such as water, especially in the context of a changing climate that either increase or decrease precipitation.
Cultural heritage impact assessment reports	Data related to the aspects of heritage and a community's way of life that may be impacted by the mine and exacerbated by climate change.
Specialist soils & land capability studies, impact and assessment and soil utilisation and management plan	Data related to management and utilisation of land and soil and how these may in turn affect mining operations when impacted by changing precipitation and temperature patterns.
Specialist Surface Water Report	Data related to increases and/or decreases in precipitation patterns and how they affect water availability and management at the mine.
Groundwater specialist report	Data related to the increases or decline in amounts and quality of groundwater for mining use and how these have been changing over time, based on current and historical observations.
Mines' sustainability reports	Data related to the mines' climate change policies and plans or lack of, as well as recorded climatic related incidents along the mines' mining value chain and how the mines dealt with these.
Carbon Disclosure project reports	Reported Climate impact incident and/or predictable incidents that the mine sees as threats to its operations.

Source: Author, 2015

It was necessary to search, retrieve and review documents such as mining firms' annual reports, sustainability reports, technical and financial reports and other related documents. In addition, publicly available documents were retrieved and analysed and any records that contained data relevant to this study. The documents were reviewed, and relevant information was used for this study. Because these documents were not compiled with the subject of this study in mind, it was crucial to use relevant keywords while searching for relevant information. Such keywords included: 'climate', 'weather', 'impacts', 'adaptation', 'exposure', 'vulnerability' ,'changes', 'flooding', 'drought', 'temperature', 'rain' and 'extremes'. These keywords located and revealed information that could be linked to climate-related concerns where applicable.

3.3.2 Historic-descriptive approach

Descriptive research involves gathering data that describes events and then organizes, tabulates, depicts and describes the data collection process. Since the human mind cannot extract the full import of a large mass of raw data, descriptive statistics are very important in reducing the data to manageable form (Glass & Hopkins, 1984). This often leads to the use of visual aids such as graphs and charts to assist the reader in understanding the data distribution. In this case, the data was coded on Excel and the Statistical Package for the Social Sciences (SPSS) and Geographic Information System (GIS) for graphic presentation and analysis (Greene and David, 1984). Data for this study comprised a number of variables that included minimum and maximum temperatures, annual, seasonal and monthly rainfall patterns that needed to be reconciled and meaning created from it. This included describing the mean, deviations from the mean, frequency of extremes, and correlation between variables. Descriptive studies are primarily concerned with finding out "what is," (Greene and David, 1984), in this case: the major questions that needed answering were "what are the impacts of Climate Change on South African coal mines?" and "how is the coal mine industry responding to these impacts?" Descriptive studies can yield rich data that lead to important recommendations.

3.3.3 Sampling

The goal of sampling is to obtain a set of cases which, taken together, contain a variation on key explanatory factors representative of their variation in the target population. The study used the purposeful sampling method to select mines that would best represent the South African coal mines' 'reality' in the context of Climate Change and Climate Change Adaptation. Strydom *et al* (2002) define target sampling as "a purposeful, systematic method by which controlled lists of specific populations within geographical districts are developed, and detailed plans are designed to recruit adequate numbers of cases within each of the targets". South Africa has over 79 coal mines in four provinces, namely: Mpumalanga, KwaZulu-Natal, Limpopo and the Free State (Global Energy Observatory, 2014). Most of these mines are owned by five major coal mining companies, namely: Exxaro, Sasol, Xtrata, Kumba and Anglo Coal. The study targeted coal mines in four provinces; in Mpumalanga (three mines), Kwa-Zulu Natal (two mines), Limpopo (1 mine), and the Free State (two mines). In the end, five mines informed the research.

The selection criteria for the mines within the same province included that the mines were at least 50 kilometres apart. This was an important criterion, given the fact that Climate Change Exposure and Vulnerability of coal mines is based on climate variability, which differs geographically. The IPCC (2011:3) provides a distinction between Climate Change Exposure and Vulnerability. Climate Change Exposure is "the presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected", while vulnerability is "the propensity or predisposition to be adversely affected". As such, each coal mine would be exposed to, and vulnerable to unique Climate Change Impacts based on its environment. In addition, mines belonging to the same mining company and located within the same province had to be a combination of open-cast and one-shaft mines. This selection criterion was motivated by the fact that coal mines are exposed and become vulnerable to Climate Change Impacts based on mine design and mining method. For example, an open-cast mine might be more vulnerable to flooding while an underground mine might be more vulnerable to persistent heatwaves. The study was able to review existing Climate Change risk assessments, possible impacts on the coal mining sub-chain, possible adaptation approaches, strategies, procedures, risk management, planning approaches, policy and practice, both at company and operational level in different mines. The mines that participated are shown in Table 3.2.

Table 3.2: Sampled mines

PROVINCE	MINING COMPANY AND/OPERATING	MINE	GEO-INFORMATION /LOCATION	MINE DESIGN AND MINING METHODS	Number of interviews conducted
Mpumalanga	Kriel Colliery	Anglo American (Pty) Ltd	Kriel, Mpumalanga Witbank	Open and underground mines	6
	New Denmark Colliery	Anglo American (Pty) Ltd	Standerton, Mpumalanga	Open cast mine	4
	Anonymous Mine	Anonymous company	Kriel, Mpumalanga	Open cast and Underground. Opencast strip mining by draglines, truck and shovel	2
KwaZulu-Natal	Spring Lake Holding Limited, Petmin	Shanduka Colliery (Pty) Ltd	Near Dundee, KwaZulu-Natal,	Underground and Opencast conventional board-and-pillar mining methods in its underground mine	3
Free State	New Vaal Colliery	Anglo American (Pty) Ltd	Banks of the Vaal River, Free State	Open cut mine. Strip mining by dragline	10

Source: Author, 2015

Using this sampling framework, mine managers, shaft managers, environmental managers and officers, and engineers at individual mine level were interviewed. Climate Change and mining experts from the Centre for Scientific and Industrial Research (CSIR), mine environmental experts from the South African Chamber of Mines, and the Department of Environmental

Affairs, engineering and technology specialists from CoalTech and geologists from Geotech, were interviewed.

3.4 PILOT STUDY

A pilot study was conducted with an open-cast and underground coal mine in the Free State and Mpumalanga, respectively. Bless and Higson-Smith (2000:155) defines a pilot study as “A small study conducted prior to a larger piece of research, to determine whether the methodology, sampling, instruments and analysis are adequate and appropriate.” The major objective of conducting the pilot study was to get pre-fieldwork involvement and creating an awareness of the complexity and dynamics of the research field. Even though no two field sites were the same, the pilot study provided a glimpse of what to expect in the main study. The second major purpose which that pilot study fulfilled was the opportunity to refine the wording on the questionnaires and interview guides.

It soon became apparent that certain words and phrases provoked and influenced different reactions from different respondents. Phrases such as “Climate Change”, “Global Warming” as were used in initial correspondence with coal mining stakeholders, were generally received with disdain, particularly by mine management. The use of such phrases was less understood by junior environmental officers. Engineers preferred to replace “Climate Change Impacts” with ‘Weather Variability Impacts” or “Weather Extremes Impacts”. In the earliest stage of this research while requesting permission to gain access into the mines, the use of words such as “Climate Change” and “Global Warming” in correspondence with mining managers resulted in a negative reaction. Access was consequently denied by many mining companies. The third benefit of the pilot study was that it assisted in reflecting and improving the research instrument layout, orientation and making sure that the instruments acquiring data would be valid, reliable, effective and free from problems and any technical errors. As such, the pilot study was a critical prerequisite for the successful execution of the main study.

Before entering the field, experts were interviewed in the discipline of Climate Change, with the focus on adaptation in mining - more specifically in coal mining. Valuable insights were gained from these interactions, especially with regard to Climate Change narratives and perspectives that are different and not biased to miners’ and environmentalists’ perspectives. As such, much more objective and balanced dialogue was achieved through interviewing independent expert respondents. Expert respondents also offered invaluable advice related to accessibility of the field and correct selection of respondents, and how they should be approached. Data from the pilot study was processed and analysed in the same manner in which data from the main study would be processed and analysed. This process further assisted in identifying and eliminating problems that would have been in the main study if a pilot study was not conducted.

3.5 DATA ANALYSIS AND INTERPRETATION

Quantitative (climate) data was received, coded and analysed on Excel and the Statistical Package for the Social Sciences (SPSS). Qualitative data collection and analysis was carried out simultaneously. Creswell (2009) and Strydom *et al*, (2002) argue that unlike traditional studies, qualitative study involves an inseparable relationship between data collection and data analysis because as data is gathered, it is automatically being analysed. Data analysis frequently necessitates revisions in data collection procedures and strategies. These revisions yield new data that are then subject to new analyses (Strydom *et al*, 2002). During the quantitative data analysis phase, climate patterns and trends were identified and explained in the context of long-term Climate Change. Furthermore, quantitative data was organised categorically, chronologically, and continually coded using the open and axial coding procedures. For qualitative data, all recorded interviews using a digital audio recorder and notes (text), were transcribed verbatim and the photographs taken were captioned.

Case study strategy requires a high level of data credibility and reliability. As a basic foundation to achieve this, Baxter and Jack (2008) note that: (a) the case study research question must be clearly written, propositions (if appropriate to the case study type) provided, and the question substantiated; (b) case study design is appropriate for the research questions; (c) purposeful sampling strategies appropriate for case study must be applied; (d) data is collected and managed systematically and (e), the data must be analyzed correctly.

To enhance credibility of data and findings, data sources were triangulated. This is a strategy that was used and supported by Baxter and Jack (2008), who state that in case study research, the phenomena must be viewed and explored from multiple perspectives. The collection and comparison of this data enhances data quality based on the principles of idea convergence and the confirmation of findings. As an additional effort, and what has become tradition in the researcher's department, the entire thesis went through rigorous peer review by colleagues who are experts in different fields of study, but necessary to this study. Peer review has proven to be a useful strategy to establish credibility, introduce new ideas, provide checks, and to balance what would otherwise not be possible from one researcher. Due to the study being a multiple case study, Greene and David (1984) recommend cross-site analysis.

The first step of the cross-site analysis is to generate a working set of propositions; these are findings from the individual cases restated so as to apply - in principle - to all the cases (Greene and David, 1984). Propositions may also come from literature, personal/professional experience, theories, and/or generalizations based on empirical data. Thus, various findings/propositions developed from literature review and from preliminary field visits (observations and discussions) were translated into statements that were subject to empirical confirmation or disconfirmation. Comparisons and references of these statements were cross-checked. Furthermore, chapter four served as a guiding framework from which the other cases (chapters) were formulated and cross-analysed.

3.6 ETHICAL CONSIDERATIONS

Ethics inform norms for conduct that distinguish between acceptable and unacceptable behaviour. They also help researchers to deal with ethical dilemmas through providing important insights, concepts, tools, principles and methods that can be useful in resolving these dilemmas (Lincoln and Guba, 1986). To comply with UNISA's research ethics standards, a request for permission to conduct research was sent to the target mining companies. Where permission was granted, the researcher set appointments with respondents. Informants within these organisations were informed of their right to consent or decline to participate in the study.

One respondent requested that his mine and the mining company's identity not be mentioned by name in the study, and this request was observed. In addition, participants were informed about the varied levels of confidentially that would determine reporting of the data that they supplied (Strydom and Venter 2002). Some coal mining companies published some of the required data in their publicly accessible sustainability reports. However, there was a need for additional data and information such as mine design layouts and previous studies of a similar nature that were not available in the public records and permission was sought. Due to the possibility of organizations' sensitive information being exposed to competing companies, the researcher took extra caution to protect all mining companies' information. All data collected was for the purpose of fulfilling the requirements of this study. Should the need arise to use this data elsewhere; the researcher will seek consent from all concerned parties. All collected data was stored in the researcher's personal computer, and hard copies were kept in the researcher's office premises.

3.7 CONCLUSION

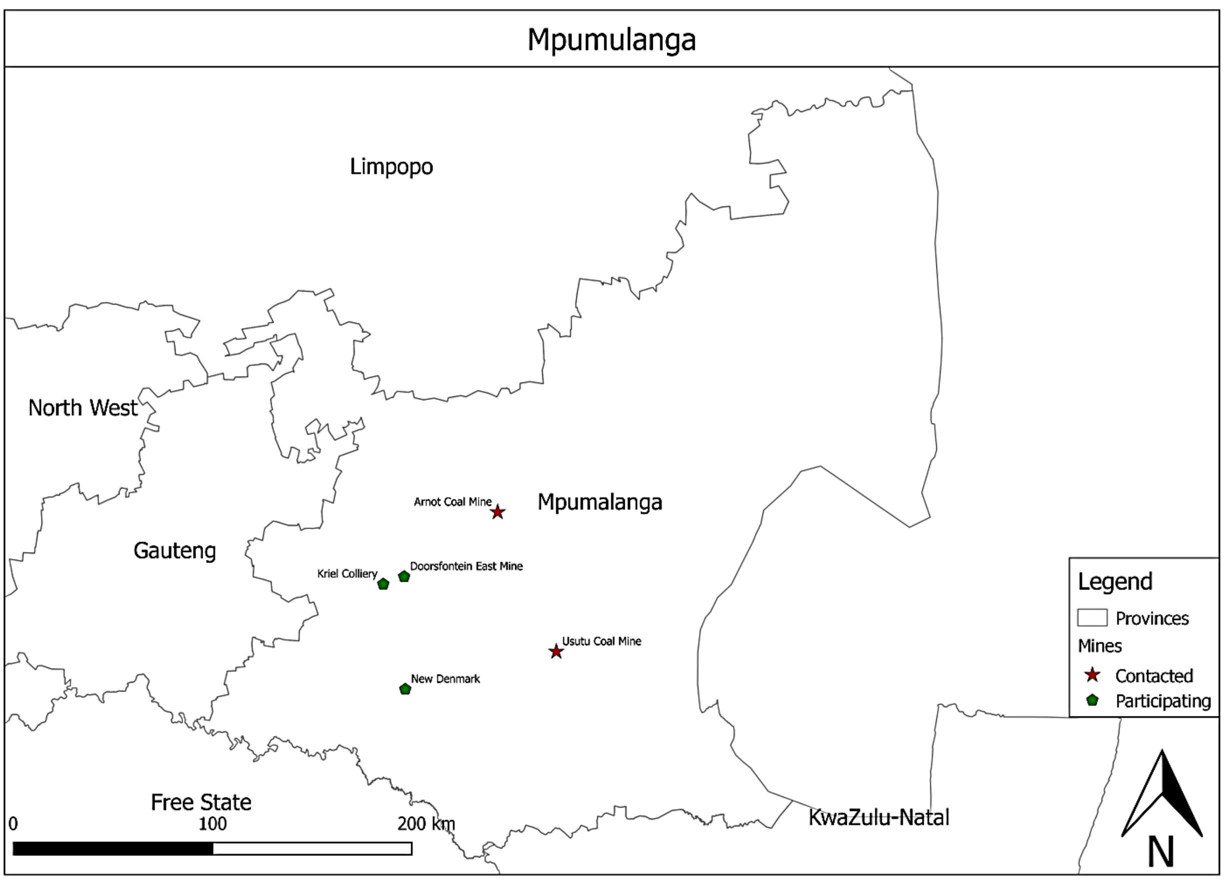
This study was multi-disciplinary in nature, involving climatic data that required a quantitative research approach, and interpretation of that data which required a qualitative research approach. As such, a mixed-method approach was most appropriate for this study, for no single approach could have created a meaningful outcome. The methods for data collection were also mixed, and included in-depth interviews, document analysis and field observation. These produced both qualitative data in terms of climate trends, and qualitative data in terms of coal mining companies' interpretation and responses to Climate Change Impacts. Fitting to the mixed-method approach, data analysis also used both qualitative and quantitative techniques. The quantitative approached produced strong and empirical mathematical outcomes. However, descriptive qualitative analysis provided flesh to otherwise meaningless and complex mathematical data. Without the merging of the hard natural scientific and soft social sciences approach, it would have been difficult and near impossible to answer the research questions and to achieve the research objectives.

CHAPTER FOUR: CLIMATE CHANGE VULNERABILITY AND ADAPTATION STRATEGIES AT THE MPUMALANGA COALFIELDS

4.1 INTRODUCTION

This chapter presents analyses and discusses the research findings focusing on climate change vulnerability and management with a specific focus on adaptation policies and practices of selected coal mines in the Kriel, Doornfontein East and Standerton towns in the Mpumalanga Province as shown Figure 4.1. As indicated in the methodology chapter, rainfall and temperature data was supplied by the SAWS for the Mpumalanga weather station(s).

Figure 4.1: Mpumalanga coal mines



Source: Author, 2015

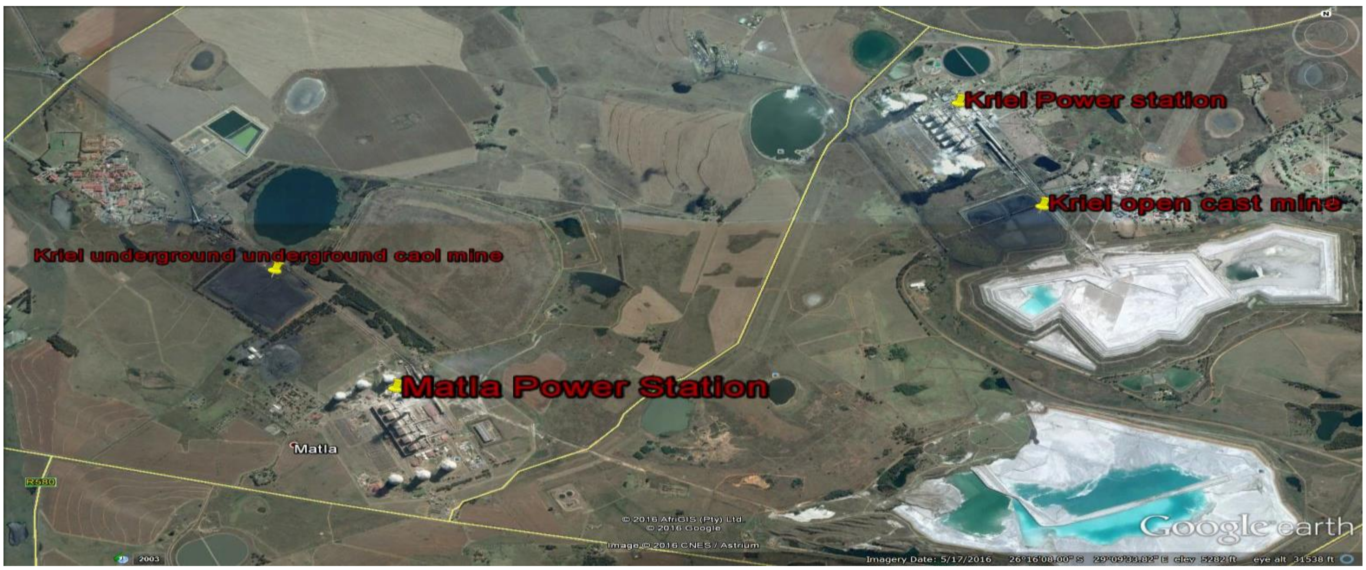
Figure 4.1 shows several mines which were targeted to participate in this study. Only three mines consented and participated. Kriel Coal Mine, based in the town of Kriel, and the New Denmark Colliery based in Standerton, consented to their identity being revealed while the third mine requested anonymity. As such, this mine was referred to as Mine X. Reference to individual respondents from all the mines is coded to preserve anonymity. Arnot Coal Mine located in Middleburg and Usutu Coal Mine, which is located in Ermelo, declined to inform the research despite numerous and persistent requests. The targeted mines were chosen based on varying geographic locations. This is because climate change impacts vary between locations and the research sought to explore this variation. In addition, the mines are different in design (open-cast and underground) and are owned by different mining companies that have different climate change management policies and plans. As such, the chapter compares and contrasts the current and possible future climate change impacts and adaptation plans, options and actions which are unique to these mines in particular, and between the respective mining houses that own them.

The research made four major findings concerning the three mines in the Mpumalanga Province. Firstly, there was inadequate climate data recording by the South African Weather Service and the selected coal mines in Mpumalanga. This compromised effective climate analysis which in turn compromised adaptation planning and implementation. Secondly, the available data showed that there had been a general decline in rainfall in Kriel and Standerton. This decline was characterized by periods of extreme high rainfall events and an increasing frequency of extreme low rainfall cases. Thirdly, the extreme weather events, mainly droughts and incidents of extremely high rainfall affected the production operations of the mines. It is projected in the future that such events will also affect closure and post-closure stages in the mining value chain. Fourth, despite evidence of climate change and its impacts, the research found very limited evidence of proactive planning and action for climate change adaptation at all the mines. This was despite the fact that the mines had climate change management policies that pledged a balanced attention to both climate change adaptation and mitigation. These findings confirmed an earlier assertion (Chapter 1, Section 1.1) that in general, climate change adaptation lags behind climate change mitigation in different industries, including mining. Details of these findings per mine are provided in the following sections.

4.2 KRIEL COLLIERY AND THE NEARBY POWER STATIONS

Kriel town is located between the towns of Ogies, Bethal and Witbank in the Mpumalanga Province of South Africa. Located in the town is the Kriel Colliery which is owned by the Anglo American mining firm through its division called Anglo American Coal. The Colliery has both underground and open-cast operations. Both operations began production in 1979 and have been supplying coal to the Matla and Kriel power stations, which are located in the proximity of the mine operations (Figure 4.2).

Figure 4.2: Kriel Colliery



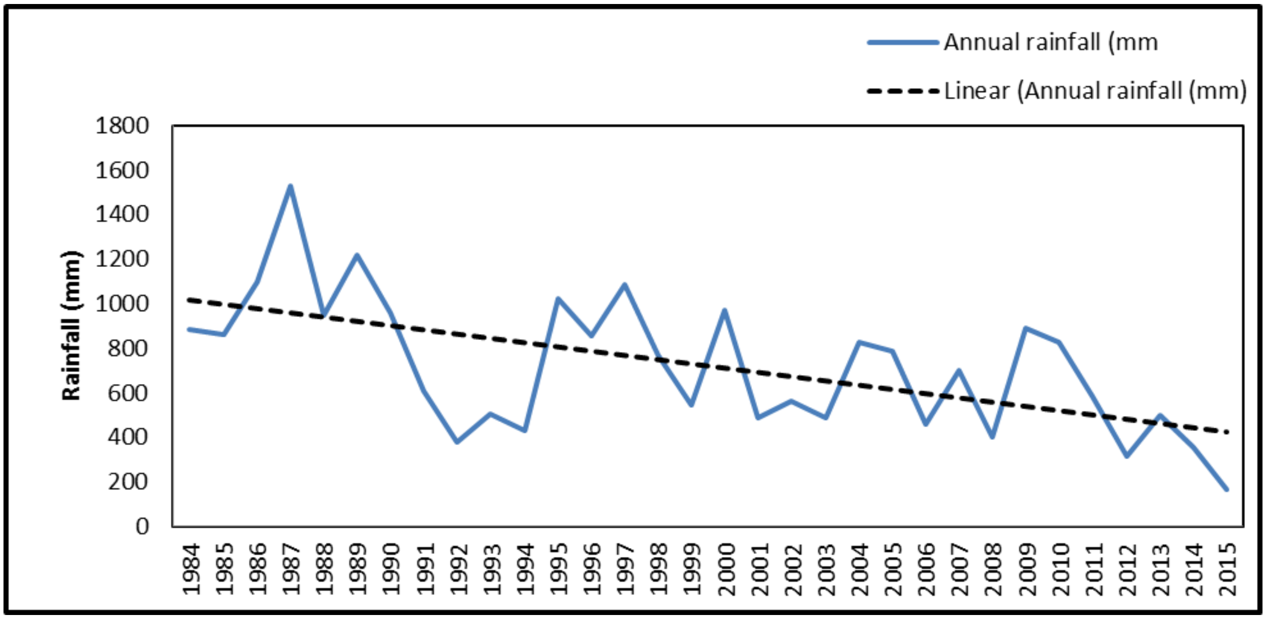
Source: Google Earth, 2015

The environmental manager at the mine stated that the underground mine was going through a closure process due to 'geological factors' that were negatively impacting productivity both in terms of quantity and quality of the coal. The open-cast mining operations are set to continue. This makes it imperative that the open-cast operations (and to an extent the closing underground operations) start developing climate change management policies and practices. An important component of this development is access to adequate, reliable and accurate climate data. At the time of this research, the South African Weather Service did not have records of temperatures for the Kriel area. However, annual rainfall data covering a 33-year-period from 1984 to 2015 was available.

4.3 ANNUAL RAINFALL TRENDS IN KRIEL

Since rainfall patterns form a critical aspect in climate change adaptation, this data was gathered for further analysis (Figure 4.3). An analysis of the annual rainfall trends (Figure 4.3) from the closest weather station to Kriel shows declining annual rainfall from 1984 to 2015.

Figure 4.3: Annual rainfall patterns in Kriel area, Mpumalanga (1984-2015)



Source: Fieldwork (Data from South Africa Weather Service, 2015)

The highest amount of rainfall was in 1987 which stood at 1,529 millimetres (mm) which translates to a monthly mean of 127 mm of rain. Since then the area has experienced a steady decline in total annual rainfall with the year (2015) receiving only 165mm of rainfall, the lowest since 1984. The 2015 rainfall translates to mean monthly rainfall of only 13mm. This indicated that the decline was steady without spikes of extreme rainfall. Additional analysis will be discussed in detail in the next section dealing with seasonal rainfall analysis where Table 4.1 will show that the year 2015 recorded a total of 165.1mm of rainfall and a mean of 13mm, the lowest since 1984. According to the South African Weather Service, 2015 was the driest year in 111 years.

Discussions with Kriel residents confirmed the case of declining rainfall. A community member stated that the declining rainfall over the years has affected his farming, especially in 2015 where there was a drastic decline in rainfall.

> "*The rains have not been coming this year* (2015). *We are now forced to buy basic vegetables such as tomatoes that we used to plant ourselves*" Extract from field interview, respondent 1.

This decline in rainfall trends corroborates observations by Lube McGeehin, *(*2008) and the United Nations Environmental Programme (2007) which projected declining precipitation trends in highlands areas due to climate change. The Kriel mines are located in a highland region (South African Coal Road Map 2011). The Anglo American Coal Stewardship and Carbon Footprint Manager stated that Anglo American acknowledges and is concerned about the impact of climate change in its different mining operations around the world, including South Africa. Despite this assertion, an interesting finding was that Kriel Colliery did not have unique climate change management plans that acknowledge its local climate change exposure and vulnerability.

The Kriel Colliery's position is not surprising. At a global level, it emerges that Canada and Australia, which are leading countries in coal mining and research, have shown few cases of climate change adaptation "flagship" projects in the mining sector broadly, and none in the coal mining sector particularly (Pearce *et al*, 2009 and CSIRO, 2011). Within the South African mining industry, the South African Coal Road Map (2011) states that key stakeholders in the coal mining industry are paying limited attention to climate change adaptation measures. This could be the result of uncertainty surrounding the exact nature of changes and how they may affect specific mining operations. This uncertainty is made worse by the lack of credible climate data from which adequate and appropriate analysis can be made, as is the case with Kriel's lack of temperature data. Hallegate (2008) states the uncertainty of climate change impact analysis and the unreliability of climate data, especially in poorer regions, makes it impossible to directly use the output of a single climate model as an input for infrastructure design, and there are good reasons to think that the needed climate information will not be available soon. He further argues that instead of optimizing, based on the climate conditions projected by models, future infrastructure should be made more robust to possible changes in climate conditions. This implies that users of climate information must also change their practices and decision-making frameworks, for instance, by adapting the uncertainty-management methods they currently apply.

All things being equal, declining rainfall should adversely affect water availability to the mine and the surrounding community. Surprisingly a mine employee (Respondent 2) stated that the declining rainfall was yet to affect mine operations. However, the employee stated that severe and frequent seasonal droughts such as that experienced in the 2015/2016 rainy season could affect operations, especially with regards to activities such as coal washing which require large quantities of clean water. To this end it was prudent that the mine planned and developed water storage facility as an adaptation mechanism to cope with declining rainfall which could adversely affect its operations. The collected water is used in mining operations and is reclaimed for reuse at the mine. The reclamation of water is a climate change adaptation mechanism that seeks to address rainfall-related water shortages during mine operation and the management of waste water during the post-mining stage. Tshwete, *et al*, (2011) note that environmental sustainability by converting a large polluted mine-water body into a saleable, potable water product, contributed to the local aquatic ecosystem revival and addressed a mine post-closure liability.

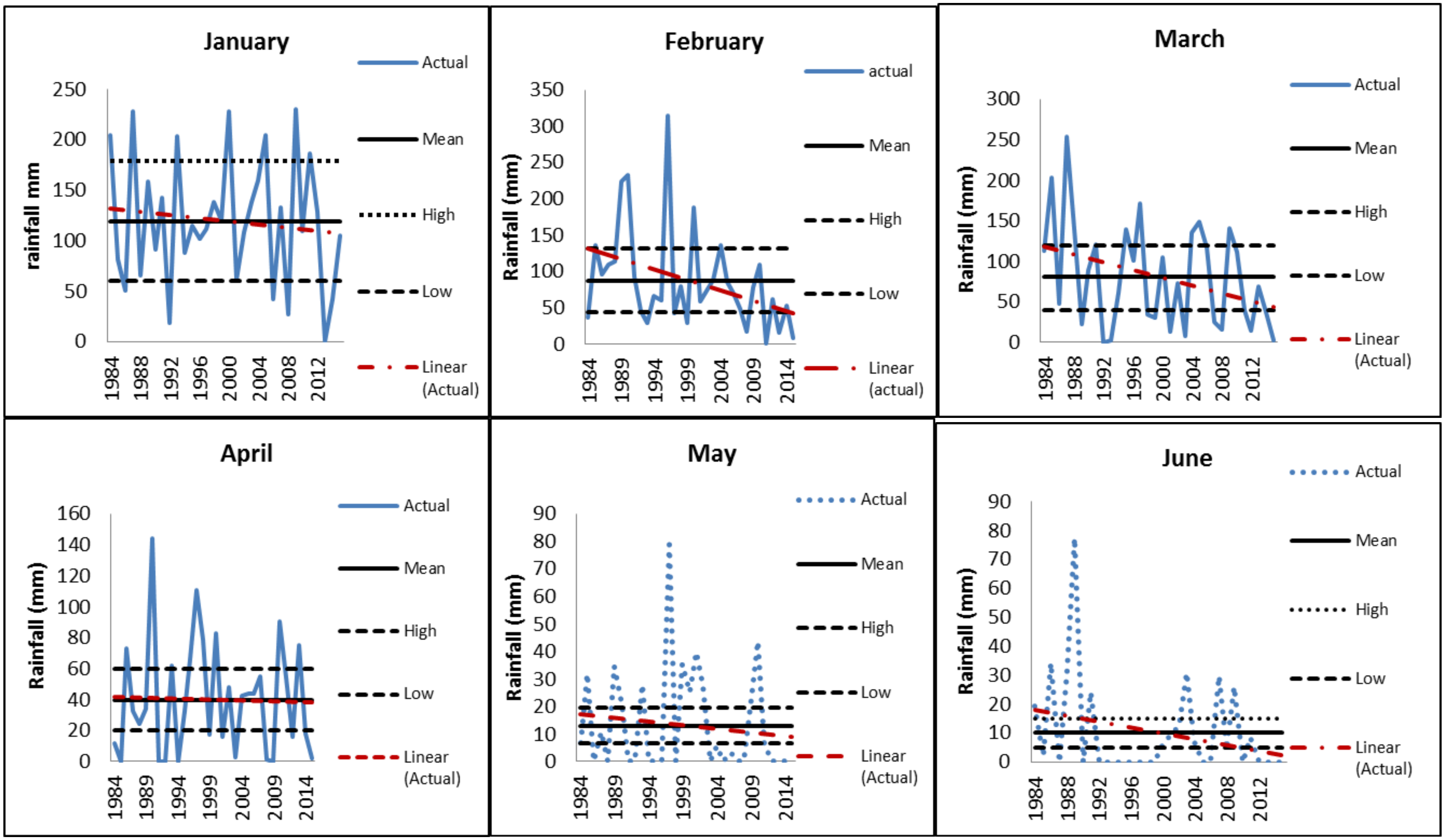
Although Kriel is experiencing declining rainfall, there have been incidents of extremely high rainfall such as in 2009 that resulted in flooding, which in turn affected both the open-cast and underground mining operations. The water pumping systems then in place were not adequate to deal with the high volumes of water. The mine has made and still is making the necessary adjustment to manage such events. For example the mine's discharge dams have been improved. In addition, and as a result of the 2009 floods, excess water had to be pumped to tailing dams and pollution control measures needed to be in place to avoid spillage to public clean water resources. Although Kriel Colliery has not been accused of water pollution, a respondent from the mine (Respondent 3) stated that old mines tend to eventually pollute water-ways. If and when this happens, it could raise tensions between different water users that include local government and local people.

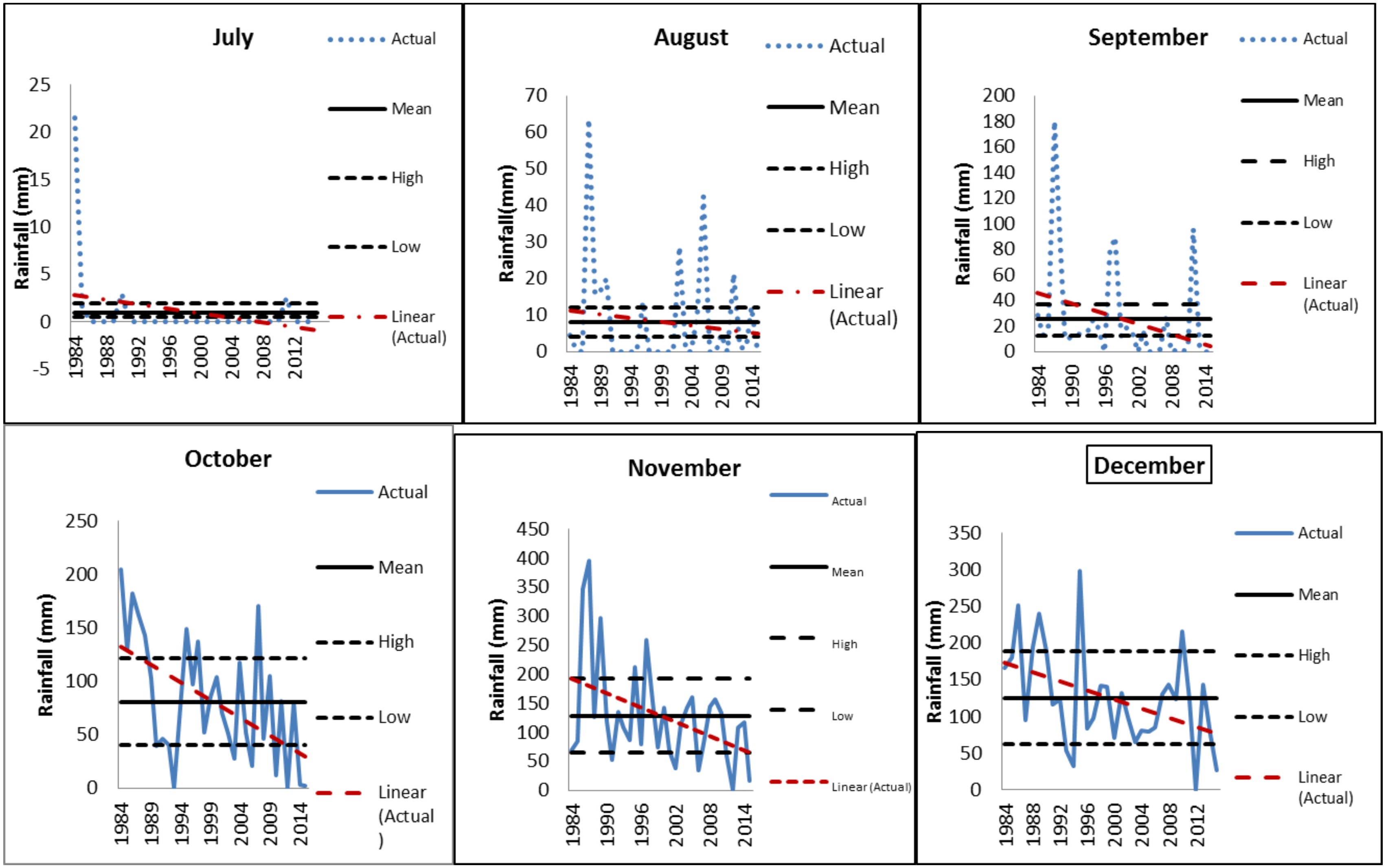
Planning for water use is not an activity that is limited to the production phase of the mining value chain. Contemporary planning straddles all the sub-chains of the value chain. A respondent (Respondent 4) at Kriel Colliery confirmed this focus, stating that current exploration (the genesis of any mining operation) and new mine construction practices should include planning for extreme climate change-induced weather events that are becoming frequent and noticeable. The most common considerations in these plans are flooding and water scarcity due to climate change-induced extreme high and low rainfall events. While Figure 4.3 shows aggregated annual rainfall indicating a decline over the stated period, a notably and interesting observations emerge from a close scrutiny of intra- and inter-seasonal variations in rainfall intensit and patterns over this period. Explaining these observations dictates a distinction of seasons in South Africa.

South Africa has four distinct seasons; summer, autumn, winter and spring. Generally spring and summer are rainy and autumn and winter are dry with a few regional exceptions most notable in the Western Cape. For simplicity, this thesis divided the four seasons into two broad categories, summer (wet) season, which starts in October and ends in April and winter (dry) season, which starts in May and ends in September. Details of changes in precipitation patterns (1984 to 2015) in Kriel, under these two broad seasonal distinctions, are given in the following section. Figure 4.4 shows seasonal and monthly average rainfall from 1984 to 2015. This figure also shows the extreme low and high rainfall incidents over the same period of time. The extreme highs and lows have been calculated as 50% above and below the mean, respectively.

The wet season is made up of months with solid data series lines while the months with dotted data series lines constitute the dry season (South African Weather Service, 2015). Figure 4.4 shows that the Kriel area experiences wet summers (October to April) and relatively dry winters (May to September). In the figure, all the rainfall outside the 50 percent demarcation below and above the mean is considered to be either an extremely low or extremely high rainfall event. Typically the summer months are the period in which extremely high rainfall is expected resulting in flooding that in some cases can adversely affect mining operations.

FIGURE 4.4 SEASONAL AND MONTHLY RAINFALL ANALYSIS





Source: Fieldwork (Data from South Africa Weather Service, 2015)

Further examination of the results shows that the rainy season is experiencing an increased frequency of extremely high rainfall cases. It is plausible that without these cases of extremely high rainfall, the decline shown in Figure 4.4 could have been worse. For example, from 1984 to 2015, January experienced seven cases of extremely high rainfall compared to five cases of extremely low average (counted as points outside the 50 percent demarcation above and below the mean). With January being an exception, other months of the rainy season show a high frequency and a high number of low rainfall incidents as well as rare, but extremely high rainfall cases. This observation shows that summer months are of concern with regard to seasonal dry spells and unexpected flooding incidents around Kriel Colliery. This is the time that the mine needs to take advantage of capturing and storing rainwater during the extremely high rainfall. Currently this is not happening.

Figure 4.4 show that the winter season is also experiencing declining rainfall. However, the decline is not as intense as that of the summer season. This is due to lesser variation between high and low extreme rainfall events as compared to the summer season. A notable observation about the extreme rainfall patterns in the winter season is the ratio of extremity. Although extremely low rainfall incidents are subtle, and their frequency predictable, extremely high rainfall occurrences are far apart and very pronounced. They also take place in winter when they are least expected. Evidence of this could be seen with the flooding in Kwa ZuluNatal, Gauteng and Cape Town in 2015 and 2016, mainly in June and July. Coal mining, supply and coal storage at the power stations is more intense in South Africa due to increased winter energy demands. In January 2011 and October 2014, some of the coal stored in the open-cast mine at Eskom's Majuba power station got wet due to unexpected heavy rains (Eskom, 2014) Although Eskom initiated their wet coal management strategy to ensure that the wet coal risk is reduced in other power stations, the South African state-owned power utility admitted that it is not possible to neutralise this risk completely, especially over periods of prolonged high rainfall. The relative frequency and number of both high and low extreme rainfalls is summarized in Table 4.1. Relative frequency tells how often something is happening. It is more of an experimental concept than a theoretical one.

The relative frequency can be evaluated using the following formula:

Relative frequency = (<u>*number of trials that are successful*</u>)

(*Total number of trials*)

In this case, the numbers of extreme rainfall events - either high or low - were divided by the total number of years (31 years) under consideration as shown in Table 4.1 to determine the percentage of occurrence probability.

Table 4.1: Monthly mean and annual extreme rainfall frequencies and number of occurrences from 1984 to 2015

Months from 1984 to 2015	Mean	Number of extremely high rain events in 31 years	Extremely high rainfall (mm) relative frequency (X % in 31 years)	Number of extreme low rain events (1984-2015)	Extremely low rainfall (mm) relative frequency (X % in 31 years)
Jan	119	7/31	22 %	5/31	16 %
Feb	87	5/31	16 %	6/31	19 %
March	80	6/31	19 %	10/31	32 %
April	39	7/31	22 %	11/31	35 %
May	13	7/31	22 %	12/31	38 %
June	10	6/31	19 %	12/31	38 %
July	1	2/31	0.6 %	20/31	61 %
August	7	6/31	19 %	11/31	35 %
Sep	25	3/31	0.9 %	9/31	29 %
Oct	81	5/31	16 %	6/31	19 %
Nov	128	4/31	12 %	5/31	16 %
Dec	124	4/31	12 %	3/31	0.9 %
		Total number of extremely high rainfall: 62		Total number of extremely Low rainfall: 110	

Source: Fieldwork (Data from South Africa Weather Service, 2015)

Table 4.1 shows that the number of extremely low rainfall events is 62 compared to 110 incidents of extremely low rainfall in the last 31 years. This sums up the declining annual rainfall in the Kriel area. The months with the highest mean in summer in the last 31 years are January with 119 mm, November with 128 mm and December with 124 mm. This comes as no surprise as traditionally these are the months that rainfall is expected. However, the months with the highest frequency of extremely high rainfall in summer are January and April each with a 22 % probability. These would be the months that are likely to pose flooding risk at Kriel Colliery. The months with the highest incidents of extremely low rainfall in summer are March with 10 incidents and April with 11 incidents in the last 31 years. These are the months that are more likely to be the driest in summer, so stored water and use of borehole water can be targeted for these months. These months, together with September, also have the highest frequency of extremely low rainfall in summer. Kriel Colliery needs to devise a targeted water conservation adaptation strategy aimed at these months or shift all water-intensive practices to months with the least amount of extreme rainfall and less frequency of such events.

In the winter season, the months with the highest mean rainfall are May and June with 10 mm and 7mm respectively. These two months also have the highest number of extremely high rainfall incidents with May having experienced 7 such incidents and in June 6 incidents in the last 31 years. Furthermore, June has the highest frequency of extremely high rainfall events with 22 %. This is equal to January and April's probability of flooding possibilities. This should place the month of June on the 'watch' list of the months with the highest possibilities of flooding at Kriel Colliery. However, detailed adaptation plans that take the monthly rainfall profile based on historic patterns, were not available at the mine at the time of conducting this study. Winter is known to have the least rainfall in any year. However, there have been extremely low rainfall incidents that are below expected standards. The month of July had 20 events of extremely low rainfall incidents in the last 31 years in winter, and has a 61 % frequency of such events occurring. The remainder of the months experienced less rain, which halves the number of these incidents. This makes July the driest month of the year in the last 31 years. July is also a coal mining intensive month in South Africa due to increased winter power demands. One of the ways to avoid water-related interruptions could be to have enough coal stock in the months preceding July, or to store enough water for the month.

4.5 OTHER CONCERNS

The winter season is also a season where low temperatures are conducive for the formation of smog. This is very prominent in coal mining towns with coal-fired thermal power stations such as in Kriel, and is caused by smoke from local power stations. In the winter season, Kriel Colliery experiences increased smog (Figure 4.5), which presents operational challenges. Most notable is visibility, which is critical for safe operations in a mining environment.

Figure 4.5: Smog at the Horizon of Kriel Colliery

Source: Centre for Environmental Rights, 2014

Generally smog forms faster and is more severe in hot and sunny weather. However, in Kriel it is persistent throughout the winter season due to increased activity at the power stations, as a result of increased winter electricity demand throughout South Africa. Smog is usually produced through a complex set of photochemical reactions involving volatile organic compounds (VOCs) and nitrogen oxides in the presence of sunlight, resulting in the production of ozone. The United States Congress Researching Health Risks (1993), states that smog occurrences are often linked to heavy motor vehicle traffic, sunshine, and calm winds. As such, weather and geography have an effect on the longevity and severity of smog.

Smog is often more severe away from the pollution sources such as power stations and petrochemical refinery plants because the chemical constituents of smog are easily moved by the wind (Chameides *et al*, 1988). Since Matla and Kriel power stations are near Kriel Colliery the pollutants they produce because severe smog that affects visibility at the nearby mines. In these mines, severe cases of smog often lead to work stoppages for safety reasons. This particularly relates to safety in the operations of moving coal, plant equipment and personnel in a mining area. The Kriel Colliery has avoided such stoppages because it uses conveyor belts to transport coal from the mine to the power stations. Another concern related to the dry season is heavy winds that raise dust, as shown in Figure 4.6.

Figure 4.6: Dust at the Kriel Colliery

Source: Centre for Environmental Rights, 2014

The lack of vegetation and mountains in areas surrounding the Kriel Colliery increase the mine's vulnerability to wind-related adverse impacts. Although heavy winds and wind storms are not frequent, when they do occur they damage infrastructure such as sub-shafts, and affect employee health as well as that of communities around the mine. This was confirmed by a community member who stated that almost everyone she knows suffers from respiratory problems related to dust from the local mines. Indeed, dust from the mine's stockpiles sometimes affects nearby communities, posing a health hazard. As a result, Mpumalanga has been identified by the Centre for Environmental Rights (2014) as a province with the poorest air quality in South Africa, resulting in a high number of respiratory and lung-related diseases (McDaid, 2014). A cause for concern is that dust from the mine and its related health impacts on the communities around the mine will continue long after the mine has been closed, particularly if the appropriate and adequate mine site management practices are not implemented.

A mining specialist (Respondent 6) from the University of Witwatersrand stated that to mitigate such occurrences, mine closure procedure must incorporate dust management in closure and post closure mining plans. Another climate change-related issue of concern at the Kriel Colliery is the case of rising temperatures. Although temperature data was not available, a respondent (Respondent 7) from the mine stated that they had observed that temperatures were rising and the surrounding areas are getting dryer. The rising temperature and dryness render the area prone to wild fires and cases of spontaneous combustion. However, these occurrences are rare and where they have occurred, they have been rather mild due to proactive wild-fire management strategies at the mine. The wild-fire management strategy involves the watering of dry areas. However, this strategy is not viable during drought periods because it diverts scarce water that could be put to direct production operation, domestic uses, and fire management operations. Therefore the declining rainfall means the use of water for this purpose, at a time when water sources are increasingly constrained, may need reconsideration, if not total abandonment. The outlined status quo indicates that Kriel Colliery and its surrounding community is exposed and vulnerable to the adverse impacts of climate change mainly caused by chronic drought, unexpected flooding, smog and dust. While these are manageable as normal occurrences, climate change increases their intensity and frequency, rendering them increasingly difficult to manage. Thus there is a need to devise site-specific climate change management policies and action plans to minimize or prevent these impacts. However, due to limited climate data, as was the case with local temperature data, it is difficult for mining companies to understand the precise changes and impacts of climate change on various levels of their mining value chain.

4.6 FINDINGS FROM THE NEW DENMARK COLLIERY

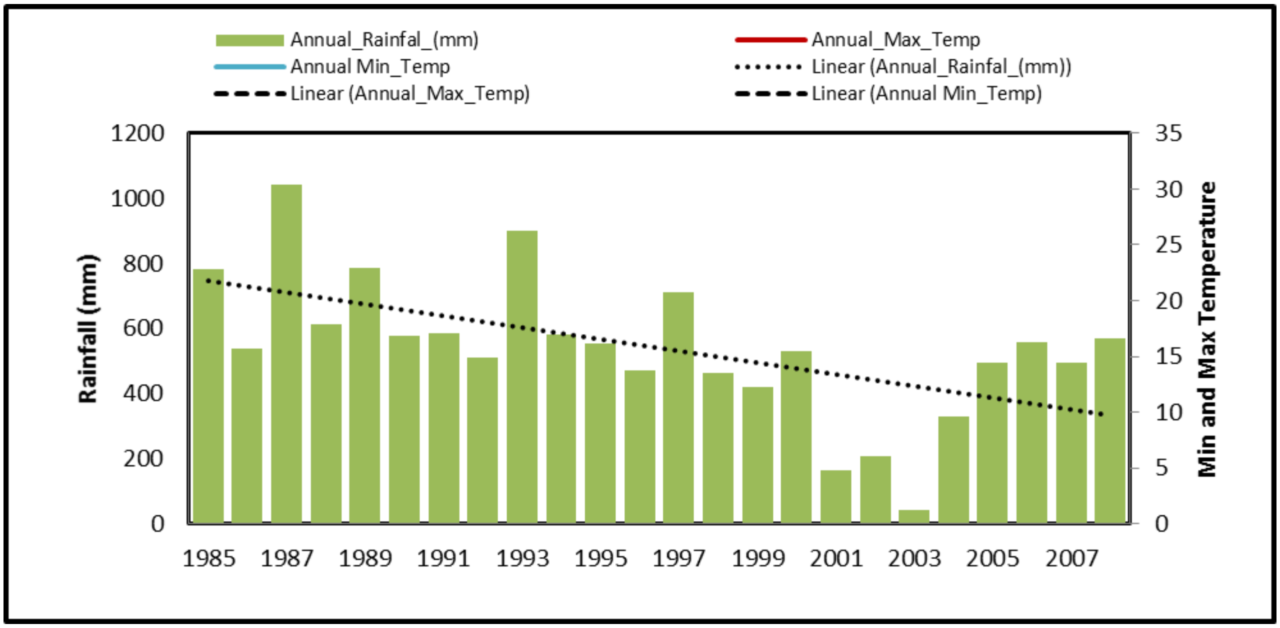
The New Denmark Colliery has both underground and open-cast mines, located in Standerton, in the Mpumalanga Province of South Africa. The mine is also owned by Anglo American and was commissioned in 1982. At the time of this research, the mine was extracting coal from its Central and Okhozini shafts. These shafts produce five million tonnes of coal per annum for Eskom's Tutuka Power Station located near the mine (Figure 4.7)

Figure 4.7: New Denmark Collieries.

Source: Google Earth, 2015

Standerton is generally dry with warm to hot summers and average daily temperatures of around 27˚C with occasional extremes of up to 36˚C. The winters are notably cooler than summer with average daily maximum temperatures of around 15˚C and occasional extreme minimum temperatures of as low as -9.2˚C (Ibid.). The bulk of precipitation is experienced during the summer months, mostly in the form of afternoon thundershowers occurring in the form of mist, drizzle, hail and more recently, thunderstorms (New Denmark Ground Water Specialist Report, 2015). The mean annual rainfall is approximately 695mm. The winter months are typically dry with the combined rainfall in the period June to August contributing 3.9% of the annual average precipitation (South African Weather Service, 2015). Figure 4.8 shows the trend in annual rainfall and maximum and minimum temperatures in the region for the period 1985 to 2008.

Figure 4.8: Annual climate trends in Standerton

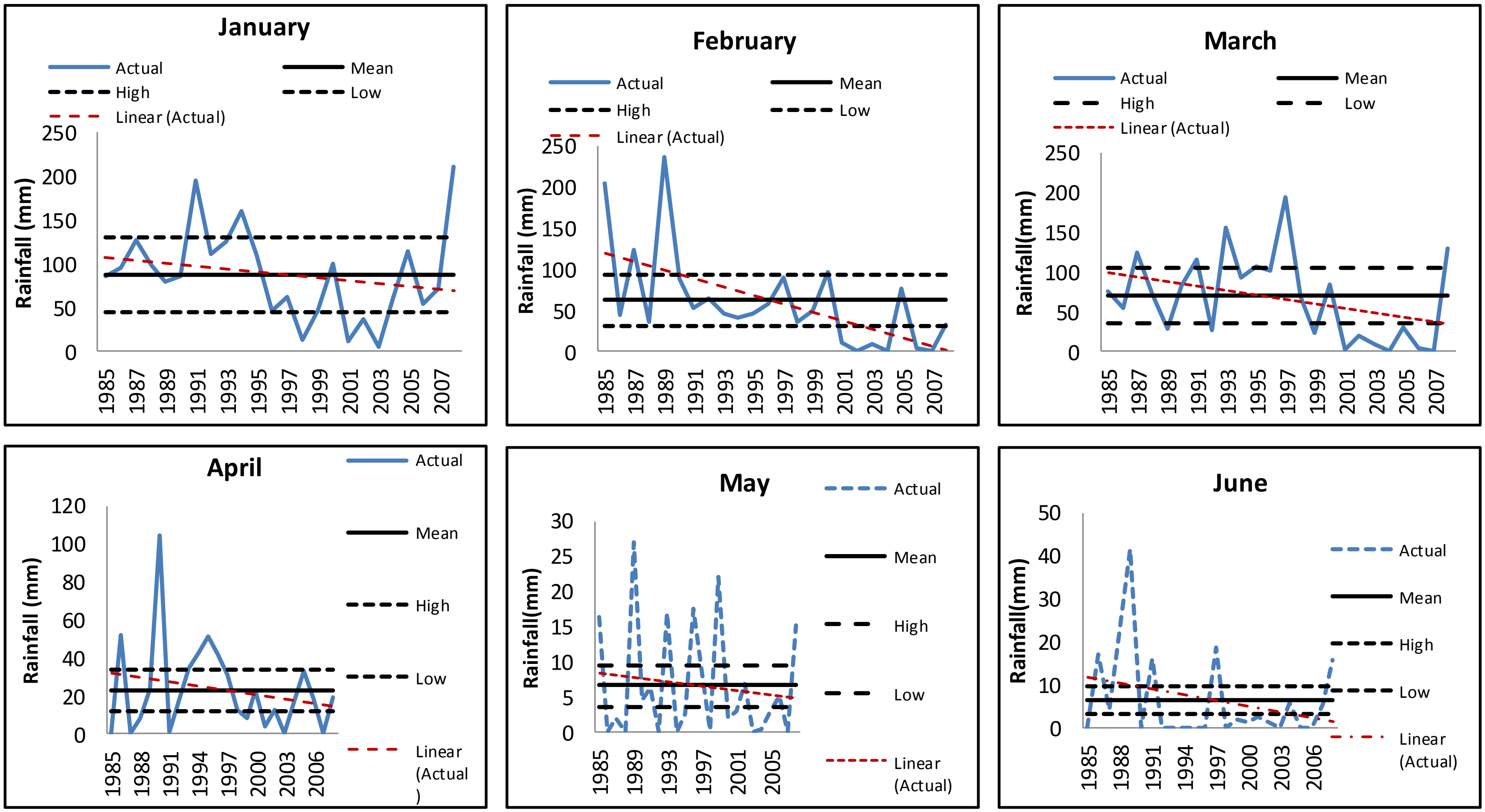


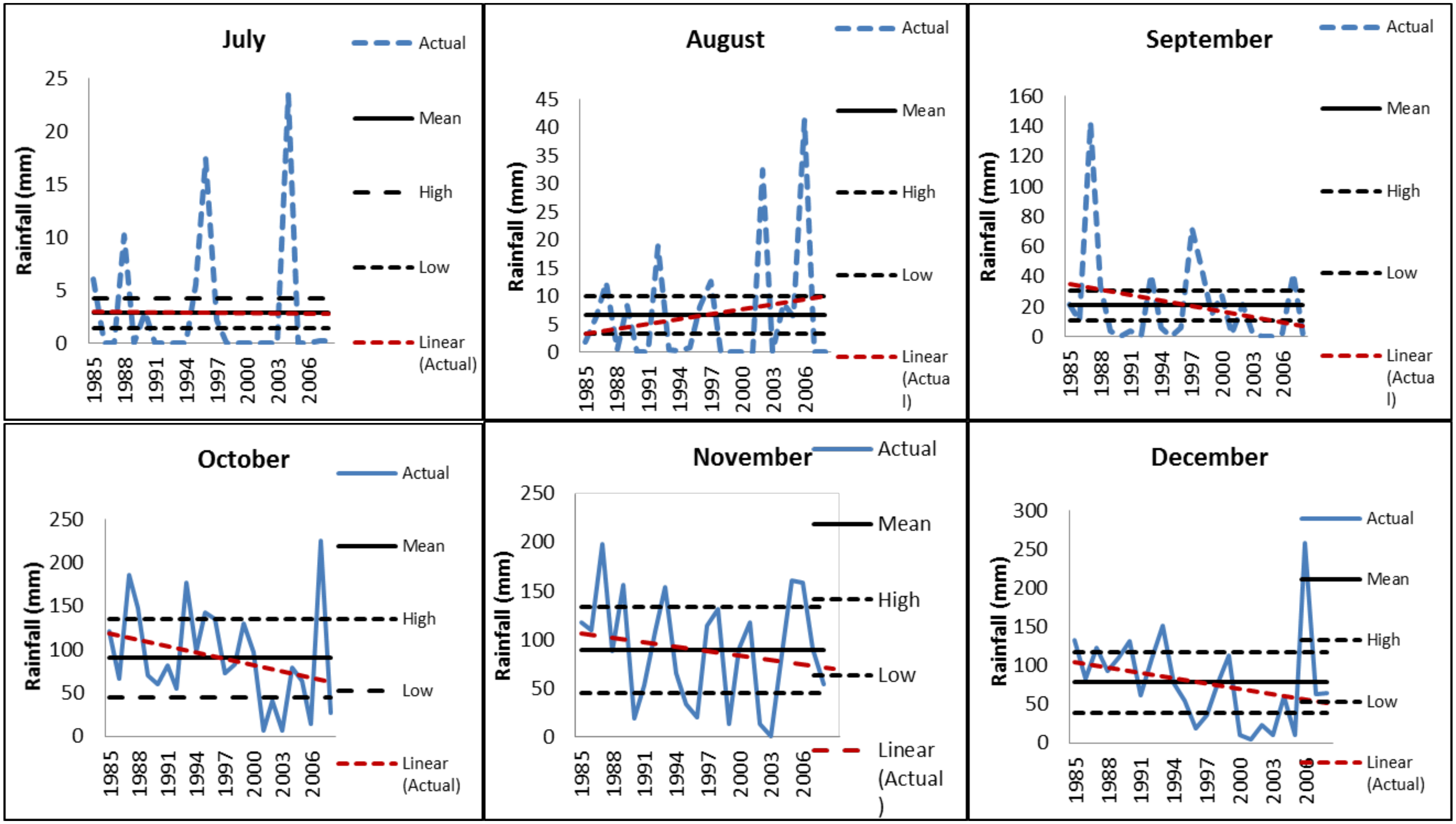
Source: South African Weather Service, 2015

Figure 4.9 shows a sharp decline in annual rainfall from 1985 to 2007 and stable maximum and minimum temperatures. Although the declining rains are leading to water shortages, this has turned out to be an advantage for New Denmark Colliery because heavy rains pose flooding risks to the underground mine. A respondent (Respondent 7) from the mine stated that the mine was using underground water to meet its water needs. He stated that the mine pumps 14 million litres of water per day from underground and only uses 2 million litres per day for mine operations. The rest is stored for emergency purposes. Although there has been a clear decline in annual rainfall over the period under review, the New Denmark's environmental manager stated that the mine still keeps a close eye on the possibility of extremely high rainfall events that may flood both the open-cast and underground mine. As was the case in Kriel Colliery, the declining rainfall in New Denmark is also as a result of seasonal and monthly rainfall declines as outlined in the following section. Figure 4.9 shows seasonal and monthly rainfall variation from 1985 to 2007. The summer season is made up of the months with solid pattern lines while winter is indicated by dotted pattern lines.

4.7 SEASONAL AND MONTHLY RAINFALL IN STANDERTON

Figure 4.9: Monthly and seasonal climate analysis





Source: Fieldwork (Data from South Africa Weather Service, 2015).

A major drawback for comparison with the Kriel Colliery case is that the South African Weather Service did not have climate data from 2007 to 2015. Gaps in the data series make adaptation planning and implementation difficult for mining operations such as that at the New Denmark Colliery. Based on Table 4.2 the total number of extremely high rainfall events is less than the total number of extremely low rainfall events in the last 23 years in Standerton. This makes Standerton a dry area whose major problem is chronic drought.

Table 4.2: Monthly mean, deviation and annual extreme rainfall frequencies

Month	Mean	Number of extremely high rainfall events in 23 years	Extremely high rainfall (mm) relative frequency (X % in 23 years)	Number of extremely Low rainfall (1985-2007)	Extremely low rainfall (mm) relative frequency (X 23 % years)
Jan	94	3/23	13 %	3/23	13 %
Feb	65	4/23	17 %	4/23	17 %
March	68	6/23	26 %	9/23	39 %
April	22	3/23	13 %	7/23	30 %
May	5	6/23	26 %	9/23	39 %
June	7	5/23	21 %	10/23	43 %
July	2	4/23	17 %	11/23	47 %
August	6	5/23	21 %	8/23	34 %
Sep	20	4/23	17 %	7/23	30 %
Oct	90	4/23	17 %	4/23	17 %
Nov	89	5/23	21 %	5/23	21 %
Dec	78	5/23	21 %	6/23	26 %
		Total number of extremely high rainfall: 54		Total number of extremely Low rainfall: 83	

Source Fieldwork (Data from South Africa Weather Service, 2015)

The months with the lowest rainfall mean in summer are April which has a mean of 22 mm of rain followed by September which has 20 mm of rainfall. However, March and September have the highest incidents of extremely low rainfall in summer which is 9 and 7, respectively. Less than expected rainfall in summer has been the major problem in drought-stricken provinces.

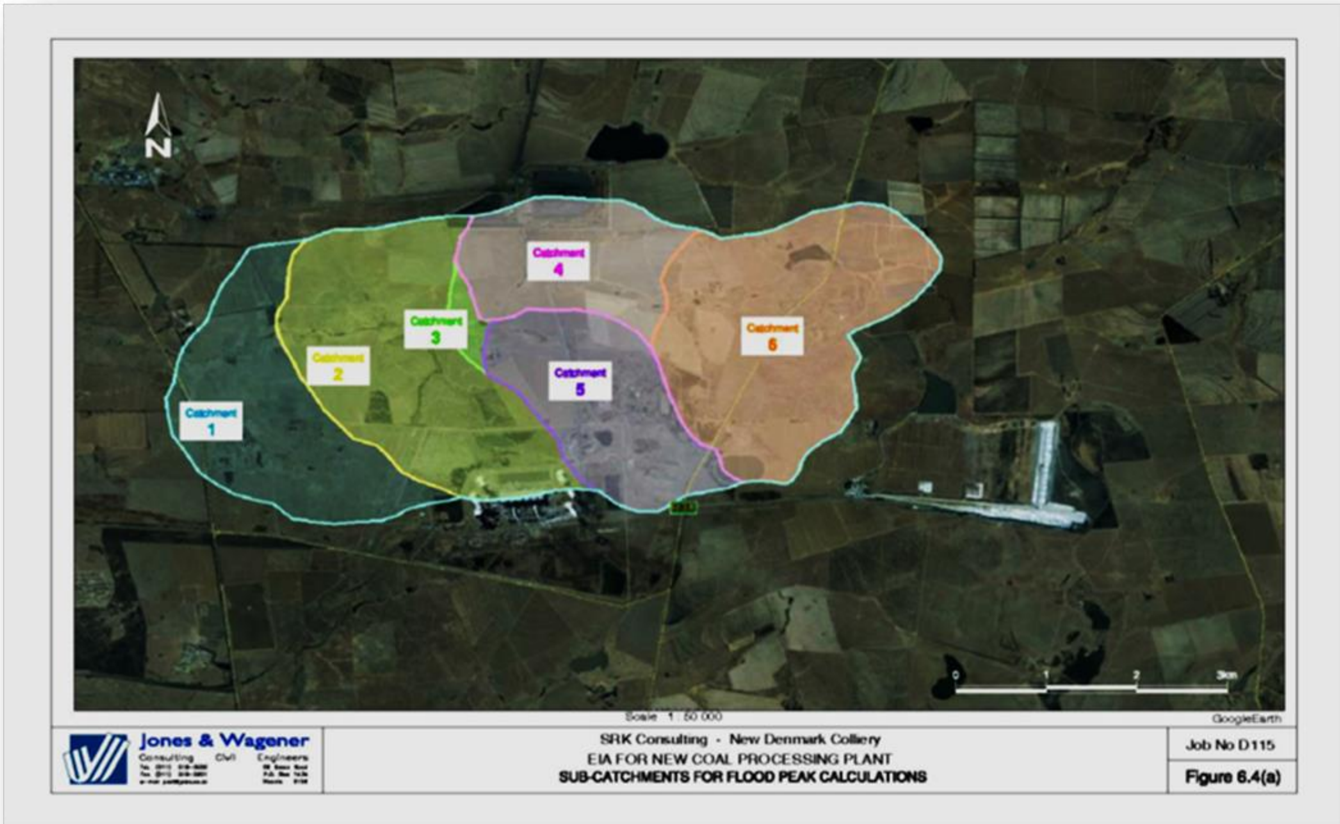
Based on this analysis, March and September should be marked as months that water adaptation planning should be implemented and whatever water intensive planning the mine has should be aimed at months preceding or prior to these two months. Another way of devising a customized and anticipatory adaptation is analysing frequency of extremely low rainfall events by studying historic patterns of occurrence. In summer the months with the highest frequency of extreme low rainfall are March with a 39% frequency followed by April with a 30% frequency and September with a 30% frequency. Frequency of extreme rainfall may assist the mine to predict the probability and rate of the occurrence of such events. This can further assist the mine to direct adaptation planning more precisely to the period during which the problem may occur. However, this is only the case if future variations do not deviate significantly from historical climatic variation. This uncertainty is a major challenge for adaptation planning. However, efforts need to be made to avoid disastrous incidents that are not planned for.

With regard to extremely high rainfall in Standerton, the months with the highest mean in summer are January which has 94 mm of rain, and November and December which have 89 mm and 78 mm respectively. However, it is March that has the highest frequency of extremely high rainfall which stands at 26%, followed by November and December which both stand at 21% in frequency of extremely high rainfall. As such, these are the months that should inform the magnitude of adaptation responses with regard to flooding. Often, extreme high rainfall events are accompanied by thunderstorms and hail, which sometimes have adverse impacts on mine infrastructure. The New Denmark mine manager stated that for proactive adaptation purposes during operations, the mine has to determine the approximate storm duration. This determination must be based on the intensity of rainfall in order to estimate the intensity and longevity of the impact.

Extreme flow events which generally happen for less than 24 hours are considered, as these are of higher intensity and generate greater flow rates (New Denmark 2014). However, for volumetric assessments, the duration used could be months, an entire season, or longer, as two or three months of high rainfall, for example, could raise a dam's water level to such an extent that a subsequent low recurrence interval storm could cause a spill event. New Denmark started designing water catchment dams during the building of its coal destoning plant as a response to possible flooding. During the design of the water catchment dams, the mine did not have flow and rainfall data to calculate runoffs in the area (New Denmark, 2014).

To mitigate this data deficiency, engineers had to make scientific estimations based on the river bed and river banks for the wetland region and the grassland regions respectively. The RiverCAD PRO software program was utilized for the flood-line determination. This program operates as a water monitoring programme that computes the water surface elevations for 50- to 100-year-flood peaks. This is a proactive adaptation technology that improves traditional flood defences. Figure 4.10 shows different water catchment dams around the vulnerable areas of the mine. An engineer interviewed at the mine stated that they had designed water catchment dams and flood line defences against possible flooding. These dams were designed to be effective for 50 years, as part of proactive adaptation planning. The dams limit or prevent the chances of the mines filling with water beyond their installed pumping capacity, which could result in work stoppages.

Figure 4.10: Water catchment dams at New Denmark Colliery



Source: New Denmark Colliery, 2014

The New Denmark Mine manager further highlighted that adapting to excess rainfall at the mine calls for two considerations with regard to surface water management and mine water balance management. For surface water management, the sizing of the Pollution Control Dams (PCD) is driven by the storm water volumes generated on the surface infrastructure during short duration (one day to a few days) events. The PCDs need to be sized to ensure a risk of spill of 2% or less per year. At New Denmark Colliery, emergency overflows from the PCDs are drained to the environment, except for Stockyard Dam, which is used as a central dirty water storage dam. Water from this dirty water storage dam is treated in a plant at Tutuka Power Station. In the case of mine water balance management, during longer term extreme events (in the order of years), the management of the large volumes of water generated need to be considered in terms of the available storage, reuse and treatment options. The risk of spill from a PCD is a function of both dam capacity (for temporary storage of storm water runoff) and the rate at which water can be extracted from the dam for reuse or storage elsewhere.

The 2015 New Denmark Environmental Impact Assessment has an adaptation measure to store water from excessive rainfall in the Stockyard Dam. The net volume of water that may have to be stored is dependent on the length and intensity of excessive precipitation and runoff from elsewhere that passes through the mine's catchment area. The rainfall forecast models predict that the area will have incidents of high rainfall between the years 2035 and 2039. Furthermore, these models predict that the mine has to plan to store approximately 46 million cubic meters of water per annum. This water will need to be treated at the Tutuka Water Treatment Plant (New Denmark, 2015a). The New Denmark Coal Mines' Surface Water Report (2015b) states that during the wettest period, the total water surplus is modelled at approximately 53 million m^3. This means an additional 8 million m^3 will need to be stored during such an event. Consideration would be given to storing this water in a brine pond compartment should the need arise. During the dry season, water storage modelling indicates that the minimum volume of water stored underground was around 32 million m^3 in 2014, increasing to about 117 million m^3 in 2040. This will be sufficient to supply the mine's water needs during extended dry periods. The planned increase in water storage shows that the mine foresees declines in precipitation, hence the need to store more water for operations, should the need arise. Proactive water adaptation plans and actions are not only a challenge to the mines' operations, but post mining operations as well.

The Surface Water Report states that for the purpose of post closure, surface infrastructure at New Denmark Colliery will be demolished and removed from the site (New Denmark, 2015c). The site is set to be rehabilitated and equipped with free-water draining systems, including pollution control dams in opencast areas. This is to ensure that post rehabilitation, all surface runoff is clean, and can safely drain to the receiving environment (Ibid.). The water levels will be actively maintained below excessive levels by pumping to the Stockyard Dam. From there, water will be pumped to the water treatment plant and treated for reuse, sale or discharge to the natural river system.

From Figure 4.9 all months of the year from 1985 to 2007 show rainfall declines with the exception of August. August has a mean of 6.6 mm of rainfall and it is typically the second driest month after July. August is also characterized by heavy winds. In the period under review, the month is characterized by cases of extremely low rainfall occurring at an average frequency of once every two years and cases of extremely high rainfall occurring at an average frequency of once every four years. The extremity is measured against the season's typical average. Low rainfall and high temperatures result in dryness which is a perfect condition for wild-fire breakouts worsened by heavy winds. As such, August must be watched as a fire breakout high risk month at the mine and nearby environments.

4.8 MIST AND POOR VISIBILITY

The winter months are characterized by cases of mist. Figure 4.11 shows a typical misty winter morning in Standerton.

Figure 4.11 Misty Standerton road

Source: Author (Fieldwork, 2015).

While the mist is a typical winter occurrence, a cause for concern is that in Standerton the mist is becoming more intense and often lasts longer than expected. A community member's observation (Respondent 7) was that mist used to start at around 6 am and would disperse by around 7 am or 8 am. However, lately there have been changes in the dispersion time. Over a five- year period (2010 to 2015), mist began early and dispersed around 11 am, sometimes persisting until mid-day (12 noon). Heavy mist has been linked to a number of road traffic accidents on roads leading in and out of Kriel and Standerton during the past four years (Table 4.3). The cause of the accidents in all the cases has been poor visibility caused by mist in winter.

Table 4.3 News reports on road accidents in Mpumalanga

Year	Headline	Cause of accident	Area
April, 2013	Poor visibility may have led to crash (Enca.com).	Mist, poor visibility	Middelburg tollgate, Mpumalanga
July, 2015	Heavy mist causes 65 car pile-up on N12, News (24.com)	Mist, poor visibility	Middelburg tollgate, Mpumalanga
June, 2015	Heavy mist in Mpumalanga causes numerous accidents, (metrotel.co.za)	Mist, poor visibility	Near Ogies and Witbank
May 2015	N12 mist accident turns fatal Thick mist on the N12 highway leads to four casualties.	Mist, poor visibility	Witbank Mpumalanga
May, 2015	A multi-vehicle pileup believed to have been caused by mist occurred yesterday on the N12/ N4 split near Emalahleni in Mpumalanga, (sowetanlive.co.za)	Mist, poor visibility	Emalahleni in Mpumalanga
April, 2016	Mist causes multiple accidents in Ogies and Emalahleni, (mpumalanganews.co.za)	Mist, poor visibility	Ogies and Emalahleni, Mpumalanga
June, 2016	Heavy mist in Mpumalanga causes numerous accidents, (sabc.co.za)	Mist, poor visibility	Near Ogies and Witbank

Source: Author (Fieldwork, 2016)

As reflected in Table 4.3, mist conditions are frequently reported in the Mpumalanga Province. In fact, Aleke and Nhamo (2016) confirm the challenge of mist in mining operations. The authors recommend mining companies should gather information on fog and mist and publish it in a mine's communications strategy and/or GIS as this may add value as a climate change adaptation strategy. With regard to increasing fatalities caused by increasingly intense mist, the Witbank News and Lowvelder confirmed this status quo and stated:

> '*Mist accidents seem like a yearly occurrence as the winter season approaches. However the N12 quickly went from bad to worse on May 23 during heavy mist when a truck ploughed into a Bantam bakkie carrying four people all of whom have passed away' (*wWitbanknews.co.za, online)

The Lowvelder added:

> *'The heavy mist is expected to continue throughout the week. While traffic officials will be on stand-by for any assistance that road users may need, motorists are also called upon to drive with heightened awareness in order to avoid crashes.'* (lowvelder.co.za).

The provinces are responding to the mist challenge by erecting a number warning signs along the affected motorways. The New Denmark mine confirms the increases in the frequency, intensity and longevity of winter mist and smog in the areas. The mist does not affect transportation of coal from the mine to the power stations as the mine conveys its coal to Tutuka power station, using self-propelling rail carriages. However, a mine worker (Respondent 8) reported that the mist has prevented workers, contractors and consultants from driving into the mine, resulting in operations delays. The mine's environmental manager stated that currently, there were no adaptation plans to counter the impacts of mist-related work stoppages. The current intervention measure involves rescheduling some of the activities that cannot be performed during a period of poor visibility. While these and other climate change impacts are impacting mine operations, other impacts are projected to affect the mine closure and post- closure processes.

As part of managing some adverse mining impacts, particularly post mining impacts, the New Denmark's mine Environmental Impact Assessment report (New Denmark, 2011) states a need for the reseeding of indigenous grasses in all the affected areas. The mine's Terrestrial Ecological and Wetland Assessment (New Denmark, 2015d) state that the mine will need to re-establish the natural systems by reintroducing natural vegetation to encourage the restoration of the damaged soil and other parts of the habitat to its, or near its, original state. While the two mines Kriel and New Denmark operate as distinct entities at a micro level, their climate change management policies emanate from their mother company, Anglo American. The holding firm formulates the grand climate change policy and strategies to guide responses at mine level.

4.9 ANGLO AMERICAN CLIMATE CHANGE MANAGEMENT POLICIES AND STRATEGIES.

Given what emerged from the mines, an effort was made to trace climate change initiatives at the holding company level – Anglo American. The Anglo-Coal Sustainability Report (Anglo-Coal, 2015) states that there are four major drivers of climate change management. The first is the rising electricity costs. In South Africa, electricity prices have been rising by an average of 15% a year from 2013 to 2016. The tariffs are likely to continue to rise significantly in all markets (Eskom, 2012). The second major driver is the imminent carbon tax. The South African National Treasury (2011) states that emitters of different scopes of GHG emissions will be taxed according to the quantity of emissions they release into the atmosphere. The carbon tax will have a material financial impact on mining companies. The third pressure is from the markets, suppliers and customers. Anglo-Coal (2015) acknowledges that by 2020 most supply chains will be actively involved in reducing their Greenhouse Gas (GHG) Emissions due to buyers dictating emissions of their suppliers as well as customers. As part of these efforts the firms will be seeking alternative energy sources to lower their carbon footprint.

The fourth and last important driver, and the most significant to this study, is the physical impact of climate change to mine operations. Anglo American notes that climate change can cause significant adverse physical impacts to its operations, infrastructure and workers' health (CDP, 2015). Extreme weather events may disrupt operations, supply chains and transport infrastructure, or cause harm to employees and local communities. As such, it is important for mines to understand their vulnerabilities and exposure to climate change. The rising energy costs, carbon tax, customers' environmental consciousness and the physical impacts of climate change to mine operations demand effective responses from mining companies in the form of climate change management policies, strategies and actions that balance climate change mitigation and adaptation actions accordingly. Anglo American climate change management policies focus on both mitigation and adaptation. However, the policy terrain shows a bias towards climate change mitigation as shown in Table 4.4.

Table 4.4 Anglo American climate change mitigation and adaptation action comparison

Adaptation	Mitigation
1. Anglo American mines 'need to build internal agility to ensuring resilience to climate change in order to understand and respond to the carbon life-cycle risks and capitalize in opportunities of their products'. 2. Anglo American is working with recognized experts on climate science to help them understand and prioritize appropriate response measures to the potential physical impacts of climate change. 3. Anglo American has appointed a UK based Meteorological office to assess the potential impact of water availability and sea-level changes on the Minas-Rio project in Brazil.	1. US $180 million in capital expenditures to fund energy efficient technologies, employment of new technologies and research that will assist in development of low carbon technology such as fuel cells. 2. Methane to electricity Project: The capturing and conversion of methane which would otherwise have been vented preventing 2.5 million tonnes of CO^2-equivalent emissions from entering the atmosphere each year – but they generate 75MW of electricity. 3. New Denmark Mine, using a mobile flaring-off mechanism at a cost of US $13 million, is expected to reduce the mine's annual methane emissions by 15%. Flaring burns off methane, rendering it 18.5 times less harmful to the environment than venting. The project is estimated to generate more than US $8 million in revenue in its first decade through the sale of Certified Emission Reduction credits. 4. Co-ordination for a global carbon market and mechanisms which are supportive of low carbon technology. 5. Employee awareness on energy saves and carbon saving behaviour. 6. Implementation of an energy and carbon management and reporting tool to improve their performance in energy and carbon savings. 7. Assess the options for using low carbon-emission energy sources for their current and future operations. 8. Development of group-wide guidance for the performance management of energy and carbon, 9. Identify and implement opportunities for energy and carbon savings throughout our business and in new projects. 10. Establish a low-carbon technology research and implementation programme which enhances our options for long-term business agility. Integrate climate change considerations within our social investment and enterprise development activities. 11. Eco2Man, which is an abbreviation for energy and CO2 management, allows us to better

	understand our future energy consumption and GHG footprint over the life of an asset. This programme is linked to Anglo American's Group. 12. Technical Standard on energy and GHG emissions Management.

Source: Author (Compiled from Anglo American Sustainability Report, 2013, page 11)

Based on the assessment in Table 4.4 there are only three adaptation plans for different mines. This is in comparison to 12 climate change mitigation plans and actions, coupled with financial investments and research. The bias towards climate change mitigation corroborate the assertions made in Chapter One (Section 1.1) confirming a greater emphasis on mitigation relative to adaptation in the climate change management space at international climate change negotiation levels, national policies and strategies as well as at sectoral level. Despite this bias, the Anglo American group climate change policies of 2010 suggest that the company's climate change management approach gives equal consideration to climate change adaptation and mitigation climate change management. It states that:

> *"Anglo American believes that climate change is one of the defining challenges of our era. We recognize our responsibility to take action in addressing the causes* (mitigation) *of climate change and to assist in protecting* (adaptation) *our employees and assets, as well as our communities and the environment, against its potential impacts"(*Anglo American, 2013: 61).

Despite this explicit statement stating a balanced consideration of mitigation and adaptation, evidence shows a bias towards the former. At the time of this research, Kriel mine was piloting a photovoltaic (PV) project (Figure 4.12) in order to reduce its energy consumption costs and reliance on coal based electricity from Eskom as well as part of the plan to reduce its carbon footprint. The solar photovoltaic (PV) project is supplying electricity to the mine housing and office facilities only. The limited scope of application of the PV project was due to the limited ability of solar PV technology, specifically the power storage batteries' capacity to power all mining operations

Figure 4.12: Solar photovoltaic at Kriel Colliery

Source: Kriel Colliery, 2015

In an interview, the New Denmark Colliery's environmental manager, acknowledged that the Anglo American Group climate change management policies and strategy was biased more towards mitigation than adaptation. He stated that:

> '*there is a need for a paradigm shift as most studies have been focusing on how the mine impacts the environment, but there has not been studies on how changes in the environment affect mining" (extract from interview with New Denmark's' Environmental Manager 2016).*

Summing up, although this section discussed some adaptation practices at the New Denmark mine, these are largely reactive and traditional adaptation measures. Proactive climate change management policies and investments at the mine heavily focus on mitigation efforts. This is because climate change mitigation is influenced by a range of low carbon initiatives that are driven by a number of organizations that *inter alia* include Carbon Disclosure Project and the Blue Carbon Initiative. There are no similar initiatives and bodies driving the climate change adaptation agenda. In addition, Anglo American is a signatory to the Carbon Disclosure Project (CDP). To this end, with regard to mitigation, the organisation has collaborated with a United

Kingdom Company, Gemini Carbon, which focuses on improving emissions and specializes in Clean Development Mechanism projects and sustainable energy systems.

Anglo American suggests that the initiative has helped to reduce annual methane emissions at the New Denmark Colliery by 15 % per cent. With income derived from carbon credits, the company anticipated that the cost of the $1.3 million project would be fully recouped in approximately three years after its inception. Despite the dominance of climate change mitigation initiatives, the environmental manager emphasized the need for adaptation stating that climate is already changing and its impacts are already felt in the entire coal mining value chain, thus coal mines need to devise adaptation measures in order to survive these impacts. To facilitate this process the New Denmark mine needs to update its climate data collection methods and records. At the time of this research the mine was not collecting or keeping up-to-date records of some critical climate data that could assist the climate change adaptation process. In addition to engaging with Anglo American-owned mines, the research also gained access to another mine here called Mine X.

4.10 MINE X

Mine X is located in Kriel, and faces climatic conditions that are similar to Kriel Colliery. A noticeable feature, but similar to New Denmark mine in Standerton, is that Mine X is investing in dry coal processing technology as a proactive adaptation strategy to counter possible future water shortages (Carbon Disclosure Projects, 2015). However, at the time of this research the technology was rather less efficient when compared to conventional water-based coal processing. A 2009 climate change modelling report, commissioned by Mine X indicated that as a result of climate change, mean precipitation would likely decrease in the north-western regions of South Africa where some of the company's mining operations are situated. This presented an opportunity for the company to proactively develop water management strategies (Table 4.5).

Table 4.5: Water efficiency objectives and initiatives

Water efficiency initiatives	Water efficiency objectives
Water treatment for re-cycle	To build awareness and sustainable management practices around water risk related issues.
Passive water treatment	To ensure water license comprehensive compliance.
Dry processing	To create a water awareness culture within mine employees and surrounding communities.
Brine treatment technologies	To implement the Water Reclamation and Reuse policy.

Source: Mine X sustainability report, 2014

These strategies involve making provisions for water storage before operations are affected by water supply disruptions. Mine X is also investigating solutions to improve water efficiency, including water re-cycling, passive water treatment, dry-processing and brine treatment technologies. The main and most obvious advantage of dry processing of coal is that no water is required. In addition, the fact that the coal remains dry improves the heat value of the coal as opposed to wet processes where the final product is wet (Lehman, et al, 2008)). The major drawback of present dry- processing techniques is the poor separation efficiency and the high cut-point density. It is also difficult to control the quality of the product from dry coal processes. Dry-processing is, however, not applicable on all mines and with all coal types. The application of the technology needs to be assessed in each case. The low capital and operating costs may be very attractive, especially for small mines, but may lead to unrealistic expectations. While this is the case, given the current and projected declining rainfall patterns, this technology needs urgent improvement and adaptation by the coal mining sector (Bersin, 1987) Brine treatment, also known as reverse osmosis, is a process of removing salts and contaminants from brackish, sea or waste waters. Reverse osmosis produces a clean stream of high purity water, as well a smaller stream of waste, referred to as concentrate or brine (Lehman, *et al,* 2008).

The overall costs associated with these investments are: R2.5 million for water treatment technologies, R 1.5 million for water re-use and recycling; and R 1.5 million for brine treatment and Passive Water Treatment on the investigation of dry processing of coal (Mine X Annual report 2014). Furthermore, Mine Xs' Water Management Programme is actively pursuing water related opportunities by promoting responsible water management which is guided by its Climate Change Response Strategy (Carbon Disclosure Project, 2014). By the end of 2015 the company was able to determine its water footprint more accurately and was better equipped to determine specific intervention areas in order to meet the programme's objectives (Carbon Disclosure Project, 2014). Additionally, Mine X is managing the risk through a Water Management programme, which measures, plans and implements water use and storage projects through investigating possibilities of alternative water sources for its mining operations in anticipation of hotter, drier periods in the northern and western areas. From the above, it is clear that most of climate change concerns at Mine X concern surrounding water scarcity. This is not surprising given the area's high vulnerability to climate change induced droughts and decreases in rainfall which will result in water scarcity. This is a common concern for Kriel and New Denmark Collieries as well.

4.11 CONCLUSION

The research findings show that the most significant impact of climate change around the reviewed Mpumalanga Province coal mines related to declining rainfall. This decline is resident in the seasonal and monthly rainfall levels. Despite this notable change, there seems to be few adaptation plans in place to deal with impending climate change (and otherwise) induced drought, increasing temperatures, increasingly intense and prolonged smog and mist extremes throughout the entire mining value chain.

Although Kriel Colliery has sufficient underground water sources, the mine admitted that frequent and severe droughts will eventually deplete its underground water sources to levels that may affect its operations. To avoid this, the mine has water catchment dams where all rain water is channelled for later use in mining operations before it is retuned to water treatment dams to be recycled for further use at the mine. The flooding incident exposed the inadequacy of Kriel's discharge dams and their pumping capacity in an event of extreme rainfall, and the environmental manager noted that these had to be improved. Further operational problems are caused by heavy smog and mist. This affects visibility in and around the mine, especially in winter. Although the mine uses conveyor belts to transport its coal to the nearest power stations, contractors and consultants cannot enter or leave the mine during heavy mist or smog. These events are expected in winter, but due to climate change, they are becoming more frequent and are prolonged beyond expected times.

At the New Denmark Mine, water adaptation plans involve strategies which are surface water management and mine water balance management. In addition, water from PCDs is recycled for reuse in production. However, extreme rains risk spillage from PCDs which can result in Acid Mine Drainage. As such, dam and pumping capacity needs to be adequate to avoid runoffs. Although much of the climate change concern is during the production phase of the mining value chain, the mine has designed Stockyard Dams for water storage and drainage when the mine is closed, and for post-closure mine management purposes. This is to ensure that post rehabilitation, all surface runoff is clean, and can safely drain to the receiving environment. Furthermore reseeding of indigenous grasses needs to take place in all the affected areas to re-establish the natural systems by reintroducing natural vegetation to encourage restoration of the damaged soils and other parts of the habitat to its, or near its, original state.

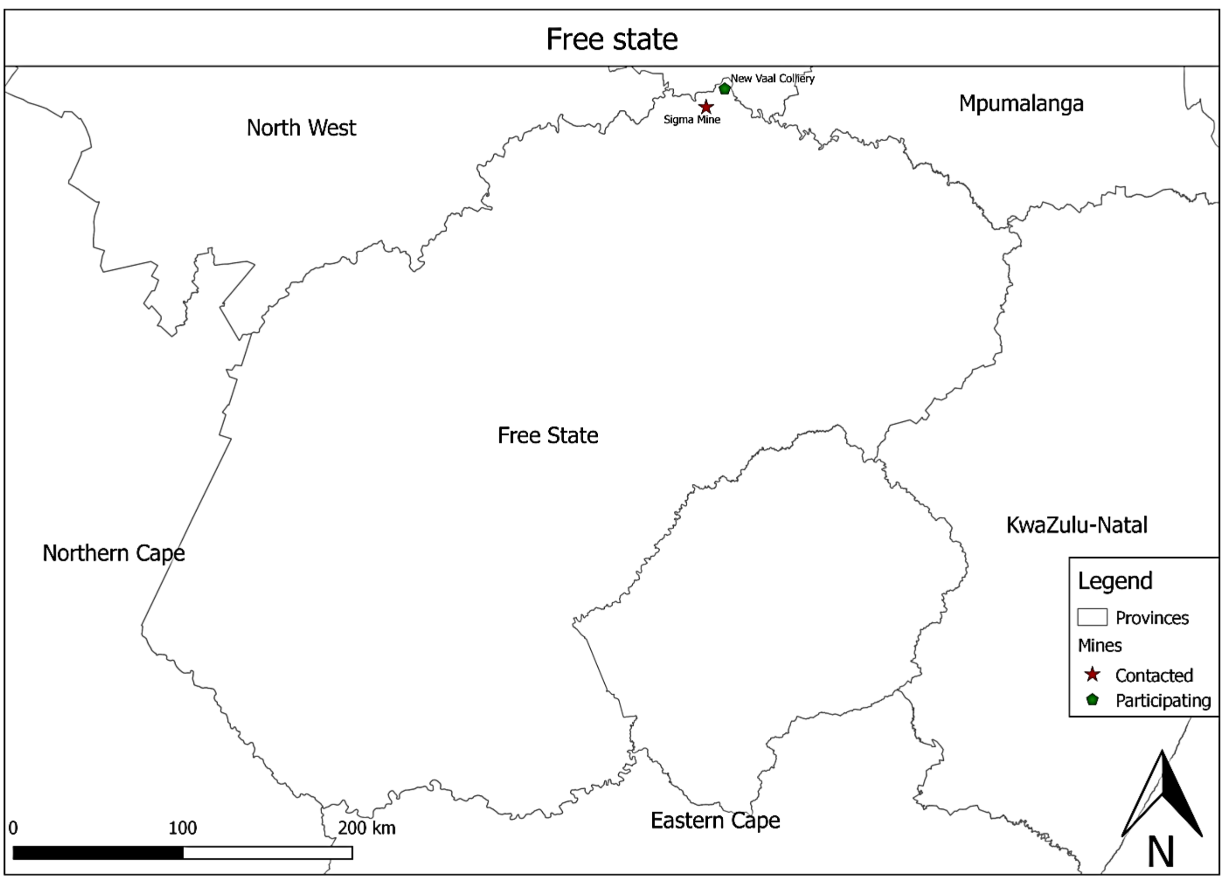
Attempts to restore the environment can be seen as a way to minimize climate change exposure to the already damaged environment especially the wetlands. Mine X is based in Kriel, and faces similar climate change exposures to those of Kriel Colliery. However, Mine X is more conscious of declining precipitation. It is the only mine that is exploring the possibility of adopting the dry coal processing technology as a proactive adaptation strategy to counter possible future water shortages. Common to both Kriel and New Denmark, Mine X plans to recycle used water, and it is ahead of the other two in passive water and brine treatment technologies. However, all these plans are placed at the production phase of the mining value chain. Based on reviewed documents and the responses from the interviews, Mine X had no climate change related plans for closure, post-closure or any other level for its future mining plans.

CHAPTER FIVE: CLIMATE CHANGE VULNERABILITY AND ADAPTATION STRATEGIES AT THE NEW VAAL COAL MINE

5.1 INTRODUCTION

This chapter presents analyses and discusses the research findings focusing on the vulnerability and exposure of Anglo American's New Vaal open-cast and underground coal mines which are located in the Free State Province of South Africa. Figure 5.1 shows participating and non-participating mines in the Free State Province As indicated in the methodology chapter, rainfall and temperature data were supplied by the SAWS situated in the Free State weather station(s).

Figure 5.1: Free State coal mines



Source: Author, 2015

The research sought to sample two mines in the Free State Province, the New Vaal Colliery and Sigma Coal Mine. However, Sigma Coal Mine, which is owned by Sasol, declined to participate stating that it was undergoing restructuring and thus could not adequately inform the study. As a result, the Free State Province's response to the research is informed by Anglo American's New Vaal. Mine Figure 5.2 shows the layout of the New Vaal Colliery.

Figure 5.2: New Vaal Colliery

Source: Google Maps (2015, 2016)

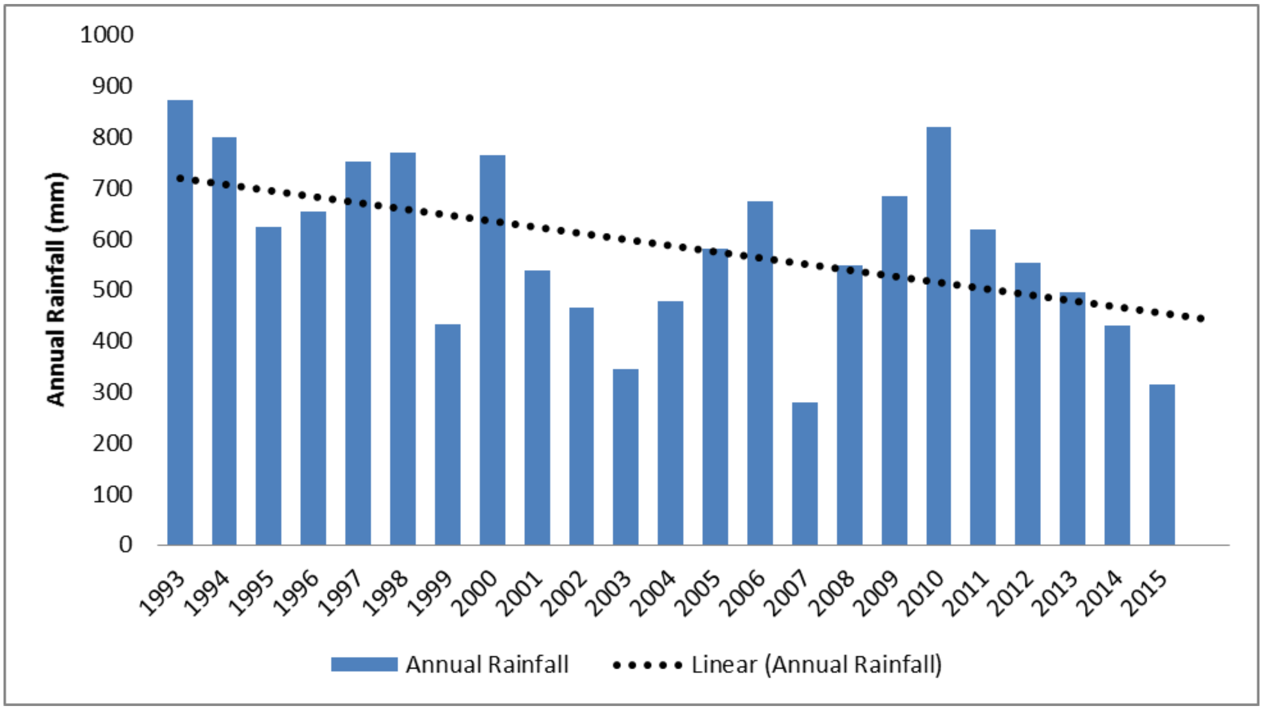
Anglo American's corporate climate change policy and strategies were presented in Chapter Four. As a result, this chapter solely presents and analyses climatic events that had an impact on the different operational levels at New Vaal mine and how the mine has responded to these impacts. The key informants at the New Vaal Mine included the Planning Manager, the Environmental Manager, the Environmental Officer, the Safety, Health Environment and Quality (SHEQ) Officer, and a section manager.

A major finding presented in this chapter is declining annual rainfall. The decline was particularly drastic in the 2015/2016 rain season resulting in the Department of Water and Sanitation declaring the Free State Province one of the drought affected provinces in South Africa (Department of Water and Sanitation, 2015). A close examination of the seasonal and monthly rainfall patterns shows that the area around the New Vaal Coal Mine has been receiving increased rainfall in winter but the summer rainfall is declining. The annual monthly maximum and minimum temperatures have been stable throughout the period under review. Nevertheless, there have been spikes in maximum temperatures that resulted in extreme heatwaves and lightning, while minimum temperatures plummeted resulting in increased and sustained fog. Details of the associated rainfall and temperatures trends, their effect and the different responses by the New Vaal Mine are presented in the following sections.

5.2 RAINFALL PATTERN

The Free State Province has witnessed an overall decline in precipitation. Noteworthy in this decline is the high frequency of extremely low rainfall incidents. Figure 5.3 shows that annual rainfall has been on a steady decline. This decline is indicative of the overall national rainfall pattern as noted by the South African Weather Service (2015). In the period under review, the lowest recorded rainfall cases were in 2007 with an annual total rainfall of 279mm, and in 2015 which received 315mm. Rainfall records by the Department of Water and Sanitation (DWS) for the period September to October 2015 show that early spring did not yield the anticipated rainfall.

Figure 5.3: Annual average rainfall and temperatures in the Free State



Source: South African Weather Service (2015)

The uncharacteristic 2015 dry and hot weather conditions experienced in Southern Africa were largely attributed to the El Niño phenomenon. The phenomenon arises from an oscillation of the ocean-atmosphere system in the tropical Pacific having important consequences for weather around the globe (Borlace *et al*, 2014). It is characterised by unusually warm ocean temperatures in the Equatorial Pacific, as opposed to La Niña, which is characterised by unusually cold ocean temperatures in the Equatorial Pacific. These two climate phenomena result in extended periods of low rainfall in parts of the world that include Southern Africa and flooding in areas such as the United States of America and Peru respectively.

The El Niño phenomenon is thought to be a natural weather event that happens periodically. A study by Cobb (2015) links the increased variability and intensity of the phenomenon to the increasing presence of GHGs in the atmosphere. This finding links El Niño to climate change. In 2016, the impact of climate change on rainfall scarcity was acknowledged by the Minister of the

Department of Water and Sanitation, Ms Nomvula Mokonyane. The Minister reiterated that water supply challenges in water-scarce South Africa were being exacerbated by climate change-induced declines in annual rainfall (Department of Water and Sanitation, 2015). The low rainfall is affecting river water levels and the social and economic activities that rely on these waters. Low water levels at the Vaal River have direct and indirect consequences for the New Vaal Mine. The New Vaal Safety, Health, Environment and Quality, (SHEQ) manager noted that although the New Vaal Mine has sufficient water sources for its operations, droughts often result in water shortages in the surrounding communities. This meant that under drought conditions the mine and the community increasingly share the limited water from the Vaal River, putting pressure on the river and increasing the risk of water contamination from effluent spillages, which cannot be effectively diluted by large water volumes in a normal rain season in the area and upstream.

Although rainfall has been on a steady decline over the 23-year-period under review, there have been cases of extremely high rainfall. Notable cases include 872mm of precipitation in 1993, and 818mm in 2010. The unexpectedly high rainfall flooded the New Vaal Coal's underground mine, raising questions about mine adaptation. The New Vaal planning manager, who at the time of this research had been working for the mine for 6 years, stated that although flooding was rare, incidents of flooding whenever they occurred were becoming increasingly severe and lasting longer than usual. The last serious flood case he remembered was in December 2010. This flooding event recorded the second highest amount of seasonal rainfall at 208mm. There was another flooding event in January 2011 with 234mm of rain recorded during the month. December 2010 flooding affected transport routes and resulted in operations suspension for two days. The 2010 flooding was reflected in the New Vaal Sustainability Report of 2010 which stated that:

> *"Heavy rain fell on 15 December 2010. All trucking and loading operations were stopped during this time. Operators spent the day pumping water from the pits in order to have the mine back in operation the next day"* Extract from Anglo American (2013:16).

Despite such cases of flooding the overall trend is that of declining average annual rainfall. The declining average rainfall is from seasonal declines as outlined in the following section.

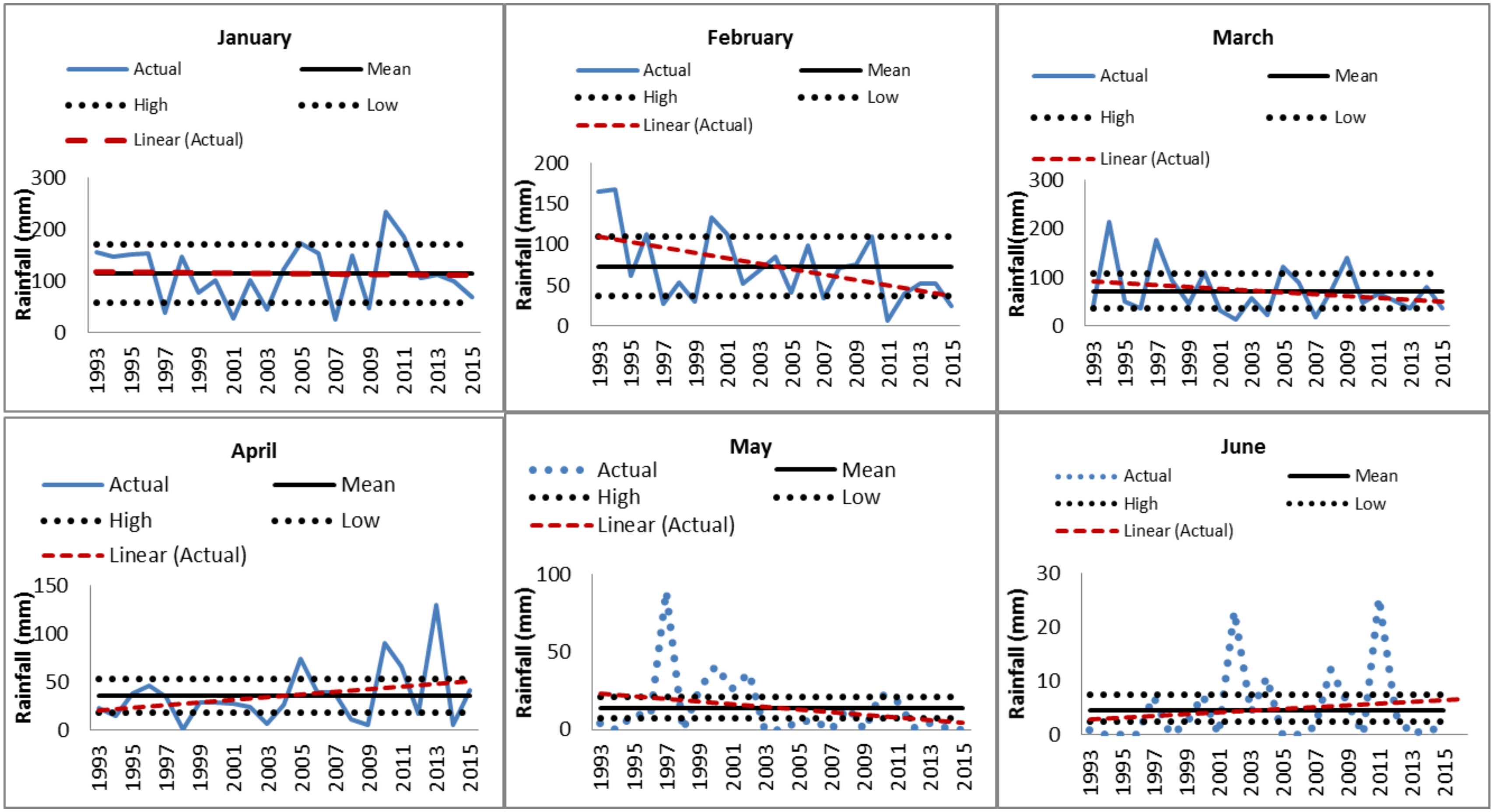
5.3. Monthly and seasonal rainfall variations

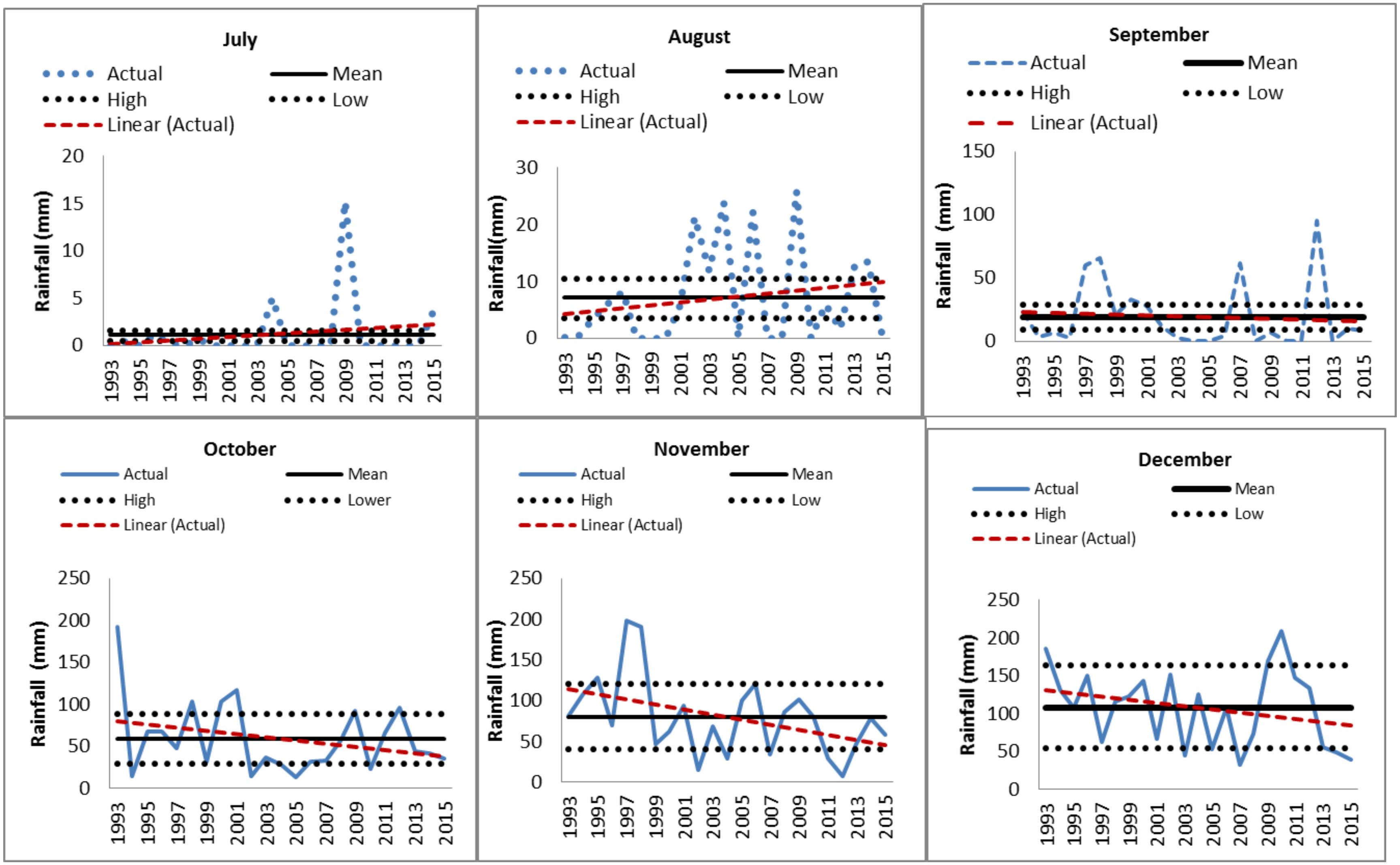
The monthly average rainfall for the area around the New Vaal Coal Mine for the period 1993 to 2015 is shown in Figure 5.4. The summer season is represented by the solid bold pattern line and the winter season is represented by the dotted pattern line. The figure also shows the cases of extremely low and high rainfall incidences over the same period of time. The extreme highs and lows have been defined as any rainfall amounts that are either 50% above or below the mean rainfall respectively (South African Weather Service, 2015). The wet season is denoted by months with solid data pattern lines while the months with dotted data series line constitute dry season (SAWS, 2015).

Figure 5.4 shows that on average, the area around New Vaal Coal Mine received its highest rainfall in December and January. The average rainfall for the two months in the period under review is 100mm. This is considerably higher than the rest of the summer months. With January and December receiving the highest rainfall, it is not surprising that the severe flooding incidences on record are in these months. For example, on 6th January 2011, the New Vaal open-cast mine was flooded. The flooding lasted for 4 days from the 6th to the 10th. The day before the flooding, the mine recorded the second highest amount of rainfall for 2011 with 44mm. The resulting flood halted work at the mine and delayed operations which caused lost production time. In addition to affecting production work at the mine, flooding events have the potential to affect supply and delivery of personnel, supplies and machine parts to the mine, by damaging roads that lead to and within the mine. Despite this severe flooding incident, the mine has not changed its mining procedure. However it has updated its rain readiness plan.

A notable update of the flooding readiness plan is the change in flood management and mitigating procedures. During the January flooding, the New Vaal Mine only followed its usual flood management and mitigating procedure of removing equipment which was in the proximity of possible flood zones in case the flood protection levee failed. In addition, the engineers and environmental officers assessed the water levels at four-hourly intervals. Equipment was moved back to the work sites only when the water level of the river had receded to a measure deemed safe to resume work. However, this procedure needs to be improved.

Figure 5.4: Monthly and seasonal rainfall at the New Vaal



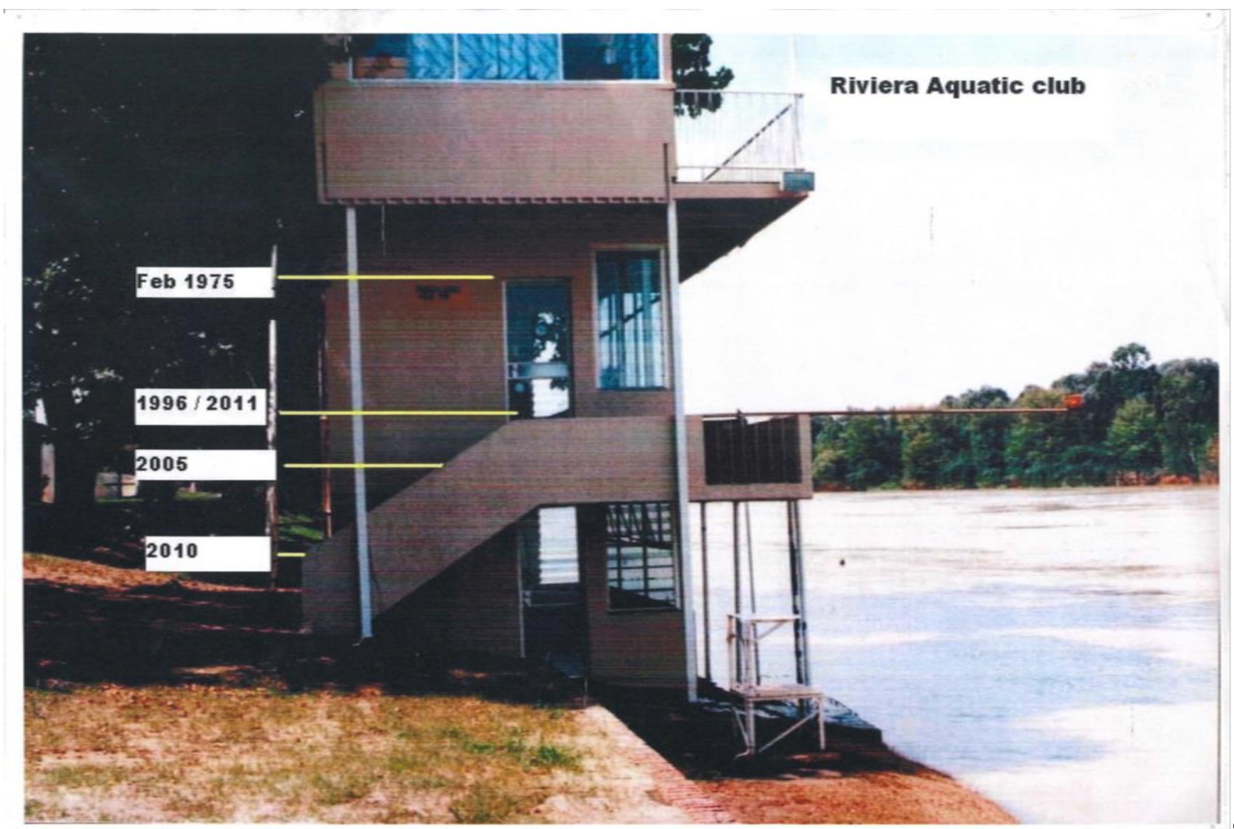


Source: South African Weather Service, 2015

According to the New Vaal Coal Mine's Environmental Officer, proactive adaptation action could include analysing historic climate data and monitoring weather patterns to ensure that infrastructure has the capacity to deal with flood events. As such, rainfall data observation and ongoing analysis of historic rainfall patterns as shown in Figure 5.5 are an integral part of climate change adaptation planning.

As is the case with Kriel and Standerton, flooding at the New Vaal Coal Mine is not due to consistent increases in rainfall, but due to single intense rainfall events. This is illustrated by the fact that although the year 2011 had relatively low annual rainfall collectively, on 11 March, the Rand Water Management Authority reported that the Vaal Dam was overflowing having reached 105% of its capacity after an incident of week-long incessant rainfall. A common practice in flood defense in mines is the incorporation of flood levees protection during mine design and flood early-warning systems during mine operation as shown on Figure 5.5.

Figure 5.5: New Vaal Coal Mine's flooding early warning system



Source: New Vaal Coal Mine (2015)

The line markings on the wall show levels which the Vaal River reached historically, the highest being in February 1976 and the lowest in 2010. Towards the edge of the river is a bar that has an alarm attached to it. When water levels reach the bar, the alarm is triggered and warns the mine of imminent flooding at the mine as was the case on 11 March 2011. It is important to note that adaptation measures carry pecuniary implications. Given that money is not always available, it becomes important that expenditure on adaptation measures is directed by the importance and criticality of that measure. This importance and criticality can be determined by the likelihood of the occurrence of an event that an adaptation measure seeks to manage. In this case, an analysis of the frequency and if possible, the intensity of rainfall is critical for proactive flood management adaptation practices.

Historical monthly and seasonal rainfall analysis as shown in Table 5.2 can assist the mine in determining the relative frequency of extreme rainfall incidents. In this case, the number of extreme rainfall occurrences, either high or low, was divided by the total number of years (23 years) under consideration as shown on Table 5.2 to determine percentage of occurrence probability. The table shows that the number of extremely high rainfall events is lower than the cases of extremely low rainfall in the last 23 years. This is shown by the total number of actual extremely high rainfall events which stand at 40 compared to 67 incidents of extremely low rainfall in the period under review. The relative frequency of these events shows the low probability (0.4 to 13 percent) of extremely high rainfall events during the rainy season compared to the high probability (13-22 percent) of low rainfall events over the same season. The dry season also shows a similar trend.

Table 5.1: Monthly mean and annual extreme rainfall frequencies and number of occurrences from 1993 to 2015

Month	Mean (mm)	Number of extremely high rainfall events in 22 years	Extremely high rainfall (mm) relative frequency (X % in 22 years)	Number of extremely low rainfall in 22 years	Extremely low rainfall (mm) relative frequency (X % in 22 years)
January	114	1/22	0.4%	5/22	22 %
February	72	2/22	0.9%	4/22	18 %
March	72	4/22	18 %	3/22	13 %
April	35	3/22	13 %	5/22	22 %
May	13	4/22	18 %	7/22	31 %
June	4	4/22	18 %	8/22	36%
July	1	2/22	13 %	7/22	31 %
August	7	5/22	22 %	8/22	36 %
September	19	5/22	22 %	9/22	40%
October	58	5/22	22 %	4/22	18 %
November	79	3/22	13 %	4/22	18 %
December	107	2/22	0.9%	3/22	13 %
		Total number of extremely high rainfall: 40		Total number of extremely Low rainfall: 67	

Source: Author, 2015

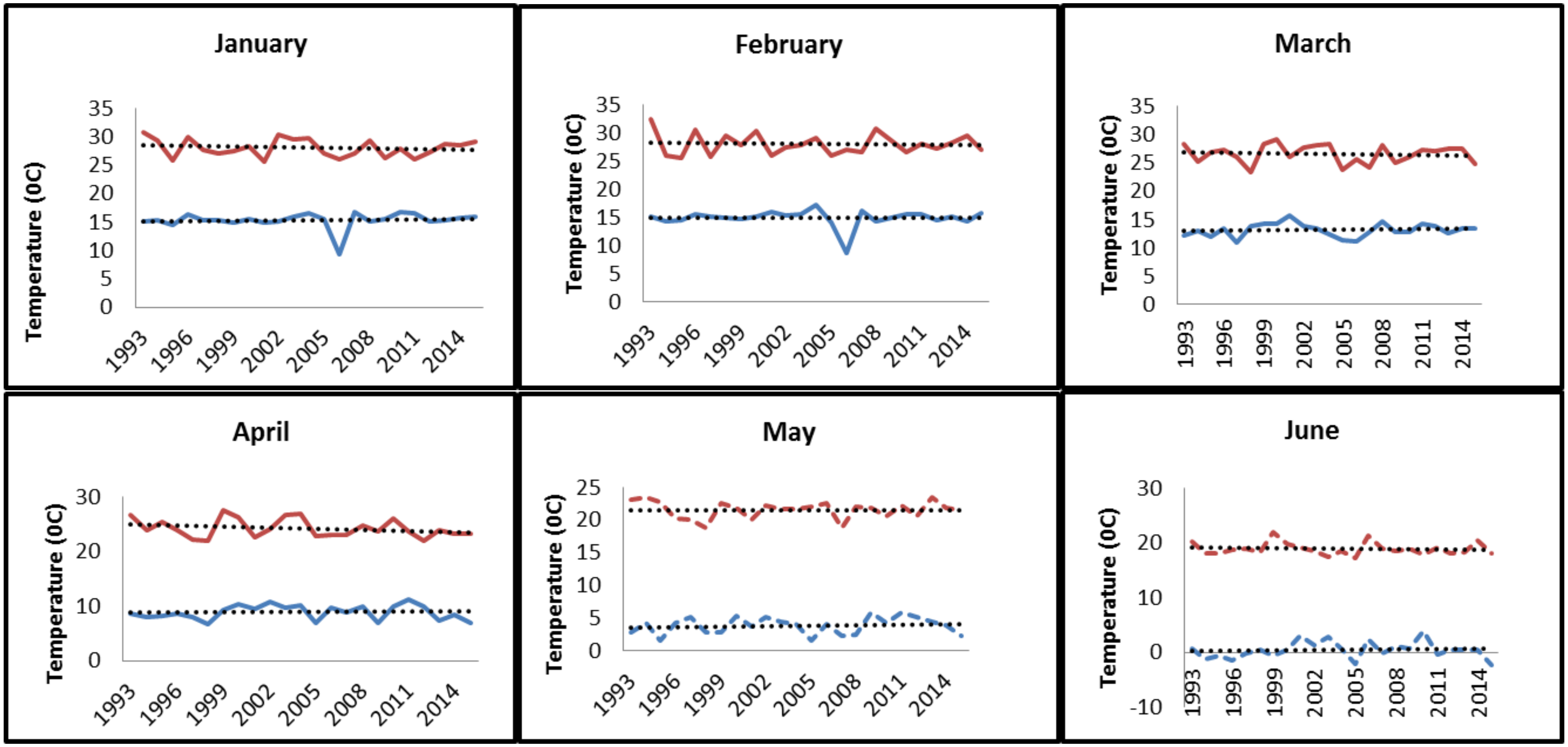
A lesson from this is that droughts and its related challenges are more likely to manifest in the New Vaal Mine region than cases of flooding. This has very important planning implications for the mine. The mine has to weigh and compare the impact of floods and droughts on its operations and thereafter direct its adaptation spending accordingly. A desired outcome is one that adapts to both excess rainfall and flooding on one hand and drought and water shortages on the other hand.

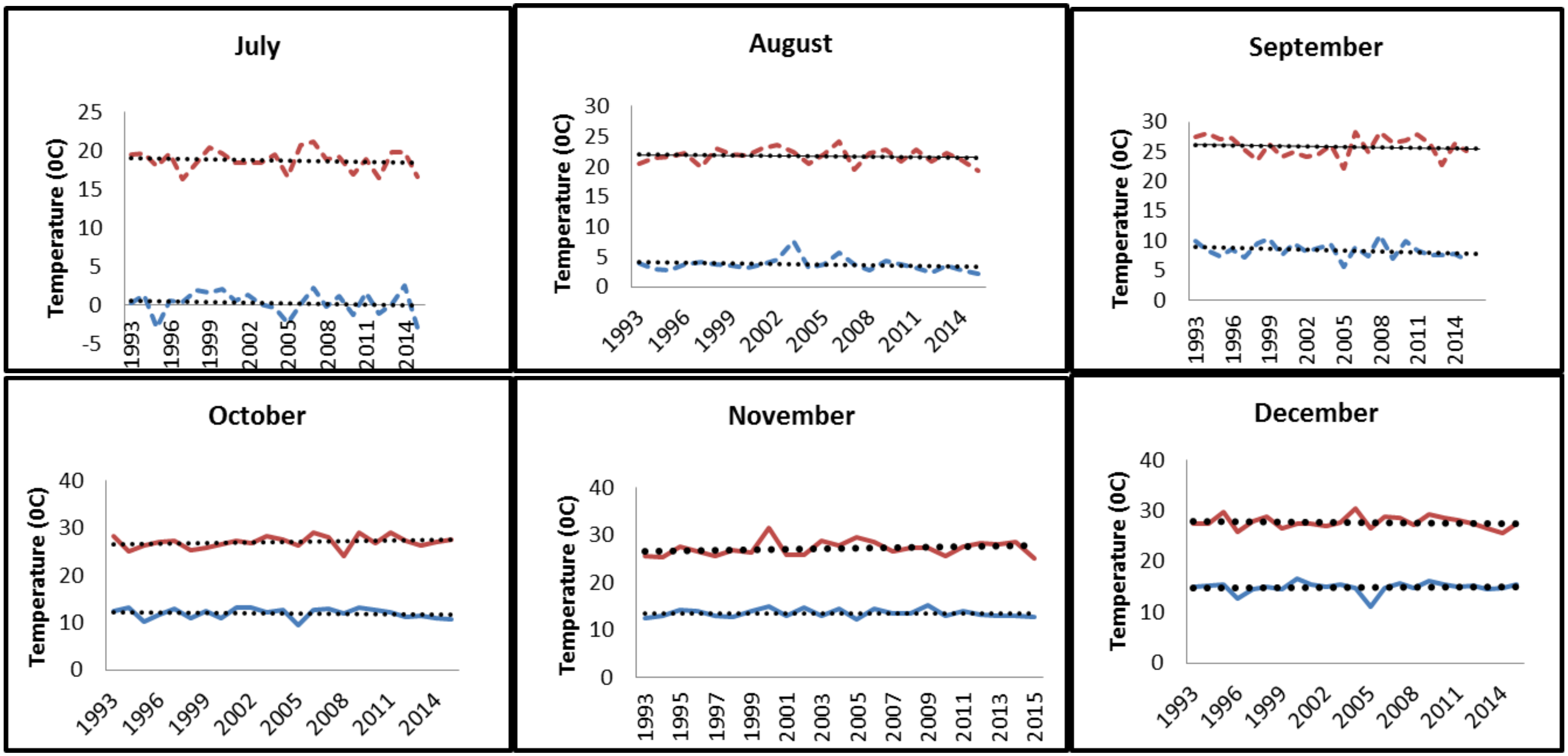
Rainfall is determined by a number of factors that include ambient temperature, winds and other factors. The next section analyzes temperature patterns and their impact at the New Vaal Coal Mine. Figure 5.6 shows the monthly (and seasonal) maximum and minimum temperatures from 1993 to 2015. The summer season is represented by the solid bold pattern line and the winter season is represented by the dotted pattern line.

Figure 5.6 shows that both maximum and minimum temperatures at the New Vaal Coal Mine area have been stable in the last 23-year-period under review. As expected, summer temperatures typically reach highs of 30^0C and above, especially in January and December. The year 2015 recorded the highest temperatures globally, with January, February and March setting new high-temperature records, since record keeping started 136 years ago (National Oceanic and Atmospheric Administration, NOAA, 2015). However, by the time of finalizing this work, indications were that 2016 could well surpass 2015 (Le Page, 2016). The global temperatures of 2015 sparked a series of heatwaves and lightning strikes in all nine provinces of South Africa, including the Free State Province. The high temperature coupled with low rainfall resulted in a significant drop in the Vaal River water levels, prompting the New Vaal Mine to review its water access and use practices.

The SHEQ manager of the New Vaal Colliery, the Environmental Manager, and other officers all concurred that heatwaves, such as the one experienced in 2015, typically result in employees experiencing heat fatigue and other severe associated conditions, with some even suffering from heat stroke. In a mining environment with its inherent hazards, fatigue management is important to prevent heat-fatigue related accidents. As a response to increasing temperature, the New Vaal SHEQ manager stated that New Vaal's underground mine has increased underground cooling systems. These are controlled by the on-site Demand Side Management (DSM) system that controls energy demands based on underground temperatures.

Figure 5.6: Maximum and minimum temperatures at the New Vaal





Source: Author, 2016

High temperatures also typically attract lightning. The New Vaal Mine has suffered a temperature-related lightning strike incident. The company's coal sustainability report (2013) indicated that on 10 January 2012 at around 18:00, a contractor's haulage truck was struck by lightning. After the strike, the concerned truck was not used for a week to ensure no fire had started in the tyres. Despite this, the mine has not enhanced nor changed its lightning protection process. It continues to rely on its lightning warning procedure that uses the lightning detector circuit. The lightning detector circuit is a very sensitive static electricity detector that can provide early warning of approaching storms three kilometers away, before an earth-to-sky return lightning strike takes place. The circuit emits an audible warning tone or flashes a light-emitting diode (LED) for each discharge detected, giving advance warning of impending storms so that precautions may be observed.

While the minimum winter temperatures appear to be generally stable, an exception is in August and September, which show a steady decline. Low temperatures are synonymous with fog in areas close to power stations. A case of severe fog was recorded in August 2012. This fog resulted in work stoppage due to poor visibility that rendered operations unsafe. Based on questionnaire responses, fog is becoming frequent, more intense and lasting longer than usual. The SHEQ manager stated that the mine has no adaptation measures against poor visibility caused by fog, except for work stoppage. This makes meeting production targets a challenge.

To sum up, the New Vaal Coal Mine climate change vulnerability assessment revealed that the mine is vulnerable to flooding due to its proximity to the Vaal River. As such, the mine has updated its flood defense wall and flood early-warning systems. The area around the mine is also vulnerable to drought due to the declining rainfall and less than expected seasonal rainfall, especially in summer. Although the mine is not short of water supply at the moment, successive and increasingly intense droughts are likely to cause problems in the future. As such, proactive adaptation plans dealing with possible water shortages need to be devised. Although temperatures are fairly stable, there have been spikes of high temperature that resulted in lightning strikes. Low temperatures have attracted increased cases of fog that at times result in poor visibility. At the time of this research, the mine had no adaptation plans to proactively minimize or prevent the adverse impacts of these problems.

5.5 CONCLUSION

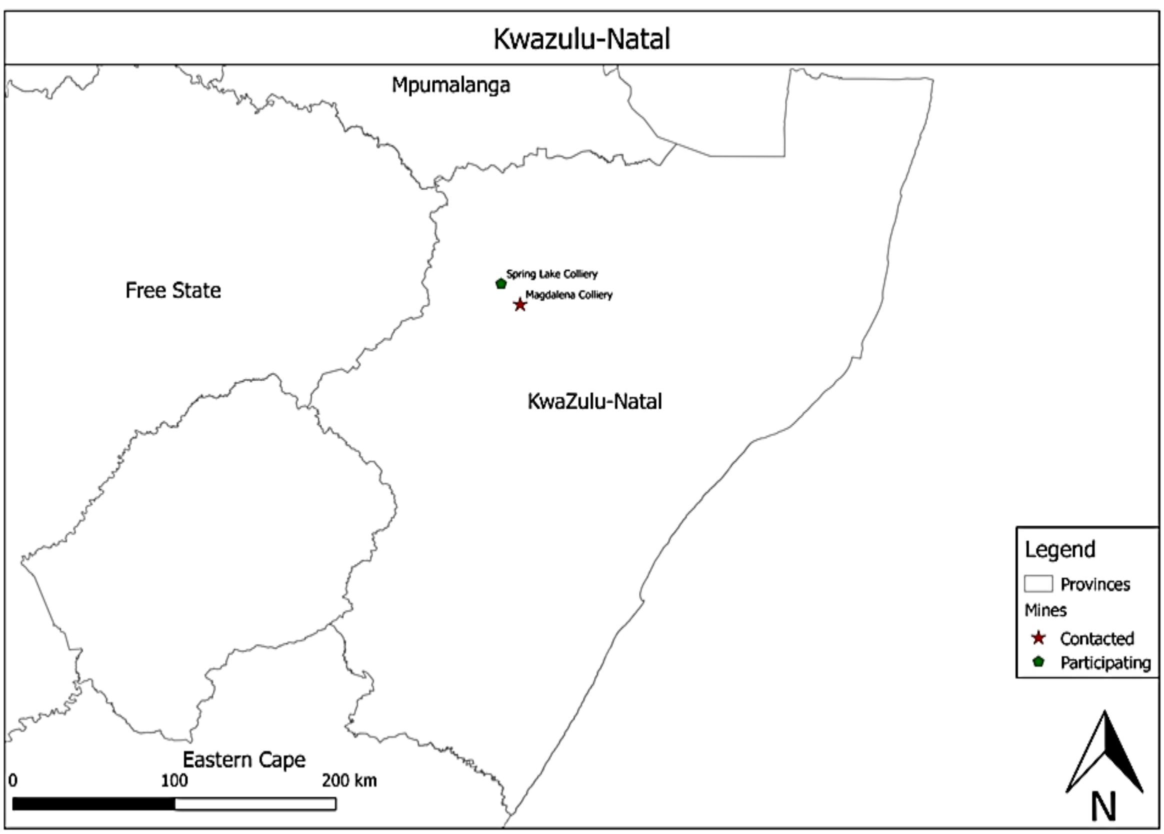
This chapter presented climate change evidence around the New Vaal Coal Mine and how these have impacted and are projected to impact different operational levels at the mine. With each impact, some adaptation actions and shortcomings were discussed. Rainfall data shows that precipitation has been on a steady decline particularly in summer - the traditional rainy season. This decline is the cause of chronic and frequent droughts in the Free State Province. Indications are that the frequency and severity of these droughts will increase resulting in competition and conflicts around the use of water between surrounding communities and mines dependent on the Vaal River content. While occasional droughts such as the one in 2015, driven by phenomena such as the El Nino, are a natural and an expected occurrence, the impact of climate change on the intensity of the phenomena is a cause for concern. Mines have to adapt to these changes. An important issue is that adaptation to drought has to be undertaken simultaneously with adaptation to acute flooding whose severity can also be as devastating as droughts. While precipitation concerns often dominate the climate change adaptation discourse, the New Vaal Mine issues show the significance of concerns around ambient temperature which result in deleterious side effects, most notably lightning and fog. This indicates the need for adaptation plans that consider all the climate change outcomes that could affect mining operations in all the stages of the mining value chain.

CHAPTER SIX: CLIMATE CHANGE VULNERABILITY AND ADAPTATION STRATEGIES FROM KWA ZULU-NATAL COAL FIELDS

6.1 INTRODUCTION

This chapter presents analyses and discusses the research findings on climate change vulnerability and management with a specific focus on adaptation policies and practices at the Spring Lake Coal Mine (Figure 6.1) located in the town of Dundee in the Endumeni Municipality of the KwaZulu-Natal Province. Magdelina Coal Mine, located in the same area and owned by Buffalo Coal Private Limited, declined to participate in the study. As indicated in the methodology chapter, rainfall and temperature data was supplied by the SAWS from weather station(s) in the province and most relevant stations close to the mine.

Figure 6.1: Springlake and Magdelina Coal Mines



Source: Author, 2016

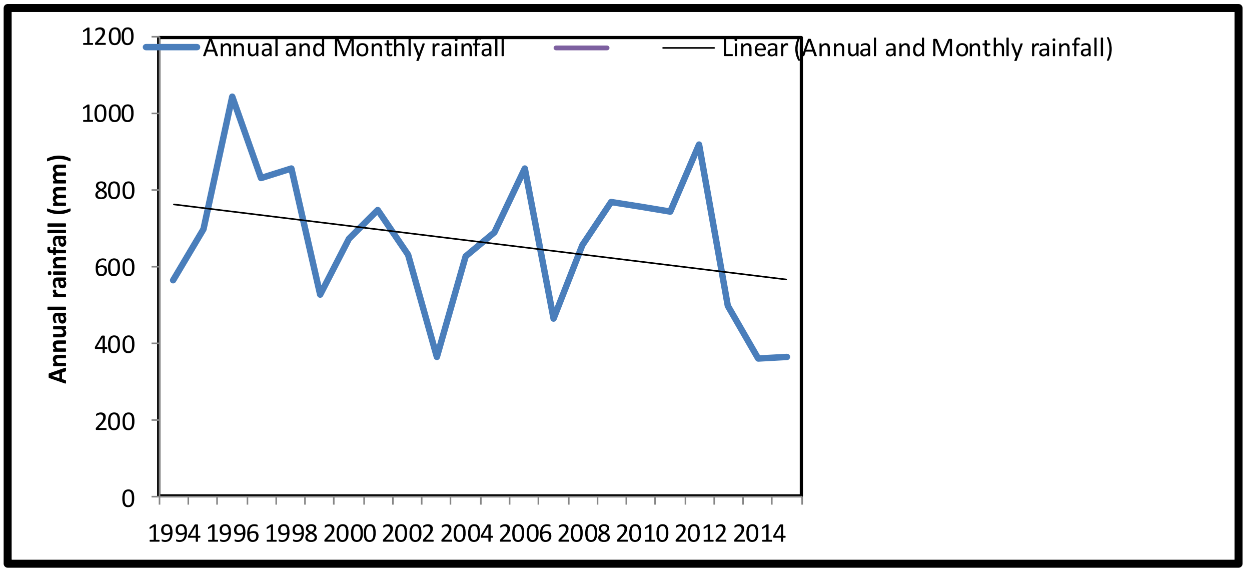
Spring Lake Mine earned its name due to its proximity to a lake. The lake's water is green in colour. Greenpeace (2015), states that changes in water colour near mines are a typical sign of Acid Mine Drainage (AMD). The acidic water arises from chemical reaction in sulphur-bearing mineral pyrite rocks that are exposed to water and oxygen caused by excavation activities such as mining (South African Chamber of Mines, 2011). Spring Lake Coal Mine is owned by Shanduka Coal Private Limited. Shanduka Coal is controlled by Glencore International AG. The mine has been in operation for 30 years and is South Africa's largest producer of anthracite coal. The underground operation consists of one incline shaft and one vertical shaft with the deepest mining taking place 120 metres below the surface. The opencast operation comprises two pits which are mined to an average depth of 30 metres (South African Chamber of Mines, 2011). A review of the mine's climate change management policies, acknowledgements and response shows that Shanduka has not been reporting on the Carbon Disclosure Project (CDP). In fact there were no publicly available and accessible documents relating to the mine's exposure, vulnerability and climate change adaptations plans and actions. However, the controlling company, Glencore, has been reporting and publishing its reports, but only for its New Zealand operations (CDP, 2015). As such, much of the mine's adaptation plans and analysis, especially with regard to drought and flooding are based on the provincial authority's and municipality's reactions.

The research made three major findings around the Spring Lake Coal Mines. The first notably finding is that Spring Lake Coal Mine sources its water from the municipal dam. This means that the municipality directly controls the mines' water use. Furthermore, it implies that the mine is directly affected by water problems that affect the surrounding community. The second major finding is that Spring Lake Coal Mine faces the double impact of climate change relating to the decreases in water availability due to an overall decline in annual rainfall and frequent flooding from extremely high rainfall events, especially in winter. The third finding is that the most prominent climate-related hazard is the incidence of fire outbreaks. Fire outbreaks have been on the increase particularly in summer due to rising temperature and the dry environment. Details of these major findings and associated reactions are discussed in the following sections.

6.2 ANNUAL RAINFALL TRENDS IN DUNDEE

The trend in the climate conditions in the Dundee area is not too different from those in the Kriel, Standerton mines in the Mpumalanga Province and the New Vaal Mine in the Free State Province. Figure 6.2 shows that rainfall has been on a steady decline since 1994.

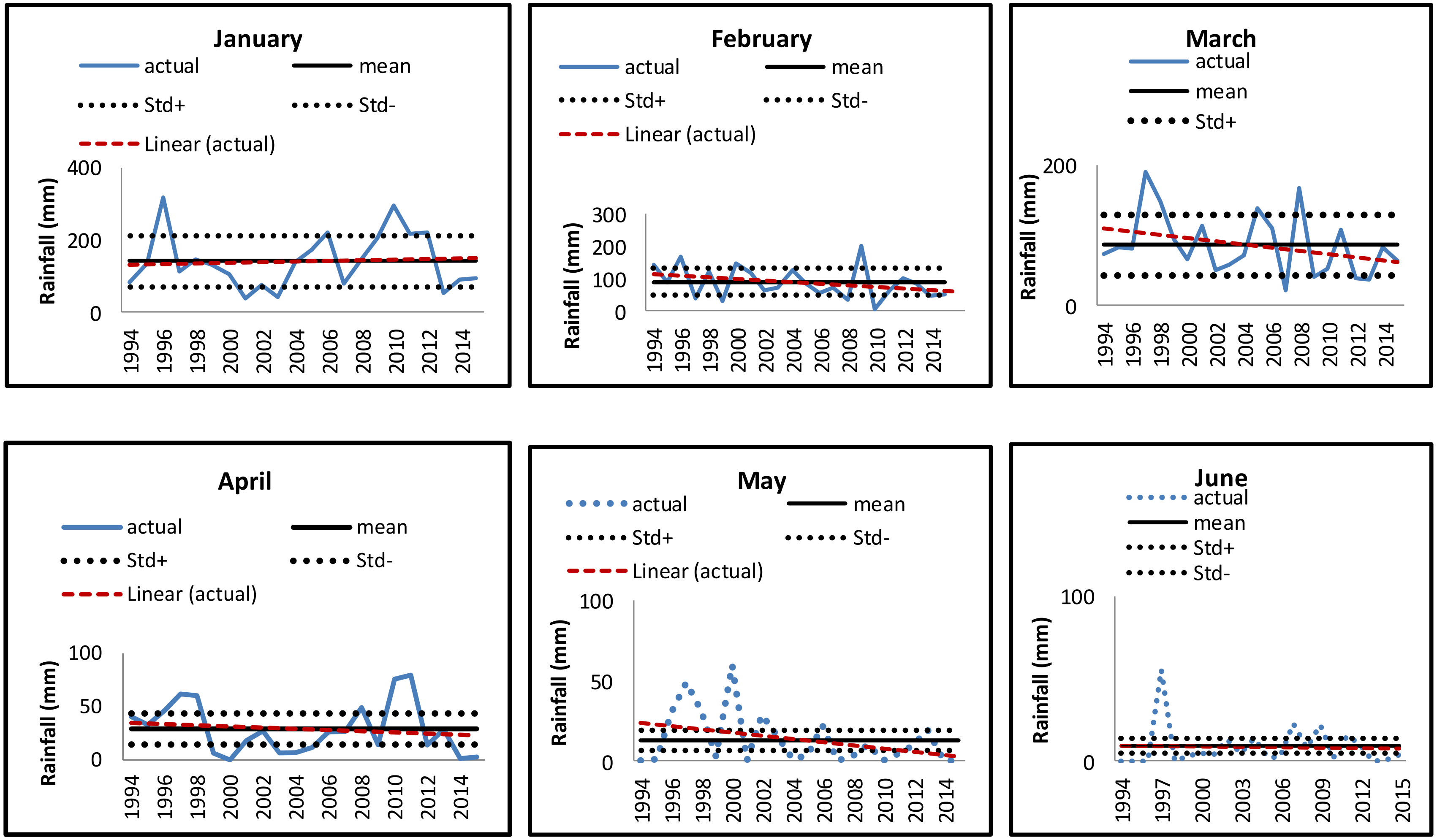
Figure 6.2: Annual rainfall in Dundee

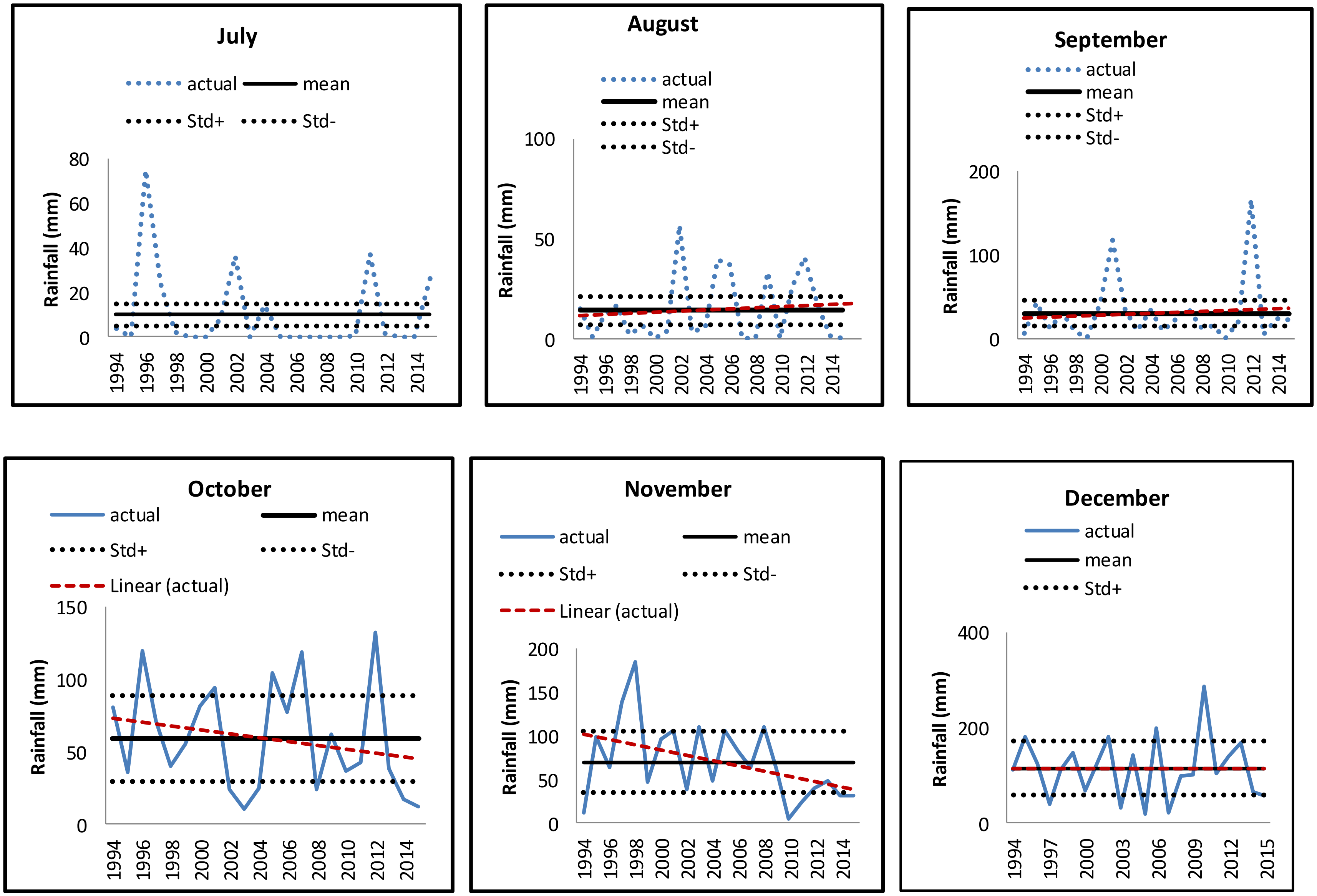


Source: Author, 2015

The decline in rainfall has been steady, leading to the 2015/16 season being the driest in over 70 years in this area (South African Weather Service, 2015). The declining rainfall has led to a decline in water levels in the various water reservoirs. This is a cause for concern for a country where 77% of its water for domestic and commercial use comes from rainfall, 14% is recycled from water treatment plants and nine percent comes from ground water. The declining rainfall is threatening this water supply and indirectly, South Africa's development efforts. The effect of climate change on seasonal and monthly rainfall pattern presents a dual challenge of increased severity of droughts and flooding from extremely high rainfall events. In the period under review, the Dundee area has been experiencing higher cases of droughts compared to cases of floods. Figure 6.3 shows seasonal and monthly rainfall analysis in the Dundee area. The summer season is represented by the solid bold pattern line and the winter season is represented by the dotted pattern line.

Figure 6.3: Seasonal and monthly rainfall analysis in Dundee





Source: South African Weather Service, 2016

Figure 6.3 shows that the summer season, typically the rainy season, has been experiencing rainfall declines over the 23-year-period under review. The summer months that have experienced the sharpest declines are October and November. For instance, in 1994 the month of October recorded 80mm of rain and this declined to only 40mm in 2015. Similarly, November 1994 recorded 100mm of rain and only 40mm in 2015. This decline is steeper compared to the months of January, September and December, which have seen a slight increase in rainfall. This means that the slight increases have not been adequate to offset or even mitigate the sharp declines of October and November. The consequence is reduced water inflows into the area's dams leading to water use and supply restrictions that are affecting domestic and commercial activities, including coal mining.

The Endumeni Municipality is mitigating the water shortage by pumping water from other sources. At the time of this research, the Municipality was pumping water from the Chelmsford Dam into the Buffalo River, its main source of water. However, continued access to water from Chelmsford Dam was not guaranteed because the water levels at that dam were declining rapidly as it also serves the Newcastle, Dannhauser and Nquthu Municipalities in the KwaZulu-Natal Province. The water availability and supply problems have been worsening over the years and have become more pronounced during the last three years of the period under review. The Minister of Water and Sanitation tagged climate change as the reason for the water shortages and advised farmers to devise adaptation strategies in order to deal with the changes (Department of Water and Sanitation, 2015). The Minister's remarks marked the first time that a government minister in this portfolio identified climate change as a cause for what has been traditionally viewed as 'normal and natural' changes in the weather pattern. As a result of the severity of the 2015 drought, the Endumeni Municipality imposed water restrictions and began planning for a sea water desalination programme as one of the long-lasting solutions. Water desalination is a process of removing salt and other particles from sea water making it potable. Additional plans to deal with the drought crisis include rehabilitating the old water system by repairing leaks and replacing some worn-out potable water pipes as well as the drilling of boreholes (Department of Water and Sanitation, 2015).

Despite the laudable intent of these plans, it is important to note that water restrictions cannot be a permanent nor a desired long-term solution because demand for water by water intensive operations such as Spring Lake Coal Mine can only intensify in dry and hot conditions. It is equally important to note that while water desalination is a plausible approach to addressing drought-induced water supply challenges, desalination is energy intensive and an expensive process. The drilling of boreholes also means access to limited underground water whose level and quantity is dependent on the amount of rainfall. Despite the plausibility of all these interventions that seek to address the area's water challenges, the importance of a normal rainfall season remains critical. This was emphasized by the KwaZulu-Natal's Provincial Cooperative governance spokesperson at the time who said;

> *"Some teams have already been sent to investigate the possibility of desalination plants (and other solutions) that can be utilized. But we* [still] *need rain. The rain must fall, and it must fall soon"*

Another important issue to emerge from a close examination of rainfall patterns in the area is the increasing frequency and number of extreme low rainfall events in the 23 year period under review. Table 6.1 shows the trend in the parameters.

Table 6.1 Monthly mean and extreme rainfall frequencies

Month	**Mean (mm)**	**Number of extremely high rainfall events in 21 years**	**Extremely high rainfall (mm) relative frequency (X % in 21 years)**	**Number of extremely low rainfall events in 21 years**	**Extremely low rainfall (mm) relative frequency (X % in 21 years)**
JAN	141	4/21	19 %	3/21	14 %
FEB	87	3/21	14 %	4/21	19 %
MAR	86	3/21	14 %	3/21	13 %
APRIL	29	5/21	23 %	6/21	28 %
MAY	13	4/21	19 %	7/21	33 %

JUN	9	4/21	19 %	9/21	42 %
JUL	10	4/21	19 %	11/21	52 %
AUG	14	5/21	23 %	12/21	57 %
SEP	30	2/21	0.9 %	8/21	38 %
OCT	59	5/21	23 %	4/21	19 %
NOV	70	3/21	14 %	3/21	14 %
DEC	115	4/21	14 %	4/21	19 %
Total		46		74	

Source: Author, 2016

Table 6.1 shows that the total number of extremely high rainfall events in the last 23year period stood at 46 and is far less than the total number of extremely low rainfall events that stood at 74 over the same period of time. This gives the impression of a chronic drought in the area. The months with the highest frequency of extremely high rainfall in summer are April and October. Both months have a 23% chance of receiving extremely high rainfall which potentially could lead to flooding at Spring Lake Coal Mine. In climate analysis, this high probability warrants proactive adaptation planning. However, there was no evidence of such planning at the Spring Lake Coal Mine despite the given scenario. The Environmental Manager stated that since the mine has not experienced flooding, the mine management pays less attention to such probabilities. However, given the dynamics of climate change and the high probability that is shown in Table 6.1, flooding at Spring Lake Coal Mine cannot be ruled out.

While flooding is a threat that could halt mining operations, its opposite drought, is an equally operations-halting possibility. An examination of the figures in Table 6.1 shows that there is a higher probability of extremely low rainfall compared to high rainfall extremes. The months of April and September with 6 and 8 incidents of low rainfall extremes during the 21 years' review period show a 28% and 38% probability of low rainfall. This data suggests the need for appropriate water supply adaptation planning to ensure that water shortages do not affect mine operations as a result of reduced rainfall. Measures to this end include recycling of grey water and desalination of sea water. So far, these are not part of Spring Lake Coal Mine's plans.

The Executive Committee Member of Cooperative Governance and Traditional Affairs stated that KwaZulu-Natal is facing droughts with increasing severity and frequency, and unless the call for coordinated water conservation is met with decisive action by all consumers, things will only get worse (Department of Water and Sanitation 2015). However, water conservation is only one part of adapting to climate change-induced drought. Integrated solutions must be sought in partnership with all extensive water consumers. The municipality, together with all extensive water users, as well as water research institutions, should partner with a vision of finding lasting solutions to the water problem in the region. With regard to the impact of water shortages on mining activities, a water resource management specialist, Naidoo (2015) stated that Prof Anthony Turton noted that many new mines, mainly in water-scarce provinces such as Free State and Kwa Zulu-Natal - and most notably in the coal sector - have been unable to progress beyond the feasibility study and design phase to actual production.

This is largely attributed to the non-availability of water. This observation places the importance and consideration of climate change impacts on the mining industry at the exploration phase of the mining value chain. To intervene in the adverse impacts of water shortages in the mining sector, the same specialist cited a number of creative solutions that may be regarded as attempts at adaptation to the water scarcity problem. The solutions included the refurbishment of leaking agricultural irrigation systems and the recovery of grey water from sewage works *inter alia*. However, at the time of this research none of the solutions was in place. Turton (2015) blames this on bureaucratic bottlenecks mainly at municipal level. Despite this, there have been some innovative developments such as the treatment of polluted mine water for reuse in a number of industrial processes (Ibid.). In winter, the months with the highest cases of extremely high rainfall are in May and August. August shows the highest number of extremely high rainfall incidents with five in the 21-year review period. This means the month has a 23% probability of receiving above normal season rainfall. This is a higher than normal probability for a winter season month. The month of May, typically a dry season had four incidents of extremely high rainfall with a 19% probability of the same event. This means that the month may pose winter flash-flood incidents.

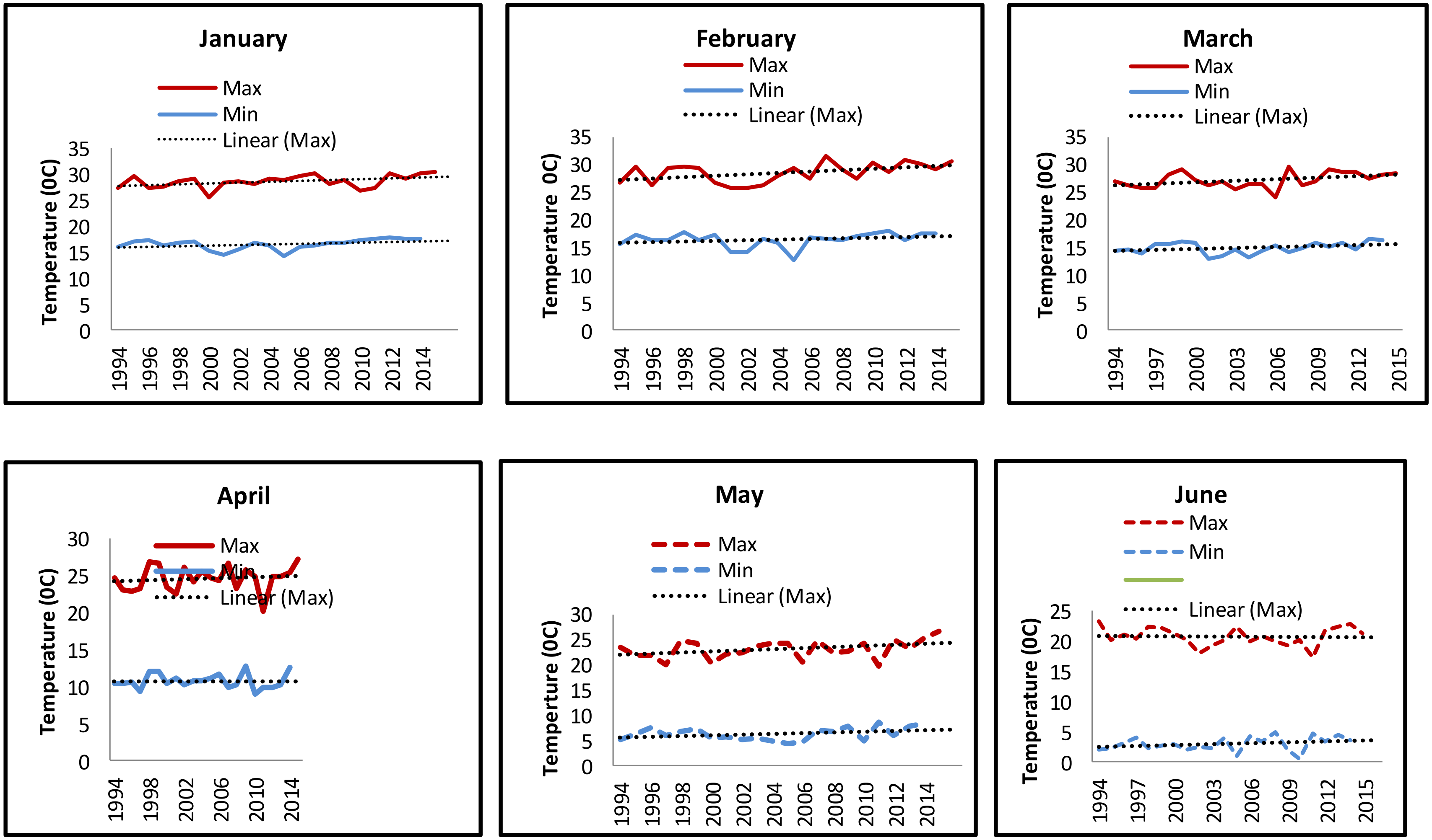
The KwaZulu-Natal Province and the Dundee area specifically, experienced flooding in June 2015 and July 2016. Winter flooding is a new phenomenon as this season has always been dry with very little precipitation. The floods are often in the form of flash-floods (Marchi *et al*, 2010). Sorooshian (1983) notes that flash-floods are most common in areas which have severe drought due to the ground being unable to absorb excess rainwater in short periods of time. As in Kriel, Standerton and New Vaal, floods at the Spring Lake Mine are not caused by overall or normal increases in precipitation, but extreme rainfall in winter. This extreme rainfall not only floods the mines, but gives the impression that the drought could be over. An important development is that the local officials are aware of this potential misconception as a member of the Executive Council for Cooperative Governance and Traditional Affairs in Kwa Zulu-Natal explained:

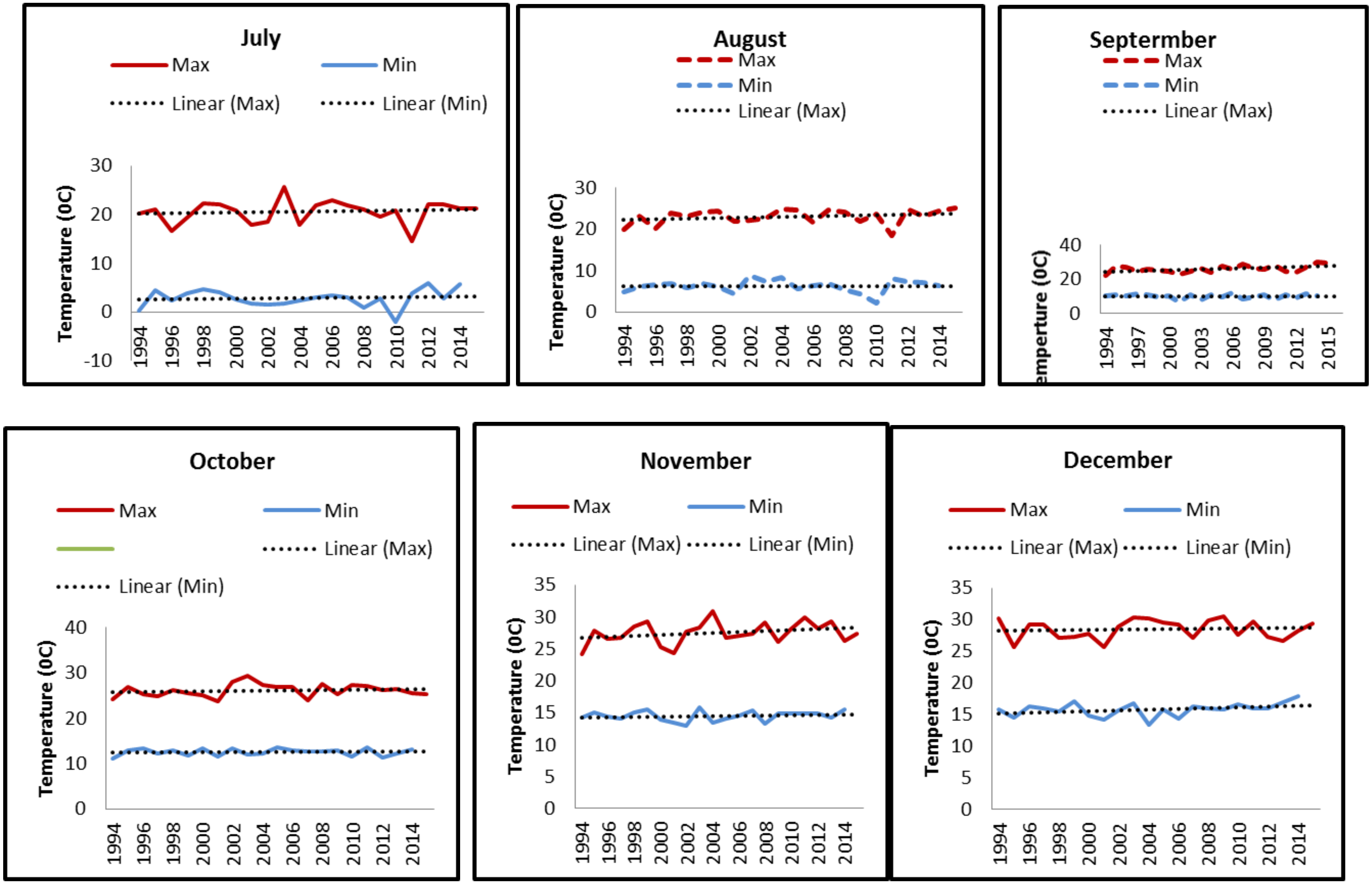
> *The recent (2015) rainfall may give the false impression that the worst of the current drought is over. The impact of the current drought has been so severe that all this rainfall is simply insufficient to relieve even the most urgent supply of water in the most affected areas of the province. Our campaign to conserve water will therefore continue.*

A significant problem that the Spring Lake Coal Mine has experienced is the frequent failures of tailing and Pollution Control Dams (PCDs) in containing large amounts of water from extreme and intense rainfall. The environmental manager stated that once the PCDs overflow, the runoff water spills into the nearby streams causing it to contaminate these waterways. As stated earlier, rainfall quantities have a link to ambient temperature. Typically high temperatures result in less precipitation (Nicholls, 2004). This link is discussed in the next paragraphs.

Figure 6.4 shows annual temperature trends in Dundee. The summer season is represented by the solid bold pattern line and the winter season is represented by the dotted pattern line.

Figure 6.4: Seasonal and monthly temperature analysis in Dundee





Source: South African Weather Services, 2016

Temperature records for the Dundee region show a slight increase in the average monthly temperatures and seasonal temperature as shown in Figure 6.3. The figure shows that both maximum and minimum summer and winter seasons temperatures have been slightly increasing over the 21- year period under review. In the summer season, the increase has been particularly intense in the months of January and February where maximum temperatures are increasingly reaching 30 degrees Celsius, especially from the year 2012. In contrast, minimum temperatures have been relatively stable throughout the summer seasons. Although the temperature increases at ground level have been slight, underground heat increases have been significant to the extent that the mine has had to increase its underground ventilation capacity. One such system was in place in 2009. However, and unfortunately, in October 2009 the system had a malfunction in the electrical cables network resulting in an underground fire. The fire led to the death of one person and injuries to 18 other employees, and many more suffered from smoke inhalation. According to Spring Lake Coal Mine's health and safety manager, solutions to this kind of fire breakout are a matter of improving health and safety standards and complying with safety requirements when installing new electrical equipment and related components.

Outside the mining pits the high temperatures, coupled with the increasingly dry conditions, render the area susceptible to veld fires. The government has programmes seeking to combat such fires. The Working on Fire (WoF) programme is a government-funded initiative focusing on implementing Integrated Fire Management in South Africa. Under the initiative, the northern KwaZulu-Natal areas which include Newcastle, Ladysmith and Endumeni Municipality are regarded as areas that are most vulnerable to veld and forest fires in the province. The WoF programme recorded 516 veld and forest fires between 2014 and 2016. Given the observed rainfall declines, the high number of incidents and the probability of extremely low rainfall, the area around Spring Lake Coal Mine will get drier, and consequently it will become more vulnerable to veld and forest fires. Although Spring Lake Coal Mine faces similar rainfall trends to those of Kriel, Standerton and New Vaal, the mine's proximity to the lake means it is more likely to pollute this water source and the surrounding area during extremely high rainfall periods or incidences. The major concerns however, are drought and high temperatures. The municipality is already restricting water use and this affects the mine's access to water. The mine's adaptation plan for accessing water is mainly through boreholes and water recycling. In this regard, the mine should explore using water desalination and dry processing technology. High temperatures and dry conditions render the mine vulnerable to fire breakouts as well as employee health and safety. The mine typically increases cooling in its underground mine in order to secure employee health and safety.

6.3 CONCLUSION

It emerges that Spring Lake Coal Mine is located in the drought-prone municipality of Endumeni. Drought is by far the biggest threat in the area, not only to the mine, but also to the surrounding farming community. The local authority has reacted to this threat by formulating and implementing a number of water shortage adaptation plans and actions. Four issues emerged from the plans. The first is that they are late because the challenge of drought-induced water supply shortages is already a real and present danger. The second issue is that, the suggested plans are expensive, especially the energy intensive sea water desalination option. Thirdly, even if the water shortage from the traditional source can be addressed by sinking boreholes, there is limited knowledge on the area's ground water quantity and availability. Fourth and lastly, the respective municipality has had to impose its largely unpopular water-use restriction bylaws. While all these can stretch the available water supplies, the only viable solution is consistent rainfall, especially in summer when it is expected and most needed, due to high temperatures. A cause for concern is the trend that shows rainfall in the area to be declining annually, seasonally, and monthly over the period 1994 to 2015. On the other hand, while drought is a major climate change-linked problem, occasional flooding is also a cause for concern. Most notably is the case of winter flooding, a new phenomenon. Traditional flooding is expected in the rainy summer months. Winter floods strain the management and maintenance of flooding control mechanisms that have traditionally been maintained and upgraded during the dry winter months. To sum up, the evidence presented in this chapter shows a need for new plans to cope with expected and unexpected climate change-induced extreme weather events, especially droughts, floods and wild fires. The season-based demarcations of these plans have to be redrawn to consider both established and anticipated changes.

CHAPTER SEVEN: SUMMARY OF FINDINGS, CONCLUSION AND SUGGESTIONS

7.1 SUMMARY OF THE STUDY

This study has sought to understand climate change vulnerability, exposure and adaptation measures in selected South African coal mines. The selected coal mines were Kriel Colliery, New Denmark Colliery and Mine X, all based in Mpumalanga Province; the New Vaal Coal Mine in the Free State Province; and Spring Lake Coal Mine based in Dundee, Kwa Zulu-Natal Province. The research established three objectives namely: (i) to identify current and future climate change impacts that may affect the selected coal mines, (ii) to establish the nature and extent to which the mines are ready to address and implement adaptation measures, and (iii) to determine and document existing climate change adaptation practices in those mines. Accordingly, the following research questions were posed to address these research objectives: What are the current and possible climate change impacts that may affect the selected coal mines? What is the extent and nature of climate change adaptation readiness at those mines?

The research adopted a multiple case study approach that employed the mixed-methods approach to address the research questions and meet the research objectives. The first action was a thorough review of literature, focusing on theories about change and adaptation in the mining sector in general, and coal mining specifically. The coal mining value chain formed the basis of tracing adaptation intervention measures. The case study mines were purposively sampled, taking into consideration varying geographical locations, mine designs and mine ownership. Geographical location was a critical element in the study as adaptation to climate change is a localized matter. Initially, nine mines in four provinces, including Limpopo Province, were requested to participate in the study. All the targeted mines in the Limpopo Province declined to participate in the study. Consequently, the research was informed by five mines from the three provinces. In addition to the five mines, the research also gathered data from the South African Weather Service (SAWS), which is the custodian of South African weather and climate data. Since the study sought to analyze the closest climate trends to the participating mines, the nearest weather stations were identified with data obtained from the SAWS which provided the requested climate information.

Additional data was collected from different sources, including the mines themselves; also from documents, local community members, climate change and mining experts from Wits University and the University of Cape Town. Such data was collected through questionnaires, face-to-face interviews, telephonic interviews, as well as from the available and accessible publications and databases.

7.2 SUMMARY OF MAJOR FINDINGS

7.2.1 Climate Change in South Africa

As expected, the findings in each mine differed based on the climate change vulnerability and exposure of each mine as determined by geographic and topographic location and the mine design of each mine. Consequently, adaptation responses also differed based on the specific issues as well as mine ownership. A notable finding was that despite the experienced and acknowledged adverse impacts of climate change on the overall mine, adaptation in all participating mines has largely remained reactive instead of proactive. In addition, climate data records are not up to date and, where available, the data is limited and characterized by some gaps. This makes it difficult for data users to employ the data to generate findings and models that could be applied to inform adaptation planning. The following section provides a summary of specific findings in each province and the mines.

7.2.2 Kriel Colliery, New Denmark and Mine X

In the Mpumalanga area where Kriel, New Denmark and Mine X are based, annual seasonal and monthly rainfall is declining, especially in summer when it is most expected. Although all three mines maintain that they are currently not affected by water scarcity due to the available underground water sources, all environmental managers at the mines admitted that this option is limited and might soon not be available if chronic droughts continue. As part of adapting to water scarcity, all three mines used their tailing and pollution control dams for water recycling, storage and reuse. However this is not a long-term solution as that water still has to come from rainfall. To deal with this, New Denmark Colliery was in the process of exploring dry processing technology for coal washing, which is the most water- intensive practice in the mining sub-value chain.

On the other hand, all three mines have been affected by flooding in the winter season when heavy rains are least expected. Kriel open-cast mine was flooded at one stage and the water pumping systems failed to drain the extra water due to extreme rainfall in the area. As a result, water catchment dams overflowed posing the risk of Acid Mine Draining (AMD) into the immediate wetlands. In addition, these mines have been affected by extensive and persistent mist and smog which often disrupt movements in and outside the mines. There were no adaptation plans in place to deal with this problem. The only advantage that all three mines have is that they convey their coal to the nearby power stations, an advantage presented by proximity.

7.2.3 Free State: New Vaal Coal Mine

The New Vaal Coal Mine is located near the Vaal River and draws its water from this river. The Vaal River system is a key national strategic resource. The mine's close proximity to the Vaal River presents both an advantage and a disadvantage. The advantage is that the mine does not struggle with access to water as the Vaal River supplies the mine and much of the Gauteng Province. The disadvantage, however, is that the Vaal River is a constant threat for flooding, especially in summer. Rainfall is more sporadic and intense than consistent in the Vaal area, meaning when it rains, it rains excessively. The open-cast mine was flooded in 2010 and this resulted in the mine raising its dam levee wall from the 100 year flood plane to a 250 year flood expectation. As a reactive adaptation strategy, the mine engineers set up a flood early–warning-system that triggers an alarm as soon as the flood level reaches the mine's flooding threshold level.

7.2.4 Kwa Zulu Natal: Spring Lake Coal Mine

Spring Lake Coal Mine is exposed to the 'double whammy' of climate change - drought in summer and flooding in winter. These conditions are exacerbated by increasing temperatures, especially in summer. Although there was limited information in relation to the climate change impacts at the mine, the Endumeni Municipality, which supplies the mine with water and is responsible for water-use bylaws, has been documenting and intervening in recent drought incidents. These interventions, especially water-use limitations, affect the mine as the mine's environmental manager stated. In addition, rising temperatures are responsible for hotter conditions in the underground mine, which call for the mine to install more or improve current ventilation and cooling systems. This has resulted in a fire breakout at the underground mine where one person died and many others were injured. Furthermore, Spring

Lake is located in a wetland and, as such, flooding events pose risk of AMD. This vulnerability was exposed in 2010 when the pollution control dams (PCDs) failed to contain extra rain water.

Having identified these vulnerabilities, the study found that although there were some efforts in reaction to climate change impacts at the selected mines, innovative and proactive adaptation actions were limited both in policy articulation and in practice, especially in other areas of the coal mining value chain. Interestingly, climate change mitigation still dominated climate change management in all the surveyed mines. This skewed attention to climate change mitigation was evident from site observations, document analysis and interviews. In some cases, the mine respondents were unable to differentiate between climate and weather when responding to the question relating to climate change impacts and potential adaptation plans. They also did not seem to understand the concept and science of climate change generally. Table 7.1 provides a summary of climate change vulnerabilities per mine and each mine's adaptation actions as well as suggestions for adaptation actions at each mine.

Table 7.1 Summary of Vulnerability and adaptation plans per mine

MINE	MINE DESIGN	MINING COMPANY	PROVINCE	VULNERABILITY AND EXPOSURE	IMPACT AREAS ON THE VALUE CHAIN	ADAPTATION PLAN	AREAS LACKING ADAPTATION AND RECOMMENDATIONS FOR ADAPTION
Kriel coal mine	• Open cast • Underground	Anglo American (Pty) Ltd	Mpumalanga	• Flooding	• Production and closure	• Water catchment dams	• Increasing of water pumping capacity from overflowing PCD's
				• Drought	• Production	• Boreholes • Partial adaptation plan	• Water recycling, dry processing technology.
				• Mist and smog	• Production	• No adaptation plan	• Strategies coal loading and transportation time
New Denmark coal mine	• Open cast • Underground	Anglo American (Pty) Ltd	Mpumalanga	• Drought	• Production and closure	• Water catchment dams	• Water recycling, dry processing technology.
				• Flooding	• Production and closure	• RiverCAD PRO for flood line determination	• Flood defence wall and flooding early warning system.
				• Mist	• Production	• No adaptation	
Mine X	Underground	Company X	Mpumalanga	• Drought	• Production	• Water treatment for re-cycling • Passive water treatment • Dry processing • Brine treatment	

						technologies	• Flooding: Water pumping capacity from overflowing PCD's. Flood defense wall or the RiverCAD PRO
New Vaal coal mine	• Open cast • Underground	Anglo American (Pty) Ltd	Free State	• Flooding • Lightning • Mist • Heatwaves	Production, closure and post closure	• Flood defense wall and flooding early warning system • Lightning detector • No adaptation plan • No adaptation	• Timing of shift change and transportation of equipment in and outside the mine • Increased cooling and ventilation at the underground mine and mine offices
Spring Lake coal mine	• Open cast • Underground	Shanduka Coal	Kwa Zulu-Natal	• Drought • Flooding • Veld fires • Heatwaves	Production	• Water use restrictions (imposed by the municipality) • Tailing and PCD's Increased ventilation and cooling at the underground mine.	• Drought: Dry processing, boreholes and improvement of water storage dams • Current Tailing and PCD are not equipped to accommodate extreme (above 50 % from the mean) rainfall. These need to be improved

Source: Author, 2016

7.3 CONCLUSION

Based on the key findings from this work, it can be concluded that under present conditions, the coal mines that informed this research are highly vulnerable to the adverse impacts of climate change. This could expose the country to interrupted power supplies due to the predicted high frequency of extreme and prolonged climate change-induced extreme weather events. As such, more work is required to elevate the importance of adaptation policies and actions in the coal mining industry. Adverse climate change induced impacts on the industry can largely be prevented by proactive adaptation planning and strategies. However, proactive adaptation requires updated and accurate climate data. Currently the limited real-time weather data makes it difficult to accurately advise and model future climate changes and the required adaptation. The reluctance to champion adaptation planning and investments in such plans is evident in the participating mines' sustainability reports.

Of all the mining companies that participated in the study, only Anglo American Coal (Pty) Ltd has a documented climate change management policy and strategy, which is often present in the company's annual and sustainability reports. In addition, Anglo American and Mine X reported their climate change impacts and adaptation plans to the Carbon Disclosure Project. However, although climate change adaptation is referred to in the climate change policies, site observations show that there is limited adaptation innovation, with the exception of New Vaal Mine. The mine elevated its flood defense wall and installed an early warning system to avoid flooding. The rest of the mines have traditional engineering and environmental mine designs and considerations. From preliminary discussions, these are not intended as climate change responses or proactive measures, rather they are seen as conventional mine design elements. From the document analysis, climate change narrative, policy and action plans are absent from all the sampled coal mines' sustainability reports. From the selected study sites, it seemed evident that the mines were not ready to deal with climate change adaptation demands.

7.4 SUGGESTIONS

7.4.1 Continuous collection and analysis of climate data

The overarching matter with regard to understanding climate change impacts in the South African coal mining sector is the availability and reliability of up-to-date and real-time climate data in areas where the coal mines are located. The study suggests that mining companies partner with the South African Weather Service and climate research institutions to strengthen the current weather stations in all areas with mining operations. Alternatively, the mines could build their own weather stations and collect data and analyse (in-house or outsource) all relevant information for the appropriate adaptation practices. Mine-based weather stations would be more precise due to their proximity to actual operations, thus assisting mines to develop better informed adaptation plans and actions.

7.4.2 Development of pro-adaptation policies and action

In principle, reliable, accurate and consistent climate data should enable all South African coal mines to develop climate change management policies and strategies. Given the identified climate change exposure and vulnerability of the profiled coal mines, the resultant policies and strategies should elevate the importance of climate change adaptation. Old policies should be amended and upgraded to meet the same goal. The major concerns across all the participating mines are declining rainfall and water availability. Adaptation technologies that hold potential for water adaptation are dry-processing technologies which do not require water. The advantage of dry processing technologies is that the coal remains dry thus improving the heat value of the coal as opposed to wet processes where the final product is wet.

The major drawback of present dry-processing techniques is the poor separation efficiency and the high cut-point density. As a result, it is difficult to effectively beneficiate coals with a high near-dense content. It is also difficult to control the quality of the product from dry-coal processes. Dry-processing is, however, not applicable on all mines or with all coal types. In addition, the low capital and operating costs of dry-processing may be very attractive, especially for small mines, but may lead to unrealistic expectations. Despite these drawbacks, this technology needs urgent improvement and adaptation by the coal mining sector, especially against the background of stretched water resources as a result of frequent and severe cases of droughts. While droughts are a major cause for concern, the cases of extremely high rainfall that lead to flooding are also an issue of note. This calls for improved excess water channeling and storage. This is important for avoiding the leakage of untreated mining waste water and its leaching into public waterways.

7.4.3 Partner with hosting municipalities for a win-win relationship

Coal mines such as Spring Lake Coal Mine operate within municipalities which control water access from water supply dams. The controls are enforced through water-use bylaws. The controls become tighter and stricter in times of drought and at times these measures may affect a mine's access to water. To ameliorate this, mines could actively and jointly formulate water access laws with neighboring municipalities with the two parties proactively seeking a win-win solution. Such a solution would balance the need for the mine to access water and so to avoid job losses and the related adverse economic and social consequences. Conversely, the solution should ensure that the mine's access to shared water sources does not threaten community livelihoods particularly when water sources are stretched by droughts.

7.4.4 Integration of climate change science in the current environmental and mine engineering formal qualifications

Currently, climate change as a science is limited in mine engineering or environmental management practices. This is understandable given the fact that concerns regarding climate change and the science behind the phenomenon are relatively recent, compared to traditional environmental concerns such as soil and water contamination and air pollution. However, global warming and climate change and their impacts on global flora and fauna has become a dominant environmental concern, arguably more pressing than any other environmental issue. If these projected impacts are serious to mining companies, mine engineers need to start incorporating climate change impact scenarios in mine design in order to achieve climate resilient mines.

7.5 Contribution to knowledge

A major contribution of this study has to be its success in using diverse coal mines in terms of geography, mine design and mine ownership to assess climate change exposure and vulnerabilities and establishing how these mines are or should respond to these impacts. Lessons learned in these multiple cases can be applied in the rest of the South African coal mines, with of cause adjustments in adaptation plans based on the unique geographical context.

7.6 SUGGESTED FURTHER RESEARCH

This research was largely confined to the production (mining) sub-chain of the mining value chain. A systemically adapted mining industry would require the appropriate adaptation throughout the mining value chain. There is a need for studies to investigate adaptation in other sub-chains, which may include the impact of climate change on coal transportation, especially by road freight and shipping as well as storage. As Prof Anthony Turton noted, some coal mines have been unable to progress beyond the feasibility study and design phase to actual production due to increasing shortages of water. These challenges needs further research to understand the extent to which declining precipitation affects new mine development and to explore alternative ways of mining in these areas. Given the fact that willingness to develop and invest in adaptation plans and strategies relies on climate change impact certainty, climate projection research needs to be improved in order to accurately predict the exact nature and magnitude of future climatic conditions at a given location. Currently, the science of climate projection is limited and, as a result, there is reluctance by decision-makers to invest resources in an uncertain science. Lastly, the South African coal mining sector can gain from the development of South African coal mining sector's climate change adaptation framework.

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LIST OF APPENDICES

APPENDIX 1: ETHICS CLEARANCE CERTIFICATE

UNISA university of south africa

CAES RESEARCH ETHICS REVIEW COMMITTEE

Date: 02/04/2015

Ref #: **2015/CAES/058**
Name of applicant: **Mr B Chavalala**
Student #: **46513078**

Dear Mr Chavalala,

Decision: Ethics Approval

Proposal: An assessment of South Africa's coal mining sector response to climate change adaptation demands

Supervisor: Prof G Nhamo

Qualification: Postgraduate degree

Thank you for the application for research ethics clearance by the CAES Research Ethics Review Committee for the above mentioned research. Final approval is granted for the duration of the project, **subject to submission of the permission letters from the mines**.

Please note points 4 and 5 below for further action.

The application was reviewed in compliance with the Unisa Policy on Research Ethics by the CAES Research Ethics Review Committee on 02 April 2015.

The proposed research may now commence with the proviso that:

1) *The researcher/s will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.*
2) *Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study, as well as changes in the methodology, should be communicated in writing to the CAES Research Ethics Review Committee. An amended application could be requested if there are substantial changes from the existing proposal, especially if those changes affect any of the study-related risks for the research participants.*

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150
www.unisa.ac.za

3) *The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study.*
4) *The researcher must submit the permission letters from the mines as they are obtained. No data collection from a particular mine may take place until permission has been obtained and submitted to the Committee.*
5) *The Committee recommends that the questionnaire be language edited before it is used.*

Note:

The reference number [top right corner of this communiqué] should be clearly indicated on all forms of communication [e.g. Webmail, E-mail messages, letters] with the intended research participants, as well as with the CAES RERC.

Kind regards,

Signature
CAES RERC Chair: Prof EL Kempen

Signature
CAES Executive Dean: Prof MJ Linington

APPENDICES 2: INTERVIEW SCHEDULE/GUIDE FOR THE MINES

Interview Schedule/Guide

RESEARCH TITLE: AN ASSESSMENT OF SOUTH AFRICA'S COAL MINING SECTOR'S RESPONSE TO CLIMATE CHANGE ADAPTATION DEMANDS

BACKGROUND

This study will examine your mines' preparedness to address climate change impacts, especially adaptation. As such, the researcher seeks to access data such as climate change policies, climate information collected by the mine and any interpretation of such data, climate change adaptation strategies and related information. Noting that climate change adaptation practices may be in their infancy, the research will also seek to engage the mines on future adaptation strategies under implementation or consideration for implementation. This study seeks to realize two major objectives. Firstly, to find out what the current and possible climate change impacts are which may affect selected South African coal mines. Secondly, to determine the extent and nature of climate change adaptation readiness in the selected coal mines in South Africa. Such specific knowledge has the potential to assist mining firms prepare for the impacts of climate change and, more importantly, remain sustainable despite some adverse impact caused by climate change on their operations.

Disclaimer[1] : The researcher guarantees that the information gathered through this instrument is for research purposes and the possible publication of academic papers. Issues of privacy and confidentiality with regard to respondents and data will be observed at all times during the research and publication process. A company and/ or representative has the right to withdraw from the research process at any time without giving reasons. The researcher(s) will not cause physical or emotional harm to research respondents. In addition, neither the researcher nor

[1] Should you require further clarity, please contact me on 0786719232/012 433 4638 or my supervisor: Prof Godwell Nhamo, Exxaro Chair in Business and Climate Change, Institute for Corporate Citizenship, University of South Africa, P.O. Box 392, Unisa 0003; Emails: nhamog@unisa.ac.za; Tel: 012-433-4725; Fax: 012-429-6896; Cell: 073-163-1114.

UNISA will take responsibility for a respondent who provides information that harms the reputation of their company.

1. GENERAL INFORMATION

Date……………………………………………………………………………………………………

Name of the mine:

……………………………………………………………………………………………………

Mine ownership:

……………………………………………………………………………………………………

Location (Province, Municipality and GPS coordinates)

……………………………………………………………………………………………………

Mine design and mining method(s)

……………………………………………………………………………………………………

2. RESPONDENTS' INFORMATION

Gender

Male	Female

Age …………………………………………….

Current employment position

…………………………………………………….

Number of years in current position

…………………………………………………….

3. CLIMATE DATA

Is climate data critical for your mines' operations plans?

Yes	No

Does your mine have a weather station from which you collect climate data?

Yes	No

If the answer is 'NO', how and where do you collected climate data…………………………………………………………………………………….

If the answer is 'Yes", can you share data that you collected from this weather station ?

Yes	No

4. **CLIMATE CHANGE POLICY. PLEASE TICK THE APPROPRIATE BOX.**

Is your mine aware and concerned about climate change?

Yes	No

If yes, what are the major climate change concerns?

……………………………………………………………………………………………

Does your mining company have climate change policy?

Yes	No

If yes, what are the major contents?

……………………………………………………………………………………………….

If not, why not?

…………………………………………………………………………………………………

Has the climate change policy resulted in any new practices in the mine?

…………………………………………………………………………………………………

If yes, what practice areas follow this policy?

……………………………………………………………………………………………………

If not, why has this been the case?

………………………………………………………………………………………………

4.1 How is government policy on climate change management affecting your operations?

5. CLIMATE IMPACT FREQUENCY

In this section, provide information related to the frequency of climate impacts you have experienced since you started operations at this mine. Rate the frequency of the weather events on a numerical scale ranging from one to three where: 1 means not intense 2 average and 3 means intense.

Code	Storms	Tick
1	Nil	
2	Seldom	
3	Quite often	

Code	Drought	Tick
1	Nil	
2	Seldom	
3	Quite often	

Code	Flooding	Tick
1	Nil	
2	Seldom	
3	Quite often	

Code	Mist	Tick
1	Nil	
2	Seldom	
3	Quite often	

Code	Wild fires	Tick
1	Nil	

2	Seldom	
3	Quite often	

Code	Hail	Tick
1	Nil	
2	Seldom	
3	Quite often	

Code	Heat wave	Tick
1	Nil	
2	Seldom	
3	Quite often	

6. CLIMATE INTENSITY

In this section, provide information related to the intensity of climate impacts you have experienced since you started operations at this mine. Rate the intensity of the weather event on a numerical scale ranging from one to four where: 1 means not intense, 2 average and 3 means intense.

Code	Storms	Tick
1	less intense	
2	No change	
3	More Intense	
Code	Drought	Tick
1	Less intense	
2	No change	
3	More Intense	

Code	Flooding	Tick
1	Less intense	
2	No change	
3	More Intense	

Code	Mist	Tick
1	Less intense	
2	No change	
3	More Intense	

Code	Hail	Tick
1	Less intense	
2	No change	
3	More Intense	

Code	Wild fires	Tick
1	Less intense	
2	No change	
3	More Intense	

Code	Heat wave	Tick
1	Less intense	
2	No change	
3	More Intense	

7. CLIMATE IMPACT DURATION

In this section, rate the amount of time these climate activities affect(ed) your operations.

Code	Storms	Tick
1	Shorter	
2	Longer	
3	No change	

Code	Drought	Tick
1	Shorter	
2	Longer	
3	No change	

Code	Flooding	Tick
1	Shorter	
2	Longer	
3	No change	

Code	Mist	Tick
1	Shorter	
2	Longer	
3	No change	

Code	Wild fires	Tick
1	Shorter	
2	Longer	
3	No change	

Code	Hail	Tick
1	Shorter	
2	Longer	

3	No change	

Code	Heat wave	Tick
1	Shorter	
2	Longer	
3	No change	

8. THE MINE'S ADAPTATION RESPONSE

Please indicate (by ticking in the appropriate box) the kind of impact your mine has experienced or envisages that could affect your operation at the different stages of the mining cycle. Also state what measures are in place or are being developed to manage the current and envisaged situation.

(a) Storms

Mine Value Chain	Experienced (Please write)	Envisaged (Please write)	Adaptation action (to be) taken
Exploration			
Design			
Construction			
Operation			
Closure			

(b) Flooding

Mine Value Chain	Experienced (Please write)	Envisaged (Please write)	Adaptation action (to be) taken
Exploration			
Design			
Construction			
Operation			

Closure			

(c) Drought

Mine Value Chain	Experienced (Please write)	Envisaged (Please write)	Adaptation action (to be) taken
Exploration			
Design			
Construction			
Operation			
Closure			

(c) Mist

Mine Value Chain	Experienced (Please write)	Envisaged (Please write)	Adaptation action (to be) taken
Exploration			
Design			
Construction			
Operation			
Closure			

(d) fires

Mine Value Chain	Experienced (Please write)	Envisaged (Please write)	Adaptation action (to be) taken
Exploration			
Design			
Construction			
Operation			
Closure			

(E) Hail

Mine Value Chain	Experienced (Please write)	Envisaged (Please write)	Adaptation action (to be) taken
Exploration			
Design			
Construction			
Operation			
Closure			

(e) Extreme heat

Mine Value Chain	Experienced (Please write)	Envisaged (Please write)	Adaptation action (to be) taken
Exploration			
Design			
Construction			
Operation			
Closure			

9. CLIMATE IMPACTS ON OTHER AREAS OF MINING

In this section identify areas that have been or will be impacted by climate change at your mine, identify the source of impacts, the impact, and suggest the required action which is/will be appropriate to deal with the impact.

Impact area	**Cause of Impact**	**Impact**	**Required action**
DISTURBANCE TO MINE INFRASTRUCTURE AND OPERATIONS			

CHANGING ACCESS TO SUPPLY CHAINS AND DISTRIBUTION ROUTES			
CHALLENGES TO WORKER HEALTH AND SAFETY CONDITIONS	.		
CHALLENGES TO ENVIRONMENTAL MANAGEMENT AND MITIGATION			
MORE PRESSURE POINTS WITH COMMUNITY RELATIONS			
EXPLORATION AND FUTURE GROWTH			

Any additional comments on the subject

……
……
……
……
……
……
……
……
……
………

Thank you!

APPENDIX 3: INTERVIEW GUIDE FOR SURROUNDING COMMUNITIES

INTERVIEW GUIDE FOR SURROUNDING COMMUNITIES

Research tittle: AN ASSESSMENT OF SOUTH AFRICA'S COAL MINING SECTOR'S RESPONSE TO CLIMATE CHANGE ADAPTATION DEMANDS

Background

This study will examine your mines' preparedness to address climate change impacts, particularly, adaptation. As such, the researcher seeks to access data such as climate change policies, climate information collected by the mine and any interpretation of such data, climate change adaptation strategies and related information. Noting that climate change adaptation practices may be in their infancy, the research will also seek to engage the mines on future adaptation strategies under implementation or consideration for implementation. This study seeks to realize two major objectives. Firstly, to find out what the current and possible climate change impacts are which may affect selected South African coal mines. Secondly, to determine the extent and nature of climate change adaptation readiness in the selected coal mines in South Africa. Such specific knowledge has the potential to assist mining firms to prepare for the impacts of climate change and, more importantly, remain sustainable despite some adverse impacts caused by climate change on their operations.

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[2] Should you require further clarity, please contact me on 0786719232/012 433 4638 or my supervisor: Prof Godwell Nhamo, Exxaro Chair in Business and Climate Change, Institute for Corporate Citizenship, University of South Africa, P.O. Box 392, Unisa 0003; Emails: nhamog@unisa.ac.za; Tel: 012-433-4725; Fax: 012-429-6896; Cell: 073-163-1114.

UNISA will take responsibility for a respondent who provides information that harms the reputation of their company.

QUESTIONNAIRE No

Province…………………………………………………………………………………………… …………………

WARD NO………………………………………………………………………………………………… …………

VILLAGE………………………………………………………………………………………… ………………….

A. HOUSEHOLD DEMOGRAPHIC CHARACTERISTICS.

A1. Gender of the household head	1. *Male* 2. *Female*
A2. What is the age of the household head?	1. *30-40* 2. *41-50* 3. *51-60* 4. *60+*
A3. What is the occupation/ job of the household head?	1. *Miner* 2. *Retired miner*

	3. Other, please specify
A4. For how long have you been staying in this area?	*1. 0-1 years* *2. 1-5 years* *3. 5-10 years* *4. 10-20 years* *5. 20+ years*
A5. Education level of household head	*1. None* *2. Primary* *3. Secondary* *4. Tertiary*
A6. Position of household head in the community	*1. Ordinary citizen* *2. Headman* *3. Religious leader* *4. Political leader*

B. CLIMATE CHANGE KNOWLEDGE AND AWARENESS

B1. Are you aware of climate change?	*1. Yes* *2. No*
B2. If the answer is yes on the above, what is the source of your knowledge?	*1. Media* *2. Local NGO* *3. Government*

	4. *Other?*
B3. Do you know what causes the climate to change?	1. *Yes* 2. *No*
B4. Does the knowledge that you have about climate change influence your perception and action in anyway in your community?	1. *Yes* 2. *No*
B5. If the answer is yes to the above question, how does climate change knowledge influence your perception and what have you done or intend to do with this knowledge?	

C. OBSERVED CLIMATIC IMPACTS IN THE COMMUNITY SURROUNDING MINES

C1. In terms of minimum temperatures, how would you describe minimum temperature trends?	1. *Increasing* 2. *Decreasing* 3. *No change*
C2. In terms of maximum temperatures, how would you describe maximum temperature trends?	1. *Increasing* 2. *Decreasing* 3. *No change*

C3. How would you describe rainfall variability in your area?	1. *Increasing* 2. *Decreasing* 3. *No change*
C4. How often do you experience drought spells in your community?	1. *None* 2. *Seldom* 3. *Often* 4. *Very often*
C5. Do you share your water sources with the local mine(s)?	1. *Yes* 2. *No*
C6. If the answer to the above question is yes, have you had any water shortages due to mining activities?	1. *Yes* 2. *No*
C7. If the answer is yes to C5, have you had water pollution/contamination in your community?	1. *Yes* 2. *No*
C8. If the answer is yes to C7, what was the cause of the pollution/contamination?	
C9. If the answer to C6 is yes, what was the cause for the water shortages?	1. *Mine(s) needed more water* 2. *Declining rainfall* 3. *Maintenance of water infrastructure*

	4. *Other…*
C10. How would you describe the intensity of drought spells in your community?	1. *Less intense* 2. *No change* 3. *More Intense*
C11. Have you experienced any flooding in your community?	1. *Yes* 2. *No*
C12. If the answer is yes to the above question, how would you describe the frequency of flooding?	1. *No change* 2. *Often* 3. *Very often*
C13. How would you describe the intensity of flooding?	1. *Less intense* 2. *No change* 3. *More Intense*
C14. Have you been experienced heatwaves in your community?	1. *Yes* 2. *No*
C15. If the answer is yes to the above question, how would you describe the frequency of heatwaves in your community?	1. *No change* 2. *Often* 3. *Very often*
C16. How would you describe the intensity of heatwaves in your community?	1. *Less intense*

	2. *No change* 3. *More Intense*
C17. Have you been experienced hail storms in your community?	1. *Yes* 2. *No*
C18. If the answer is yes to the above question, how would you describe the frequency of hail storms in your community?	1. *No change* 2. *Often* 3. *Very often*
C19. How would you describe the intensity of hail storms in your community	1. *Less intense* 2. *No change* 3. *More Intense* 4. *??*
C20. Have you been experienced wild fires in your community?	1. *Yes* 2. *No*
C21. If the answer is yes to the above question, how would you describe the frequency of wild fires in your community?	1. *No change* 2. *Often* 3. *Very often*
C22. How would you describe the intensity of wild fires in your community?	1. *Less intense* 2. *No change* 3. *More Intense*

C23. Have you been experienced mist in your community?	1. *Yes* 2. *No*
C24. If the answer is yes to the above question, how would you describe the frequency of mist occurrence in your community?	1. *Nil* 2. *Seldom* 3. *Often* 4. *Very often*
C5. How would you describe the intensity of mist occurrence in your community?	1. *Less intense* 2. *No change* 3. *More Intense*

D. Any additional comments on the subject?

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Thank you!

APPENDIX 4: INTERVIEW GUIDE FOR THE DEPARTMENT OF ENVIRONMENTAL AFFAIRS

Interview guide for the Department of Environmental Affairs

a) What is the role of your department with regard to climate change and the mining industry?

b) According to the department's view, which type of mining has been or is most vulnerable to climate change impacts?

Gold mining
Platinum mining
Coal mining
Other

c) What policy approaches do you have for the mining sector with regard to climate change and, specifically, climate change adaptation?

d) Is there legal obligation for the mining sector to comply with regard to climate change adaptation?

Yes	No

If the answer is no to the above question, why is this the case?

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e) Is climate change adaptation included in the environmental impact assessment of mines?

Yes	No

If the answer is no to the above question, why is this the case?

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f) What has the department done to encourage climate change mitigation from the coal mining sector?

g) What has the department done to encourage climate change adaptation in coal mining?

Additional notes:

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Thank you!

APPENDIX 5: INTERVIEW GUIDE: FOR CENTRE FOR SCIENTIFIC AND INDUSTRIAL RESEARCH (UNIVERSITY OF WITWATERSRAND/ CSIR)

a) What is the role of GCSRI in relation to mining in South Africa?

The GCSRI has research interest on climate change mitigation and adaptation in South African mines.

b) Which type of mining has been or is most vulnerable to climate change impacts?

Gold mining
Platinum mining
Coal mining
Other

c) What has the research at GCSRI observed with regard to the following climate variability in South African mining communities?

Minimum temperatures
Maximum temperatures
Monthly rainfall patterns
Annual rainfall patterns

d) What climate impacts has the GCSRI noted in the South African mining communities?

Drought
Flooding
Hails storms
Heat waves
Mist

e) What are the climate-induced incidents that the GCSRI has noted in the South African mining value chain?

Value chain	Impact	Adaptation option(s)
Exploration		
Design		
Construction		
Operation		
Closure		
Exploration		

Additional notes:

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Thank you!