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An assessment of water security and hydrology resources in the face of climate variability: The case study of Nkonkobe Local Municipality, Eastern Cape, South Africa

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A thesis submitted in fulfilment of the requirements for the Master of Science degree in Geography in the Department of Geography and Environmental Science at the University of Fort Hare

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Abstract

South Africa is regarded as a semi-arid and water scarce country due to its low annual precipitation with a mean annual rainfall of 490mm. This study seeks to assess the effects of water security in the face of climate variability on hydrological resources in Nkonkobe Local Municipality, Eastern Cape, South Africa. The main objective of the research was to investigate climate variability parameters affecting water security in the Nkonkobe Local Municipality. The variability and trends in rainfall and temperature were analysed using descriptive statistics. Bivariate (Pearson) Correlation analysis was used to describe the effect of rainfall distribution and reservoir's holding capacity. A vulnerability index model was applied to determine the water security status in the study area. The results showed that the inter-annual rainfall variability trends are not statistically significant at the 95% confidence level since the P = 0,197. This means that there is no relationship in the inter-annual rainfall variability trends. The regression model is represented by $y = 3.0184x + 70.329$ with $R^2 = 0.0499$ suggests that there is a weak linear relationship. The intra – annual rainfall variability over time is not statistically significant at the 95% confidence level means that there is no strong relationship in the intra – annual rainfall variability trends. From the linear regression the precipitation concentration index (PCI) decreased from 14.1 to 12.4 mm. The rainfall distribution and reservoir holding capacity of Binfield reservoir test of significance was positive (p value: 0.01) indicating that the two variables had a strong relationship and same is for Kat River reservoir which has a statistically significant linear relationship ($p < .005$).Temperature distribution and reservoir holding capacity of Kat River and Binfield reservoir have a statistically significant linear relationship ($p < 0.01$) and (p ‹ .005) respectively. The Binfield Reservoir has high resilience to climate variability, but the magnitude of impact could be managed as it falls under Type IV where there is Low Impact. Kat River and Binfield reservoirs faces great exposure or sensitivity, this is evidenced by the reservoir holding capacity that is in the Type I of the vulnerability index. The vulnerability index showed that the reservoirs water security is highly vulnerable. One of the key findings of this research was that vulnerabilities to form and function can be linked. For example, where reservoir level fluctuations change in response to the change in the climate variabilities, this affects the water security of the reservoirs. The findings illustrate the importance to enhance adaptation efforts both at the micro (Nkonkobe Local Municipality) and macro (national) levels, particularly for communities where the reservoirs are more vulnerable to climate variability.

Keywords: Nkonkobe Municipality, Climate variability, water security, rainfall, temperature and vulnerability

Declaration by candidate

I, **Tineyi Herbert Pindura**, the undersigned candidate, hereby declare that the content of this dissertation is my original work and has not been formerly submitted to any other university for an award of a qualification either in part or in its entirety.

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Signature Date

Acknowledgements

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Dedication

I dedicate my thesis to my family and many friends.

Acronyms

CSIR – Council for Scientific & Industrial Research

DEA - Department of Environmental Affairs

ADM - Amathole District Municipality

IPCC - Intergovernmental Panel on Climate Change

CHAPTER ONE

1.1 Introduction

This chapter introduces the study on assessment of water security and climate variability on hydrology resources: The case study of Nkonkobe Local Municipality, Eastern Cape, South Africa. Background to the study, problem statement, the objectives, hypotheses, justification and limitations on the research are presented.

1.2 Background

There are many definitions water security has attained in the recent past, yet even the most lucid of them as estimated by Grey and Sadoff (2007) considers it a critical issue. Grey and Sadoff (2007) define water security as that quantity and quality of water reliably available to a given population that can support their daily requirements with acceptable minimum related risks. This definition by implication clarifies those questions often asked around water issues; questions such as; is the water enough for the targeted population? Is the quantity reliable and of adequate quality to sustain the wellbeing of the community in question? Does management of the available quantity pose a serious threat to the water security? Would usage pose any threat to or impact on the country's social welfare and economic activity (Muller et al., 2009; UNESCO-WWAP, 2006).There are a number of complex and interconnected factors that determine water security. These factors range from socio – political through climate change, resource constrains, water quantity, water quality, biophysical, to financial, infrastructural and institutional (UNESCO IHP, 2006).

The impact of climate variability on world economies is fast taking centre stage in socio-economic and political debates and policies across the world (IPCC, 2001). This is because the hazards of climate variability have manifested themselves inter alia in, large temperature variations, rise in sea levels, unprecedented levels of air pollution, frequency of floods and droughts, and an increase in water and vector borne diseases (Midgley et al., 2005). Such severity and frequency of natural disasters associated with climate change is increasingly making climate variability a major threat to development in the 21st Century (Midgley et al., 2011). Although every economy is vulnerable to the hazards of climatic variability, the vulnerability is not equal and it is disproportionately distributed across continents and regions (Midgley et al., 2011). It is not of significant value that this disproportionate impact and vulnerability to climate variability has not spared the urban and rural areas across the globe.

The unpredictable climate of the world and depleted water resources pose critical challenges to water shortage (Mukherji et al., 2009). Even the world over, the cause of global water crisis is perceived to be far from the scarcity problem but rather a result of poverty, inequality, unequal power relations and flawed water management policies evident in most developing countries (UNDP, 2006). South Africa is regarded as a semi-arid and water scarce country due to its low annual precipitation with a mean annual rainfall of 490mm (Perret, 2002), which is half the world's average (DWAF

2008). According to Davies et al., (1998) the greatest challenge is that, only about 8% of rainfall is converted into usable runoff. The result of this challenge is high variability in reservoir storage, groundwater storage and river levels over time (DWAF 2008). This study will focus on how temperature and rainfall variability affect the reservoir storage.

In semi-arid climates, rainfall variability is an important feature (Ramos and Martinez-Casasnovas, 2006) and there is likely to be an increase in variability as a result of climate change in many of these regions (Batisani and Yarna, 2010). More so, fluctuations of rainfall will occur over the entire continent (Jagadish et al., 2012; Kozo, 2008). There is a significant differences in the underlying mechanisms driving rainfall variability in Africa's southern - and northern - hemisphere (Vincent, et al., 1995), and in Southern Africa intra and inter-annual rainfall variability is strongly affected by the El Niño - Southern Oscillation (ENSO) phenomenon (Anyamba et al., 2002; Cao and Prince, 2005).

Contemporary trends in rainfall distributions and potential impacts of climate variability are difficult to assess because of the variability of rainfall (Cook et al., 2004; Reason and Jagadheesha, 2005). Most countries of southern Africa are among the many semi-arid climates of the world, including South Africa which experiences highly variable rainfall patterns (Reason and Mulenga, 1999). In South Africa, water demand already exceeds supply in many parts of the country and more so the country is expected to experience this imbalance in the near future (Muller et al., 2009). As a result of these imbalances in the near future, water storage has become important, in order to impound water (Keller et al., 2000; Muller, 2000).

Around the world, water can be stored in dams or reservoirs as means of water security, even if there is no economic value in the capturing (Keller et al., 2000). Muller (2007) states that water should not be made a commercial product; instead water should be a free service to the community. In addition, Muller (2007) argues that water should be conserved for future use. More so, reservoirs support a numerus number of ecosystems functions, economic, social and cultural activities (Mostert, 2008; Katambara and Ndiritu, 2009). Reservoirs are constructed as a mechanism to respond to the problem of water scarcity as revealed by Inocencio et al. (2003). The reservoir capacity is increased by the amount of rainfall received over its surface area (Fargo, 2002).

The change in climatic conditions directly affects water resources, will shrink the resources of freshwater (Kiker, 2000). The existing hydrological resources in Southern Africa are expected to be negatively altered by climate change and this in return will apply pressure on the eventual water resources (Schulze and Perks, 2000). In light of this, it is paramount to investigate and account for the impact of climate variability on water resource of South Africa.

However, this study selectively focuses on the following; types of water sources, water quantity and quality which are considered to be very determinant when issues of household vulnerability are discussed in Nkonkobe Local Municipality, South Africa (Bakker, 2012).

The Nkonkobe Local Municipality (NLM) receives its water services from Amathole Water Services (Mqola, 2010) which was made a water service authority (WSA) in 2003. The new water status of the municipality stipulated the terms and responsibilities for service delivery. Water provision required the service delivery authority (WSA) to respect quality, quantity and sustainability. Furthermore, considering the compulsory National Standards for portable water (2001) WSA was required to implement quality water monitoring and management programmes to improve and report on drinking water. This was with the knowledge that water security is the dependable availability of a satisfactory and acceptable quantity and quality of water, for health, production and livelihoods. Over the years, climate variability has affected the water resources in the municipality, making it difficult to achieve the desired ends. This experience confirmed the World Bank's (2013) prognostics that poor countries are more likely to face challenges to water security due to climate variability. These variabilities in climate have concomitantly brought into effect water insecurity.

1.3 **Problem statement**

Climate variability has amplified many climate related ecosystem events (drought, floods) in the various parts of the world, and made natural hazards a growing concern. The uncertainties associated with temperatures, rainfall and water security has left the population in many localities vulnerable to the caprices of weather uncertainties.

Climate variability in the Eastern Cape Province, South Africa has resulted in water reduction in reservoirs due to low rainfall. To better understand these events in the Eastern Cape Province, the Nkonkobe Local Municipality was chosen for these reasons of climate trends to assess water security. The study set to answer the question, will the net balance in the water availability sustain the population of the municipality if the factors of climate variability (rainfall and temperature) are considered.

1.4 Objectives

1.4.1 Main objective

The main objective of the research is to investigate how temperature and rainfall variability affect the reservoir storage in the Nkonkobe Local Municipality.

1.4.2 Specific objectives

- ❖ Determine the changing trends of the temperature and rainfall of Nkonkobe Local Municipality.
- ❖ Characterise the relationship between rainfall and water reservoir volumes.
- ❖ Establish the relationship between minimum and maximum temperature and the water reservoir volumes.
- ❖ Determine the vulnerability index of water security of the reservoir in the study area

1.5 **Hypotheses**

1.5.1 Major hypothesis

- ❖ Temperature and rainfall variability has had and continues to have adverse effects on the livelihoods of people notably resource-poor communities in the Nkonkobe Local Municipality.

1.5.2 Specific hypotheses

- ❖ There has been high vulnerability to water security of the reservoir due to limited adaptive capacity within the municipality.

1.6 **Justification and limitations of the study**

1.6.1 Justification of the study

The study seeks to assess the water security of the reservoirs as they are highly affected by the rainfall and temperature variability. There is a dearth in climate related research in most of the Eastern Cape Municipalities. The range of data problems vary from the absence of continuity in data collection where the infrastructure exist, through the absence of gauging stations to gaps about data on reservoir management (water in flow and out flow, evaporation rate, absence of monitoring instruments). To circumvent this problem especially on climatic events related to variability through a special algorithm to fill missing data are resorted to in an effort to determine the rainfall and temperature variability is impacting the water security of the reservoirs in the Nkonkobe Local Municipality. This study will outline the awareness of the vital need for weather stations for up to date data on climate variability and hydrological data. It is expected that through the research finding that the importance antecedent data for climatic prognostic and water security projection will outlined. The local municipality will be able to address the problems of the water security of the reservoirs.

1.6.2 Limitations of the study

Most of the secondary data from the weather stations was not available and also the hydrological data was only for two reservoirs out of the five that service the Municipality. The study area also has only two weather stations (Fort Beaufort and Hogsback) with long-term rainfall and temperature data.

1.7 **Organization of the dissertation**

Chapter 1: Introduction

This first chapter sets the contextual background of the climate variability, water security and vulnerability matters and also definition of terms. The problem statement, objectives, hypothesis and justification and limitations of the study are also outlined.

Chapter 2: Literature review

In this chapter, a review of water security issues, climate variability and vulnerability assessment studies are examined to contextualize the study

Chapter 3: Materials and methods

The chapter provides a description of the area of interest for the research. This chapter also describes the research process of performing the water security assessment using climate variability model. The materials and methods for the research are presented.

Chapter 4: Results and analysis

The outcomes of the research are presented in form of graphs, figures with relevant captions. Valid statistical procedures used to test significance of results are explained in this chapter.

Chapter 5: Conclusion

The major conclusion of the research is presented based on the results.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter explores the effects of climate variability (rainfall and temperature) on the reservoirs that have an influence on the fluctuation of water volumes in the study area. The review of these climatic effects provides an understanding to the background of the vulnerability of reservoirs and the role of climate variability in affecting water security Nkonkobe local municipality.

2.2 Water security

Water security can be characterized as the capacity to get adequate amounts of clean water to keep up satisfactory models of sustenance and merchandise generation, fitting sanitation, and feasible human services (Lenton and Muller, 2009; Grey and Sadoff, 2007). FAO (2009) United Nations water organization (UN-Water) study noted that "the total usable freshwater supply for ecosystems and humans is only about 200,000 km^3 of water – less than one percent (<1%) of all freshwater resources. Specifically, water withdrawals are predicted to increase by 50 percent by 2025 in developing countries, and 18 per cent in developed countries. By 2025, 800 million people will face water scarcity, and two-thirds of the world population could be under stress conditions."

Water security in Africa remains a key issue with great implications for the freshwater situation; however of the estimated 800 million people living on the African continent, more than 300 million reside in water-scarce environment (UN water, 2006). Africa with a large part of the population deficient in access to clean and safe water, there is a need to understand the continental dynamics (UN, 2010). Figure 2.1 shows populations using improved drinking water, and disparities between Africa and the rest of the world.

According to UNICEF/WHO (2012), the region of Sub-Saharan Africa makes available the greatest insight into these water issues, yet there have been great improvement in water coverage in most regions throughout the world. More so the Sub-Saharan Africa region currently has an improved access to drinking water sources which stands at 61%. (UN, 2010). Water is a scarce resource for development in Southern Africa and a change in water supply affects the water security (Mukheibir and Sparks, 2002). Seasonal and inter-annual variations in rainfall are some of the factors that contribute to vulnerability in water systems in Southern Africa (Schulze and Perks, 2000).

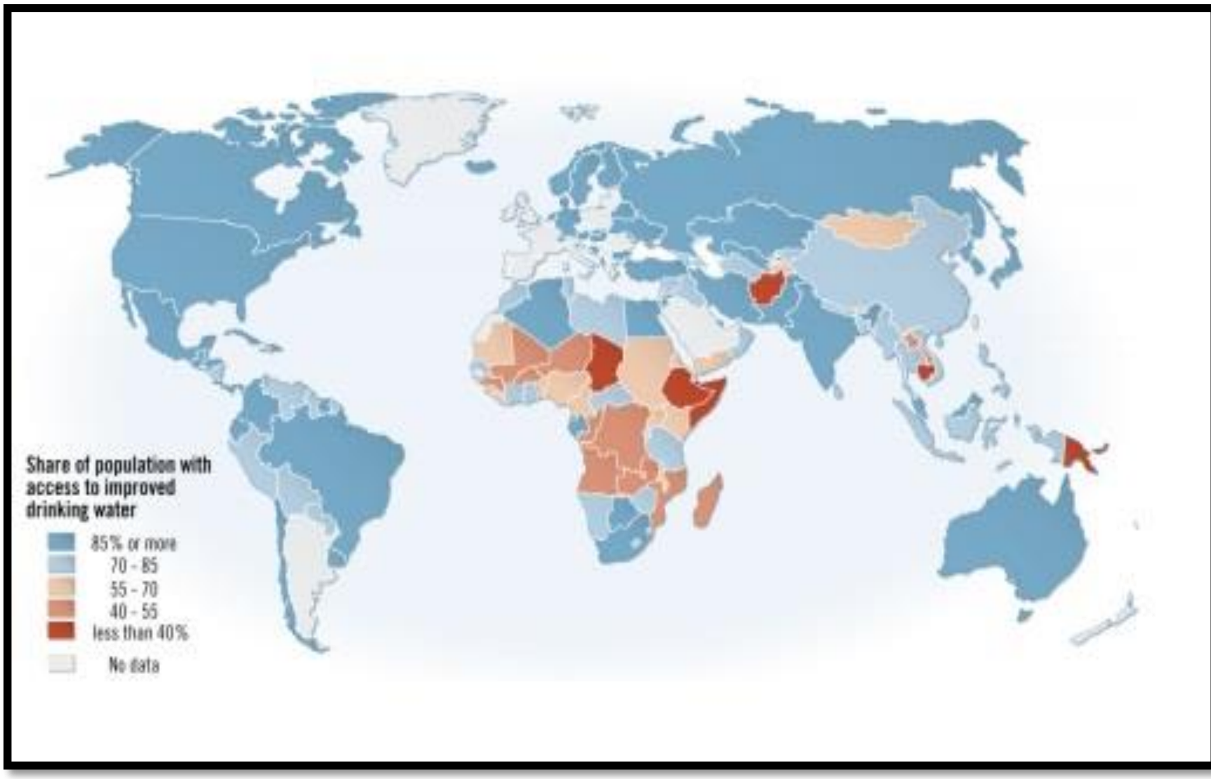

Figure 2.1: Population with access to drinking water
(Source: UN, 2010).

2.3 Water Security Hot Spots

Africa is greatly affected by water security issues (Grey and Sadoff, 2007; Lenton and Muller, 2009; UNICEF/WHO, 2012). Ethiopia is suffering from water stress with huge part of the population unable to access clean and safe drinking water and the increasing climate variability is a significant challenge to water security (Carius et al. 2008). Kenya is said to be vulnerable to climate changes and variability that have resulted in water scarcity challenges due to high heat stress and evaporation (Kahl, 2005; Saferworld, 2009). Although countries in central Africa (Burundi and Democratic Republic of Congo) have relatively abundant water compared to other countries in Africa, these countries experience extreme weather conditions with alternating dryness and heavy rains leading to floods (Ndaruzaniye, 2009).

Rising water scarcity in the Nile basin induced by climate variability and growing population levels in the Sudan may amplify tensions related to water security if not addressed (UNEP, 2008). Due to climate change and climate variability, Southern Africa is likely to become significantly drier in the coming decades, this will increase water stress (Swatuk, 2007). The annual average precipitation has decreased and high temperatures over the past decades have been experienced as in the case of Mozambique (One World, 2010). Consequently, this has affected the water security of the country leaving more areas under the effect of droughts (UNDP, 2008; One World, 2010).

2.4 Water availability in South Africa

South Africa is considered the 30th driest country in the world (McDonald and Pape, 2002; Baatjies and Hendrickse 2014). South Africa has an average annual rainfall of 500mm that varies across the country. A critical water stress has been projected for the near future, where annual renewable water resources fall below 1000 cubic metres (Water Research Institute, 1996, cited in Lange and Hassan, 2006). With an increase of the rate of water usage, this might lead to high demand and is likely to exceed supply. This makes water security a key national priority. According to the Institute of Directors

Southern Africa (2012), some projections estimate that South Africa already exploits about 98% of its available water supply resources and this will affect water availability which is most likely to be further restricted as a result of future climatic conditions and an increase in demand is eminent from the ever increase population growth.

According to the Minister of Water and Sanitation water crisis in South Africa has reached breaking point (SABC news, 2015). Due to climate change and variability Rand Water's area is now vulnerable to water security as evidenced by long queues of residents in search of water (Figure 2.2). There is a high strain in bulk water supply system in Rand Water area due to persistent high temperatures in the country's hub, Johannesburg (REUTERS, 2015, November 1). According to Muller (2015) where rainfall is variable and unpredictable, the cities have to plan to store enough water to supply the needs of each region.

Figure 2.2: Johannesburg hit by long queues for water

(Source: SABC news, 2015, November 1 accessed 09:00)

The social inequities currently visible in South Africa are due to the policies of the apartheid government. These policies favoured white people based on race. Thus white people enjoyed benefits and resources that were not readily accessible to the black community, including water provision and sanitation. The post-apartheid government has the responsibility to redress these inequalities through developing new policies that will cater for all its citizens. According to Maharaj and Narsiah (2012), the Reconstruction and Development Programme (RDP) has a strong basic needs and social justice orientation, and was a strategy to address social and economic inequalities of the apartheid era - in particular, the reduction of inequalities and poverty, amongst those who were formerly deprived of these opportunities.

Water is a basic need, and in terms of the RDP, the provision of water services especially to disadvantaged communities. The Eastern Cape, a historically disadvantaged province is still facing a large back log in ensuring that its communities have secure safe water and sanitation. Since the provision of water services come at a cost, the majority of the municipalities are from the former “home lands” where the poor communities are not in a position to pay for water. This has an implication on the provision of adequate access to water for everyone. In light of this, in Nkonkobe Local Municipality a preliminary field research was undertaken in November 2014 by the researcher. The preliminary field work revealed challenges associated with the provision and delivery of water services to the majority of black poorer communities. As result of this evidence this research seeks to address the problems associated with water security in the face of climate variability on hydrology resources in the Nkonkobe Local Municipality.

2.5 Climate variability in the Eastern Cape Province

The UN Climate Change Conference Report (2012) acknowledges that the world continues to be warmer due to the drivers of climate variability. The 20^{th} Century has brought better and improved technology to monitor and forecast weather patterns, more so this has presented more reliable information on top of the already existing data and brings more clarity to climate information.

"*Africa is one of the most vulnerable continents to climate change and climate variability, a situation aggravated by the interaction of 'multiple stresses', occurring at various levels, and low adaptive capacity*", (IPCC, 2011).

According to Midgley et al. (2011), South Africa has great variability of climate with a warming trend across the country. The Eastern Cape experiences high temperature that increase towards the North West interior and the high temperatures are associated with an increase of intense droughts and increase of evaporation rates (Figure 2.3).

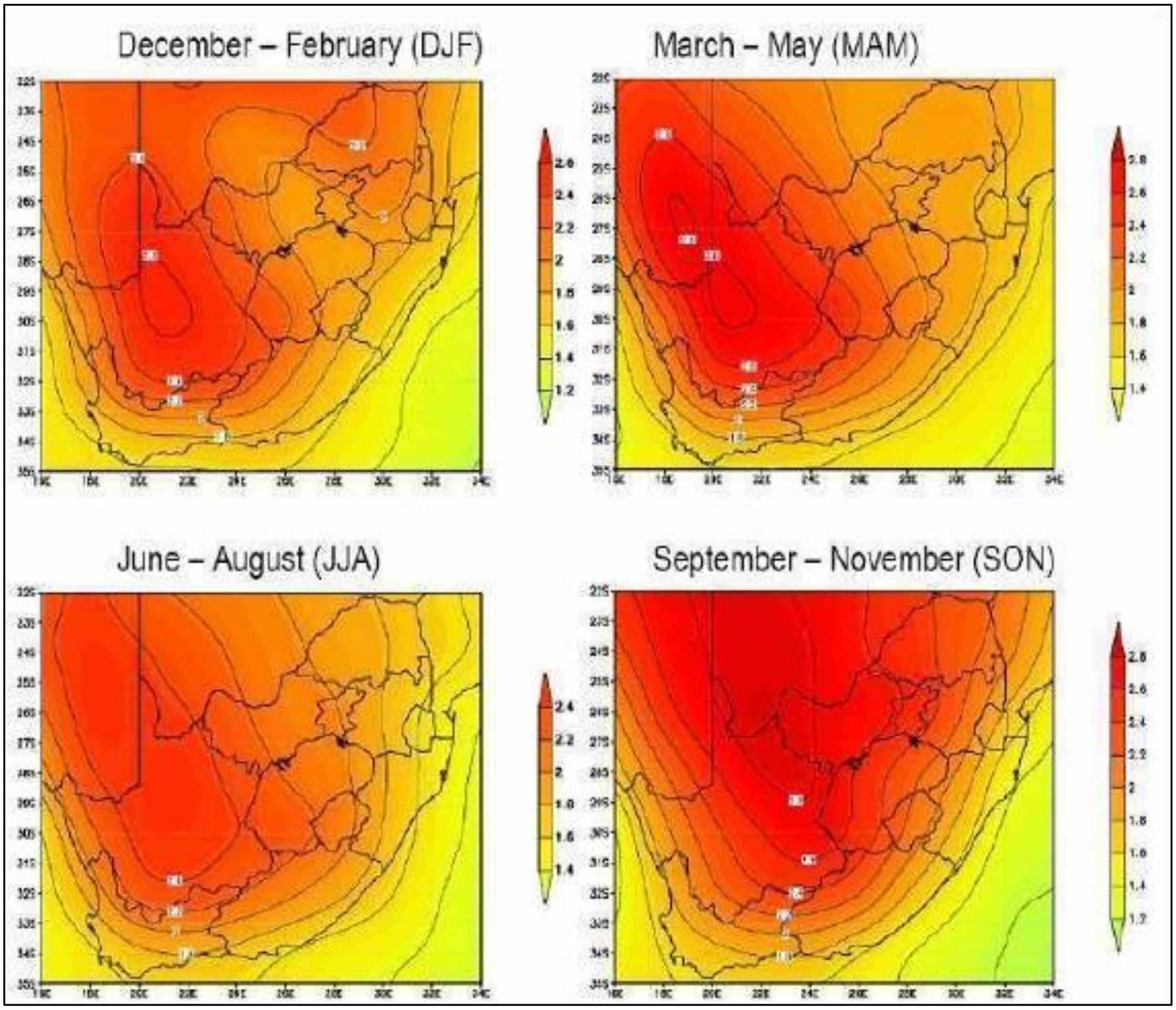

Figure 2.3: Projected median change in maximum surface temperature by 2050 (Source: Midgley et al. 2007)

Figure 2.4 projects precipitation for South Africa which shows a wetting trend to the East and North East of the country. The South and South West are show a drying trend (Midgley et al. 2007). The wetting trend is expected eastwards in the Eastern Cape Province, it is also projected that durations of droughts will increase as the same with rainfall intensity.

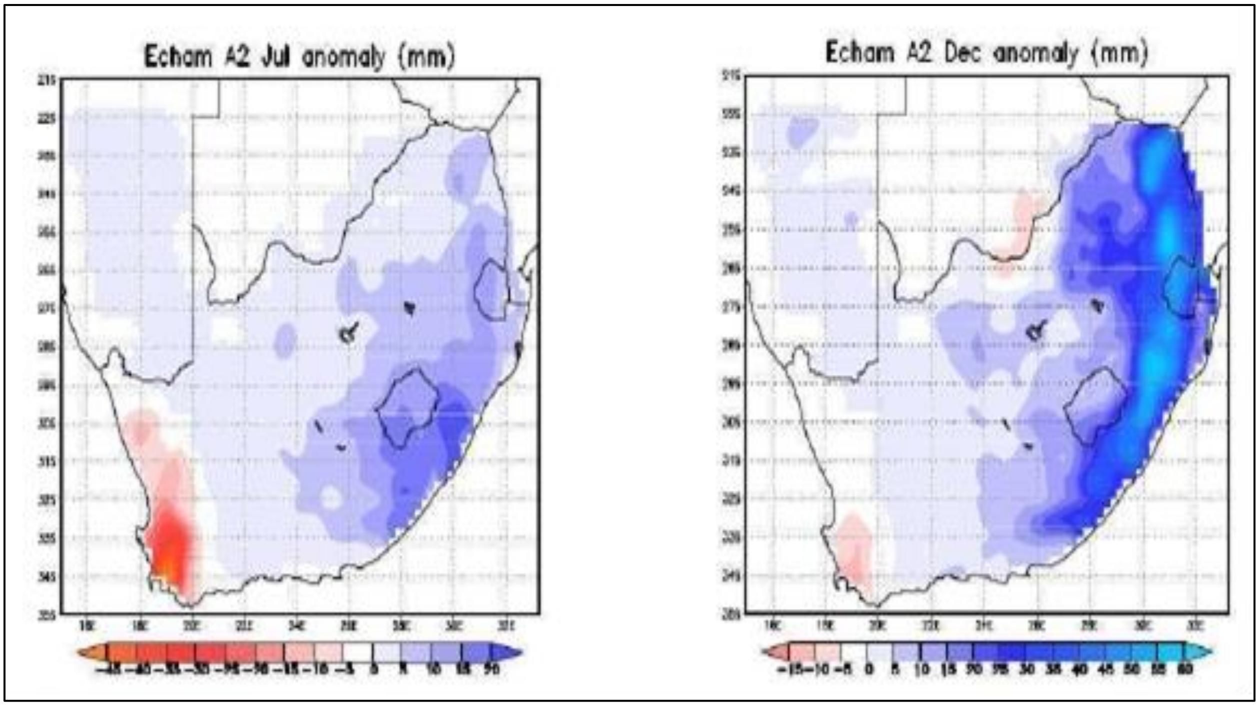

Figure 2.4: Projected change in total annual rainfall (mm month-1) for July and December (mid-century)

(Source: Midgley et al. 2007)

Johnston et al. (2011) predicted a decrease in summer rainfall of 25% in the Eastern Cape in the next 50 years indicating nothing similar to today's patterns. These changes in climate might cause changes in reservoirs and increasing variability in water resources; given that African countries are extremely sensitive to precipitation.

Rainfall changes are likely to vary across the continent, especially with southern Africa which may see a decrease, however for many other regions, available data does not permit any conclusions to be arrived at whether there will be an increase or decrease in rainfall (Midgley et al. 2007). Nevertheless, there are indications that variability will likely multiply which increases the likelihood of more frequent and severe rainfall.

This invariably would increase the risks of floods and disasters, and would negatively impact human health, economic development, and overall human development, simultaneously creating refugee flows together with displaced persons. It is very likely that Africa's population will doubles from its current (2010) level to over two billion by 2050 (Global resource database, 2010). The Intergovernmental Panel on Climate Change (IPCC) asserts that by 2020, 75 million people in Africa will be experiencing acute water scarcity and this number is likely to rise to some several hundreds of million by 2050 (Droogers, 2009). Water demands are currently likely going to rise sharply, as climate variability becomes more pronounced exacerbating the competition amongst user groups creating livelihood challenges. The absence of regional data poses a real challenge currently because it renders projection at country specific levels difficult. Hence adequate assessments become literally impossible on concrete national impacts of climate change.

2.5 The impact of climate variability on vulnerability

Human society is likely to be vulnerable to environmental change due to climate change or variability (UNEP, 2002). "Vulnerability is the extent to which a natural or social system is susceptible to sustaining reservoirage from climate variability" (IPCC, 1997). The Intergovernmental Panel on Climate Change-IPCC (1997) framework on vulnerability outlines that sensitivity of a system is part of the function of vulnerability and adaption of the system. Sensitivity refers to the point to which vulnerability react to a given change in climate, counting both beneficial and harmful effects. Adaption of the system refers to the capability of the system to adapt to changes in climate for example the extent to which changes in practices or structures as a result of a given change in climate.

Smit and Wandel (2006) argue that a system is less vulnerable if it is less exposed, less sensitive or has a strong adaptive capacity. Figure 2.5 shows adaptation action required to identify vulnerable systems, since many of our human and natural systems are intensely influenced by climate factors (Allen Consulting, 2005). Exposures, sensitivity, potential impact, adaptive capacity are all functions that lead to vulnerability that need adaptation strategies. IPCC (2014) identified exposure as component of vulnerability that outlines the presence of people, livelihoods, services and resources that may well be unpleasantly affected by climate variability. Sensitivity echoes the alertness of a system to climatic influences, and the degree to which changes in climate might affect it in its current form.

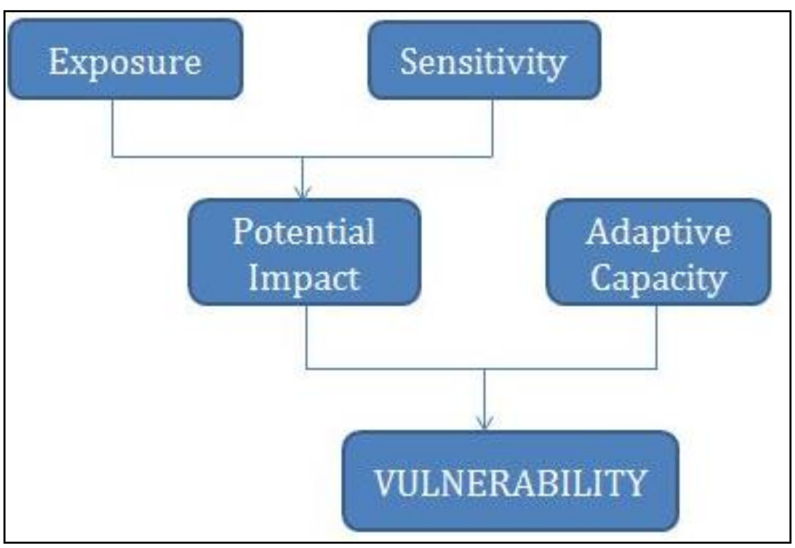

Figure 2.5: Vulnerability conceptual framework

(Source: Allen Consulting, 2005)

Vulnerability is understood as a hierarchical aggregation of three components: exposure, sensitivity and adaptive capacity. Water Resources Vulnerability (WRV) assessment is significant to uphold the security of hydrological resources. Vulnerability is the self-owned objective aspect of a water resource system, the water resource vulnerability owns potent characteristics and regional characteristics and its vulnerability within a certain time period is stable relatively (Turner et al. 2003).

Vulnerable water resource system has a poor ability to resist external interferences and a poor self-restoring ability. Water resource vulnerability includes two aspects which are water quality vulnerability and water quantity vulnerability. In terms of vulnerability forming factors, it can be classified into three kinds including natural vulnerability, artificial vulnerability and bearing vulnerability (Takama et al. 2015). Among them, the natural vulnerability reflects the static characteristics of water resource vulnerability and its influencing factors mainly include annual mean precipitation, annual mean evaporation, annual mean temperature, annual mean runoff, drought index, gradient, water resources quantity per capita and cultivated land area.

The artificial vulnerability reflects the dynamic characteristics of water resource vulnerability and its influencing factors mainly include forest coverage, water conservancy project flood storage capability, water utilization efficiency, water qualification rate, water resource allocation rationality, water resource price and water resource development and utilization ratio (Takama *et al.,* 2015). Several vulnerability assessment studies have been done in different fields including climate, agricultural sciences, social sciences, geography and environmental sciences. Some analysts have used theoretical perspectives to define the nature of vulnerability (Cutter 1996, Villa and McLeod 2002, Turner et al. 2003), while the others have developed some quantitative measures for vulnerability (Gogu and Dassargues, 2000; Cutter et al. 2003). Vulnerability assessments are subjective and difficult to quantify due its complexity.

For preparing adaptation measure, climate variability impact has been assessed in terms of vulnerability. Vulnerability assessment is a process for assessing, measuring, and/or characterizing the exposure, sensitivity, and adaptive capacity of a natural or human system to disturbance. Exposure is a measure of the magnitude and extent (that is spatial and temporal scales) of exposure to climate variability impacts. Sensitivity is a measure of how a system is likely to respond when exposed to a climate-induced stress. Adaptive capacity is a measure of the potential, ability, or opportunities available to decrease exposure or sensitivity of a system to a climate induced stress (Fussel and Klein, 2006; Glik et al. 2011). Several studies on vulnerability/sustainability assessment, the development of vulnerability/sustainability indicators, and mitigation and action assessment have either been completed or are currently underway in various parts of the world (Gleick, 1990; Lane et al. 1999; Meigh et al. 1999; Vogel, 2001; IPCC, 2001; Adger et al. 2004; Brooks et al. 2005).

Bates et al. (2008) assert that adaptation to changes in water availability and quality have to be made, not only by the water management agencies but also by individual users of the water environment, including industry, farmers (especially irrigators) and individual consumers. Adaptation actions in response to climate variability depend on local conditions of vulnerability. Some actions are driven by indigenous knowledge, while some are integrated into a multi-sectoral approach to adaptation such as ecosystem-based adaptation. Community-based adaptation (CBA) can be considered as an additional layer of community-based development activities, practices, research and policies. The hope is that experiences and knowledge learned on the plethora of pilot activities undertaken at the community level will be shared among the practitioners, policymakers, researchers, funders and the communities at risk (Bates et al. 2008).

2.6 Vulnerability Index

In examining climate vulnerability in the Eastern Cape Province, a vulnerability assessment model was applied to assess the impact of climate variability on reservoirs reliability. The vulnerability model has been used by several studies to assess climate vulnerability (IFPRI, 2009; Midgley *et al*., 2011). East Bay Municipal Utility District (EBMUD) (2009) identified four key areas of potential vulnerability to climate change and variability: (1) flooding and sea level rise, (2) hydropower generation, (3) water supply and demand, and (4) water quality. However, for this study vulnerability will be based on the IPCC variability definition, where a region's vulnerability to climate change and variability is described by two elements: exposure and sensitivity (IPCC, 2001).

Exposure interpreted as the direct danger (the stressor), and the nature and extent of changes to a region's climate variables (temperature, precipitation, extreme weather events). Sensitivity describes the human environmental conditions that can worsen the hazard, ameliorate the hazard, or trigger an impact. Exposure and sensitivity are intrinsically linked and together affect potential impact (Thornton *et al*., 2006, Takama *et al.,* 2015). To assess reservoir vulnerability to climate variability, vulnerability indicators should represent both the biophysical conditions of the Reservoirs and the socio-economic conditions of the reservoirs (Sullivan and Meigh, 2005). The selection of indicators was done through an extensive review of reports (Aandahl and O'Brien, 2001; Moss *et al.*, 2001; Brenkert and Malone, 2005; Brooks *et al.*, 2005; Thornton *et al.*, 2006).

From the vulnerability conceptual framework, the vulnerability of a given system largely depends on its exposure and sensitivity, which combined provides the potential impact and the potential for effectively coping with the impacts and associated risks. A higher adaptive capacity is associated with a lower vulnerability, while a higher impact is associated with a higher vulnerability (IFPRI, 2009; Midgley *et al.*, 2011). Vulnerability is defined as a function of a range of biophysical and socio-economic factors, commonly aggregated into three components that estimate the adaptive capacity, sensitivity, and exposure to climate variability and change (IFPRI, 2009).

2.8 Conclusion

This chapter has presented the reviewed literature and described the various combinations of climate variability affecting water security. These climate variability factors (rainfall and temperature) affect water security in most parts of the sub-Saharan region. This chapter also presented climate vulnerability and impacts in Africa and South Africa in particular. The implication is that changes in climate attributes will have significant impacts on water security. Increasing and decreasing trends respectively, climate attributes (rainfall and temperature) will have a direct implication on the availability of water in the hydrology resources (reservoirs). Further, the chapter discussed adaptation options viable for African countries central to the climate change issue.

2.9 Methodological framework

The research study methodological framework is shown in Figure 2.6. The method followed included literature review, problem statement, study area, data collection, data analysis, results interpretation and discussion and lastly the presentation of the final thesis document.

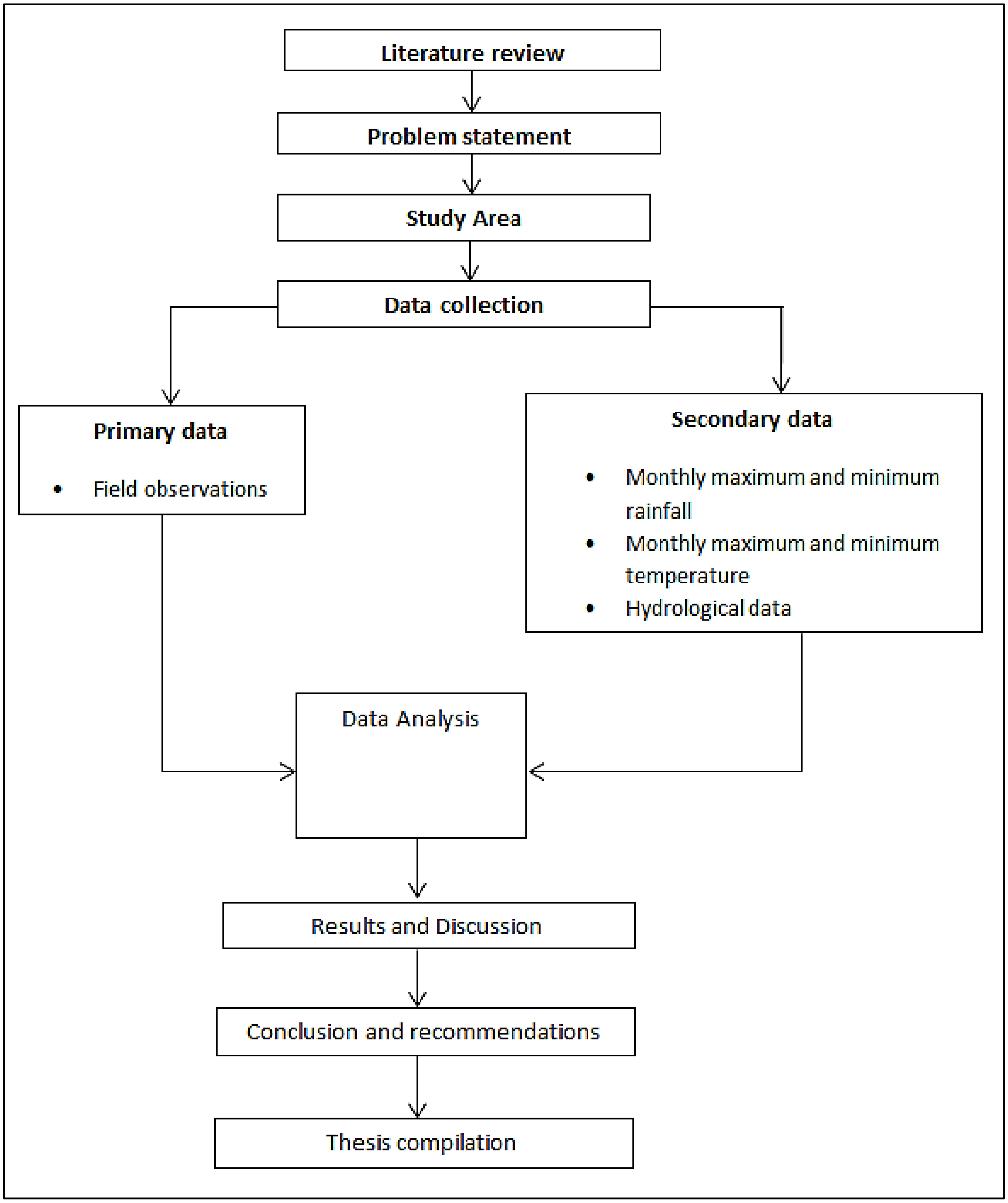

Figure 2.6: Methodological framework used to assess water security in the study area

CHAPTER THREE

MATERIALS AND METHODS

3. 1 Introduction

This chapter presents the methods used to accomplish the aim and objectives of the study. It outlines the research approach and design that was followed by a description of the study area, conceptual framework, data collection, and data analysis. The methodological procedures that were carried out in implementing the study are outlined in this chapter.

3.2 Study Area

Nkonkobe is a local municipality, situated at the center of the Eastern Cape Province of South Africa. Nkonkobe Local Municipality is the second largest municipality in the Amathole District, which was established in 2000 (Figure 3.1). The Municipality is geographically located between 32˚47’0” S and 26˚ 50’ 0” E and covers an area of approximately 3,725 km^2. The municipality was named after the Winterberg Mountain Range (Nkonkobe in IsiXhosa), (Nkonkobe IDP, 2012). Nkonkobe is made up of the following small towns and villages Alice, Middledrift, Fort Beaufort, Hogsback and Seymour/Balfour which are now disestablished Transitional Local Councils (TLCs). Nkonkobe Local Municipality has 21 wards and an estimated population of 135,660 (Statistics SA, 2011).

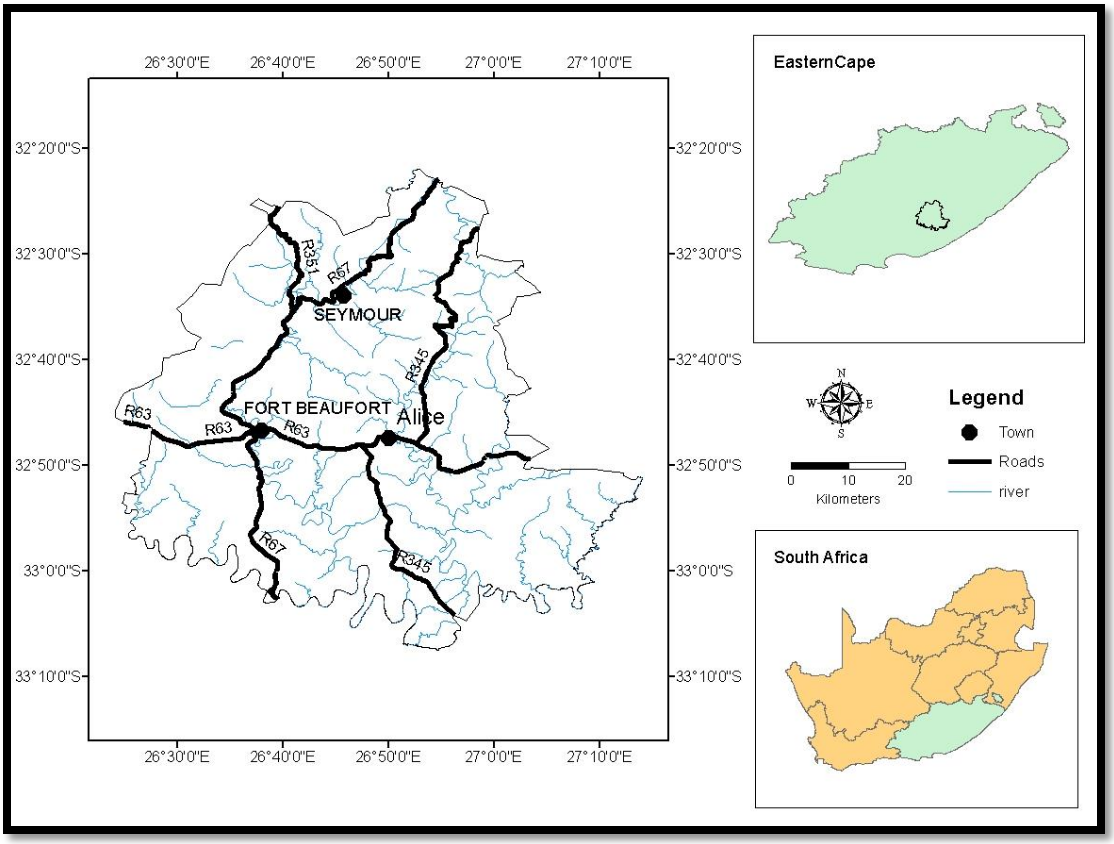

Figure 3.1: Study area

Major urban centers are mainly in Alice and Fort Beaufort. An estimated 74% of people living within the municipality are poor (Nkonkobe IDP, 2011/12). The majority of the population (72%) resides in both villages and farms and 28% resides in urban settlements. The study involved high populated townships of Alice, namely Golf Course. In Fort Beaufort densely population areas covered include eMahobini, eDamini) and Tinis (Zwide, Daweti).

Nkonkobe Local Municipality (NLM) vegetation includes four biomes covering 372411.7ha (DWAF, 2012). Vegetation of the area is divided into four biome categories:

albany thicket, forests, grassland and savanna (Mucina and Rutherford, 2006). Albany thicket is the largest, covering 47.63% of municipality (177378.8ha); followed by the grassland that covers 28.51% of municipality (106180.1ha). Savanna has 87842.9ha which makes 23.59% of the municipality. Lastly the forests have the lowest percentage of the biomes (0.27) cover of the municipality which makes 1009.9ha. The type of vegetation in NLM shows that the area receives low levels of rainfall and the temperatures are most likely to be high.

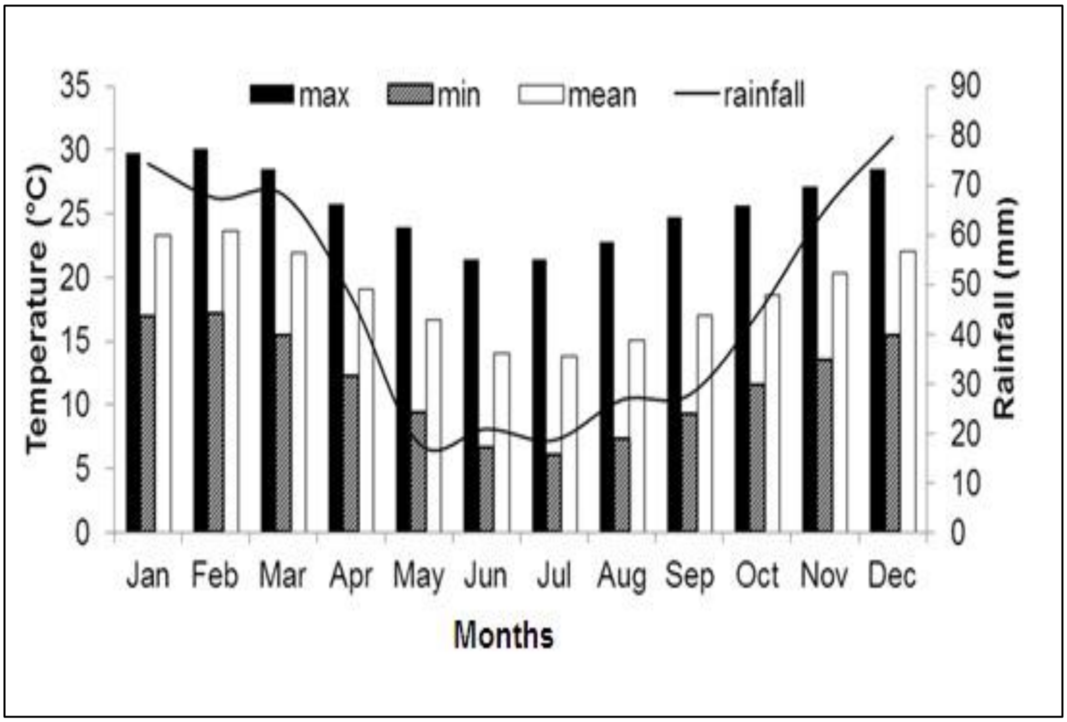

Figure 3.2: Monthly temperature and rainfall of the study area, (1993–2012). (Source: South African Weather Service, http://weathersa.co.za)

Annual rainfall varied between 284 mm and 1315.9 mm for the Nkonkobe area over the past 30 years. The monthly temperature between the years 1993–2012 and precipitation between the years 1993–2012 are illustrated in Figure 3.2. Summer season has the highest amount of rainfall with an average of 548.4 mm, indicating that the study area receives most of the precipitation in this season. Average temperature of the study area is relatively high during summer, with the highest monthly average recorded in February (30.9 °C). The winter period has the lowest temperature, with the lowest monthly average recorded in July 3.7 °C. Due to the fluctuation in the rainfall and temperature, water levels in NLM reservoirs vary over time from short-term, annual wet season rises and dry season declines to long-term fluctuations caused by multi-decade rainfall trends.

3.3 Triangulation approach

This research followed a triangulation approach, which blended qualitative and quantitative methods of information and data generation, and analysis. Triangulation helped to get a clearer understanding of the research problem, that is, to answer the question, will the net balance in the water availability sustain the population of the municipality if the factors of climate variability (rainfall and temperature) are considered. Qualitative research is a means for exploring and understanding the meanings individuals or groups ascribe to a social or human or an environmental problem (Creswell, 2007).The qualitative technique that was used is visual observations, to observe the reservoirs and the settlement pattern surrounding the reservoirs.

The quantitative research techniques characteristically attempt to define relationships among variables statistically and also to present a numerical analysis of the climate variability data and hydrological data. Charles and Mertler (2002) argue that quantitative research relies mainly on numerical data. According to Creswell (2007), whilst carrying out a quantitative research, the researcher has to decide on what type of variables, methods and instruments to use, also establish the magnitude and frequency of the variable relationship in order to achieve the best reliable and valid results. According to Neuman (2006), the agreement between two or more data-gathering techniques enhances the belief that the results are valid. In this study climate data and hydrology data was used as quantitative data. A trend analysis was carried out , same a model was developed to establish the relationship between temperature and rainfall on the reservoirs.

Digital photography was used to clarify and triangulate the visual observation carried out in the study and compare with the results acquired for analyzing quantitative data (climate data and hydrology data). An interpretation of the digital photography was narrated to clarify the visual observations observed in the data collection. Triangulation provides additional sources of valuable insight that cannot be gained from using one source of data in result interpretation and triangulation reduces the impact of bias. Triangulation was used in data collection stage.

3.4 Data collection

3.4.1Field data

The purpose of this field survey was to make a visual observation of the reservoirs and the vulnerability faced by communities in Nkonkobe Local Municipality. The visual observation followed the field guided below (see Table 1). Observation is a core research practices that grounds and contextualizes every method that is qualitative

(Cosco, Moore and Islam's, 2010; Hay, 2010). Only visual observations were used since the use of visual images allowed the researcher to communicate knowledge, experience and ideas gained during field work. Visual images are informative and also help the reader understand better (Cameron & Gibson 2005; Hale 2006). Furthermore, observation methods are put to a variety of uses for example, to collect certain kinds of enumerative data, to provide complemative methods before or after data is collected (Cosco, Moore and Islam's, 2010).

Visual observation was used in this research. The researcher went into the field to observe the problems, observe the state of the Reservoirs and spent time with the community members in areas affected by water security. Observations were made on nine days in November 2014, three days on the water reservoirs in different reservoir location and two days in each of the three residential areas that were chosen as study locations. This allowed the researcher to gain direct experience and understanding of the water problem which are water supply in the settlement area and water quantity in reservoirs. Table 1 below shows the observation instrument that was used in the study.

Table 1: Field Guide

	Yes	No
Is the Binfield or Kat River reservoir located on the given position by Water Service Authorities in South Africa?		
Are all the facilities fuctioning at the reservoirs?		
State what can be observe on the reservoir?		
Describe the condition of the reservoir?		
	Yes	No
Is there pollution(solid waste)		
State the type of pollution evidenced		
What is the water level of the reservoir		
	Yes	No
Are there any other source of water near the reservoir		
If yes describe the alternative source		
How far is the nearest settlement from the reservoir?		
	Yes	No
Is the community water secure?		
If No what are the problems		
How best can you decribe the settlement pattern?		
Collect temperature and rainfall data for South African Weather Service		
Collect hydrology data from Water Service Authorities in South Africa		

3.5 Trends of the climate

Daily rainfall data of Nkonkobe Local Municipality for 34 years (1980 to 2014) were collected from South Africa Weather Service in October 2014. Quality assurance method ISO 9000 series was used in the process of checking and validation of the data, but making use of quality control not the wider topic of quality assurance. Infilling of missing data was carried out using the Kolmogorov-Smirnov (KS) test. Using one of the seven methods of infilling of missing data. The method used data at the nearest weather station being assigned directly to the target weather station. All the data was carefully observed, any suspicious data was cross-checked with rainfall data of proximate station.

A descriptive statistical analysis for two types of data: i) annual rainfall and ii) inter and intra annual rainfall variability trends was conducted. According to Yerukala et al. (2011) descriptive statistics deals with organization and summary of large scale data. This statistical data includes graphs, tables and raw data represented by numbers (Ott and Longnecker, 2010).The first equation shows mean rainfall of the year.

First moment (mean):

$$\bar{y} = \frac{\varepsilon y_i}{n} \qquad (1)$$

Second moment (inter-annual variability):

The second statistical analysis of temporal variability to be discussed is inter-annual variability. This method count up to the point to which the total annual rainfall of the research area differs from year to year (Nel and Sumner, 2009).The analysis of the inter variability is usually limited to a comparison of annual amounts of rainfall in different years. This measure is defined as Eq. (2).

$$cvm_k = \frac{\sigma(P_t)}{\mu(Pt)} \quad (2)$$

Where P_t is the total annual rainfall in year t for Nkonkobe Local Municipality.

The third statistical analysis Intra-annual or seasonal variability is defined as the monthly rainfall totals as a percentage of the total annual rainfall (Nel and Sumner, 2009).The intra-annual variability and its temporal trends can be best defined by a modified version of the precipitation concentration index (PCI) (Ceballos et al. 2004). PCI was applied: Eq. (3).

$$PCI = 100\ \frac{\sum_{i=1}^{12} P_i^2}{(\sum_{i=1}^{12} P_i^2)} \quad (3)$$

Where *Pi* is the precipitation of the month, *i*. Values below 10 indicate a uniform distribution of rainfall throughout the year. PCI values from 11 to 20 indicate a seasonal trend and values above 20 indicate a considerable variability of the distribution of monthly rainfall (Ceballos *et al*., 2004). Therefore, an increase in the PCI value over time indicates an increase in the variability of the distribution of monthly rainfall.

3.6 Relationships between rainfall distribution, temperature distribution and reservoir’s holding capacity

Secondary data were used in this study. Monthly rainfall and temperatures, reservoir inflows, and reservoir storage data for the reservoir’s in NLM were obtained from the Department of Water Affairs (DWA) Hydrology Services and the South African Meteorological Services. Afterwards data cleaning and analysis of the Hydrological Service data was carried out for both Reservoirs. Observations were carried out at the reservoirs and interviews conducted so as to obtain more data. The researcher in the study used descriptive statistical methods. The descriptive methods include linear regression, correlation and graphs.

Correlation of the meteorological variables temperature and rainfall on hydrologic and reservoir’s variables were computed to determine the strength of the relationship between the variables.

3.7 Vulnerability index

A statistical method principal component analysis (PCA) or factor analysis to determining vulnerability index was used in the study. The PCA was used to assign weights to indicators in each of the two components that estimate the sensitivity and exposure (Cutter et al., 2003; Thornton et al., 2006). PCA is a technique for extracting from a set of variables those few orthogonal linear combinations of variables that most successfully capture the common information (Filmer and Pritchett, 2001). Following

Piya (2012), PCA was run for the selected indicators of exposure and sensitivity in Data Analysis and SPSS. The loadings from the PCA were used as the weights for the indicators. The weights assigned for each indicator varied between -1 and +1.

The sign of the indicators denotes the direction of relationship with other indicators used to construct the vulnerability index. The magnitude of the weights describes the contribution of each indicator to the value of the index. Figure 3.3 shows vulnerability types by impact-adaptive capacity axis. The greater the exposure or sensitivity, the greater is the vulnerability, while the greater the adaptive capacity, the lesser is the vulnerability. Reducing vulnerability would involve reducing impact, or increasing adaptive capacity

Type I: High Impact, Low AC

- most vulnerable, higher priority for adaptation measures
- differential adaption measures dependent on vulnerability characteristics
- governance, education and non-structural measures in the short term are needed

Type II: Low Impact, Low AC

- exposure to potential risk, little concern in climate change
- awareness raising and capacity building needed

Type III: High Impact, High AC

- capacity to reduce high risk - prevention system for effective adaptation
- differential adaptive capacity building dependent on its composing elements

Type IV: Low Impact, High AC

- high resilience to climate change, but the magnitude of impact could be managed

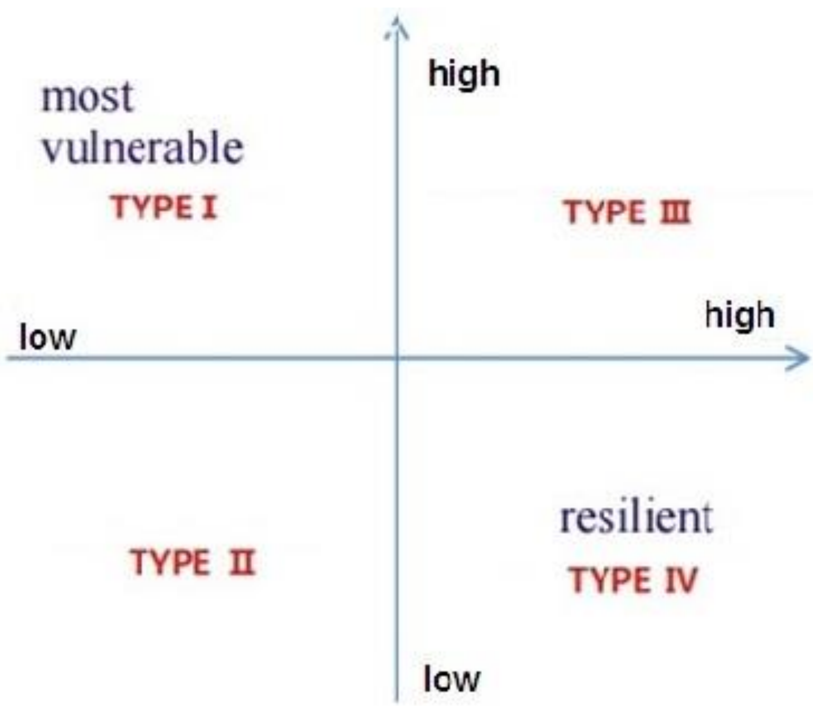

Figure 3.3: Vulnerability Index Model (Source: Sullivan and Meigh 2005)

3.8 Conclusion

This chapter provided a description of the study area, research design and data collection, explaining what data was collected and how it was obtained. Some of the observed data were captured and presented in photographs. The analytical methods used to obtain results are also discussed in the chapter. The chapter further explains the use of both primary and secondary data in the analysis. For the assessment on the vulnerability to climate variability in the Nkonkobe local Municipality, a vulnerability assessment model was used. The chapter discussed the vulnerability assessment model and how it was used in this study. Lastly, the data were analysed and explained according to the proposed conceptual framework and the themes from the literature review in relation to the aims and objectives of this study.

CHAPTER FOUR

RESULTS AND DISCUSSION

4. Introduction

This chapter presents and discusses the results of the descriptive analysis from the data collected from the study areas. Within the chapter, descriptive statistics such as inter and intra annual variability; scatter plots and line graphs are used. The first section begins with brief explanations of the field work carried out. Other sections will cover the changing trends of the climate; relationships between rainfall or temperature distribution and reservoir holding capacity and lastly the vulnerability index of the reservoirs.

4.1 Field Data

This field guide is based on qualitative research that prepared the researcher with foundational, practical information to guide through the data collection (table 2). A visit was made to Binfield local community located in the Amathole Mountains as part of the selected communities in Nkonkobe Local Municipality for ground truthing. Binfield park reservoir was chosen as suitable location because it is one of the two main reservoirs within Nkonkobe Local Municipality; hence the majority of the livelihoods are dependent upon the reservoir. The two reservoirs are the major drivers of the livelihood adaptive capacity to climate change within the municipality since they are the only main water sources readily available.

Table 2: Field guide report

	Yes	No
Is the Binfield or Kat River reservoir located on the given position by Water Service Authorities in South Africa?	X	
Are all the facilities fuctioning at the reservoirs?	The facilities on the reservoirs are not fuction at both reservoirs	
State what can be observe on the reservoir?	Binfield resevoir the facilities are vandalized,the fence is not covering the whole reservoir,solid waste pollution Kat River reservoir there is no fence ,the facilities are not functioning Bells settling pound, the pound bed is exposed and there is solid waste pollution	
Describe the condition of the reservoir?	Both reservoirs where not in the required standards. No proper management.	
	Yes	No
Is there pollution(solid waste)	X	
State the type of pollution evidenced	Plastic containers,shopping bags and papers	
What is the water level of the reservoir	Water levels are low	
	Yes	No
Are there any other source of water near the reservoir	X	
If yes describe the alternative source	Jojo tanks and windmills	
How far is the nearest settlement from the reservoir?	100 metres	
	Yes	No
Is the community water secure?		X
If No what are the problems	Poor water provision and delivery in the communities	
How best can you decribe the settlement pattern?	Nucleated settlement near the reservoirs and linear patterns in the urban area	
Collect temperature and rainfall data for South African Weather Service	collected and cleaned data	
Collect hydrology data from Water Service Authorities in South Africa	collected and cleaned data	

Binfield Park reservoir is a gravity reservoir on the Tyume River, near Alice, Eastern Cape, South Africa. The water is mainly used for irrigation and drinking purposes. The reservoir height is 60m and length is 1555m with a total capacity of 36 830 000m^3 and surface area estimated to be 187 hectares. A number of settlements are scattered around the Binfield reservoir since it is the main supply of water to the entire community. The pattern of settlements in Binfield is nucleated, this is because it is influenced by the opportunities related to accessibility to water.

Figure 4.1: Communities in Binfield using jojo tanks, Eastern Cape, South Africa (2014)

The majority of community members situated at a distance away from the reservoir depend on rainwater harvesting from roof tops, the water is collected in jojo tanks as illustrated in (Figure 4.1). Due to water scarcity, especially during the dry-season people depend on ground water (see Figure 4.2). Families that use water from such sources are very limited within the community. Water is pumped from the Binfields reservoir to the surrounding communities.

Figure 4.2: Windmill for pumping groundwater to households in Binfield, Eastern Cape, South Africa (2014)

A field visit was also done to Kat River reservoir, one of the largest reservoirs within the municipality. The reservoir is located in Seymour town which is one of the four main towns in the municipality. Most of the houses within the rivers' catchment area have been demolished by environmental management authorities for being constructed in high flooding-prone areas (Figure 4.3). Figure 4.4 shows how the settlement pattern (nucleated) is influenced by the reservoir, for easy access to the water resource.

Figure 4.3: Demolished houses (10m) next to Kat River Reservoir, Seymour, Eastern Cape, South Africa (2014)

Figure 4.4: Nucleated settlement pattern in Kat River reservoir, Seymour, Eastern Cape, South Africa (2014)

The town of Fort Beaufort depends on a Kat River for its source of water since there is no reservoir to supply the area, also the water is drawn straight from Kat River into a settling pound. Figure 4.5 shows the state of the Bells Reservoir in Fort Beaufort. The purpose of the settling pond is to suspend matter in raw water supplies, so as to provide water suitable for domestic purposes and most industrial requirements. There is evidence of water on the low levels in the reservoir indicated by the visible reservoir bed floor. In addition to this there are solid waste materials noticeable in the reservoir. The water settling pond is not a secured source of water since there is no fence protecting the reservoir from the unguided animals and human activities in the area.

Figure 4.5: The state of Bells Settling pond next to the Fort Beaufort Water Works Plant, Eastern Cape, South Africa (2014)

The properties that are situated at the Binfield Reservoir are vandalized and show that the facilities are not functioning (see Figure 4.6). The fence surrounding the reservoir has been vandalized with and the reservoir is now vulnerable to both human and physical factors.

Figure 4.6: Vandalized property at Binfield, Alice, Eastern Cape, South Africa (2014)

Zwide Location is one of the oldest locations in the township of Fort Beaufort. There is no functional water and sanitation infrastructure servicing the area for a long time. The Municipality supplies the communities with water tanks that often came to fill jojo water tanks in the area. The residents stand in long queues for hours to collect water due to a large number of people depending on the jojo water tank (figure 4.7). The residents of Zwide are responsible for fetching water for their household use, evidenced by the both men and women waiting for the Amathole District Municipality (AMD) truck. This meant that poor households relied on the small quantities of water they fetch from the water truck.

Figure 4.7: Residents waiting for the ADM water truck in Fort Beaufort, Eastern Cape, South Africa (2014)

Amathole District Municipality (ADM) as the WSA in the area tried to find alternatives to solve the problem of water service delivery. One of the strategies was to provide water tanks to the areas mostly affected by the problems of poor provision of water services, including Golf Course location found in Alice, (Figure 4.8). The trucks delivered water in the affected areas on certain times and days but the schedule was not communicated to the community by the ADM.

Figure 4.8: Water Truck delivering water to Golf Course, Alice, Eastern Cape, South Africa (November 2014)

To sum-up, historically during the apartheid era people had to manually fetch water directly from the source, hence in the study area most of the settlement is nucleated around the reservoir. Post-1994 the government introduced policies and legislation to address inequalities in service delivery. The RDP was the first initiative aimed at eradicating poverty and removing past inequities, one of its goals was to improve the provision of water services to poor communities as a priority. However, not much has been done in the study area as evidenced by the residents trying to find alternative means of adaption to water security issues.

Majority of the community is situated a distance away from the reservoir, they depend on rainwater collected in jojo tanks in Binfield because of water scarcity. In addition to this, in the areas surrounding Binfield during dry-season people depend on ground water pumped using the windmills although, they are very limited within the communities so as to improve water supply due to low level of water in the reservoir. In Fort Beaufort and Alice (Golf course) the municipality provided jojo water tanks in the area and often came to fill those tanks. However, the tanks were not distributed evenly so that everyone could have access to them; this was evidenced by the residents standing in long lines for hours to collect water due to the large number of people depending on the water tank.

The state of the reservoir was in a poor state, all the reservoirs are neglected. There is no proper management. Noticeable are the high level of solid waste pollution in the reservoir which means that there are human actives near a source of drinking water, which is not allowed as evidenced by the nucleated settlement near the reservoir banks. The reservoirs have inconsistence data which is prove off failure reservoir management; the buildings where abandoned and where vandalized. Lastly there was evidence of water retreating in the level in all reservoirs.

The findings of these observation revealed problems associated with poor provision of water services which prompted the researcher to seek out the cause of these water security issues. The researcher seek to establish if the fluctuation in water volumes in the reservoir was the major cause of these poor water provision and lastly if the climatic conditions of the area had a major effect on the vulnerability of the water sources which will lead to poor water provision.

4.2 Climate variability data and reservoirs holding capacity data

The total rainfall received in a given period at a location is highly variable from one year to another. The variability depends on the type of climate and the length of the considered period. In general it can be stated that the drier the climate, the higher the variability of rainfall in time. In Table 3 shows the total annual rainfall observed in Nkonkobe Local Municipality for the 1980 – 2014 period. Annual rainfall varied between 343.4 mm (year 1992) and 797.8 mm (year 1985). PCI values from 1980 to 2014 indicating a variability of the distribution of monthly rainfall, it ranges from the PCI 11.4 to 18.44. The absolute deviation of annual rainfall fluctuation in the values, that ranges from 0.80 to 293.10. Average minimum temperature refers to the lowest temperature value recorded that year over the study period, average maximum temperature refers to the highest value recorded during the same period (Table 4). Either or both of these temperatures vary throughout the years. The min of minimum temperature value(s) recorded in study period, with the lowest temperature value(s) remaining 7 °C. The max of maximum temperature value(s) recorded in study period, with the highest temperature value(s) ranging from 27.25 °C to 31.13 °C.

Table 3: Rainfall variability data

Year	Annual Rainfall Total	PCI	ABS	SUMMER	WINTER
1980	515.30	12.46	121.20		
1981	723.60	12.26	87.10	268.60	131.30
1982	433.80	11.73	202.70	112.50	107.10
1983	512.50	14.77	124.00	60.20	94.50
1984	511.70	11.49	124.80	270.80	77.40
1985	797.80	18.44	161.30	208.90	15.80
1986	571.80	14.03	64.70	479.50	29.30
1987	444.50	13.31	192.00	143.40	43.80
1988	631.30	11.97	5.20	109.80	74.70
1989	714.70	18.15	78.20	245.50	37.40
1990	469.60	12.74	166.90	298.40	26.60
1991	556.00	15.17	80.50	154.20	36.20
1992	343.40	12.24	293.10	138.40	41.30
1993	655.90	14.56	19.40	177.90	41.40
1994	470.80	13.56	165.70	351.10	58.30
1995	668.90	14.81	32.40	217.10	32.60
1996	565.10	17.91	71.40	317.60	20.50
1997	654.60	14.40	18.10	325.70	156.00
1998	554.30	11.94	82.20	110.20	21.70
1999	637.30	14.06	0.80	246.70	86.40
2000	752.90	14.45	116.40	325.80	23.10
2001	676.50	11.11	40.00	251.00	44.80
2002	694.10	11.82	57.60	284.60	78.10
2003	454.20	11.71	182.30	172.80	95.40
2004	627.10	11.79	9.40	172.40	53.30
2005	606.30	16.18	30.20	157.00	43.00
2006	795.60	12.50	159.10	313.50	90.50
2007	589.10	11.98	47.40	137.00	104.60
2008	598.30	12.84	38.20	267.40	26.20
2009	534.40	11.32	102.10	220.00	88.40
2010	559.00	13.14	77.50	196.50	70.70
2011	803.60	11.05	167.10	316.80	292.40
2012	666.40	12.11	29.90	228.80	89.50
2013	1 210.80	11.92	574.30	227.40	128.50
2014	1 276.40	15.25	639.90	340.30	41.80

Table 4: Temperature variability data

Year	Average of Minimum°C	Min of minimum°C	Average of Maximum°C	Max of maximum°C
1980	10.85	4.72	24.92	29.49
1981	10.33	4.07	23.49	27.39
1982	11.36	5.35	24.54	29.03
1983	11.46	6.12	24.87	30.64
1984	10.49	4.85	24.41	30.29
1985	11.43	4.23	24.89	28.37
1986	12.00	4.76	24.36	27.25
1987	11.23	5.11	24.81	30.14
1588	10.69	2.90	24.07	28.40
1989	10.38	3.08	23.93	28.68
1990	10.36	4.01	24.09	29.25
1991	11.13	5.05	24.61	28.26
1992	10.68	0.22	25.08	30.17
1993	11.70	6.77	25.17	29.76
1994	10.76	3.07	24.90	27.75
1595	10.79	4.23	24.17	28.20
1996	10.32	3.19	23.97	27.97
1997	10.87	3.79	23.94	28.35
1998	11.20	4.08	24.57	28.69
1999	12.41	5.82	25.60	30.30
2000	11.07	5.30	24.04	28.22
2001	11.49	4.41	24.39	28.44
2002	16.19	4.93	24.72	29.47
2003	11.21	4.27	22.81	31.13
2004	11.80	4.32	25.20	29.90
2005	11.33	4.71	24.81	28.20
2006	11.31	5.00	23.96	28.57
2007	10.98	3.80	25.15	29.10
2008	10.69	5.10	25.00	28.40
2009	15.65	5.80	25.45	29.40
2010	11.70	5.60	25.99	30.65
2011	11.60	4.40	24.14	32.00
2012	11.17	4.40	24.73	32.00
2013	10.52	5.30	25.45	30.40
2014	11.32	5.80	25.66	31.30

The Binfield reservoir reveals great fluctuations in its water holding capacity largely as a result of the fluctuating rainfall events registered annually in this water basin see (table 5). The trend is generally unpredictable because it is neither linear with increasing years nor does it reveal any cyclical pattern over time. This holding capacity reflects the annual precipitation intensity and the volume the reservoir is able to store from the rainfall events.

Table 5: Binfield reservoir holding capacity data

Period	Reservoir holding capacity on cubic metres
1990	5.656
1991	4.18
1992	0.253
1994	0.952
1995	3.073
1996	7.664
1997	10.306
1998	1.134
1999	0.009
2000	17.865
2001	9.076
2002	7.636
2003	1.869
2004	6.59
2005	7.725
2006	11.252
2007	5.895
2008	4.85
2011	16.77
2012	12.146
2013	9.014
2014	15.813

Kat River reservoir manifests a similar trend observed with the Binfield reservoir in light of storage capacity (see Table 6). Here the only difference is that the annual volumes are far greater in the reservoirs revealing greater rainfall intensity events. However it neither reveals any linearity nor pattern over time.

Table 6: Kat River reservoir holding capacity data

Period	Reservoir holding capacity on cubic metres
1991	5.824
1992	2.463
1993	11.439
1994	16.980
1995	8.959
1996	44.008
1997	48.815
1998	9.599
1999	5.448
2000	105.044
2001	38.419
2002	43.798
2003	5.683
2004	10.620
2005	43.053
2006	72.987
2007	20.175
2008	16.369
2009	3.724
2010	6.286
2011	81.479
2012	64.278
2013	41.623
2014	28.562

4.3 Climate trends

A statistical correlation technique was used to determine whether there are any significant differences between the summer and winter rainfall. If the change in one variable is accompanied by a change in the other, then the variables are said to be correlated. Correlation can tell you something about the relationship between variables. The F-test in the ANOVA table indicates a linear relationship between Y and at least one of the X's. The F-statistic will always be at least 0, meaning the F-statistic is always nonnegative. This F-statistic is a ratio of the variability between groups compared to the variability within the groups. If this ratio is large then the p-value is small producing a statistically significant result.

Table 7: Linear regression for summer and winter rainfall (1980-2014) of the study area

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	796.033	1	796.033	.098	.756[b]
	Residual	260150.596	32	8129.706		
	Total	260946.629	33			

a. Dependent Variable: SUMMER

b. Predictors: (Constant), WINTER

In Table 7 above the F-test is 0.098 and the p-value (0.756) which is large than the F-test. This means that the variables are not statistically significant and a linear relationship is observed. However, this does not mean data cannot be analysed. Figure 4.9 shows a fluctuation of distribution of summer and winter rainfall (mm) over the study area. The period 1984 – 1986 experienced a sudden peak in summer rainfall 480mm and the lowest winter rainfall of about 2mm. However, the trend in summer and winter rainfall continue to fluctuate with summer rainfall recording the highest points in 1985,1989,1993,1996,1999,2005,2009 and 2013; also the lowest winter rainfalls were received in 1984, 1995,1997,1999,2007 and 2012. These fluctuations have a direct effect on the water volumes of the reservoir since there is no constant amount of rainfall received in the area. Due to the inconsistency of the rainfall, the reservoirs water security is left vulnerable.

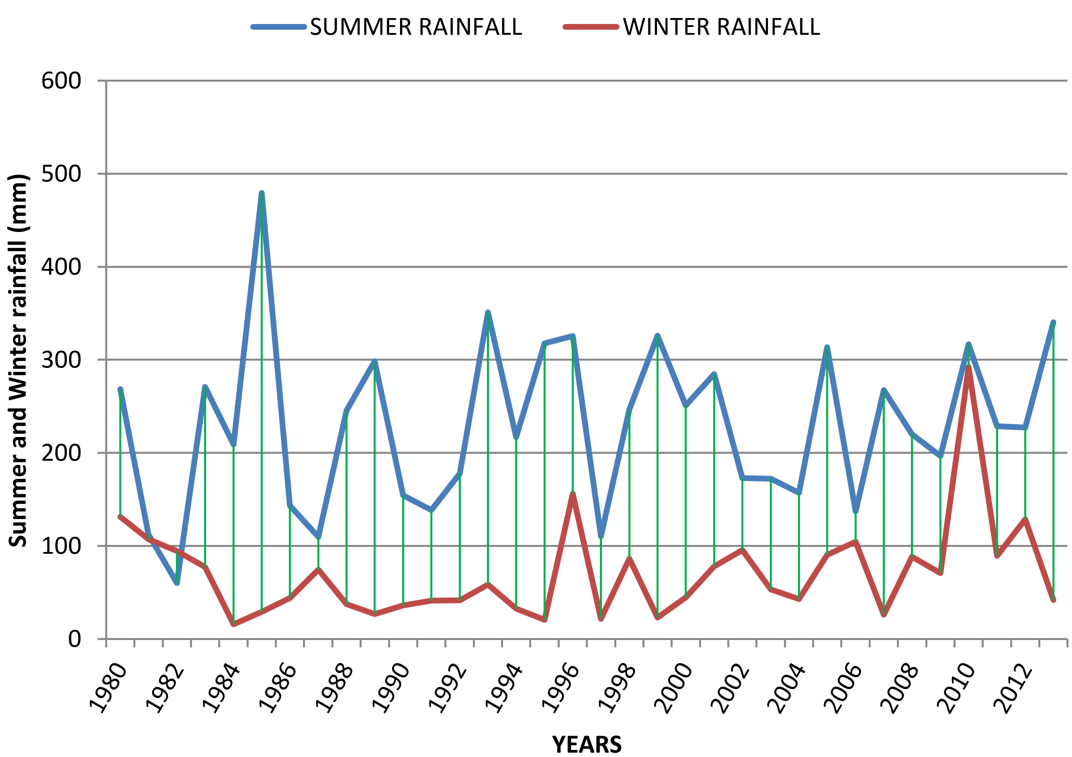

Figure 4.9: Distribution of summer and winter rainfall (mm) over the study area

Table 8 below has F-test which (1.735) is greater than 0, this means the F-statistic is positive. Which makes the p- value (0.197) be great than 0.05. Table 8 shows that there is no statistical significance in the linear relationship. This means that there is no relationship in the fluctuation of rainfall in the study area. The trend is generally unpredictable because it is neither linear with increasing years, with this reason the reservoir is facing uncertainties of having constant water supply which as a result affects water security.

Table 8: Linear regression for Intra-annual rainfall variability (1980-2014) of the study area

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	32525.409	1	32525.409	1.735	.197[b]
	Residual	618662.715	33	18747.355		
	Total	651188.124	34			

a. Dependent Variable: ABS

b. Predictors: (Constant), YEARS

The absolute deviation of annual rainfall (absolute deviation) was analysed (Figure 4.10), as well as linear regression, were applied to rainfall data to discern any temporal trends with the related degree of significance. The distribution of inter-annual rainfall variability of the study area shows a steady rise of the linear trend. Throughout the period of 1980 – 2014 the inter-annual variability shows great variations in the amount of rainfall received. Lastly none of the inter-annual rainfall variability trends are statistically significant at the 95% confidence level since the P = 0,197. The variability has had and continues to have adverse effects on the livelihoods of people notably resource-poor communities in the Nkonkobe Local Municipality. The regression model is represented by $y = 3.0184x + 70.329$ with $R^2 = 0.05$, the regression of the variable is weak since $R^2 \leq 0.1$. The fluctuation of the annual rainfall shows that the reservoirs in the area are most likely to have fluctuation water levels, which will directly affect the water security of the reservoirs.

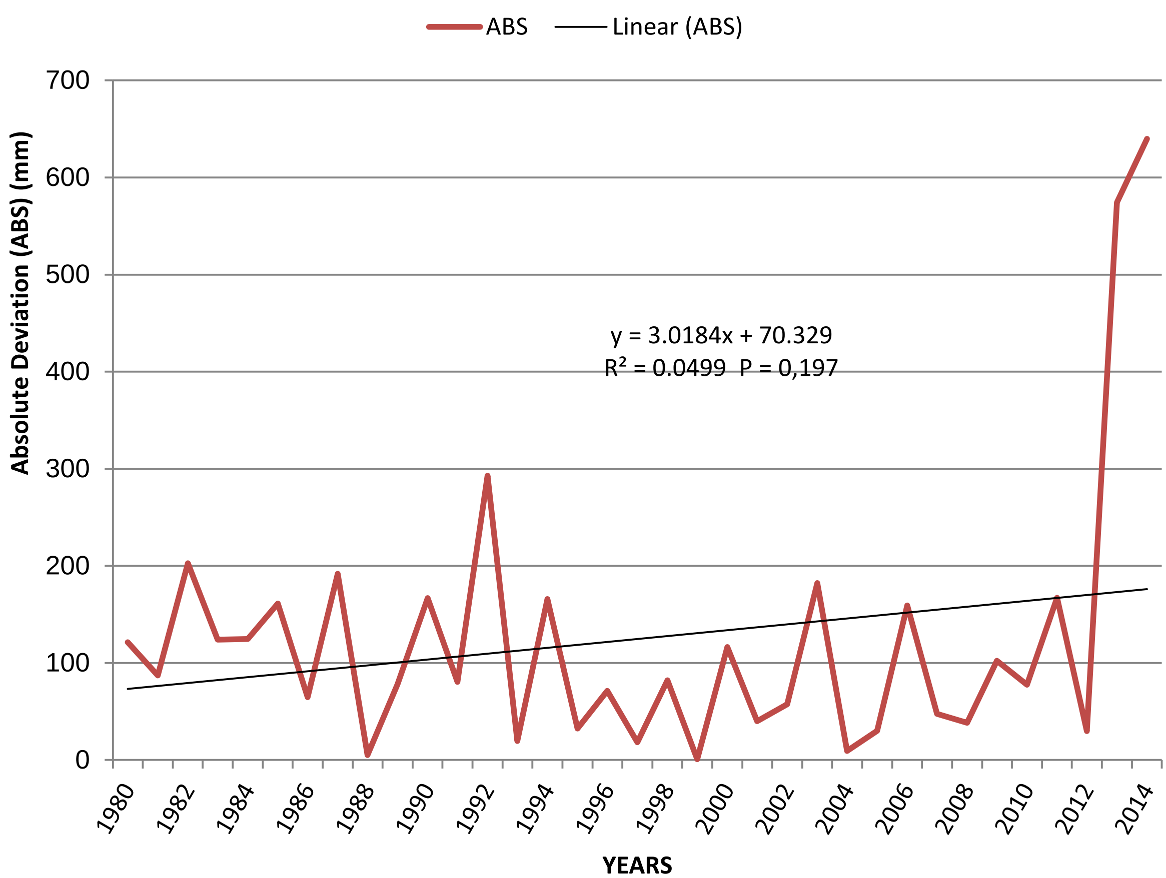

Figure 4.10: Inter-annual rainfall variability (mm) for the study area (1980 to 2014)

There is no statistical significance in the linear relationship as illustrated in Table 8. The distribution of inter-annual rainfall variability of the study area has been on a steady rise as shown by the linear trend. This means that the rainfall is seasonal and is most likely to affect the water volumes of the reservoirs.

Table 9: Linear regression for Intra-annual variability (1980-2014) of the study area

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6.826	1	6.826	1.734	.197[b]
	Residual	129.913	33	3.937		
	Total	136.739	34			

a. Dependent Variable: PCI

b. Predictors: (Constant), YEARS

Rainfall in the Nkonkobe Local Municipality is seasonal, as Nel and Summer, (2009) described the seasonality through monthly rainfall totals as percentage of the total annual rainfall. Increases in precipitation concentration index (PCI) values indicate an increase in the seasonality of monthly rainfall in the Nkonkobe Local Municipality (Figure 4.11). Since rainfall in the municipality is strongly seasonal a decrease in PCI values could suggest a decrease in summer rainfall and a decrease in winter rainfall. Figure 4.11 shows a decrease in PCI values from 1980 to 2014 indicating a decrease in the variability of the distribution of monthly rainfall. However, an increase in PCI over time is still not statistically significant at the 95% confidence level. From the linear regression analysis the PCI decreased from 14.1 to 12.4 mm. The water security of the reservoir is under threat since the trend is generally unpredictable. It is neither linear with increasing years nor does it reveal any cyclical pattern over time.

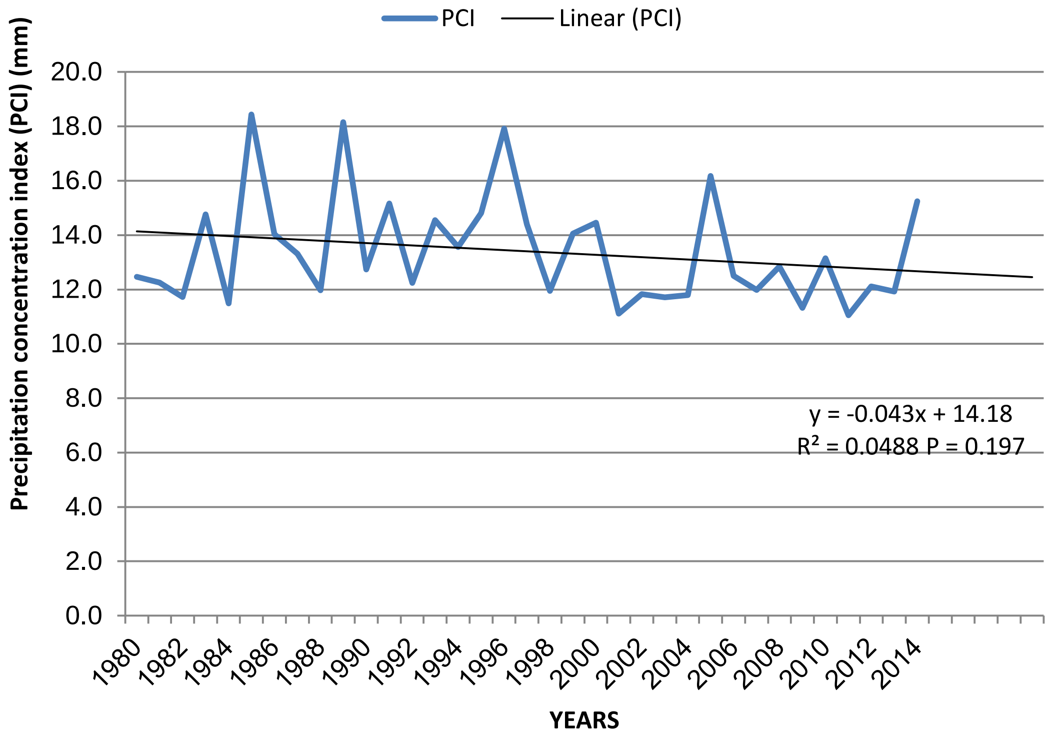

Figure 4.11: Intra-annual rainfall variability for the study area (mm) (1980 to 2014)

Linear regression analysis for Min of minimum temperature (1980-2014) shows a steady increase from linear regression line of 4 to 5 °C. The regression model is represented by y = 0.0205x + 4.1612 with $R^2 = 0.0324$, the regression of the variable is weak since $R^2 \leq 0$. An increase in Min of minimum temperature over time is still not statistically significant at the 95% confidence (Figure 4.12). There is a sharp decrease in the Min of minimum temperature in 1992 as indicated by 0.02 °C registered which is followed by a sharp increase in the following year (1993) by 6.8 °C. This fluctuation shows that the level of evaporation of the reservoir water will be low as affirmed by Midgley et al. (2007). The lower the temperature the less evaporation will take place.

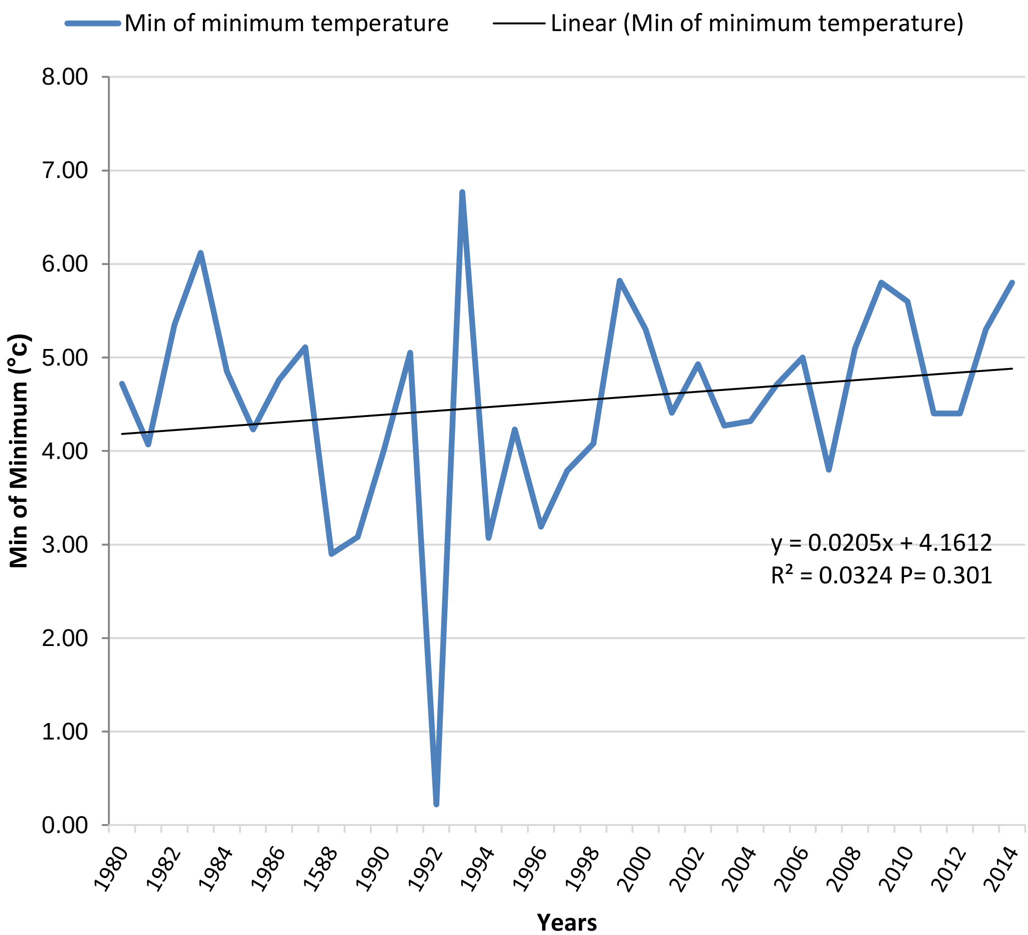

Figure 4.12: Min of minimum temperatures for the study area (°c)

An increase in Max of maximum temperature values indicates an increase in the temperatures in the study area (Figure 4.13). From linear regression analysis the Max of maximum temperature increased from 28.4 to 30.1 °c. The p-value (0.014) is less than the significance level 0.05 this shows that the temperature variables are statistically significant. There is a strong relationship between Max of maximum temperature values, this is influenced by the El Niño / Southern Oscillation (ENSO) warm events. The figure 4.13 shows variation of max of maximum temperature indicated by linear trend from 1980 – 2014. The evaporation rate is high during max of maximum temperature, this is because the air is dry due to ENSO oscillation which is associated with high and dry temperatures as affirmed by Midgley et al. (2007). According to Midgley et al. (2007), high temperatures are associated in with an increase of intense droughts and increase of evaporation rates.

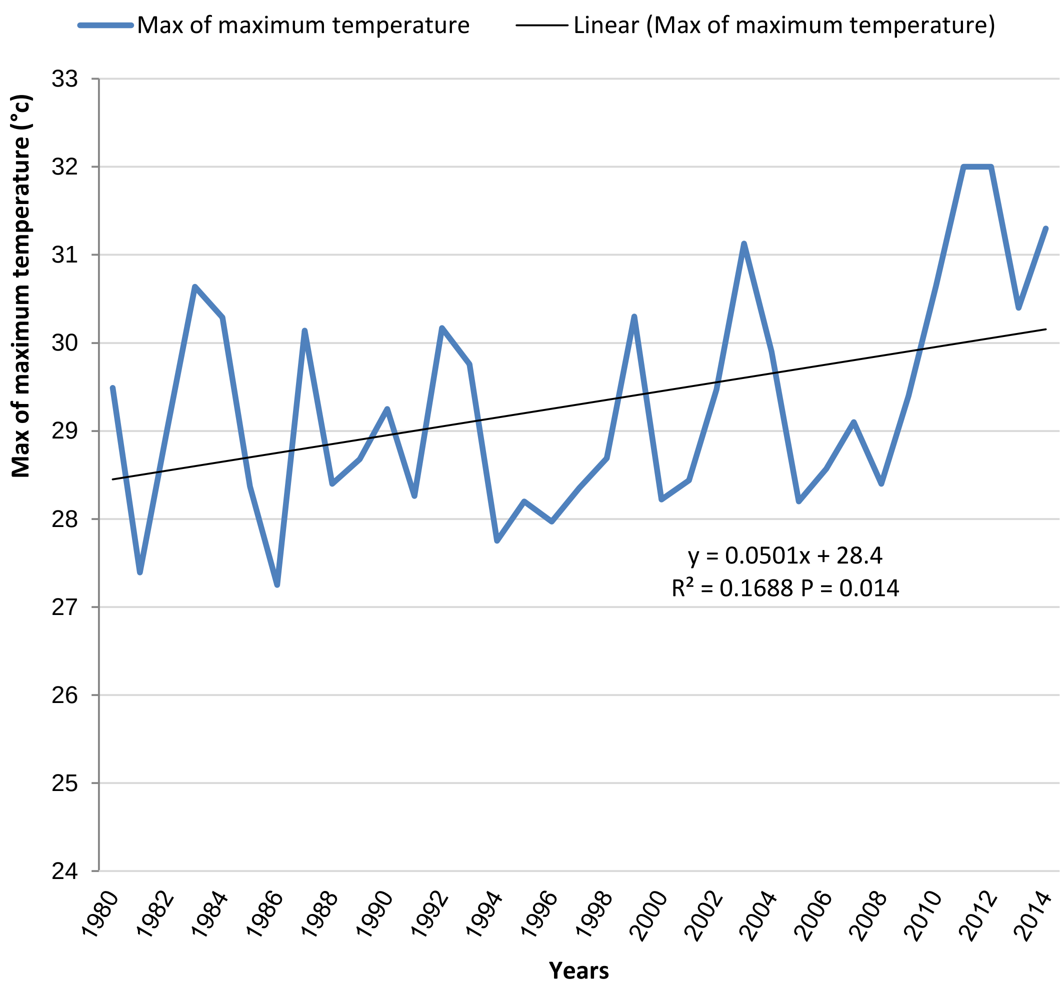

Figure 4.13: Max of maximum temperatures for the study area (°c)

4.4 Relationships between rainfall distribution and reservoir holding capacity

Bivariate (Pearson) Correlation analysis was used to describe the effect of rainfall distribution and reservoir's holding capacity. This correlation expresses the strength of linkage or co-occurrence between rainfall distribution and reservoir holding capacity in a single value between -1 and +1. The bivariate (Pearson) Correlation analysis in SPSS was used to create a scatter plot to visualize the relationship between rainfall distribution and reservoir holding capacity. In order to the test significance the A two-tailed test was used to test significance.

SPSS generated scatter plot for the rainfall distribution and reservoir holding capacity represents Pearson's bivariate correlation (Figure 4.14). The two-tailed test of significance was positive (p value: 0.01) indicating that the two variables had a strong relationship. The regression model is represented by $y = 19.891x + 48.196$ with R^2 0.2802, the regression of the variable is strong since $R^2 \geq 0$. This was expected since the reservoir is highly affected by the rainfall variability.

This entails that the water volume of the reservoir depends on the amount of rainfall the study area receives. As shown by the figure, there is an increase of the reservoir holding capacity when Binfields receives more rainfall. Most of the time the dam holding capacity is less or equal to one million cubic meters, which is the lowest holding capacity. This means that Binfield reservoir water security is vulnerable base on the p-value as mentioned above.

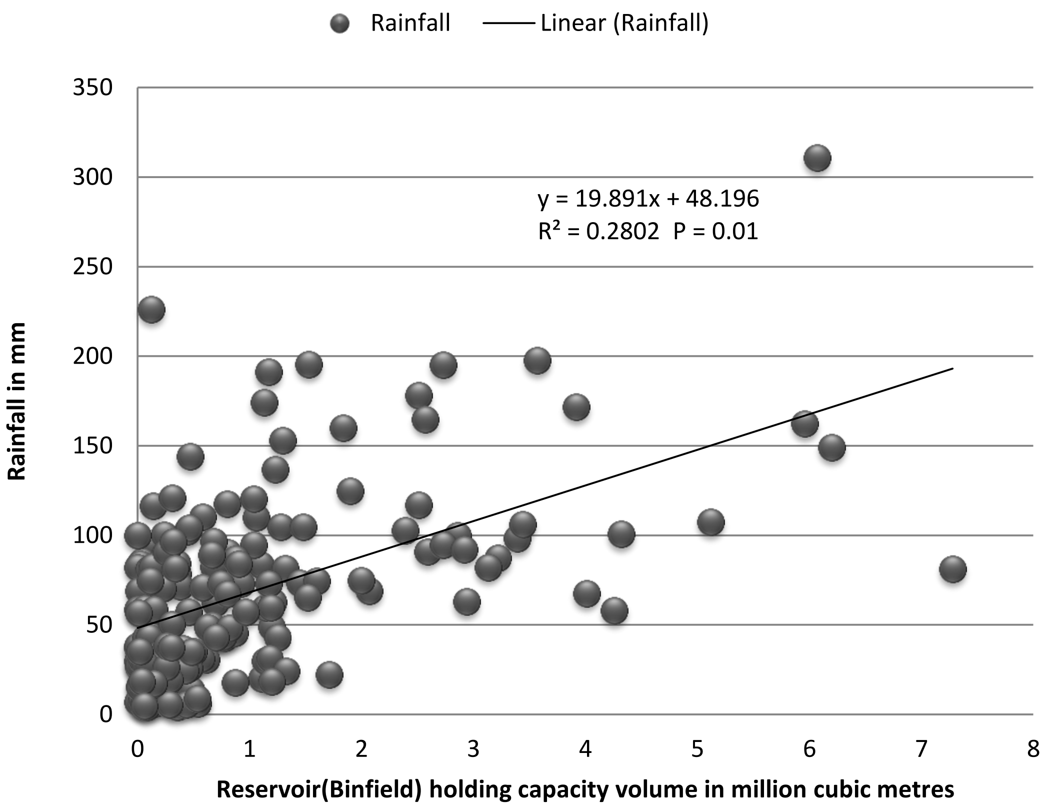

Figure 4.14: Relationships between rainfall distribution and reservoir's holding capacity (Binfield Reservoir).

Based on the results in Figure 4.15, the following is observed that rainfall distribution and reservoir holding capacity of Kat River reservoir has a statistically significant linear relationship ($p < .005$).The direction of the relationship is positive (i.e., rainfall and reservoir water holding capacity are positively correlated), meaning that these variables tend to increase together (i.e., the greater the rainfall is the greater the volume in the reservoir).The magnitude, or strength, of the association is moderate ($.2 < | r | < .5$). Kat River reservoir has a strong relationship with the amount of rainfall that in the study area. The more rainfall the study area receives the more the volume of water increases, as evidenced by Figure 4.15 the holding capacity of the reservoir is low 10 million cubic meters, it fluctuates to a high of 40 million cubic meters. However the reservoirs water security is vulnerable since the amount of rainfall it receives is low.

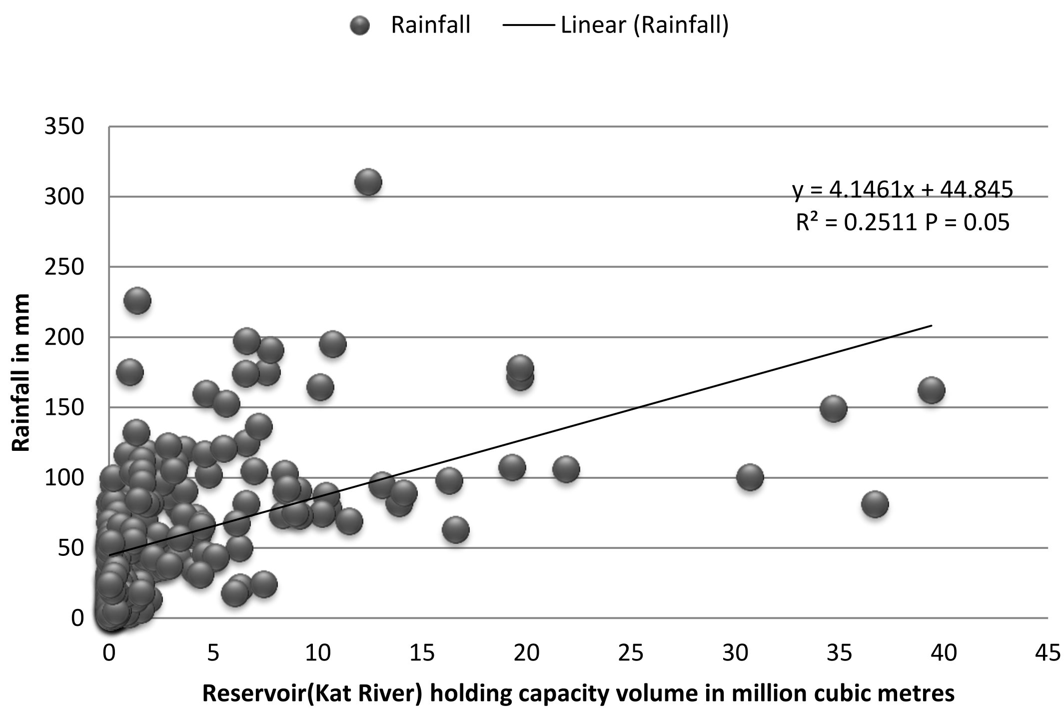

Figure 4.15: Relationship between rainfall distribution and reservoir's holding capacity (Kat River Reservoir).

4.5 Relationship between temperature distribution and reservoir's holding capacity

Temperature distribution and reservoir capacity of Binfield Reservoir have a statistically significant linear relationship ($p < .005$) see (figure 4.16). The direction of the relationship is positive (i.e., temperature and reservoir holding capacity are positively correlated), meaning that these variables tend to increase together (i.e., the greater the temperature is the greater the evaporation rate).The magnitude, or strength, of the association is strong ($.009 < | r | < .1$). This was expected since the reservoir is highly affected by the temperature variability.

There is a strong relationship between the temperature and reservoirs holding capacity as evidenced by the p value above. The higher the temperature the lower the reservoirs holding capacity. The reservoirs water security more vulnerable since it experience high temperatures. Most of the time the maximum temperature ranges from 30 °c to 20 °c this causes high evaporation rate in the reservoir as affirmed by Midgley et al. (2007).

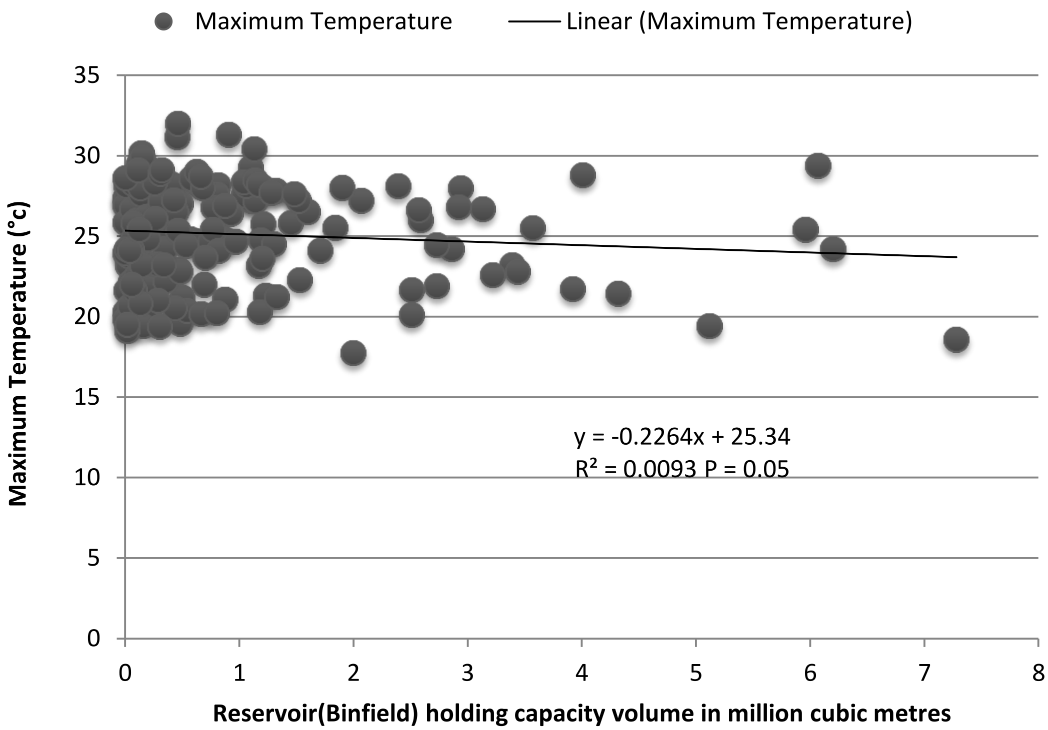

Figure 4.16: Relationships between temperature distribution and reservoir holding capacity (Binfield Reservoir).

Figure 4.17 shows temperature distribution and reservoir holding capacity of Kat River reservoir have a statistically significant linear relationship ($p < 0.01$). The direction of the relationship is negative (i.e., temperature and reservoir holding capacity are positively correlated), meaning that these variables tend to increase or decrease together (i.e., the greater the temperature is the greater the evaporation rate).The magnitude, or strength, of the association is weak ($0.03 < | r | < .1$). The reservoirs holding capacity is affected by the rate of evaporation, this evidenced by Figure 4.17 the greater the temperature the lower the reservoirs holding capacity. This makes the reservoir water security vulnerable.

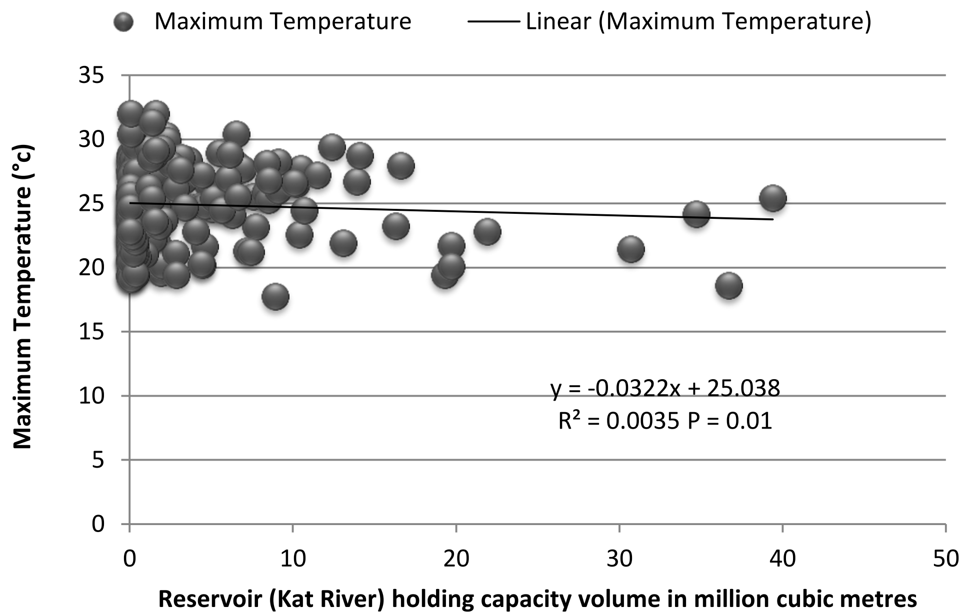

Figure 4.17: Relationships between temperature distribution and reservoir holding capacity (Kat River Reservoir).

4.6 Vulnerability of the Reservoirs in Nkonkobe Local Municipality

Kat River reservoir faces great exposure or sensitivity, this is evidenced by the reservoir holding capacity represented by KRD[1] that is in the Type I of the vulnerability index (Figure 4.18). It shows that the area is most vulnerable and need high priority measures to reduce the risk of water shortages, also the local governance has to take into consideration short measures brought by water shortage. Rainfall and temperature fall under type III, the index indicates that there is high vulnerability impact and needs capacity to reduce high risk. There is need to address vulnerability in the area as the reservoir water security is most vulnerable.

[1] KRD means Kat River Reservoir

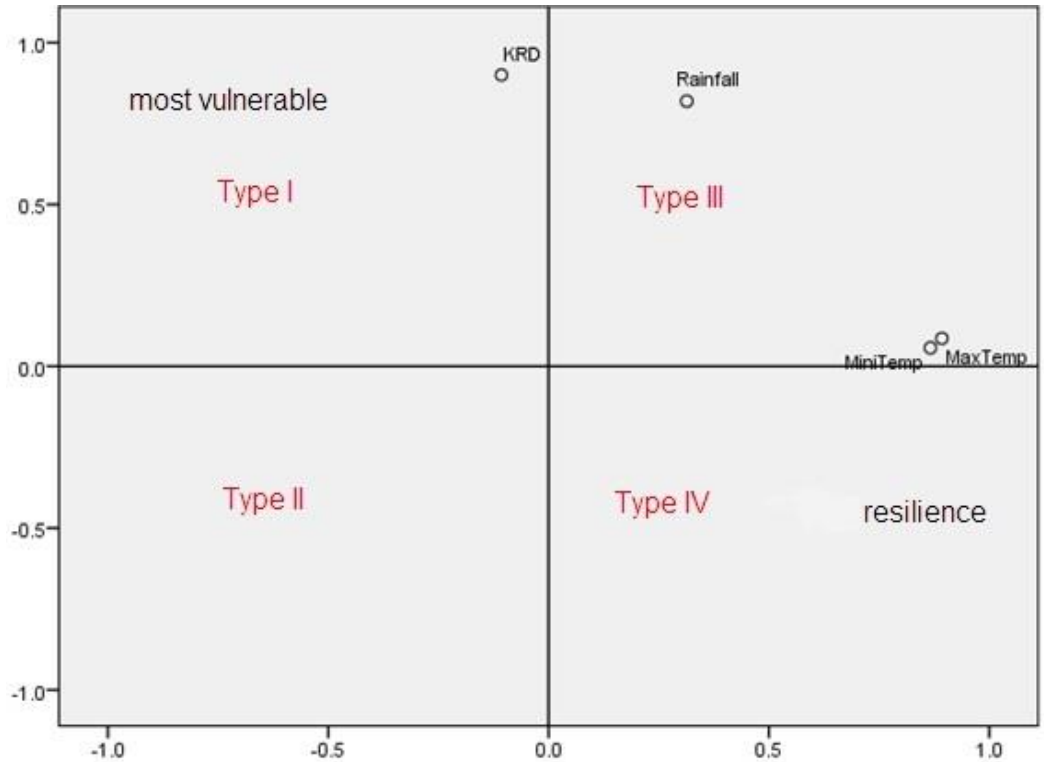

Figure 4.18: Vulnerability types for Kat River reservoir

The Binfield Reservoir (BD) has high resilience to climate variability, but the magnitude of impact could be managed, it falls under Type IV where there is Low Impact (see Figure 4.19). The rainfall and temperature are exposed to potential risk, but at a manageable capacity in order to reduce risk. The magnitude of vulnerability depends on the composing elements of the risk. There is need for the NLM to start considering adaptive measures as the rainfall is not reliable.

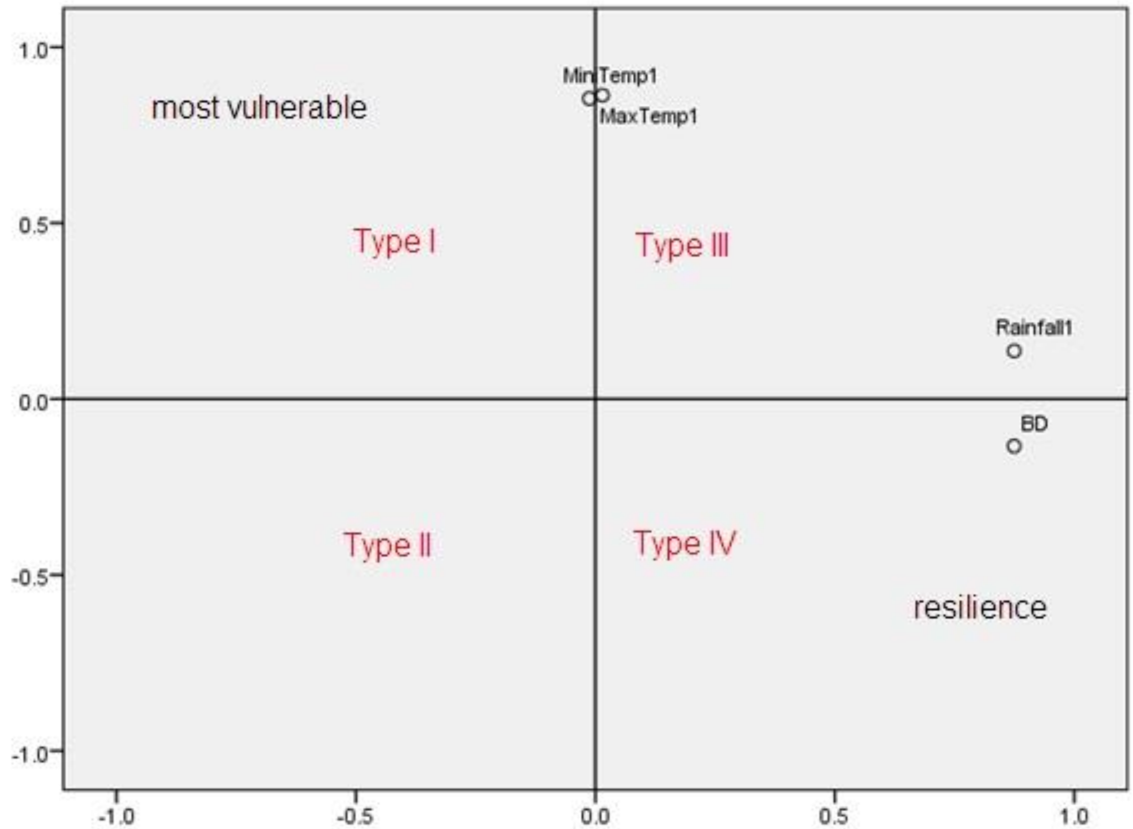

Figure 4.19: Vulnerability types for Binfield reservoir

The results show that the exposure is the direct danger to the reservoirs, this is because the nature and extent of the changes in rainfall and temperature vulnerability affect the volumes of the reservoirs. This means that the sensitivity worsen since exposure and sensitivity are intrinsically linked and together affect potential impact as affirmed by Thornton *et al*., (2006) and Takama *et al.,* (2015).

4.7 Conclusion

This chapter presented and discussed the results of the descriptive analysis of the water security of the reservoirs in the study area. Within the chapter, descriptive statistics such as inter and intra annual variability; scatter plots and line graphs are used. The results showed that the reservoirs in the study area are greatly affected by rainfall and temperature variability. In Table 3 the total annual rainfall observed in Nkonkobe Local Municipality for the 1980 – 2014 period varied between 343.4 mm (year 1992) and 797.8 mm (year 1985) annually. This shows that there would be great fluctuation in the amount of rainfall received by the reservoirs. Temperatures vary throughout the years with the lowest temperature value(s) remaining 7 °C and the highest temperature value(s) ranging from 27.25 °C to 31.13 °C see Table 4. The Binfield and Kat River reservoir reveals great fluctuations in its water holding capacity largely as a result of the fluctuating rainfall events registered annually in this water basin see (Table 5 and 6). The rainfall and temperature variability directly influences the water levels of the reservoirs.

The fluctuations of the rainfall cause the changes in water level of the reservoirs that leaves the NLM water security more vulnerable, since the rainfall is seasonal. The direction of the relationship of rainfall and reservoirs holding capacity is positive this because rainfall and reservoirs holding capacity are positively correlated, meaning that these variables tend to increase together for example the greater the rainfall is the greater the volume of water in the reservoir.

The temperature shows that there is a high rate of evaporation that shows how vulnerable the reservoirs are to high temperatures, these results are similar to what was found by Midgley et al. (2007). Midgley et al. (2007) outlined that draughts and high evaporation rate are related to high temperature. The relationship of temperature distribution and reservoirs holding capacity is positive as shown by the p value that is 0.01. This means that these variables tend to increase together for example the greater the temperature is, the greater the evaporation rate the less the reservoir capacity is.

The vulnerability index showed us that the reservoirs water security is highly vulnerable. Kat River reservoir faces great exposure or sensitivity, this is evidenced by the reservoir holding capacity represented by KRD that is in the Type I of the vulnerability index which most vulnerable and Binfield Reservoir (BD) has high resilience to climate variability, but the magnitude of impact could be managed since it falls under Type IV where there is water security vulnerability is Low Impact.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Introduction

The main objective of the research is to investigate climate variability parameters affecting water security in the Nkonkobe Local Municipality. The first objective of this study was to determine the changing trends of the climate of Nkonkobe Local Municipality. The second objective was to characterise the relationship between rainfall and reservoir water volumes. The third objective was to establish the relationship between minimum and maximum temperature and the reservoir water volumes. The fourth objective was to determine the vulnerability index of water security in the study area. This chapter summaries and concludes the main findings of the study and also highlights the policy implications.

5.2 Conclusion

Rainfall in the Nkonkobe Local Municipality (NLM) is seasonal and the seasonality can be described through the monthly rainfall totals as percentage of the total rainfall. The PCI value ranges from 11 to 20 mm over time, this indicate a seasonal trend. The decreases in PCI in Nkonkobe Local Municipality are not statistically significant at the 95% confidence level. Since the rainfall in the NLM is strongly seasonal this decrease in PCI values could suggest a increase in the summer rainfall and a decrease in the winter rainfall. This affects the water security since the water levels fluctuates due to seasons.

The analysis of the long term trend in the inter-annual variability in the Municipality for the period 1980 – 2014, showed a steady rise of the linear trend and a great variation in the amount of rainfall received throughout the period of 1980 – 2014. The study area shows an increase in the variability of annual rainfall ranging from 90 – 200 mm, however, the linear trend of inter-annual rainfall variability is statistically not significant at 95% confidence level. Since the relationship of the variables is not positive, it means that the fluctuation of the variables does not depend on each other, as result the impact is less controllable. The fluctuations of the rainfall cause the changes in water level of the reservoirs that leaves the NLM water security more vulnerable, since the rainfall varies annually that makes the reservoirs not have a consistent inflow of water.

The temperature of the NLM is seasonal and can be described through the changes in the min of minimum temperature or max of max temperature. The Linear regression analysis for min of minimum temperature (1980-2014) shows a steady increase from linear regression line of 4 to 5 °C. However this increase in min of minimum temperature over time was not statistically significant at the 95% confidence, this showed that there is no relationship in the variables of the mini of minimum temperature. The relationship of temperature distribution and reservoirs holding capacity is not positive this means that these variables tend to increase and decrease independently and this affects the rate of evaporation of the reservoir.

A different story was told by the increase in max of maximum temperature values that indicated an increase in the temperatures in the study area. In addition to this there linear regression analysis showed that the temperature variables are statistically significant. There is a strong relationship between Max of maximum temperature values that might be influenced by the El Niño / Southern Oscillation (ENSO) warm events. The relationship of temperature distribution and reservoirs holding capacity is positive, this because temperature and reservoir holding capacity are positively correlated, meaning that these variables tend to increase together for example the greater the temperature the greater the evaporation rate

The bivariate (Pearson) Correlation analysis was to visualize the relationship between rainfall distribution and reservoirs holding capacity. The two-tailed test of the rainfall distribution and reservoir holding capacity of Binfield reservoir was positively significant indicating that the two variables had a strong relationship. Also the same observation was carried out at Kat River reservoir and the rainfall distribution and dam holding capacity was statistically significant. The direction of the relationship are both positive. This means that the water security of the reservoirs highly depends on the amount of rainfall received in the area, as evidenced by the graphs. More so these variables tend to increase together for example the greater the rainfall is the greater the inflow.

Temperature distribution and reservoirs holding capacity of Binfield reservoir and Kat River reservoir have a statistically significant linear relationship. The direction of the relationship is positive this shows that there is a strong relationships in the variables being investigated. The results are evidence that the temperature and reservoir holding capacity are positively correlated and also the variables tend to increase together. This show that the reservoir water security is vulnerable, since the relationship of temperature distribution and reservoirs holding capacity is positive. The greater the temperature is, the greater the evaporation rate and this results in less reservoir capacity.

The vulnerability of the dams in Nkonkobe Local Municipality are at a different level of risks index. Kat River dam faces great exposure or sensitivity that is in the Type I of the vulnerability index evidenced by the greater is the vulnerability of the dam inflow represented by KRD. Rainfall and temperature fall under Type III, the index indicates that there is high vulnerability impact and needs capacity to reduce high risk. To sum up the dam is most vulnerable and need high priority measures to reduce the risk of water security, also the NLM has to take into consideration the short comes since the vulnerability index highlight high vulnerability.

Binfield Dam (BD) has high resilience to climate variability the level of the impact is on Type IV it shows that the magnitude of impact could be managed since the vulnerability is on the Low Impact. The rainfall and temperature are exposure to potential risk (Type III), but at a manageable capacity in order to reduce risk. However this does not mean that the dam water security is safe, there is still vulnerable to climate variability because the variables are strongly related as evidence by the bivariate (Pearson) Correlation analysis. The change in one variable means the greater the vulnerability impact on the dam since the magnitude of vulnerability risks depends on the composing elements of the climate variability.

The results show that that the reservoirs water security is highly vulnerable. Generally, the necessary capacity of reservoir systems in the Municipality is determined by within-year varying climatic trends. Over the years the ever changing trends affect the water volumes in the reservoirs leaving them more vulnerable with years. One of the key findings of this research was that vulnerabilities to form and function can be linked, for example where reservoir level fluctuations change in response to the change in the climate variabilities, this affects the water security of the reservoirs. The ability to predict reservoir vulnerability to these climate trends would provide information critical for decision making, hazard prevention and management of the water volumes in the reservoirs.

5.3 Recommendations

The reservoirs are becoming increasingly vulnerable to increased climate variability that can affect both the magnitude and seasonal cycles of water budget components that influence the availability of clean freshwater. The findings illustrate the importance to enhance adaptation efforts both at the micro (Nkonkobe Local Municipality) and macro (national) levels more particularly for communities where the reservoirs are more vulnerable to climate variability. Water supply in reservoirs is affected both by climate variability. There is need for government policies and strategic plans that would support improved water security in the face of climate variability. To ensure the viability and availability of clean freshwater in the reservoirs there are specific knowledge requirements and recommendations that need to be followed. Monitoring of such factors as seasonal changes in hydrological characteristics of reservoirs in response to climatic variability is required to reduce knowledge gaps and uncertainties relating to climate impacts on reservoirs. Through monitoring is critical to develop historical databases to detect changes in water resource availability.

5.4 Limitations of the study and areas for further research

The study has some limitations that should be taken into consideration. Other studies on vulnerability have revealed that a wide range of factors influence levels of vulnerability. This study only used a vulnerability assessment in terms of selected climate variability factors and also the approach used in this study for vulnerability assessment did not focus on the adaptive capacity of the study area.

The model approach used estimated the impact of climate variability impact on the water security, did not include all the climatic conditions and also the other environmental factors affecting the vulnerability index of the study area. Another limitation in this study is that the model fails to predict future impacts. Further research and study should focus on using more advanced models, such Climate Vulnerability Index and CGE models to measure the impact of climate change and variability on water security.

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