EVALUATION OF WATER RESOURCE MANAGEMENT SYSTEMS IN ETHEKWINI MUNICIPALITY

BY

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DECLARATION

I, **MRS NOSIPHO BUHLE FAYA**, with student No.: 20506983, certify that this dissertation's intellectual content is entirely the result of my effort, except for the references and bibliographies cited. This research work, in whole or in part, has never been submitted to any other university for review, publication, or any other purpose.

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DEDICATION

This thesis is dedicated to me and my husband, Dr AKM Faya, who supported and motivated me to finish my studies. To my son, nieces and nephews, to be inspired to study further.

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ABSTRACT

Water is an essential and critical resource for human, animal and plant survival and our continuing existence on planet earth. Water is increasingly becoming a scarce resource, and the issue of water scarcity has been exacerbated in intensity by climate change, as well as aging water resource infrastructure in many countries; such as the republic of South Africa. This study aimed at evaluating the water resource management systems, in that is rooted in a qualitative research method and phenomenological paradigm. Thus, primary data were collected from personnel in high and strategic positions in the government entity, eThekwini Municipality Water and Sanitation. This qualitative data was then subjected to content analysis and themes. The study findings are based on the eThekwini region and its resiliency and adaptability to climate change. In order to achieve that, this study utilized an in-depth interview and semi-structured interview approach to garner respondents' perceptions, opinions, expertise, judgement and experiences on issues of water resources management systems and infrastructure resiliency and adaptability to the impact of climate change in Durban. The data revealed that the current state of water resource infrastructure is not satisfactory, or resilient enough to withstand the impact of climate. The study findings also indicated the urgent need for the eThekwini municipality's water resource infrastructure to be upgraded for optimal operation and for resiliency to environmental and technical challenges. The study further reveals that the eThekwini municipality is considering embarking on joint venture projects that would adopt the innovative concept of reusing, remixing and recycling treated wastewater, as well as the installation of desalination plants for effective water resources management. From our findings, we saw that eThekwini municipality needs to adopt new technologies that would enable integrated and adaptive, resilient components in their water resource management systems. The study recommended that eThekwini municipality should endeavour to strive towards upgrading the current state of its water resource infrastructure so that it is in a satisfactory state, and resilient enough to withstand impact of climate change.

Keywords: climate change, eThekwini municipality, resilient infrastructure, water resource infrastructure.

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CHAPTER ONE: RESEARCH BACKGROUND AND PROBLEM SETTING

1.1 Introduction

According to Beker and Kansal (2022) accessibility to potable water is a necessity for every human being's survival, sustainability and overall wellbeing. Water is the basic elixir of life and an important gift to mankind. Thus, effective water resource management is imperative for optimising its usage and sustainability (Sundararaman, Kumar, Deivasigamani and Devarajan, 2022). Water is an essential and critical resource for human, animal, and plant survival and continued existence on planet earth (Amonovich, Ahrorogli and Hamzaqizi, 2023). Supporting this view, the Water Institute of Southern Africa (2023) affirms that water is the most important and valuable resource for life on earth. Water, as a valuable resource, is being utilised for domestic and industrial activities, such as drinking, cooking, and manufacturing purposes, and for medicine, agriculture and generation of electricity (Water Institute of Southern Africa, 2023).

Amonovich *et al.* (2023) claim that the most natural source of fresh water, such as rivers, are becoming so polluted that it is extremely challenging for water-bodies to clean themselves naturally. Thus, the polluted river and lake water is usually unsafe for domestic consumption or for industrial needs, causing people to fall ill with various diseases. The main causes of fresh water pollution are related to the rapid development of urbanization and industrial production (Amonovich *et al.*, 2023). Loukas, Mylopoulos and Vasiliades (2007) add that the water crisis is becoming more complicated due to industrialisation, human interference with the water cycle and climate change, as well as the continual depletion of freshwater resources. Dalu and Shackleton (2017) claim that, recently, many parts of the country have experienced variations in weather patterns, such as heavy rainfall or extreme heat with minimal rain. Kabat and van Schaik (2003) add that the rapidly growing catalogue of storms, floods and droughts from

across the globe has made the climate variability a challenging issue in managing water resource effectively, as extreme, record weather is disrupting lives and national economies. Thus, Climate patterns that present significant obstacles to the management of the world's water resources lie behind the disaster statistics. (Kabat and van Schaik, 2003).

According to the Water Institute of Southern Africa (2023), without a strategic and resilient intervention in water resources management, the future of humanity is bleak. Water management systems have become a necessity, where weather variations adversely affect communities. To an extent, adequate infrastructure capacity remains a reliable remedy that would allow communities to adapt to sustainable means of water management (Padre, 2001). Thus, decisive actions are urgently needed in the area of water resource management, as innovative interventions would assist in advancing and enhancing water resource sustainability and resilience (Water Institute of Southern Africa, 2023). Lenton and Muller (2012) affirm that effective water resources management would consist of systematic activities such as the development of infrastructure; resource allocation; the implementation of incentives for its efficient use; protection; and the financing and maintenance of existing water infrastructure systems (Lenton and Muller 2012). For governments, local organizations, and communities attempting to deal with a changing climate, adaptation is essential in relation of water resource management. Thus, the first step in recognizing and mitigating our vulnerability to extreme weather events like typhoons, floods, and droughts is to differentiate between short- and medium-term climate variability (CV) and long-term climate change (CC) (Kabat and van Schaik, 2003).

At the municipal level, water resource management systems are crucial in maintaining the integrity of the environment and the processes employed have various objectives, such as to

improve the quality of wastewater; to kill pathogens; to protect aquatic life; and to make waste water reusable for agriculture and aquaculture. The 21st century is witnessing a rising plethora of challenges in relation to water resources management, and these issues have become a major concern due to pressure enforced by climate change on the environment, and the increasing need for more, and better quality, water. In recent years, many parts of the globe, such as South Africa, have experienced variations in weather patterns, with heavy rainfall, or extreme heat with minimal rain (Dalu and Shackleton 2017). This has exposed the need for an effective regulation of water resources. This regulation would allow for sustainable development in local municipalities. However, shortfall of water availability is increasingly becoming a global concern due to climate change, as many countries are either facing drought with extreme heat; or heavy rains with floods (Eckstein, 2009).

1.1.1 Global Challenges of Water Resource Management

Due to a variety of factors, including shifting consumption patterns, economic development, and population growth, the world's demand for water has been rising at a rate of about 1% annually. Over the next 20 years, this demand is expected to increase significantly (Vörösmarty, Green, Salisbury and Lammers, 2000). Agriculture will still be the largest user of water overall, but industrial and residential demand will rise far more quickly than agricultural (Hamdy, Ragab and Scarascia-Mugnozza, 2003). Most of the countries with emerging or developing economies will see an increase in the demand for water. This demand has to be mitigated by continual government investment in novel infrastructure to curb the economic effects of water scarcity (Dolan, Lamontagne, Link, Hejazi, Reed and Edmonds, 2021).

These are facts and figures of what the world has been challenged with (UN Sustainable Development Goals, 2018),

- A basic water service is lacking in one out of every four healthcare facilities
- Only 30% of the population has access to drinking water services that are safely managed, and 60% of the population does not have access to sanitation facilities that are properly managed.
- Continued open defecation is practiced by at least 892 million people.
- Eighty percent of households without access to on-site water sources rely on women and girls to collect water.
- The share of the world's population that uses an improved source of drinking water rose from 76% to 90% between 1990 and 2015.
- A growing percentage of the world's population—more than 40%—is expected to be affected by water scarcity. In river basins where water use outpaces recharge, there are currently over 1/7 of a billion inhabitants.
- The lack of access to latrines or other basic sanitation facilities affects 2.4 billion people.
- More than 80 percent of wastewater resulting from human activities is discharged into rivers or sea without any pollution removal.
- Almost 1,000 children perish every day from diarrheal illnesses that can be avoided with proper water and sanitation practices.
- Drought uses account for about 70% of all water taken out of aquifers, lakes, and rivers.
- Seventy percent of all deaths associated with natural disasters are caused by floods and other water-related disasters.

All the above-mentioned facts and statistics point to some things that South Africa identifies with. The current challenge we are faced with, as a country, is how we manage the influx of water caused by heavy rains for reuse. The infrastructure development is required to place us at an advantage in times of extreme weather conditions, through using modern building technology, such as green building technology, and the development of sponge cities, as well as porous paving systems, to mention a few.

1.1.2 The impact of climate change globally and locally

According to Pahl-Wostl (2007), water management is experiencing severe problems as a result of increased unpredictability induced by climatic and worldwide change, as well as rapidly changing socioeconomic situations. Climate change is defined as a shift in global or regional climate patterns that began in the mid-to-late twentieth century and is mostly linked to higher amounts of atmospheric carbon dioxide generated by fossil fuels (Jafari and Jafari, 2020). Current climate models project that global temperatures will rise by one to several degrees Celsius over the next 100 years, depending on greenhouse gas emissions and the sensitivity of the climate system (Vairavamoorthy, Gorantiwar, and Pathirana, 2008). Even a little increase in global temperature can drastically alter the natural equilibrium of the world's climate. We have to brace ourselves for catastrophic incidences due to disruptive heavy rainfalls that leave our people with damaged roads, houses and other infrastructure (Vairavamoorthy *et al.,* 2008).

Table 2: Dam Data: Umgeni Water, Durban

This information is updated daily (when possible) and the figures reflect the previous 24 hour.

Dam	Capacity Million m^3	Percentage	Rainfall (mm)	Last updated on
Spring Grove Dam	102.16	73.26	2.0	06 Nov 2023
Mearns Dam	4.43	86.65	2.0	06 Nov 2023
Midmar Dam	183.75	78.05	14.5	06 Nov 2023
Albert Falls Dam	265.39	91.79	5.8	06 Nov 2023
Nagle Dam	22.29	95.93	2.0	06 Nov 2023
Inanda Dam	239.35	99.03	0.0	06 Nov 2023
iMvutshane Dam	2.07	65.11	2.5	06 Nov 2023
Hazelmere Dam	22.27	59.98	0.0	06 Nov 2023
Nungwane Dam	2.17	101.45	0.0	06 Nov 2023
E.J.Smith Dam	0.89	100.08	0.0	06 Nov 2023
Umzinto Dam	0.42	100.28	0.0	06 Nov 2023
Mhlabatshane Dam	1.51	101.75	2.0	06 Nov 2023
Ludeke Dam	10.58	70.81	20.0	06 Nov 2023
Woodstock Dam	347.94	93.22	18.0	06 Nov 2023
Spioenkop Dam	254.85	94.16	7.0	06 Nov 2023
Wagendrift Dam	48.08	86.01	15.2	06 Nov 2023

Source: Umgeni Water (2023)

Although eThekwini Municipality has a Water and Sanitation Unit, it has partnered with Umgeni Water for many years. Umgeni Water is a public entity that provides water services, and a portable water supply to the KZN province. Umgeni Water currently provides water services to the eThekwini Metropolitan Municipality, the ILembe, Harry Gwala, Umgungundlovu, and Ugu district municipalities, and the Msunduzi Local Municipality, among other customers. This accounts for a total bulk water sales volume of 440 million kiloliters per year. (Table 1). Furthermore, Umgeni Water provides water to 6.1 million people. (Figure 1). Below is a table of dam and rainfall data within the KwaZulu Natal region which shows recent low rainfall.

Figure 1: Umgeni Water Operational Area

Source: Umgeni Water (2023)

1.2 Research Problem Formulation

Beker and Kansal (2022) claim that the availability of sanitation, and adequate and safe water, is closely linked issues of related to public health and a good quality of living in any society. Thus, inadequate, or insufficient, drinking water and poor sanitation services have the potential to cause the spread of diseases. The WHO and UNICEF (2015) report states that in developing countries, almost one-third of all deaths and about 80% of diseases are related to water. Additionally, individuals spend almost one-tenth of their productive time dealing with water-related illnesses (Beker and Kansal, 2022).

South Africa is a potentially drought-stricken country and, as such, effective water resource management has become a key government imperative (Loucks, 2000). However, in particular the eThekwini region in KwaZulu Natal, has been experiencing flooding, which could be one impact of climate change. For example, devastating flooding incidents were observed on the

N2 freeway in Durban, in October 2017; and south of Durban, in March 2019 (Ritchie, 2017; de Greef, 2019). Grab and Nash (2023) categorised the 2022 flood in Durban as disastrous natural disaster ever recorded in KwaZulu-Natal (KZN) with regard to loss of lives and destruction of homes and infrastructure (such as water infrastructure assets); the transportation road network, and the devastating economic impact.

According to Gilrein *et al.* (2019), there is a need to strategically evaluate the technical measures in place with regard to water resource management systems and infrastructure adaptability in the face of climate change (Gilrein *et al.,* 2019). Thus, effective strategic and technical measures would enhance the Durban/ eThekwini region's capacity in conserving the excessive water, and in curbing the potential infrastructural damage caused by floods. Therefore, water management systems have become a necessity, especially in drought stricken areas where weather variations adversely affect communities (Kundzewicz *et al.,* 2001). Thus, effective water resource management systems and resilient infrastructure for water control remain reliable remedies to allow regions and communities to adapt to efficient water harvesting and recycling techniques. Water management systems have become a necessity where weather variations adversely affect communities and, to an extent, adequate infrastructure capacity remains a reliable remedy that allow communities to adapt to sustainable means of water management (Padre, 2001). According to Jochimsen (1966), infrastructure encompasses all the physical, institutional, and human resources and information that are accessible to economic entities, and that help to achieve fair compensation for similar inputs through efficient resource allocation, leading to full integration and high levels of economic activity (Jochimsen, 1966).

Water management is essential at both the community and government levels. At the local level, it is important to have the skills necessary to effectively manage water and advocate for improvements. (Giacomello, Meigh and Sullivan, 2003). These may be indicated and achieved by educating people about the implementation of the government policies and their response to local needs in a constructive way. Based on the status quo of our country in relation to service delivery, and how the communities respond to the lack thereof, the government ought to engage with the notion of economic water scarcity more robustly and also develop community engagement initiatives that facilitate community participation in government projects at the conception stage.

1.2.1 Research Problem

An inadequate, non-resilient water infrastructure to effectively manage increasing climate change may in future exacerbate the challenge in the eThekwini region to realise its economic, social and environment sustainability.

1.3. The Aim of the Study

This study aims to assess the effectiveness of water resource management systems with a focus on sustainability, resilience, and equitable distribution.

1.3.1 The Research Objectives:

i. Evaluate the current conditions of water resource infrastructure within the eThekwini region.

ii. Assess eThekwini Municipality's innovative and intervention strategies to tackle the impact of climate change and its impact on water resource infrastructure.

iii. Evaluate the strategic measures that eThekwini municipality have adopted to maintain existing, and build new, water resource infrastructure.

1.4 The Research Question

What is the current condition and capacity of the eThekwini Municipality's water resource management and system to contend with the impact of climate change and related incidents within the region?

1.4.1 Research Sub-Questions

i. Are eThekwini Municipality's current water resource infrastructure and systems in a good condition and resilient enough to contend with the impact of climate change within the region?

ii. What are the eThekwini Municipality's innovative and intervention strategies to be implemented in order to minimise the impact of climate change?

iii. What are the eThekwini Municipality's strategic measures to protect and maintain the aging, existing water resource infrastructure?

1.5 Significance of/Justification for the Study

There are many benefits to well-managed water resource systems, which the public and government can enjoy. There are factors that influence the ability to provide communities with water services which differ from region-to-region, subject to a number of factors including, among others: water resource availability; the capacity of the water supply infrastructure; access to enough funding; and the ability to attract and retain the right combination of

managerial and technical skills; as well as a functioning institutional arrangement (Schwartz, Tutusaus and Savelli, 2017; van Donk and Swilling, 2008).

The threat to these factors, as observed in previous years, would have been water scarcity; old, dilapidated infrastructure; insufficient funding from the government and investors; poor development of skills in relation to current technology; and our very own South African policies that have developed from our living conditions and spatial dynamics.

The objective of this study is to explore strategies that will aid the water management system within the region of eThekwini, in conjunction with the latest building models or technologies for renewable water resources. Furthermore, the researcher seeks to develop an approach that will be beneficial to eThekwini Municipality's water management systems, which will ultimately cascade down to providing better service delivery.

1.6 Study Area

Figure 2 shows the province of KwaZulu-Natal, in South Africa, highlighting eThekwini Municipality's wastewater treatment works (WTW), whose data and infrastructure were used for the study. Eight of the nine, that were initially intended, were visited. KwaDabeka WTW was decommissioned. The following WTWs were visited:

- Tongaat Central
- Verulam
- Umhlanga
- KwaDabeka
- Hillcrest

- Cato Ridge
- KwaNdengezi
- Amanzimtoti
- Umkomaas

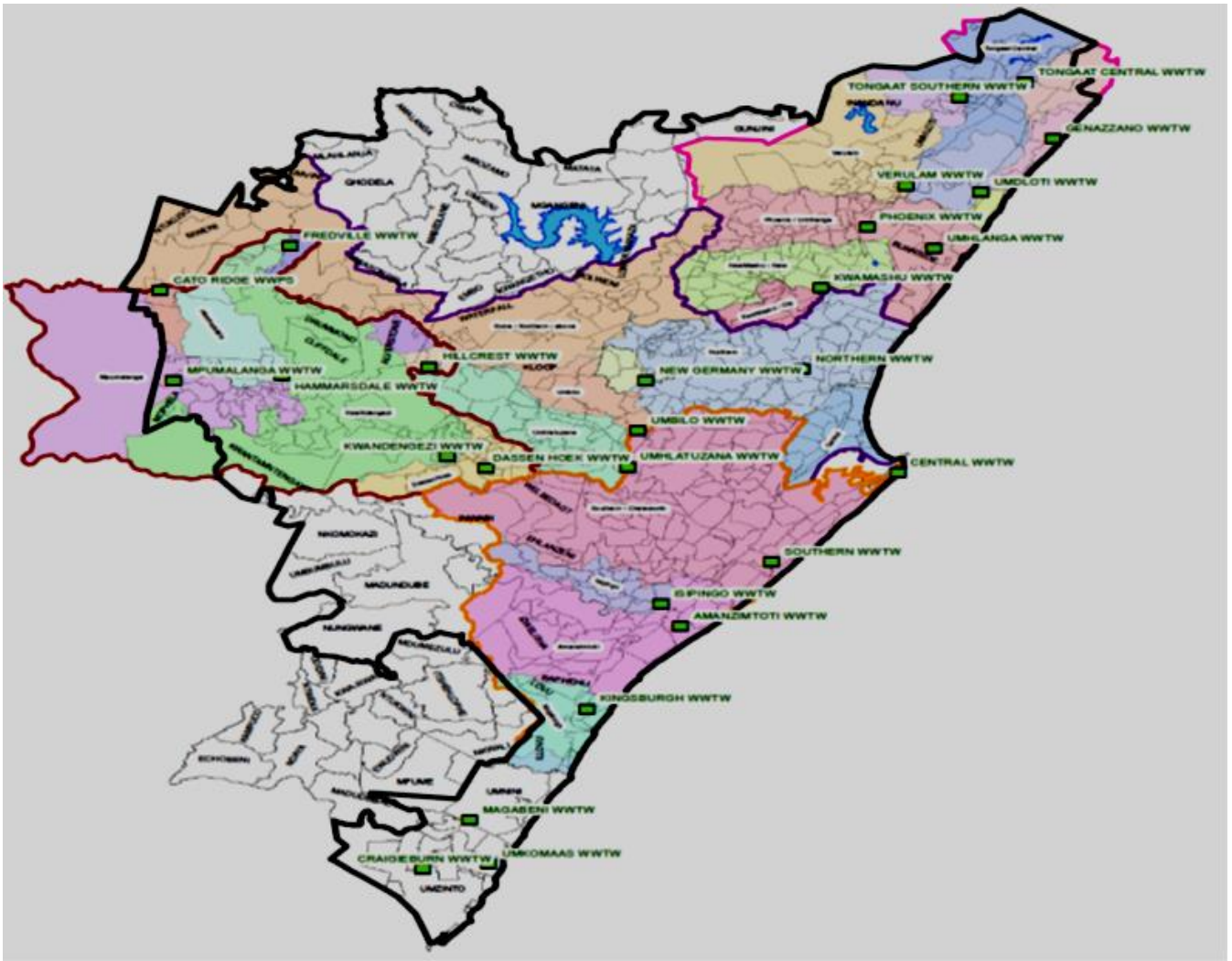

Figure 2: EThekwini Municipality's Wastewater Treatment Plants

Source: EWS Planning of Water and Sanitation (2015)

1.7 Delimitations/ scope

The study was conducted online, on the Zoom platform, as well as in the offices of the three entities (Water and Sanitation, Umgeni Water and Department of Water Affairs) in the eThekwini region, in the province of KwaZulu-Natal (KZN), when all the COVID-19 regulations were adequately adhered.

1.8 Brief Research Methods

An in-depth interview research approach has been adopted in this study, which is rooted in the phenomenological paradigm, and using an ethnographic research approach. A structured in-depth interview protocol was used to gain an understanding of the senior management's point of view on a number of issues regarding water management. An unstructured, in-depth interview was used in order to elicit vital information from the superintendents of the wastewater treatment facilities within eThekwini Municipality. This approach aimed to evaluate the capacity and functionality of the existing water infrastructure facilities in the eThekwini region. The obtained qualitative data was analysed using content analysis and themes.

1.9 Structure of Study

The research study is set out in the following crucial chapters:

Chapter 1 reviews the current literature regarding the global challenges for water resource management, and the emerging implications, as well as the background to the study.

Chapter 2: This chapter aims to is to identify key issues about current challenges and the condition of water resource infrastructure; the impact of climate change on water resources and infrastructure management; and elements of strategic innovation to effectively resolve water resources system issues.

Chapter 3: This section of the study discusses issues in relation to the research methodology, and the research method chosen, in the study; and the data collection and sampling techniques used in the study.

Chapter 4: This chapter discusses the data gathering and analysis, and the results from the study in relation to the adopted research methodologies, as explained in Chapter 3.

Chapter 5: This chapter concludes by summarising the research findings and offering recommendations for future research work.

CHAPTER 2: LITERATURE REVIEW AND STUDY BACKGRONUD

2.1 An Overview of eThekwini Municipality

Water Resources Management (WRM) is the process of planning, developing and managing water resources, in terms of both water quantity and quality across all water uses. EThekwini Municipality's Water and Sanitation Unit is in partnership with Umgeni Water – a state-owned entity in water management services. Umgeni Water provides water supply and sanitation services to the public and specialised water services institutions (Umgeni Water, online). Currently, 440 million cubic metres of drinkable water are supplied each year to a population of six million, or 1.64 million households, through a system of water distribution networks. This amounts to 1205 million litres per day (Umgeni Water, online). According to the Umgeni report, 2018/2019, The uMgeni River is home to four main dams: Midmar, Albert Falls, Nagle, and Inanda. All of these dams serve as integral components of the water supply system. Table 2, below, shows the capacity of each dam:

Table 3: Dams that are part of the water system and their capacity

Impoundment	River	Capacity (Million m^3)	Purpose
Spring Grove Dam	Mooi	139.5	Domestic
Craigie Burn Dam	Mnyamvubu	23.5	Irrigation
Mearns Weir	Mooi	5.1	Domestic
Midmar Dam	uMngeni	235.4	Domestic
Albert Falls Dam	uMngeni	289.1	Domestic
Nagle Dam	uMngeni	23.2	Domestic
Inanda Dam	uMngeni	241.7	Domestic

Source: Umgeni Water (2023)

In 2015, the agricultural sector was the largest consumer of water in South Africa, using approximately 9.7 km^3 (Donnenfeld, Crookes and Hedden, 2018). The next largest user was the municipal sector, which used about 4.2 km^3 in 2015 (Donnenfeld *et al.,* 2018). Finally, the industrial sector accounted for about 1.6 km^3. However, in 2020 the situational analysis of these

sectors revealed an increase of water consumption as a result of the demand created by drought conditions (Guan, Mascaro, Sampson and Maciejewski, 2020). In the eThekwini region, a similar pattern of water usage was also observed because of the increased demand (Ziervogel *et al.,* 2014). It is clear that the irregular weather patterns are affecting the water distribution to all the sectors, hence the need to find multiple water sources (Urama and Ozoro, 2010). Innovative approaches are now required, which would incorporate different strategic management tools to harness the exploitation of surface water, with the collaboration of residents, town planners, architects and others (Drangert *et al*., 2003). Drangert *et al.,* (2003) suggested that, if the increasing volumes of wastewater can be effectively treated and reused, then the demand on the surface water resources would reduce drastically. As a way to come up with other means to use water treatment for multiple purposes, Liu *et al.* (2016) described an approach called 'sea water for flushing' (for sanitary use). The 'sea water for flushing' approach supports environmental sustainability, but it is application depends on the distance to the coast, and the population density of a given city (Liu,Dai, Wu, Jiang, Chen, Chui, and van Loosdrecht , 2016).

According to Mutambara *et al.* (2016), Farmers must participate actively and contribute capital to the establishment and rehabilitation and maintenance of water resource infrastructure for their sustainable irrigation schemes. Mutambara *et al.* (2016) state that through the promotion of private sector participation in the sector, the government should directly and indirectly support the exploration and exploitation of underground water for irrigation. This strategic approach would provide the opportunities to strengthen the institutional support system for the donors/non-government organisations that are involve in water development project service delivery (Mutambara, Darkoh and Atlhopheng, 2016).

2.2 Climate Change and its Effects on the eThekwini Region's Water Resources Management

Climate change means an increase in extreme weather events, which could be linked to changes in the reliability of seasonal weather patterns. Thus, these changes are causing serious flooding, drought and extreme heat spells (Easterling, Meehl, Parmesan, Changnon, Karl and Mearns, 2000). Similar to numerous other African cities, Durban might experience disastrous weather events in the future, as a result of the impact of climate change. These may include an increase in the frequency and intensity of extreme weather events, increasing the incidence and severity of heat waves, flash floods, extended drought events, and coastal storms. This entire phenomenon would, potentially, lead to a rise in sea level (Easterling *et al.,* 2000). These climate changes may affect the Durban's ecosystems, resulting in the loss of biodiversity and ecosystem services (Livesley, McPherson and Calfapietra, 2016). The projected impacts climate change include a rise in annual temperatures, which will adversely affect dam levels; and an increase in aggregate rainfall, which will lead to flooding and infrastructure damage. The challenge to water management in the current era of climate change is, amongst other things, the uncertainty of rainfall and the amount of ice melting that raises the sea levels. The results from Deng, Cardin, Babovic, Santhanakrishnan, Schmitter and Meshgi (2013) study show that integrating uncertainty (such as climate change effect) and a pragmatic approach into the decision-making process could reduce initial capital expenditure, and improve investment value. This would also enable the decision-makers to learn more about system requirements during the life cycle of water resource infrastructure projects (Deng *et al.,* 2013)

The impacts of climate change on water availability and water quality will affect many sectors, including energy production, infrastructure, human health, agriculture, and ecosystems (Kundzewicz, Mata, Arnell, Döll, Jimenez, Miller, Şen and Shiklomanov, 2008). The Agricultural Research Council (ARC) conducted a study showing the impact of drought in the province of KwaZulu-Natal. The ARC showed the different levels of climate change impact, from extremely to mildly wet, as well as extreme to mild drought, in 2015, on various areas within the eThekwini region. Another study conducted by Strydom *et al.* (2020) indicated an increase in atmospheric temperature and a significant change in the uMngeni catchment.

Ndlovu and Demlie (2020) wrote a paper on the assessment of meteorological drought and wet conditions using two drought indices across KwaZulu-Natal Province, South Africa, the location map is shown in figure 3 below.

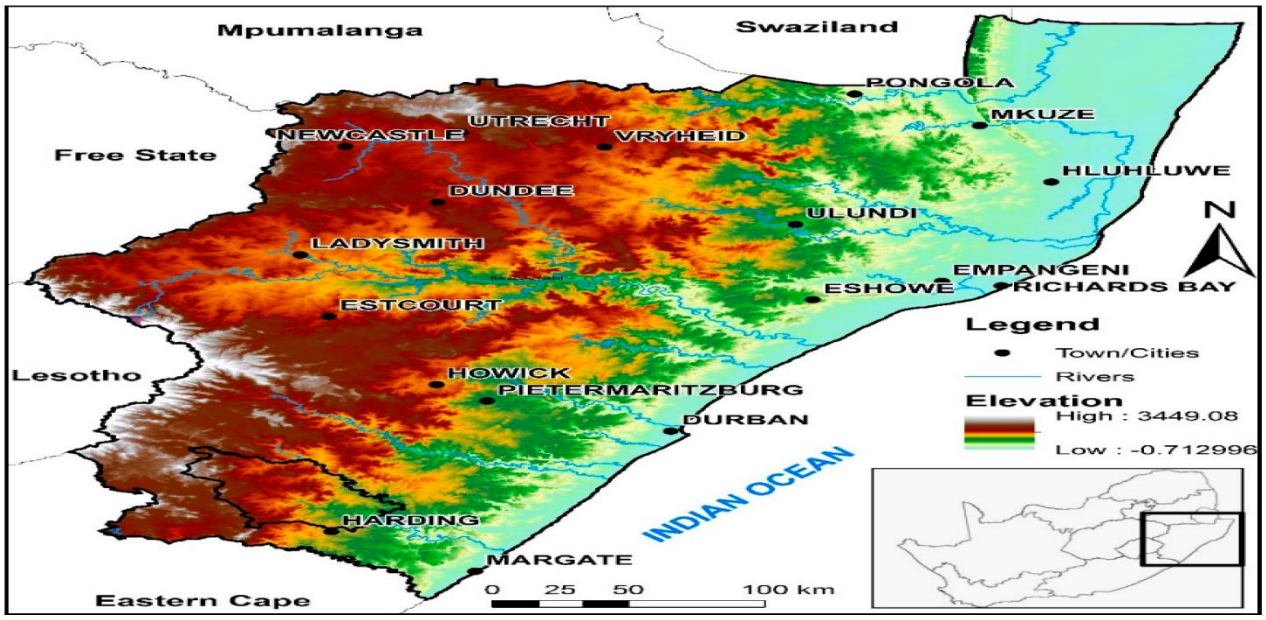

Figure 3: Digital elevation model indicating variations in topography

Source: Ndlovu and Demlie (2020)

2.3 Overview of Integrated Water Resource Management

Water resource management in South African water institutions places great emphasis on benefitting the public in terms of water resource management through an integrated network approach (Claassen, 2013). This had led to an integrated approach for water resource infrastructure and its management. Therefore, integrated water resources management (IWRM) has often been interpreted and implemented in a way that is only really suited to countries with the most developed water infrastructures and management capacities (Butterworth, Warner, Moriarty, Smits and Batchelor, 2010). Integrated water resource management (IWRM) is a holistic approach that seeks to integrate the management of the physical environment within the broader socio-economic and political framework (UNESCO, 2009). The ideas of IWRM are a call to consider water resources and their management more holistically, i.e., to manage it across sectors, and to ensure wide participation in decision-making (Giordano and Shah, 2014). The integrated approach is geared to promoting ways of enabling participation among a broad spectrum of stakeholders for sustainable environmental benefits. Thus, the need for sustainable development is the core driver of IWRM, which is to enhance the preservation of natural resources, such as water and ecosystems. The United Nations (UN) (1972) Conference on the Human Environment presented objectives to inspire and guide people (public and private entities) in the preservation and enhancement of the human environment. The conference put forward 26 principles to address that need, which include the safeguarding of natural resources for the benefit of present and future generations through careful planning or management; and a call on states for an integrated and co-ordinated approach to development planning. IWRM is a useful and necessary model for emphasizing the systematic interconnectedness of human activities and the environs (Tejada-Guibert, 2015). However, this approach has been less effective as a result of climate change, scarcity of water

resources, regional political challenges and aging infrastructure. At the International Conference on Water and the Environment, January 1992, in Dublin, key principles were identified in integrated water resource management, such as:

i. Freshwater is a finite and vulnerable resource, essential to sustain life, development, and the environment.

ii. Water development and management should be based on a participatory approach involving users, planners and policy makers at all levels.

iii. Women play a central part in the provision, management and safeguarding of water.

iv. Water has an economic value in all its competing uses and should be recognized as an economic good.

The approach to the implementation of the IWRM principles in the South African context would need to be revisited in order to address the changing environment as a result of climate change. According to Spring (2011), there is a lack of awareness among citizens of the needed paradigm shift from the government to an integrated management of water systems. The integrated management of water resources includes rainwater harvesting; maintenance and replacement of infrastructure; restoration of ecosystems; and urban planning (Spring, 2011).

2.4 Challenges in Managing Water Resources and its Infrastructure

Kabat and van Schaik (2003) note that the rapidly growing catalogue of storms, floods and droughts from across the globe have made climate variability challenges issue, as extreme weather is disrupting lives and national economies. Thus, behind the disaster statistics are climatic trends that pose serious challenges to the management of the world's water resources (Kabat and van Schaik, 2003). Water is essential for human existence and survival, as well as

for the economic development of any nation (Tallis, Kareiva, Marvier and Chang, 2008). However, there are some major challenges facing water resource management and supply. In South Africa, the provision and management of water will be a continuing challenge due to the need to keep pace with the rapidly growing population, climate change, increased industrial demand, and infrastructure development (Gumbi and Rangongo, 2018). There is a growing need to allocate water resource between different sectors in a way that optimizes economic growth and sustainability (Gumbi and Rangongo, 2018). However, the issues of climate change have the potential to exacerbate the risks associated with water scarcity and quality. Some of the challenges are poor maintenance of infrastructure, drought and floods, and vandalism of infrastructure:

2.4.1 Poor Maintenance of Infrastructure and its Implications

The deterioration of water resource infrastructure, as a result of ageing and poor maintenance, has been one of government's biggest challenges. South Africa's approach to water infrastructure maintenance seems largely to be reactionary as opposed to preventive, raising the costs of repair unnecessarily, and reducing the functional life span of infrastructure (Gumbi and Rangongo, 2018). Thus, failure to replace and upgrade the water infrastructure in South Africa poses a severe risk to both the quality and quantity of the country's water supplies and management (SAPPMA, 2016). Most water resource infrastructure is poorly maintained, aged and defective. Defective infrastructure includes pipes that are leaking, thereby resulting in water leakage and loss (Kola, 2018). In addition, aging infrastructure is vulnerable to issues like constant pipe bursts that lead to further loss of water (Dzombak, van Briesen, Garrett and Soibelman, 2012). In the case of sanitation, a burst pipe can cause health hazards in the affected area(s) (Gumbi and Rangongo, 2018). Unfortunately, municipalities lose about 35% of

water through damaged pipes and subsequent leakage of water (National Water and Sanitation Master Plan, 2018).

2.4.2 Drought and Flood Challenges on Water Resources Management

Water quality variability, in floods and droughts, may have an adverse socio-economic impact (Hirabayashi, Kanae, Emori, Oki and Kimoto, 2008). In many regions, the variability of water resources is projected to increase as a result of climate change, raising the risk of disasters and outstripping the capacity of societies to adapt (Smakhtin, Pavelic, Amarnath, McCartney and Campbell, 2014). Floods and droughts are the most economically and socially destructive of all natural disasters and they pose a great challenge in water resource management (van der Bliek, McCornick and Clarke, 2014). Flooding events generally lead to erosion; an increase in storm debris; interference with the functioning of water diversion structures such as bypass pipes (Ramsbottom, Sayers and Panzeri, 2012); flooded spillways; and the destruction of infrastructure, which impacts negatively on the sustainability of water resource management systems (Neuhold, 2013). Drought is of particular concern because extended periods of low stream flows often result in significant ecological damage from high surface water temperatures; reduced levels of dissolved oxygen; higher concentrations of pollutants; the landward migration of salt-water estuaries; and threats to aquatic life (Karambas, 2015). The impacts of drought on human activity is anticipated to be more severe in the future because of a rapidly growing population (Bradbury, Dingman and Keim, 2002).

2.4.3 Impact of Vandalism of Water Infrastructure in Communities

The vandalism of water infrastructure is one of the major contributors affecting water supply and security to those in marginalised communities (Selvakumar and Tafuri 2012). The effects

of vandalism have not only resulted in major financial costs for the department and stakeholders in the water and sanitation sector in South Africa (Gay and Sinha, 2012), they too often pose a serious threat to a sustainable water supply, countrywide. A report by the SA Local Government Association (SALGA) said the replacement value of water and sanitation infrastructure stood at R44 billion, as of 2011. These acts of vandalism pose a great challenge in the management and maintenance of water resources. Collaboration is required to determine joint goals, objectives and actions; but ongoing interaction requires a greater investment in network structures, time and resources, to support a co-ordinated approach (Margerum and Robinson, 2015). The increased complexity and competition in the management of natural resources is demanding more collaborative partnerships (Margerum and Robinson, 2015). Hence, there is a need to obtain a comprehensive overview of water resource management and its effective infrastructure system within the eThekwini municipality. Thus, a systematic review was conducted in order to understand the water resources management and its infrastructure adaptation responsiveness.

2.5 Water Resource Management Systems' Resilience and Adaptability to Climate Change

Chelleri, Schuetze and Salvati (2015) claim that the impacts of climate change are increasingly threatening the resilience and sustainable management of urban areas and infrastructures, such as water resource infrastructure, globally. Thus, there is a need to cope strategically with such threats and vulnerabilities by ensuring that concept of resilience is developed and integrated in the sustainability of built environments. Chelleri, Schuetze and Salvati (2015) further state that climate-related hazards, such as droughts, flooding, or storms, are emerging as a research endeavour, as they form part of the important agenda of climate change and climate change adaptation. Thus, the term 'climate resilience' refers to the resilience of a social

entity to climate change (Boltz *et al.,* 2019) The term resilience has become increasingly acknowledged as an imperative for any prospect of sustainable development, because it strongly links to our ability to sustain human well-being and progress within the created built environment and to generate future prosperity.

Chelleri, Schuetze and Salvati (2015) define resilience as the capacity of a system, community, or society, to resist change, or to change, in order that it may obtain an acceptable level of functioning and structure. In addition, Rodina (2018) affirms that the concept of resilience has being increasingly used in relation to water systems and water governance in tackling issues – from drought and flood management; to adaptation to climate change in the water services sector; and to watershed and catchment-scale water resource management. Rodina (2018) notes that resilience is increasingly applied in the context of water systems, and water governance more broadly, in response to the impact of climate change; hydrologic variability; and uncertainty associated with various dimensions of global environmental change. According to Chelleri, Schuetze and Salvati (2015), resilience should be measured and ascertained, as it determines the degree to which our social and infrastructure systems are capable of organizing themselves, and their ability to increase capacity for learning and adaptation, including the capacity to recover from a disaster.

According to Shin *et al.* (2018), the concept of resilience has become an important concern in the effective planning and management of water infrastructure systems. Thus, there is a need for municipalities and governments to strategically enhance water infrastructure systems' reliability in order to prevent undesirable consequences and all potentially disruptive events (Shin *et al.,* 2018). Shin *et al.* (2018) recently added that there has been a paradigm shift to resilience-based strategies, such as mitigation and recovery options, which make critical infrastructure systems (including water systems) more adaptively reliable. Shin *et al.* (2018)

further assert that the concept of resilience can be regarded as the capacity of a comprehensive water infrastructure system to withstand and absorb disruptions and to quickly recover to the pre-disrupted condition. Thus, the resilience concept has also gained increasing prominence in designing and managing water infrastructure systems.

Shin *et al.* (2018) claim that concept of resilience in water systems has evolved. Resilience measures have been recognized as important in the decision-making process for developing strategies for preparedness, response, and recovery of water infrastructure systems against unexpected, disruptive events. Shin *et al.* (2018) further state that a resilient water resource infrastructure framework should focus more on any form of physical damage and functionality of a water distribution system in response to natural disasters. For Shin *et al.* (2018), a water infrastructure system, especially the water distribution network, can be seen as a spatially organized network of multiple interconnected components. Expansion of the water system network and an increase in components' interconnection provides an opportunity to improve system resilience.

2.6 Innovative and Intervention Strategies to Tackle Impact of Climate Change on Water Resource infrastructure

According to Rodina (2018), municipal systems are usually critically affected by global environmental change; and water systems – from watersheds to urban water infrastructure systems – are most sensitive and highly prone to cause crises. Crabb and Robin (2006) affirm that local municipal government is the most relevant political actor and social agent in implementation and to enforce the national and provincial policies through supplying essential services, such as drinking water and sanitation, through effective water infrastructure systems and networks. Rodina (2018) states that water systems globally are rooted in infrastructural legacies and design paradigms that have been inflexible and slow to adapt to change. Rodina

(2018) further stated that calculating from a water security point of view, the implications of these changes are vast and far-reaching, posing threats to economic growth and human livelihoods. Thus, there is a need to transform water governance towards sustainability, by integrating complexity and uncertainty in water-related decision-making and planning (Rodina, 2018). This attitude calls for transformation and a paradigm shift to seamlessly adopt fundamentally innovative and transformative practices.

Akamani (2016), states that the uncertainties and complexity associated with water resource systems have been gaining widespread recognition. In this context, the concepts of resilience and vulnerability are increasingly receiving attention in efforts to enhance the sustainable governance of water resources in the face of uncertainties from climate change and other drivers of change. Crabb and Robin (2006) claim that adaptation is a necessary strategy at all levels, to complement climate change mitigation efforts through innovation and strategic intervention. According to Chelleri, Schuetze and Salvati (2015), the municipal and urban management and engineering sector is usually inadequate to deal with issues of water management complexity. Thus, there is a need for municipalities to change, adopt and integrate innovative technologies for water management best practices, which would ensure urban management and water culture resilience, and adaption against the threat of climate changes implications (Chelleri, Schuetze and Salvati, 2015).

Crabb and Robin (2006) add that municipalities need to develop a comprehensive and innovative strategy for climate change, for both adaptation and mitigation, with regard to water resource management systems. Crabb and Robin (2006) affirm that the adaptive management of climate change is part and parcel of municipalities' sustainable management of all natural infrastructure, especially its water resource infrastructure. Chelleri, Schuetze and Salvati (2015)

claim that it is feasible to effectively manage or hedge against flood risks and seasonal droughts, if the municipalities adopt innovative and appropriate management strategies in the collection, treatment, storage and use, of both rainwater and storm water. Thus, an innovative strategy may contribute to determining a new, sustainable water equilibrium, within resilient functioning water infrastructures (Chelleri, Schuetze and Salvati, 2015).

2.7 Strategic Measures to Improve Municipality Water Resource Infrastructure System

Loucks and van Beek (2017) claim that managing water resources infrastructure systems requires knowledge of the relevant physical sciences and innovative technology. Loucks and van Beek (2017) further state that effective and innovative planning, designing, and managing of water resource systems remains the key factor in ensuring innovative and impactful solutions. According to Rodina (2018) municipalities should ensure they adopt effective and strategic measures that would ensure the adaptability, flexibility, optimal functionality and connectivity of their water infrastructure systems. These strategic measures should be considered as key characteristics of any resilient water resource system, by government (Rodina, 2018). Crabb and Robin (2006) claim that extreme events, such as climate change, mean that strategic water and wastewater treatment provision needs to be adaptive in nature in order to cope with a larger amount of water and larger and longer peak periods, including peaks for water demand during drought periods. Crabb and Robin (2006) further state that a municipality's ability to develop and implement a comprehensive strategy to address climate change may be called its adaptive capacity or resilience. Thus, municipal adaptive capacity is a function of various factors: the range of available technological options; the availability and effective management of water resources and the supporting systems in terms of distribution measures, optimal functionality of the structure of critical institutions and the criteria for decision

making; the capacity of human and social infrastructures; the adoption of innovative measures to access risk-spreading mechanisms; and the ability of a municipality's decision-makers to manage credible information; and their own credibility (Crabb and Robin, 2006). According to Rodina (2018), strategic municipal measures for effective water resource management would need to focus on developing an innovative water supply interconnectivity, and exploring opportunities for effluent recycling or desalination in order to overcome the extreme impact of climate change on water infrastructure systems.

Akamani (2016) notes that, globally, the governance of water resources systems is geared towards integrated water resource management (IWRM) and adaptive management, as a result of the inadequate, conventional command-and-control paradigm of water resource management. According to Pahl-Wostl (2007), integrated water resource management would strategically take into account of issues of environmental, human and technological factors and their interdependence. Thus, the concept of IWRM broadens the strategic planning goals and the scope of water resource governance through integration and co-ordination across levels and sectors. The pursuit of adaptive governance could contribute to enhancing good governance, reducing conflict management, and building social-ecological resilience for sustainable water resource management (Akamani, 2016). Pahl-Wostl (2007) claims that adaptive water resources management is being regarded as a systematic process for continually improving water resource infrastructure systems, as well as practices, by learning from the outcomes of implemented management strategies. Thus, the municipal's water resource management authority has the duty to provide protection from water-related risks of any kind (Akamani, 2016).

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

Research methodology is the approach used to find an answer for a specific issue. It simply refers to the practical 'how' of any given piece of research. The methodology used in this study specifies the techniques, methods and procedures that were used for achieving the information desired from the research questionnaire, data collection and data analysis, in order to present findings. The methodologies undertaken in this research are discussed in the accompanying sections.

3.2 Research Methodology

This study adopted a qualitative research method based on a case study of eThekwini Municipality's water resources-related entities. It utilised an in-depth interview approach, which is rooted in the phenomenological paradigm, as well as an ethnographic research approach, in order to directly observe the current condition of eThekwini Municipality's water resource infrastructure assets. Therefore, this approach enables the researcher to interact with the operational personnel who are responsible for the operation and maintenance of the water infrastructure assets. Phenomenology is the study of experience, particularly as it is lived and is structured through consciousness (Finlay, 2012).

3.3 Research Design/Strategies

This study adopted a qualitative research method based on a case study of eThekwini Municipality water resources-related entities, such as Umgeni Water, eThekwini Municipality's Water and Sanitation Unit, and the Department of Water Affairs. All the COVID-19 regulations were adhered to whilst undertaking the random, routine observations (taking photos of the

facilities) and the interaction (semi-structure interviews) with the personnel at the selected water infrastructure facilities within the eThekwini region. The selected water infrastructure facilities within the eThekwini Municipality region are:

- Tongaat Central Wastewater Treatment Works
- Verulam Wastewater Treatment Works
- Umhlanga Wastewater Treatment Works
- KwaDabeka Wastewater Treatment Works
- Hillcrest Wastewater Treatment Works
- Cato Ridge Wastewater Treatment Works
- KwaNdengezi Wastewater Treatment Works
- Amanzimtoti Wastewater Treatment Works
- Umkomaas Wastewater Treatment Works.

In addition, an in-depth interview research approach, which is rooted in the phenomenological paradigm was adopted in this study. The unstructured in-depth interview was used in order to elicit vital information from the HoDs within eThekwini Municipality's water resource infrastructure entities (such as Water and Sanitation). This approach aimed to evaluate the impact of climate change on the existing water infrastructure facilities within the eThekwini region. Therefore, the obtained qualitative data was analysed using content analysis and themes.

3.4 Research Paradigm

According to Mackenzie and Knipe (2006), the term paradigm in educational research refers to the worldview of the researcher. This worldview is the viewpoint, way of thinking, school of thought, or collection of accepted ideas that guides the analysis and interpretation of study findings. A research paradigm, as Lather (1986) elucidates, is a natural reflection of the researcher's worldview and aspirations. The abstract beliefs and principles that influence a researcher's perception, interpretation, and behaviour in the world are constituted by this. A paradigm is made up of the abstract ideas and precepts that influence a researcher's perspective on the world, as well as how he or she interprets and behaves in it. This is what we mean when we state that it define the researcher's worldview. A researcher views the world through this lens. In order to choose the research techniques to be applied and the data analysis strategy, the researcher looks at the methodological aspects of their project through this conceptual lens. Leadership figures in the field Guba and Lincoln (1994) define a paradigm as a fundamental set of beliefs, or a worldview, that directs research action or an investigation.

Expert in qualitative research Denzin (2000) similarly characterizes paradigms as human constructs that deal with ultimate or first principles and reveal the researcher's perspective in order to create meaning from data. For researchers in a given field, paradigms are crucial because they offer convictions and guidelines that impact what should be investigated, how it should be investigated, and how the study's findings should be interpreted. As per Mertens (2007), there is a suggestion that the researcher's theoretical framework influences the precise definition of research. The paradigm, which is the theoretical framework as opposed to a theory (Mertens, 2007; Bogdan and Biklen, 1997), is a

concept that affects the analysis and interpretation of knowledge. The purpose, driving force, and standards for the research are established by the paradigm selection.

3.5 Population and Sampling

The interview and semi-structured questionnaire was administered to a sample that included eThekwini Municipality Water and Sanitation Unit employees, at the level of senior managers and superintendents of the wastewater treatments facilities, with more than three years' experience, accompanied by a relevant qualification. The selection of this group gave more credibility to the findings.

Therefore, in this study the sample consisted of the following number of expert professionals employed at the eThekwini Municipality Water and Sanitation Unit:

Table 4a: Study sample frame based on in-depth interview: purposive sampling techniques

S/N	Respondent's Rank/ Position/ Job Title for In-depth Interview Approach	Number of sampled Participants
1	Project Executives	1
2	Professional Chemical Engineer	1
3	Senior Manager: Wastewater Treatment	1
4	Senior Manager: Commercial and Business	1
5	Deputy Head: Customer Services	1
	Total Sample/ Selected	**5**

Source: Researcher's Construct (2023)

Table 5b: Study sample frame based on site visit at the wastewater treatment facilities: purposive sampling techniques

S/N	Respondent's Rank/ Position/ Job Title for In-Semi-Structured Interview conducted on site at the wastewater treatment facilities	Number of sampled Participants
1	Wastewater Treatment Superintendents	6
2	Technician	1
3	Process Controller	1
4	**Total Sample/ Selected**	**8**

Source: Researcher's Construct (2023)

3.7 In-depth Interview Approach and Site visits to the wastewater treatment facilities- Methods of Data Analysis

The data collected was analysed to ensure that dependable conclusions were made. Virtual interviews (via Zoom and MS Teams) were done with the five senior managers. Other interviews were conducted on site, on visits to the wastewater treatment facilities. Enough data was collected in terms of quality to reach reliable conclusions. Most of the data used was primary data that was obtained in the interviews and observations. The data was captured efficiently and sorted properly so that they were easily accessible during the analysis stage.

3.8 Reliability and validity

Data was collected over a period of 2 months in order to gain an idea of what was happening on the ground. The data was adequate in terms of quality in order to draw conclusions that were reasonable and reliable for the analyses. The instruments that were used to collect data were those that were being used in the industry at the time of the study. There was one facility which could not be visited because it had been decommissioned. The credibility of the data was critical because it determined the outcomes of the study after the data had been analysed and results produced. The data met the requirements for rigorous research.

Cypress (2017) states that it is critical and imperative to understand rigour in research, as rigour is simply regarded as the quality or state of being very exact, careful, or with strict precision, or the quality of being thorough and accurate. The concept of research rigour has also been used to express attributes related to the qualitative research process, as without rigour, research is worthless, becomes fiction, and loses its use. Thus, research rigour indicates the strength of

the research design adopted and the appropriateness of the method to answer the questions (Cypress, 2017).

According to Cypress (2017) and Cope (2017), the rigour of quantitative and qualitative research differs in methodologic approach. Reliability and validity are considered in quantitative research; whilst credibility and trustworthiness are important in qualitative research are. Trustworthiness addresses methods to ensure one has carried out the research process correctly (Cypress, 2017). Cope (2014) acknowledges, that to develop trustworthiness in qualitative research, criteria such as credibility, dependability, confirmability, transferability, and authenticity should be adequately observed and implemented accordingly.

Credibility: Truthfulness of the data or participant perspectives, as well as the researcher's interpretation and portrayal of them, are all considered aspects of credibility. By outlining their experiences as a researcher and having participants confirm the study results, the researcher build credibility. (Cope, 2014). Thus, to support for a qualitative study to be credible, the researcher has to show involvement, observational techniques, and audit trails. (Cope, 2014). According to Cypress (2017), credibility refers to the accurate and truthful rendition of a participant's lived experience, through effective engagement and persistent observation, to learn the context of the phenomenon under investigation in order to minimize potential bias that might creep into the data. Therefore, the researcher ensures and strives for credibility by building trust and effective engagement and observation between the researcher and participants during the course of data collection, and by ensuring clear and open channels of communication throughout the data collection process. Thus, this approach assisted in obtaining rich and credible data in this study.

Dependability: Dependability refers to the stability, consistency and reliability of the data in similar conditions; that is, when another researcher concurs with the findings, based on a similar research study at another time. (Cope, 2014). Cypress (2017) claims that Dependability as a concept in qualitative research and "reliability" as a concept in quantitative research are closely related. In addition, Cypress (2017) and Cope (2014) state that, If the study results were repeated with comparable participants under comparable circumstances, the investigators' methods and descriptions would be used to determine the reliability of the study. Thus, the researcher would maintain dependability by reflecting on the researcher's own knowledge and behaviour and how it can affect data that is obtained, which includes guarding against sentiment, bias, or judgement regarding the participants' narratives of lived experience of the subject matter.

Confirmability: According to Trochim (2020), confirmability is the extent to which other people could verify or corroborate the study findings. Being able to show that the data accurately reflect participant responses rather than the researcher's prejudice or point of view is known as confirmability (Cope, 2014). Cope (2014) further states that researchers can demonstrate confirmability of their studies by describing how conclusions were drawn, and interpretations made, and by exemplifying how the findings were derived directly from the data obtained from participants. In reporting qualitative research, this can be achieved by providing rich quotes from the participants that show each emerging theme (Cope, 2014). The researcher ensured that confirmability was achieved by eliminating potential elements of bias during data collection, interpretation, analysis and conclusions, based on the data obtained from the participants, thereby ensuring confirmability. Thus, in-depth interviews were used in this study, and they were audio-recorded with the permission of the participants. This approach ensured

that information/data obtained from the participants were analysed and interpreted in a truthful and accurate manner.

Transferability: Transferability is the extent to which the findings of qualitative research can be applied or extrapolated to different situations or environments, according to Trochim (2020). Thus, from a qualitative perspective, transferability primarily reflects the concept of generalizing. A thorough description of the research context and the underlying assumptions of the data collected from participants can help the qualitative researcher improve transferability (Trochim, 2020). To help the reader determine whether the results "fit" or are transferable, researchers should give enough details about the study's participants and background (Cope, 2014). But transferability standards depend on the purpose of the qualitative investigation and might only apply if the goal of the study is to draw broad conclusions about the topic or phenomenon (Cope, 2014).

Authenticity: The capacity and degree of the researcher's expression are referred to as their authenticity, perceptions, feelings and emotions, and knowledge of the participants' lived experiences in a faithful manner (Cope, 2014). Thus, data collection and descriptive analysis should be presented so that readers can grasp the essence of the experience through the participants' quotes; as well as the researcher's decision process and critical appraisal of the evidence; and to uphold valid interpretation of the data obtained accordingly (Cope, 2014). Therefore, authenticity was achieved in this study by the researcher ensuring that the audio-recorded data was transcribed verbatim to give readers a better knowledge and understanding of the issues under investigation in relation to the water resource management system within the municipality.

3.8.1 Recruitment Procedure

Once the DUT Institutional Research Ethics Committee (IREC) had granted the researcher ethics clearance, the researcher approached the Heads of Departments (HoDs) within eThekwini Municipality's water resource infrastructure entities – the Department of Water Affairs; eThekwini Municipality's Water and Sanitation Unit; and Umgeni Water, to request gatekeeper's permission to carry out the research study. Gatekeeper's permission was requested from the HoDs of each department/institution (See Appendix A: Letter of Request to Conduct Research, submitted after obtaining ethics clearance from IREC). Once gatekeeper permission had been granted by each selected department/institution/unit, the HoDs were provided with a letter of information (See Appendix B- Letter of information and consent form) for digestion and distribution to all the relevant units and operational/technical personnel who are responsible for the operation and maintenance of the water infrastructure assets within the eThekwini region. The selected water infrastructure facilities within the eThekwini Municipality region are:

- Tongaat Central
- Verulam
- Umhlanga
- KwaDabeka
- Hillcrest
- Cato Ridge
- KwaNdengezi

- Amanzimtoti
- Umkomaas

All the operational/ technical personnel at the selected water treatment plants (above) were requested to participate in a semi-structured interview and random site observations in order to understand the routine operational and maintenance strategies of the water infrastructure assets within the eThekwini region at the selected sites. In addition, all the HoDs were requested to participate in an in-depth online interview on the Zoom platform or similar media, or in the offices of the research participants. Permission to record voices take notes taking during the interview was requested from each research participant.

3.8.2 Inclusion and exclusion criteria

Only the nine (9) operational/technical personnel on duty at the nine (9) selected water treatment plant facilities in eThekwini Municipality, and the three (3) Heads of Departments (HoDs) from the government entities, namely Umgeni Water; eThekwini Municipality's Water and Sanitation Unit; and the eThekwini Municipality: Water Affairs Unit; were selected for this study. The selection was based on their expertise in the field of water, and their strategic positions within the organisations, and in line with the objectives of this study. Thus, other personnel who that were not clearly listed were not included in this study.

3.8.3 Data Analysis

Narrative data analysis was used to analyse the data collected from the interviews and site observations. According to Earthy and Cronin (2008) narrative analysis is an approach taken to interview data that is concerned with understanding how and why people express their lived experiences based on their worldview. Narrative analysis is an umbrella term for a family of

methods that share a focus on stories (Riessman, 2008). The researcher adopted this research technique as it is most appropriate to understand the first-hand experiences and opinions of research respondents' of the subject matter under investigation.

3.9 Ethical considerations

- Research ethics are among the most crucial aspects of the field. The following ten points, as stated by Bryman and Bell (2007), are the most crucial guidelines for ethical considerations and will be followed in this investigation:
- There should be no harm done to research participants in any way.
- Prioritising respect for research participants' dignity is imperative.
- Prior to the study, the participants should give their full consent.
- Participants in research must have their privacy protected.
- It is important to guarantee that the research data will remain sufficiently confidential.
- It is imperative to guarantee the anonymity of both individuals and organisations involved in the research.
- It is necessary to refrain from lying or making exaggerations regarding the goals and purposes of the study.
- All forms of affiliations, funding sources, and potential conflicts of interest must be disclosed.

- All correspondence regarding the research ought to be conducted in an open and sincere manner.

- Misleading information of any kind must be avoided, as must biased reporting of primary data findings.

Therefore, it is crucial that respondents voluntarily participate in the study. Therefore, if they so choose, participants are free to leave the study at any time. Therefore, the researcher observed the principle of informed consent, by providing sufficient information about the nature of the study, as well as assurances that participation in the study was voluntary and was not pressured or coerced. In addition, this study commenced after the DUT Institutional Research Ethics Committee (IREC) had granted ethics clearance.

3.10 Chapter Summary

The primary data was obtained in interviews. The secondary data used was collected from a number of international and national sources: journals, articles, theses, books, conference papers, standards, reports and the internet. A quantitative approach was most applicable because the purpose of the research was to explain the various factors influencing water resource management within the eThekwini Municipality. The composition of the study sample included water and sanitation employees, between the levels of senior managers and superintendents; and with more than three years' post-graduation experience, accompanied by a relevant qualification. A non-probability sampling technique was employed, namely, a selective method of expert sampling. Thirteen Water and Sanitation Unit employees were researched and sampled. The method of data analysis employed was descriptive.

CHAPTER 4: RESULTS AND DISCUSSION OF THE RESEARCH RESULTS.

4.1 Introduction

The methods and strategies for gathering data for this study were covered in the previous chapter. The data gathered for this study is presented, discussed, and examined in this chapter. The results pertain to the interviews conducted with the senior municipal management representatives and wastewater plant superintendents in the Water and Sanitation Unit, which is part of the water resource management system in eThekwini Municipality.

The deductive method was applied to the analysis of the gathered data. This method involved analysing the data after it had been sorted and coded to see if the interviewees' evidence, experiences, opinions, and perceptions of the eThekwini Municipality's water resource management systems showed any patterns. Two questionnaires were utilized for the research: one main questionnaire, and a subsequent questionnaire, which were analyzed, with the results reported in this chapter.

4.2 The Data Collection Process

The study aimed to evaluate the water resource management systems in the eThekwini region, and their resilience and adaptability to climate change (see Section 1.3); and also to gain an in-depth understanding of the actual ‘in process’ management of water resources in the eThekwini municipality region.

The qualitative approach served as the foundation for the research design, and in-depth, in-person interviews were used; but in this case interviews were conducted via zoom, due to the covid-19 regulations and protocols. A total of 13 interviews were conducted over a period of three months. Out of the 27 wastewater treatment plants, only eight were visited; and only five

senior managers were allocated and available to do the interviews. The data collection process commenced by sending a letter to the Municipal Institute of Learning (MILE), which serves as the gatekeeper for the municipality in research studies. MILE thereafter communicated to the department/unit concerned in this study, for their participation; and co-operation and permission were granted. This was done via email because physical distribution proved to be impossible because of the covid-19 regulations prohibitions and related matters. It was requested of the respondents to take part in the planned research interviews. A cover page outlining the goals of the study and the interview was attached to the letter asking for their participation. It also contained the researcher's phone number and email address for comments and interview appointment scheduling. With regards to the total number of interviews, the researcher was guided by the availability of the respondents at that particular time.

4.3 Limitations during the Data Collection Process

The covid-19 pandemic presented a challenge for many sectors in service delivery. As a result, our movements as citizens were regulated by the alert levels that were announced by the president, based on the increase or decrease number of covid cases and infections. A few days prior to the interview, the researcher confirmed appointments with the participants. However, some participants postponed the appointment due to work commitments.

Nonetheless, the collected data were significant and meaningful, as most respondents had a vast amount of experience in the field of water and sanitation. The respondents who took part in the interviews showed a strong desire to be involved in the study and gave a wealth of insightful information that helped to develop a thorough understanding of the actual ‘in process’ operational element of water management systems; wastewater treatment; organizational strategies; and the operational framework in the treatment plants.

4.4 The Outline of the Research Data

The following goals were attained by using voice recordings, transcriptions, interpretations, and documentations of unstructured, in-depth interviews as the source of the research data:

Prior to evaluating the research response rates, the respondents' profile was first shown and examined. The second step involved the transcription and analysis of the narrative data. Section 1 of the interviews collected data on the profiles of the participants. Section 2 investigated the water resource management systems in eThekwini Municipality. Section 3 dealt with the eThekwini Municipality's innovative and intervention strategies for water resource management. Section 4 dealt with climate change (drought and floods). Lastly, Section 5 focused on infrastructure adaptability within the eThekwini Municipality.

4.5 Main Interview Protocol

The main interview is sub-divided into five sections. The first section collects the profiles of the respondents. The second section addresses the water resource management systems in eThekwini municipality. The third section seeks information about the eThekwini municipality's innovative and intervention strategies for water resource management from the respondents. The fourth section addresses climate change (drought and floods) and the fifth section speaks to infrastructure adaptability.

The interview protocol was designed to provide the respondents with the opportunity to choose the uncertain option instead of responding incorrectly. The respondents were assured of confidentiality and anonymity. The length of the interviews was kept to between 45 minutes and an hour.

4.5.1 Section 1: Respondents Profile: Demographic Data

This section describes the demographic of the respondents considered in the research:

- the position held by the respondent in the department
- respondents' level of education
- the total number of years of the respondents' employment at eThekwini Municipality
- the positions held by the respondents;
- the department/unit in the municipality

The respondents were asked to identify themselves by providing their profiles (see Table 4 and Figure 4); to state their current position held in the organization; the number of years they have served in the municipality; whether or not they are qualified in the field of water; and their highest qualification.

Table 6a : Profiles of the respondents in senior positions in an In-depth Interview Protocol

S/N	Respondent's Code	Gender	Position	Highest Qualification	Years of Employment at the Municipality
1	B1	F	Professional Engineer	MSc Chemical Engineering	6 years and 9 months
2	B2	M	Senior Manager: Treatment Works	BEng Degree in Chemical Engineering	14 years
3	B3	M	Deputy Head (Customer Services)	MBA	11 years
4	B4	M	Senior Manager: Commercial and Business	BCom Degree and Honours	24 years
5	B5	M	Project Executive	Master's in Public Administration	16 years

Source: Researcher's Construct (2023)

Table 5b: Profile of the respondents in operational positions for On-site visit and observation

S/N	Respondent's Code	Gender	Position	Highest Qualification	Years of Employment at the Municipality
1.	C1	M	Superintendent	N3 in Wastewater	16 years
2.	C2	F	Superintendent	Diploma in Chemical Engineering	24 years
3.	C3	F	Superintendent	BTech in Chemical Engineering	7 years
4.	C4	M	Superintendent	T2-Analytical Chemistry and Wastewater Certificate	38 years
5.	C5	F	Technician	BTech in Chemical Engineering	8 years
6.	C6	M	Superintendent	Diploma in Chemical Engineering	5 years
7.	C7	M	Process Controller	N3 in Wastewater	12 years
8.	C8	M	Superintendent	BTech in Chemical Engineering	6 years

Source: Researcher's Construct (2023)

Note: (M = Male; F = Female; BTech = Bachelor of Technology; N3 = National Technical Certificate; MSc = Master of Science; MBA = Master of Business Administration; BCom = Bachelor of Commerce.)

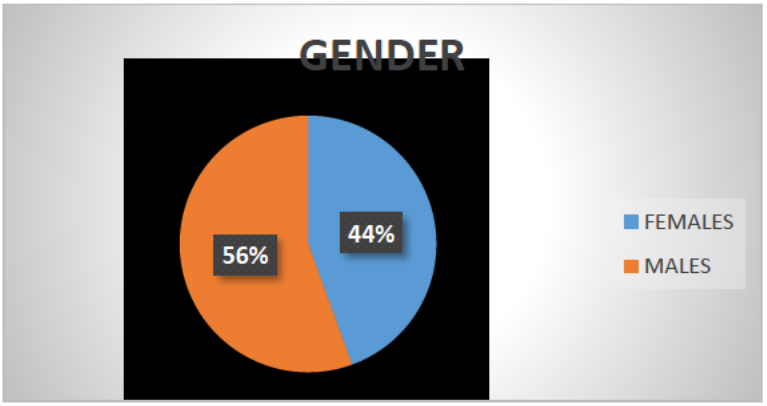

Figure 3: Respondents' Gender Profile

4.5.2 Respondents' Organizational Designations

The respondent's organizational designations are listed in Table 4. The 44% of the respondents who were females all had a qualification in Chemical Engineering (from National Diploma to MSc). One (1) respondent was a professional engineer, which is a senior position within the Water and Sanitation Unit. Two (2) respondents we were superintendents at their respective wastewater treatment facilities and one (1) was a technician who was overseeing the operations of the wastewater treatment plants. Furthermore, 56% of the respondents were males who had qualifications ranging from N3 to MBA in wastewater. Two (2) respondents were senior managers at treatment works, and commercial and business, respectively. One (1) respondent was deputy head of customer service and one (1) was a project executive in the Water and Sanitation Unit. Four (4) respondents were superintendents at their respective wastewater treatment facilities. One (1) respondent was a process controller in one of the treatment facilities.

4.5.3 Educational Background of the Respondents

The educational qualifications of the respondents, with Bachelor's Degrees as the most common, are illustrated in Figure, 5 below. Up to fifty (39%) of the interviewees held Bachelor Degrees in areas such as chemical engineering and commerce. Twenty-three (23%) held a Master's Degree in chemical engineering, public administration or business administration. Twenty-three (23%) of the interviewees had Diplomas in chemical engineering as their highest educational qualification. Fifteen (15%) of the respondents held national certificates and most of them have extensive hands-on experience in the water and wastewater treatment sector.

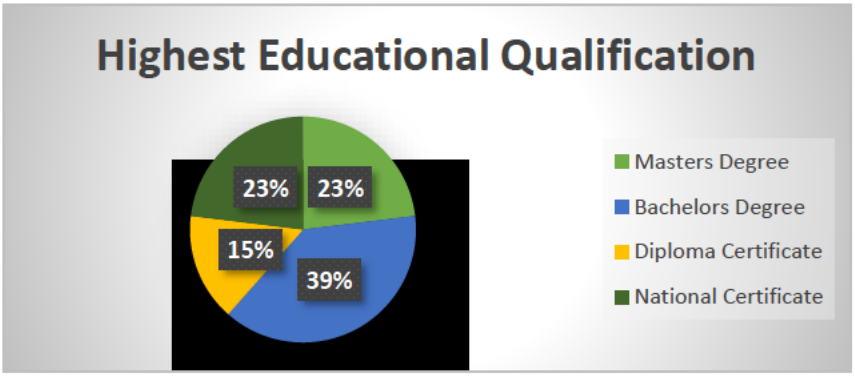

Figure 4: Educational Background of the Respondents

4.5.4 Section 2: Water Resource Management Systems in eThekwini Municipality (Study Objective 1)

This section was seeking to ascertain the current state of the Water Resource Management Systems in eThekwini Municipality, and whether the infrastructure can withstand the impacts of climate change. The respondents were also asked whether, in the past 10-to-15 years, the water management systems have been functioning at their full capacity; and whether the budget allocated is enough to sustain the municipality's water resource management and infrastructure development.

Themes (current state of water resource management Systems): "*Current condition not satisfactory"; "need for upgrade water infrastructure"; "infrastructure not resilient enough"*

Respondents B1 and B2 (as in Table 4) stated that the current condition and capacity of the water management system is not in a satisfactory state. They (B1 and B2) also said that the municipality has been grappling with maintaining the old infrastructure, which has required a lot of money.

Respondents B1, B2 and B5 further explained that the demands of the city have increased, but the municipality has not increased in its resources to meet the demand by upgrading the water infrastructure. On the question of resilience of the municipality's infrastructure to the impact of climate change, the answers were different from each respondent.

B1 said: "*I don't think our infrastructure is resilient enough, based on where we currently are. Because of the demand (as it is increasing), people need more than what the municipality has.*" B3 indicated that: "*The municipality's water resource infrastructure was previously resilient against climate change impacts, but not so much in the recent years*". B2 explained that the existing infrastructure is outdated (close to 40 years old) and it is deteriorating and unable to contend with the ever-changing climate, demands and technology. Furthermore, B2 added that: "*These conditions has led to major malfunctions in the system, which points to the lack of budget allocated to maintain and sustain the development that is happening in the city*".

Respondents B1 and B2 were of the same opinion, that because of the increase in population as a result of urbanization, it has become more and more difficult to meet the demands of the customers of eThekwini Municipality. In addition, B5 stated that: "*The allocated budget has not been enough. Over and above that, in the last financial year their budget has been cut to R500 million. The cutting of the budget exerted so much pressure, not only in the municipality's infrastructure, but also the capacity and capabilities to deliver the services*". B5 continued to explain that, at a strategic management level, they have developed what is termed '*water and sanitation infrastructure levy*', but are finalizing the finer details on its implementation. Table 5 gives an idea how the current water tariffs are structured. B4 added that: "*There are projects, like the desalination of water, that have been piloted and they are funded privately by the municipality's programme called Public-Private Partnership*".

4.5.5 Section 3: eThekwini Municipality's innovative and intervention strategies on water resource management (Study Objective 2)

This section sought to discover the innovative and intervention strategies that are being implemented by the eThekwini Municipality to minimize the impact of climate change to improve integrated water resource management in eThekwini Municipality; as well as to ascertain the challenges and opportunities encountered in the implementation process.

Themes (innovative and intervention strategies): "*Reuse, remix and recycle of treated wastewater"; "renewable energy projects"; "desalination plants"; "joint venture project"; "failing to accept the innovations and new ways of doing things"*

According to respondent B1: "*The municipality has been looking at the reuse of treated wastewater and there is a water recycling plant in the Bluff area, where the treated water produced is below drinking standard and that water is sold to Mondi and Sapref Refinery at a lower price than normal drinking water. Thus, this alleviates pressure on the side of the municipality since these industries use a lot of water."* Furthermore, this respondent explained in detail that there are a few projects that are in their feasibility stage at the moment, where eThekwini Municipality looks at reuse and remix of treated wastewater. There has been a pilot joint venture project with the Japanese that looked at desalination plants, together with treated wastewater. This will decrease the demand that the municipality would place on Umgeni Water. There are also ongoing educational initiatives to the customers with regards to saving water."

B4 also added that: "*The municipality has renewable energy projects, where they have solar panels at over 240 reservoir sites; and they have also looked at reducing our energy consumption in the city to bring down our carbon footprint."*

On the issue of challenges encountered in the implementation of some innovative and intervention strategies, one of the respondents (B2) explained that the challenge is always around resources, skills, and the budget that is allocated to implement these strategies. "*The willingness or lack thereof on the part of the municipality to invest in implementation of these strategies, and lack of understanding the importance of making sure that our infrastructure is protected from the impacts of climate change".*

B4 stated that the challenge when it comes to reuse of water resources is community buy-in; but the municipality has communication strategies that will be endorsed soon to mitigate those challenges. Respondent B5 added: "*The challenges we normally face is that of the public resistance, failing to accept the innovations and new ways of doing things. We have developed a stakeholder engagement meetings and partnerships with the communities, particularly from the central side, so that we create an understanding that when the water is given to the public, they will actually know that we have followed the necessary standards (SANS 241).*" (B5).

Respondent B3 explained that, as an organization, they are involved in a lot of innovative engagements. As the Water and Sanitation Unit, they are involved with the Bill Gates Foundation to modernize and implement projects to ensure that the sanitation service, in particular, is delivered in a more dignified and modern way. This speaks directly to climate change, because if sanitation issues are not being addressed, they become a health hazard. In 2014 they received an accolade for being the best innovator in the water services sector, worldwide.

Respondent B2 contradicted these sentiments by saying that: "*I don't think we've done much to be honest. We've looked at innovations but we haven't implemented any of them to deal with climate change. In our case, storm water management, a big thing. We have started with storm*

water management plans for our treatment works. Once that is done, we will start looking at the engineering and costs of the implementations". B2 added that: "*We have also tried to deal with issues of ingress into our systems that limit the capacity at the plants. We are looking at how other countries deal or combine their systems (stormwater treatment and wastewater treatment).*"

4.5.6 Section 4: Climate Change (drought and floods) and its impact on water resource infrastructure (Study Objective 2)

This section explored the avenues which the government has initiated to educate the public about the impact of climate change, and water sustainability measures such as harvesting of heavy rains for irrigation purposes and reuse. The section also sought to determine the government's perspective and plans for the future in managing the excessive water from the floods, as a result of climate change.

Themes (Climate change (drought and floods): "*not fully ready to address the potential huge climate change impact*"; "*reality is that climate change is here"; "It will impact our infrastructure"; "We need to protect our infrastructure"*

One of the respondents (B1) believed that the municipality is not fully ready to address the potential impact of climate change, which will surely occur in the future; but when South Africa was experiencing a drought, the eThekwini Municipality was able to adapt more quickly. It was quite responsive and did not end up in a situation like Cape Town (level 0). B1 continued to say that the actions that needed to be taken required a political will and buy-in to what they wanted to implement, and they learnt from that experience. According to respondent B2: "*My perception is that we need to move from the planning and studies mind-set to implementation mind-set. We keep doing research, planning and reports, whereas the reality is that climate change is*

here and it is not going to wait for us while we convince ourselves that it will impact our infrastructure. We need to act so that we protect our infrastructure."

On the question of whether the government has done enough to educate the public, two respondents (B1 and B2) were of the opinion expressed that it has not done enough. Respondent B2 stated that: *"I don't think so. It will not be enough. People still waste water, especially in the affluent areas where we have 'more educated people'. People continue to damage water infrastructure and people continue to steal water, and it costs a lot. In my opinion, it needs to be entrenched at school level and form part of the curriculum. Kids should grow up understanding the importance of this resource called water and what climate change is going to do it and what they need to do to mitigate that. We need a culture and mind-set change for the older people*".

Respondent B1 stated that: "*I don't think government has done enough because, if it has, then everybody would be harvest rainwater and everybody would be reusing wastewater. You may find that poor people may be the ones that harvest rainwater since they might feel the pinch in their pockets; but personally, I don't harvest water because I can afford to pay for water. This requires us as citizens to be proactive once we see the bigger picture (drought being imminent), and as South Africans we are not there in our thinking and that's where we fail.*" (B1).

B5 noted that repetition is important in order to change the minds of the people, with the view that their behaviours will change. "*The more information people have, is the more they become empowered and the more empowered they are, is the more non-resilient they become in implementing that which we propose they do. Having said that, there will never be a stage where we say it is enough, because we are in a quest of constant information dissemination*

and I believe the more informed our citizens are, is the more reason they will find to pay for the services with which they've been provided."

B3 shared a different view on the question of the government doing enough to educate the public about water sustainability measures such as harvesting of heavy rain for irrigation and domestic use and reuse, and his response was: "*In my opinion the government is doing enough. Even our parliamentary leaders always talk about this. What, in my view, is lacking as a country, is the sense of internalising what keeps being said to us and understanding that the infrastructure belongs to us, the users.*"

4.5.7 Section 5: The adaptability of the Municipality's infrastructure (Study Objective 3)

In this section, questions were asked to discover whether eThekwini Municipality has employed any new building techniques in line with water preservation and environmental sustainability; and also to ascertain whether the municipality has initiated strategic measures to protect and maintain aging, existing water resource infrastructure.

Themes (Municipality's infrastructure adaptability): "*Enabling a resilient environment in the municipality"; "the need for newer technology in order to consolidate our infrastructure in an integrated and adaptive manner"; "PPP models"*

It was indicated, by respondent B1, that there is a new green building policy that the municipality was discussing in public engagements. It focuses on energy and water, and seeks to help in the area of climate change and enabling a resilient environment for the municipality's water resource infrastructure. This policy has not been approved, as yet. It also seeks to incentivise the community to drive the idea of a green economy in relation to water resource management.

It was also indicated by respondents B2, B3 and B5 that the water and sanitation customer service building in the CBD is green building-compliant. On the question of what the eThekwini Municipality's strategic measure are for protecting and maintaining the aging, existing water resource infrastructure to be adaptive and resilient, respondent B2 stated that: "*The strategic plan document speaks about measures we should be taking to ensure adaptative and resilient water infrastructure. One of them is regionalisation, where we need to consolidate our infrastructure in an integrated and adaptive manner, and to close down some of the older plants, and subsequently to build new ones that will be bigger, which can deal with the impacts of floods and droughts as resilient infrastructure."*

Respondent B2 further explained that, in terms of maintaining the infrastructure to be resilient, the Municipality wants the latest technology. Not just is the infrastructure aging; but also the type of effluent that comes into the plants is changing; newer technology is needed to deal with the changes in the type of effluent which is treated. Strategically, this needs more funding, so the Municipality is looking at different funding models, such as grant funding or PPP models. People also need to be educated, so that they protect the infrastructure. There is a desperate need to upgrade the current infrastructure.

4.6 Semi-Structured Questionnaire (site visits to wastewater treatment plants)

Eight visits were conducted to observe the conditions and operations at the wastewater treatment facilities, and to interview the supervisors of each facility.

4.6.1 Section 1: Respondents' Profiles

The respondents asked to provide information about their personal details (see Table 5); to state their current position in the organization; the number of years they have served in the

municipality; whether or not they are qualified in the field of water; and their highest qualification. In their years of employment within the municipality, most respondents would have carried out different functions until occupying the current position.

4.6.2 Section 2: Water Resource Plants' Operation and Maintenance Routines

This section sought to discover the daily operations and maintenance routines at the water resource plants. The researcher also observed, by walking around the facilities, the condition each facility is in.

4.6.2.1 Capacity performance of the water plants' infrastructure (See section 1.4 – research question)

The respondents were asked about the capacity of each water plant's infrastructure (answers could be 'full', 'moderate' or 'lower' capacity). Three treatment facilities were operating at moderate capacity, while three were operating at full capacity (having exceeded their intended .capacity), and the other two were operating at low- capacity.

4.6.2.2 Maintenance and technical inspections

The follow-up question sought to discover how the maintenance and technical inspections are carried out on a daily basis; the intervals between site inspections; and the frequency of routine site maintenance of the plant and other machinery. The respondents were given a choice of answers to these questions, from hourly to daily to weekly to monthly and to yearly. Although some plants require more attention and others may need more at a particular time, the site maintenance and technical inspection is scheduled to take place daily for all treatment plants. The operational maintenance of machinery and equipment takes place monthly and it is done by another department. The maintenance plans for the maintenance of the water infrastructure

components, such as mechanical adjustments, repairs, replacements and corrections of defects, at these plants are mostly being carried out preventatively. The reason for the mostly preventative approach is because of the lack of funds for other activities.

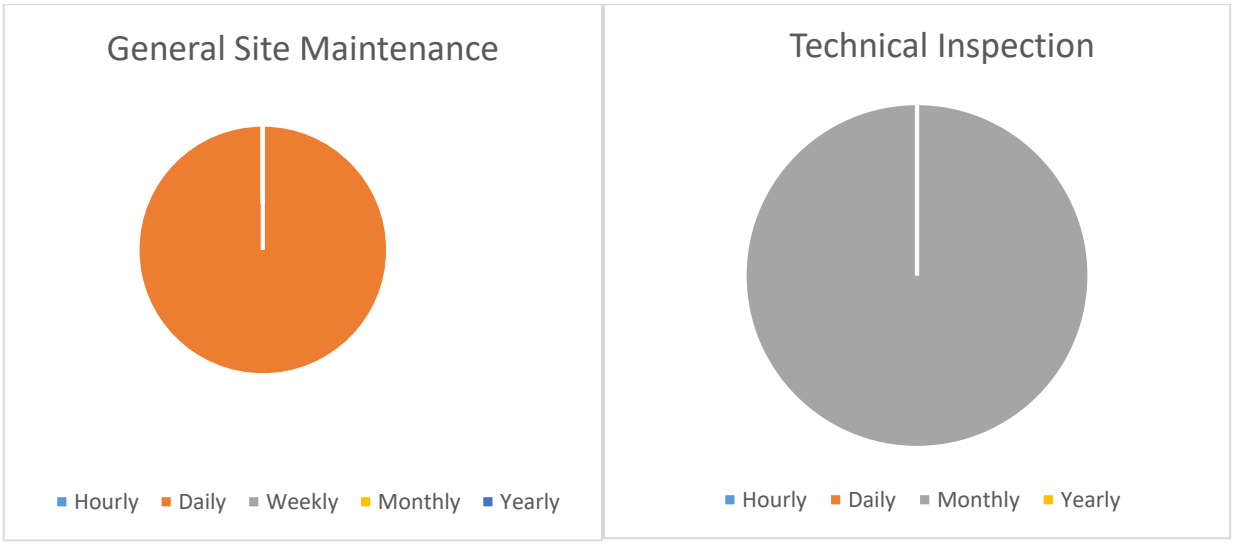

Figure 6: The responses of the interviewees on the question of the intervals which the general site maintenance and technical inspection takes place.

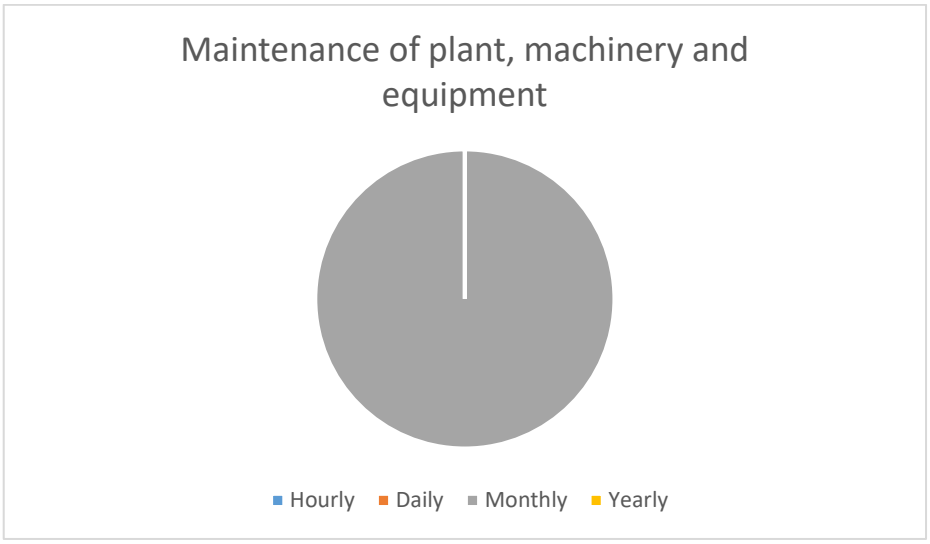

Figure 7: The responses of the interviewees on the question of the intervals at which the maintenance of the plant, machinery and equipment take place. It is done on a two-monthly basis.

The type(s) of maintenance plans that are being implemented with regard to the maintenance of the water infrastructure components, such as, mechanical adjustments, repairs, replacements and corrections of defects are done routinely because of budget constraints; but ideally it should be done preventively.

The treated wastewater from the treatment facilities does not go to domestic use, but the treated water is fed back into the nearby rivers, like the Umlazi River; the Mbokwodweni River; the Umkomaas River; the Umhlathuzana River; and the Ohlanga River.

4.6.2.3 Security measures in the treatment facility

The only security measures in place to protect the municipality's water resource assets are security guards (one guard during the day and two guards at night) from Isidingo Security Company (7:30 to 16:00), and fencing at all the facilities.

4.6.2.4 Incident plan for reporting emergencies

The respondents were asked to explain the comprehensive incident reporting plan that could be employed in an emergency to manage the situation. They were given scenarios of emergency cases such as a power failure; storms and flooding; fire; earthquakes; explosions; breakdown of the water supply system; sabotage or vandalism; and water supply bio-terrorism, to answer this question.

The following diagrams (Figures 8 and 9) show the incident reporting flow for attending to an emergency.

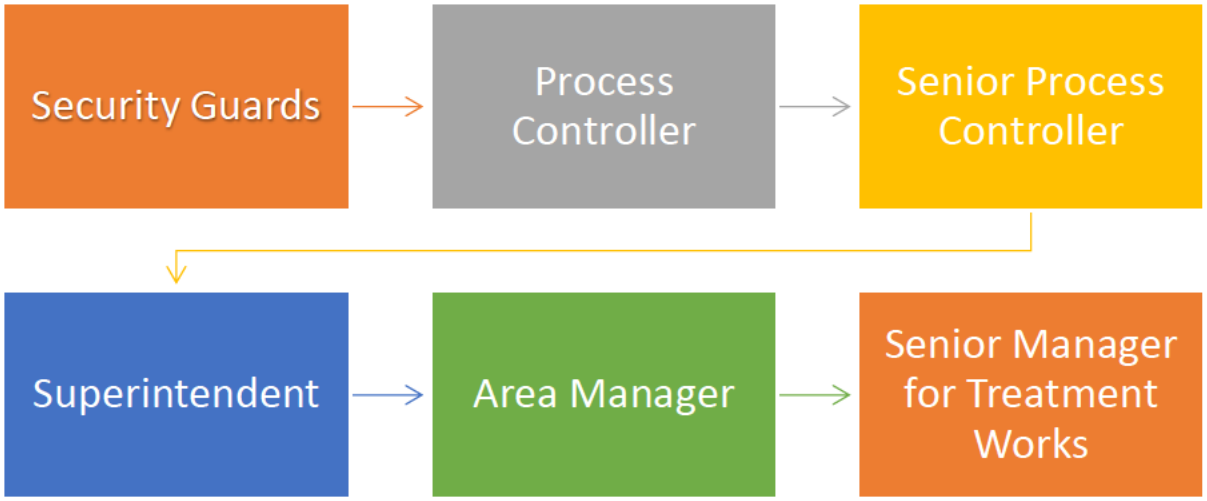

Figure 8: Incident reporting flow (in the case of load shedding)

Source: Researcher's Construct (2023)

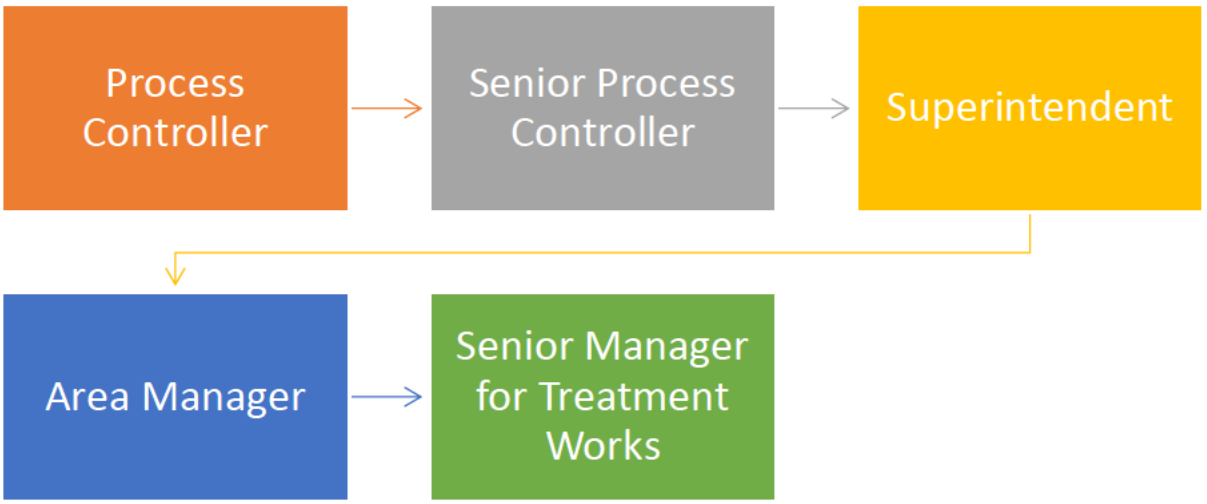

Figure 9: Incident reporting flow (for incidents concerning the processes at the plant)

Source: Researcher's Construct (2023)

Respondent C7 stated that the reporting of an incident may start with the security guard, depending on the incident and when that incident happened. He then explained the emergency response flow as follows:

- In the case of load shedding, especially at night, the plants have a generator that kicks in during blackouts and the guards will make a note of when the blackout occurred. When the process controller arrives in the morning, he needs to check if the generator is still running. If the generator is still running, that would mean the power outage is serious and he will then contact the call centre to find out if there are any outages in nearby areas. If there are outages in nearby areas, he will get the necessary information – for example, the reference number; and after he has done his own investigation, he will then report to the senior process controller. The senior process controller will gather all the information from the investigation and report the incident to the superintendent of that particular plant and then the information will be passed to the area manager and then to the senior manager for all treatment works in the Water and Sanitation Unit (B2). Respondent C7 added that the reporting protocol is the same for all incidents.

4.6.2.5 Wastewater treatment process flow

During the walk-about at one treatment facility, respondent C5 explained the process flow for treating the wastewater in the municipality's treatment plant. Figure 4 shows the process flow of the wastewater treatment facility.

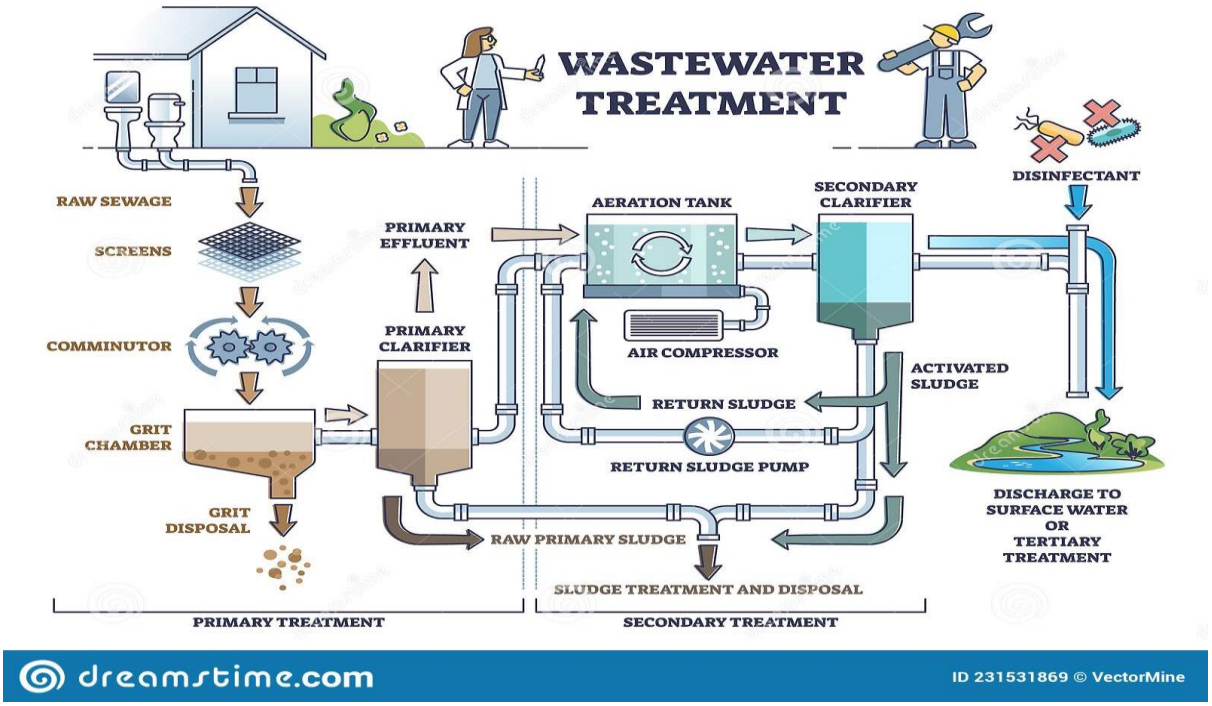

Figure 10: Wastewater Treatment Process Flow

Source: Adopted from online: Dreamstime.com

The process is as follows:

- After passing through the bar screen on its way through the sewer system, the wastewater is cleared of big solids like sticks and rags. The wastewater flow is slowed down as it passes through the bar screen and enters the grit tank, allowing heavy materials like sand and gravel that were too small to pass through the bar screen to sink to the bottom. The grit tank and bar screen debris is all gathered and dumped at a sanitary landfill.

- When treating wastewater, primary treatment is the next step. The physical separation of grease and solids from wastewater is made possible by it. The separated wastewater enters a primary settling tank and is left there for a few hours so that the oil and grease float to the top and the solid particles settle to the bottom.

- Biological treatment, or secondary treatment, is the process used to rid wastewater of dissolved organic material. The settling tank's partially treated wastewater enters an aeration tank through gravity. Microorganisms and oxygen are used by the mixture of water and solids to feed on the leftover organic matter in the wastewater (air bubbles are used for mixing and oxygen flow).

- The final clarifier receives the liquid mixture, which consists of solids combined with water and microorganisms. When solids in the clarifier settle to the bottom, part of the material is recycled back into the aeration tank to replenish the population of microorganisms that treat incoming wastewater, and the remaining material is sent to the solids handling process.

- The cleaned water is disinfected as the last step in the treatment process before being released into rivers and streams or used for wastewater reuse. Disinfection is achieved primarily through the use of chlorination and/or UV radiation.

- Digesters receive the primary solids from the primary settling tank and the secondary solids from the clarifier. Methane gas and water are byproducts produced by microorganisms using the organic material found in the solids as a food source. 90% fewer pathogens remain after digestion, and a moist, soil-like substance known as "bio solids" is produced; this material contains 95-77% water. Before the biosolids are disposed of in a landfill, burned, or positively utilized as fertilizer or soil amendment, some of the water is extracted using mechanical devices like centrifuges or filter presses.4.6.2.6 Capacity building programmes

The respondents were asked to explain the strategies for capacity building programmes for the Operations and Maintenance personnel in each treatment plant, offered by the

government/municipality. Respondent C3 stated that there are regular workshops that they attend. However, these were paused because of covid-19. She also indicated that the staff attend first aid training; chlorine handling courses; process workshops; and health and safety talks.

4.7 Discussion of findings

- The municipality's water infrastructure is not functioning at its intended best because it is too old. The current infrastructure is over 40 years old and it needs to be upgraded. The assets have deteriorated to the extent that there are major malfunctions in the system, which point to the lack of budget allocated to maintain and support the developments that are occurring in the city.
- The maintenance of the infrastructure requires that a lot of contractual work is done; and it also requires a lot of money to run the systems. The lack thereof has led to the deterioration of the system since 2014. There is not enough in the budget to replace the old water infrastructure; but a desalination plant has been piloted in partnership with a private investment company from Japan, through the government programme Public Private Partnership (PPP). Desalination is expensive, and there is still a need for more funding in order to build more desalination plants.
- The municipality is not ready for the impacts of climate change, such as flooding. The floods of 2016/2017 left major damage to one of the wastewater treatment plants in the south of Durban, and it took about six months to get it back online. The non-resilience of the infrastructure to the impacts of climate change poses a threat to the most vulnerable in the informal settlements. Furthermore, there was enormous devastation in KwaZulu Natal during the 2022 floods, which resulted in a death toll of close to 500. The

municipality was corrective, rather than preventative, in their response to this incident. A newly formed wing has been established (under the Disaster Management Unit) to forecast and look at the areas that might be in danger from flooding.

- There is a need to move from planning and studies to implementation, because we are living with the reality of climate change, and it is not going to wait for us while we convince ourselves that it will impact our infrastructure. There is a need to act so that we protect our infrastructure.

- The government has not done enough to educate communities about water harvesting, conservation and reuse, because then everybody would be harvesting rainwater and everybody would be reusing wastewater. It is possible that poor people may harvest rainwater, since they might feel the pinch in their pockets more. Wastage of water has been identified by the municipality, especially the affluent areas, where there are 'more educated' people. People continue to damage water infrastructure and some people continue to steal water. This all increases costs. This requires us, as citizens, to be proactive once we see the bigger picture (drought is imminent). As South Africans we are not there in our thinking; and that is where we fail.

- The strategic plan document speaks about measures we should be taking. One of them is regionalisation, which speaks to consolidating the infrastructure and closing down some of the older plants, building new ones that will be bigger and better able to deal with the impacts of floods and droughts. In terms of maintaining the infrastructure, the latest technology is necessary. Not only is infrastructure aging, but the type of effluent that comes to the plant is also changing. Newer technology is needed to deal with the changes in the type of effluent that has to be treated.

- Chemical engineering is an essential qualification in the field of water, especially for persons working at the treatment plants. Some of the municipal employees (managers/superintended) do not possess a related qualification to the field of water. Others have been employed for many years and they ended up 'learning on the job' to qualify for their current occupation.

This section presents a summary of the major findings of the research, as aligned to the study objectives:

4.8.1 Current Conditions of Water Resource Management Systems in eThekwini Municipality

The findings are summarised and presented in line with Objective 1 of this study.

a. The current condition of the water infrastructure not at satisfactory level, and there is a need to upgrade the water infrastructure for it to be resilient to climate change.

It was discovered from the findings that the municipality has been challenged by the condition and capacity of the water management system, and also by the need to maintain the old infrastructure. It seems there is not enough in the budget to meet the demands of upgrading and up scaling to more modern technology in order to mitigate the deterioration of the old infrastructure. The increase in the population in the city compels the municipality to roll out what they term a 'water and sanitation infrastructure levy', which will alleviate the pressure exerted by the budget cuts which resulted from the period of the COVID-19 pandemic. These findings corroborate with the conclusions of Ziervogel *et al.* (2014) and Donnenfeld *et al.* (2018) in the existing literature, as mentioned earlier in this study.

4.8.2 Ethekwini Municipality's Innovative and Intervention Strategies on Water Resource Management

The findings are summarised and presented in line with Objective 2 of this study

a. Proposed innovative and intervention strategies for improvement of water resource management system – Joint Venture/PPP; and no innovative strategies

The findings revealed that there is only one intervention strategy that has been employed by the municipality, with the help of the PPP, in order to relieve the pressure of water supply. This is the desalination project. The municipality has not implemented any innovative strategies. This lack adequate innovation strategies by the government validates the findings of Rodina (2018), who stated that most water systems, globally, are rooted in infrastructural legacies and design paradigms that have been inflexible and slow to adapt to change.

b. Proposed innovative and intervention strategies for the improvement of the water resource management system – reuse and remixing of treated wastewater; the solar energy alternative.

There are projects that are at their feasibility stage, where the municipality is looking at 'reuse and remixing of treated wastewater'. In another intervention, the municipality has installed solar panels at over 240 reservoir sites, with the aim of reducing the city's carbon footprint. This in accordance with Shin *et al.* (2018). An arrangement of interconnected components arranged spatially is what makes up a water infrastructure system, particularly the water distribution network. There is a chance to enhance system resilience through strategic networking by growing the water system network and the interconnectedness of its components.

Proposed innovative and intervention strategies for improvement of water resource management system – accept and adopt new approaches, employ skilled human capital

It was mentioned by one respondent that one of the challenges is human resource (skills). However, one would argue that, according to STATS SA (2022-Q1), about 55% of young graduates in South Africa are unemployed. The issue, then, might not be human resources or skills, but it may be the issue of budget. This finding corroborates that of Chelleri, Schuetze, and Salvati's (2015) study. Thus, resilience could be measured by degree to which our social and infrastructure systems are capable of organizing themselves, and their ability to increase their capacity for learning and adaptation, including their capacity to recover from a disaster. Another challenge that is encountered by the municipality in implementing their innovative and intervention strategies is community buy-in. There is still more to be done in communicating and educating the public in order for them to accept and adapt to new ways of doing things. These findings are in line with the results of Drangert *et al.* (2003), as mentioned in Chapter Two of this study.

4.8.3 The impact of Climate Change (Drought and Floods) on The Water Resource Infrastructure System.

The findings are summarised and presented in line with Objective 2 of this study

a. **No adequate action plan to mitigate climate change; feasibility study conducted in order to mitigate impact of climate change; inadequate funds to upgrade current infrastructure against climate change's negative impact.**

It was ascertained in the findings that the municipality is not ready for extreme weather patterns, like flash flooding or extreme heat which causes drought. The study findings revealed that the municipality has carried out a number of feasibility studies and some research pertaining to the subject of climate change; and the challenge is now implementing what needs to be done, in order for them to prepare for the effects of climate change. This challenge was associated with lack of funds, as it is believed that upgrading the current infrastructure will place us in a better position to survive the impacts of climate change. Some of these findings resonate with the studies of Gumbi and Rangongo (2018) and SAPPMA (2016) that, in South Africa, the provision and management of water will be a continuing challenge due to climate change; the ageing and poor maintenance of its infrastructure; being reactionary as opposed to carrying out preventive maintenance; as well as the need to upgrade existing infrastructure assets (Gumbi and Rangongo, 2018; SAPPMA, 2016).

The government has not done enough to educate the public about water harvesting or rainwater harvesting. There are many media the government can use to reach the public in different communities with information and practical ways of harvesting and saving water: social media (Facebook, Twitter, Instagram and TikTok, to name a few); radio; television and the newspapers. Repetition is another vital component in delivering information to the public, especially if the aim is to educate them. It was suggested in the findings that, perhaps, there is a need to include schools in the programme to reach the public, and to start educating the younger generation on how to save and harvest this important element (water) for survival in the future. These findings validate the studies by Kundzewicz, *et al.* (2008); Claassen (2013) and Giordano and Shah (2014), that the Energy generation, infrastructure, human health, agriculture, and ecosystems are just a

few of the industries that will be impacted by the effects of climate change on water availability and quality. Thus, there is a need for an integrated water resource management network, in order to encourage a more holistic approach; i.e., to manage it across sectors, and to ensure wide participation in decision-making, enabling participation across the spectrum of stakeholders, for sustainable environmental benefits (Giordano and Shah, 2014).

4.8.4 Strategic Measures to Improve the Municipality's Water Infrastructure Resilience and Adaptability.

a. Aging infrastructure; green building; need for financial injection

The study findings revealed that the aging infrastructure within the eThekwini municipality region requires urgent attention, considering that there has also been a rapid change in the effluent that needs to be treated in the wastewater treatment plants. Based on the findings, all the infrastructure changes require a financial injection in order to realize the changes needed. These findings validate the studies of Chelleri, Schuetze and Salvati (2015), and Crabb and Robin (2006), that the municipality's engineering sector is generally inadequate to deal with issues of water management complexity. Notwithstanding this, there is a need for the municipality to change, adopt and integrate innovative technologies for water management best practices which would ensure a water culture which is resilient, and able to adapt to the effects of climate change (Chelleri, Schuetze and Salvati, 2015).

It was established from the respondents that the municipality has only implemented the green building technique in one building (the Water and Sanitation customer service building on 3 Prior Road, Durban CBD). It is important to keep up with the new ways and

new techniques of building in order to meet the demands of climate change – like the green building technique, which is also environmentally friendly and appealing in the eyes. The benefits of green buildings (Thatcher and Milner, 2014; Wiley *et al.,* 2010; Ashuri and Durmus-Pedini, 2010) include that green buildings are energy efficient; emit fewer greenhouse gases; produce less waste; and enhance the occupants' productivity and health; as well as ensuring higher job satisfaction and a lower absenteeism rate. The municipality can use some of these benefits to its advantage in order to get maximum productivity.

4.8.5 The overview of the waste water treatment plant operations.

The processes at the wastewater treatment plants, facilities that process sewage and other wastewater to remove contaminants and pollutants before releasing it back into the environment, were observed. Here follows an overview of the wastewater treatment plant operations:

1. Preliminary Treatment: The first step in wastewater treatment is the removal of large debris such as sticks, rags, and other solids. This is done through a process known as screening, which involves passing the wastewater through a screen or mesh to remove large solids.
2. Primary Treatment: After preliminary treatment, the wastewater enters a sedimentation tank where heavy solids settle to the bottom and lighter solids float to the top. These solids are then removed and treated separately. The remaining wastewater is then passed to the next stage of treatment.

3. Secondary Treatment: In this stage, the wastewater is mixed with bacteria that break down organic matter and other pollutants. This process is called biological treatment, and it takes place in large tanks called activated sludge reactors.

4. Final Treatment: After secondary treatment, the wastewater is treated with chemicals to remove any remaining organic matter or other pollutants. The treated water is then disinfected to kill any remaining bacteria and viruses.

5. Sludge Treatment: During the primary and secondary treatment processes, solids are removed from the wastewater. These solids are then treated separately through a process called sludge treatment. This can involve dewatering, composting, or incineration.

6. Discharge: Once the wastewater has been treated, it is discharged back into the environment. The discharge may be into a river or ocean, or it may be used for irrigation or other non-potable purposes.

   Overall, wastewater treatment plants play a crucial role in protecting the environment and public health by removing pollutants from wastewater before it is released back into the environment.

   Observing the current state of our infrastructure, it is concluded that the eThekwini Municipality has much work to do in upgrading the deteriorating treatment facilities, and it has become evident that most of our frustrations as a metro can only be fixed by money and/or a well-managed budget, coupled with qualified and skilled human resources; not forgetting the element of community buy-in to the implementation of new technology that will bring about much-needed transformation.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter connects the findings to the literature and examines and summarizes the data that were reported and interpreted in this study's Chapter Four (4). The chapter concludes the various discussions.

5.1.1 Research Problem

An inadequate, non-resilient water infrastructure to effectively manage the increasing threats from climate change may, in the future, exacerbate the challenge the eThekwini region faces to realise its economic, social and environment sustainability.

5.1.2 Research Questions

What are the current of conditions and capacity of the eThekwini Municipality's water resource management and systems to contend with the impact of climate change and related incidents within the region?

5.1.3 Research Sub-Questions

i. Does the current condition of eThekwini Municipality's water resource infrastructure and systems make them resilient enough to contend with the impact of climate change within the region?
ii. What are the eThekwini Municipality's innovative and intervention strategies to be implemented in order to minimise the impact of climate change?
iii. What are the eThekwini Municipality's strategic measures to protect and maintain the aging, existing water resource infrastructure?

5.1.4 Research Objectives

i. Evaluate the current condition of the water resource infrastructure within the eThekwini region.
ii. Assess eThekwini Municipality's innovative and intervention strategies to tackle the impact of climate change and its impact on the water resource infrastructure.
iii. Evaluate the strategic measures that eThekwini municipality has adopted to maintain existing; and build new, water resource infrastructure.

5.2 Conclusion

The conclusions of this study are based on the respondents' perceptions, opinions, expertise, judgement and experiences on issues of water resources management systems and infrastructure resiliency and adaptability to the impact of climate change in Durban, South Africa. The study revealed that the water resource infrastructure is not in a satisfactory state, and not resilient enough to withstand the effects of climate change. The eThekwini Municipality's water resource infrastructure is in critical need of upgrading and adequate maintenance for optimal operation; and to become resilient to environmental and technical challenges. The study discussed the intention of the municipality to embark on an innovative joint venture project to reuse, remix and recycle treated wastewater; as well as the installation of desalination plants for effective water resources management.

From the findings, the study has concluded that the municipality's water resource infrastructure systems are not fully ready to withstand the challenges associated with the potential impact of climate change. Based on the findings, it can be concluded that eThekwini Municipality's water resource infrastructure systems need to be protected against the potential impact of climate change as soon as possible. It can be further be concluded that eThekwini municipality needs

to adopt new technologies that would enable integrated and adaptive, resilient components in their water resource management systems. This adoption of innovative, integrated and adaptive concepts for the water resources management system would provide the necessary assurance that eThekwini Municipality's water resource infrastructure would be restored to a state so that it can withstand the impact of climate change.

5.4 Recommendations

Based on the findings and conclusions of the study, the following suggestions are made, as strategic and innovative ways to address the potential, challenges that could be associated with climate change, such as floods and droughts, on eThekwini municipality's water resource management systems.

The study makes the following recommendations:

The municipality should strive to ensure that the current state of its water resource infrastructure is satisfactory, by updating and upgrading its structural integrity in order to ensure it is resilient enough to withstand the impact of climate change;

This study recommends that the municipality's intention to embark on joint venture projects to reuse, remix and recycle treated wastewater, and to install desalination plants, be thoroughly studied and effectively implemented to ensure the optimal functionality and resilience of its water resources management systems; and

Finally, the study recommends that the municipality should invest in new technologies that would enable integrated and adaptive, resilient components in their water resource management systems.

5.5 Limitations

This study focused on only a few units/departments, such as the Department of Water and Sanitation, and Umgeni Water in Durban, KwaZulu-Natal. Therefore, the findings can only be generalised to the eThekwini municipal region. The covid-19 pandemic regulations and restrictions presented a challenge during the study, as it was an extremely difficulty time for researchers and research respondents during the data collection.

5.6 Recommendations for Further Research

There should be more research studies carried out to investigate how the elements of the Fourth Industrial Revolution and emerging technologies could be planned and implemented in order to holistically improve eThekwini municipality’s water resource infrastructure system to increase one's resistance against the effects of climate change.

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APPENDICES

Appendix A: Letter of Request to Conduct Research

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26th August 2020

To:

The, eThekwini Municipality' Water and Sanitation

Pod 7-8, Intuthuko Junction, 750 Mary Thiphe Street,

Umkhumbane, Cato Manor,

Durban 4001.

Dear Sir/Madam

LETTER OF REQUEST TO CONDUCT RESEARCH

Ms Nosipho Buhle Khanyi, with DUT student number 20506983 is a Master student in the Department of Construction Management and Quantity Surveying, Durban University of Technology, Durban, South Africa. She is currently conducting a research titled 'Evaluation of Water Resource Management Systems in eThekwini Municipality" under my supervision. The research required that she carry out a walk-through observation and interaction in the water infrastructure sites within eThekwini region as well as an in-depth interviewing among the Heads of Department from , eThekwini Municipality' Water and Sanitation, the Department of Water Affairs, and the Umgeni Water.

Ms. Nosipho has identified the eThekwini Municipality' Water and Sanitation, the Department of Water Affairs, and the Umgeni Water as a potential source of information for her study. The above mentioned government entities are selected because of their involved in the planning,

operation and management of eThekwini region's water resource related issues in Durban. As her academic supervisor, I would like to kindly request your permission to provide us with a gatekeeper's approval letter for ethical purposes.

The letter should indicate that Ms. Nosipho is a registered student, currently studying for her Master degree in Construction Management, and has been granted permission by the eThekwini Municipality to conduct research among the its water resource infrastructure sites and with the HODs from eThekwini Municipality' Water and Sanitation, the Department of Water Affairs, and the Umgeni Water. Participants are anonymous. There are no known risks, current or anticipated, to any participant in this research and all information received will be treated with utmost confidentiality.

With regards to any queries, please do not hesitate to contact chwane@gmail.com and IrukaA@dut.ac.za, and bhekisiphot@dut.ac.za.

Thank you in anticipation of your favourable consideration of this request.

Dr IC Anugwo

Supervisor and DRC Member,

Department of Construction Management & Quantity Surveying

Durban University of Technology, Durban, South Africa.

(+27) 031 373 2468

Appendix B: Letter of Information and Consent

LETTER OF INFORMATION

Title of the Research Study: Evaluation of Water Resource Management Systems in eThekwini Municipality

Principal Investigator/s/researcher: Nosipho Buhle Khanyi - BTech. Construction Management

Co-Investigator/s/supervisor/s: Dr I. Anugwo (PhD) and Prof B. Twala

Brief Introduction and Purpose of the Study: I am conducting research on "Evaluation of Water Resource Management Systems in eThekwini Municipality". I would like to invite you to participate in the research. Research is a systematic search or enquiry for generalized new knowledge. And so the aim of the study sought critically evaluate on issues relation to water resource management systems, and infrastructure resiliency and adaptability within the eThekwini region. This study outcome would assist to enhance knowledge management about building resilience water infrastructure against climate change impact.

Greeting

Good Day Sir/Madam

I hope you are doing well.

Introduce yourself to the participant: I am a postgraduate master's degree candidate in the Department of Construction Management and Quantity Surveying at the Durban University of Technology (DUT).

Invitation to the potential participant: I would like to invite you to participate in the research

What is Research: Research is the systematic investigation into and study of materials and sources in order to establish facts and reach new conclusions.

Outline of the Procedures: You will be asked to answer/respond to questions about the study. The interviewing process will be scheduled at your convenience, and will be conducted in your office or on Zoom. Because of covid-19 pandemic, all covid-19 regulations will be strictly adhered accordingly. Interview questions will be used as a data collection instrument, which will involve in-depth interviews. The interview will take about 30 to 45 minutes with each research respondents.

Risks or Discomforts to the Participant: There are no known risk or discomforts associated with this study. However, as you share your business time with me, and may experience interruptions from your work, breaks will be given during interviewing session. Please, may I request for your permission to audio

record the interview session, and I guarantee that your identity will be protected and treated in most confidential manner.

Explain to the participant the reasons he/she may be withdraw from the Study: Please be informed that your participation in this study should be voluntary and there will be no adverse consequences should you (research respondent) choose to withdraw at any given time during or prior to the interview.

Benefits: It is envisaged that this research will result in the expansion of knowledge on water management in the context of eThekwini and South Africa. I believe this research will also aid in the systemic coordination between the community and the municipality as well as industry awareness of the current challenges brought on by floods and the trajectory of infrastructure development.

Remuneration: There will be no remuneration for this study.

Costs of the Study: You will not incur any cost, the interview would takes place online, thus, you may incur cost in term of time and internet data bundle.

Confidentiality: I will record your responses in writing and on audio, in order to enable me to have valid and reliable obtained data. The audio/transcripts will only be viewed by principal investigator and authorized members of the research team at the Durban University of Technology. You should understand that the results of this study will be kept confidential unless you ask for a copy. The results of this study may be published in professional journals or presented at professional conferences, but your record or identity will not be revealed and I will use coded names. The information will be kept in a safe, password secure hard drive.

Results: The results of this study will be published in a professional journal and presented at professional conferences, but your record or identity will not be revealed and I will use coded names.

Research-related Injury: In this research, there will be no injury or exposure to risk.

Storage of all electronic and hard copies including tape recordings: The information will be kept in a safe, password secure hard drive where it is accessible to the main investigator and co-investigators. The data will be kept for a period of five years and will be discarded accordingly.

Persons to contact in the Event of Any Problems or Queries: Please contact the researcher (0733479747), my supervisor (0784784636) or the Institutional Research Ethics Administrator on 031 373 2375. Complaints can be reported to the Director: Research and Postgraduate Support Dr L Linganiso on 031 373 2577 or researchdirector@dut.ac.za.

CONSENT

Full Title of the Study: Evaluation of Water Resource Management Systems in eThekwini Municipality

Names of Researcher/s: Nosipho B. Khanyi

Statement of Agreement to Participate in the Research Study:

- I hereby confirm that I have been informed by the researcher, Nosipho B.Khanyi , about the nature, conduct, benefits and risks of this study - Research Ethics Clearance Number: _____,
- I have also received, read and understood the above written information (Participant Letter of Information) regarding the study.
- I am aware that the results of the study, including personal details regarding my sex, age, date of birth, initials and diagnosis will be anonymously processed into a study report.
- In view of the requirements of research, I agree that the data collected during this study can be processed in a computerised system by the researcher.
- I may, at any stage, without prejudice, withdraw my consent and participation in the study.
- I have had sufficient opportunity to ask questions and (of my own free will) declare myself prepared to participate in the study.
- I understand that significant new findings developed during the course of this research which may relate to my participation will be made available to me.

Full Name of Participant **Date** **Time** **Signature / Right Thumbprint**

I, Nosipho B. Khanyi, herewith confirm that the above participant has been fully informed about the nature, conduct and risks of the above study.

Full Name of Researcher **Date** **Signature**

Full Name of Witness (If applicable) **Date** **Signature**

Full Name of Legal Guardian (If applicable) **Date** **Signature**

Appendix C: Research Instrument: Interview Schedule (Semi-Structured) for Site Visits.

Research Instrument: Interview Schedule (Semi-Structured) for the operation and maintenance personnel/team on the selected water infrastructure facilities/plants within eThekwini region.

Nosipho B. Khanyi (Master's Candidate)

(20506983)

Department of Construction Management & Quantity Surveying

Research Title: Evaluation of Water Resource Management Systems in eThekwini Municipality

Section 1: Research Respondent's Profile

What is the name of your organisation and treatment plant you are representing?

What is your current job position in this organisation?

1.1 How long have you worked for this organisation?

1.2 How has your experience been in the water sector?

1.3 Are you a graduate in the field of water?

1.4 What is your highest qualification?

Section 2: Water Resource Plant's Operation and Maintenance Routine

2. Question	Full capacity Performance	Moderate Capacity Performance	Lower Capacity Performance
2.1 How is the capacity performance of this water plant's infrastructure and equipment per day? And why?			

3. Question	**Hourly**	**Daily**	**Weekly**	**Monthly**	**Yearly**
3.1 How are general site maintenance (weeds, locks, and painting, cleaning) and					

technical inspection carried out and at what intervals?					
3.2 Readings/physical site inspection of dam level and water storage are carried out at what interval?					
3.3 The operations and maintenance of the water resource system such as plant, machinery and equipment (valves etc.) are routinely carried out at what intervals and why?					

4.Question	**Mostly preventive maintenance**	**Mostly corrective maintenance,**	**Mostly Emergency maintenance**
4.1 What type(s) of maintenance plans are being carried out with regard to the maintenance of the water infrastructure component such as, mechanical adjustments, repairs, replacements and corrections of defects at this plant? And why?			

5. Could you please explain the existing Water Supply Network System Composition of this plant?

6. Could you please describe the water production schedules and supply requirements to various areas with regard to this plant?

7. Could you please explain the security measures in place that assure protection of the water resource assets, equipment, and the water operator during the day and night hours?

8. Does your organisation employ Geographic Information System (GIS) based maps in monitoring its water resource infrastructure?

Probe question: “If yes”, what is the importance of GIS in this regard, and “If no” why not using them?

9. In an emergencies case such as power failure, storms and flooding, fire, earthquakes, explosions, breakdown of the water supply system, sabotage or vandalism and water supply bio-terrorism, please explain the comprehensive operation and maintenance plan that could be employed to manage these situations?.

10. Could you please explain the strategies for capacity building programmes for the O&M personnel in this site by the government?

11. Could you please describe the supervisory capacity of this plant site’s operation and maintenance team?

Appendix D: Research Instrument: Interview Schedule

Research Instrument: Interview Schedule

Nosipho B. Khanyi (Master's Candidate)

(20506983)

Department of Construction Management & Quantity Surveying

Research Title: Evaluation of Water Resource Management Systems in eThekwini Municipality

Section 1: Research Respondent's Profile

1.1 What is the name of your organisation and department/ unit you are representing?

1.2 What is your current job position in this organisation?
1.3 How long have you worked for this organisation?
1.4 How has your experience been in the water sector?
1.5 Are you a graduate in the field of water?

1.6 What is your highest qualification?

Section 2: Water Resource Management Systems in eThekwini Municipality

2.1 Please describe the current state of conditions and capacity of the eThekwini Municipality's water resource management systems?

2.2 In your opinion, how resilient is eThekwini Municipality's water resource infrastructure in contending with the impact of climate change and related incidents within the region?

2.3 Could you also please share your thoughts, whether the eThekwini Municipality's water management systems have been functioning at its full capacity in the past 10 or 5 years ago?

2.4 Could you share your thoughts on how financially sustainable is/are the eThekwini Municipality's budget allocated for water resource management and its infrastructure development for the past 5 years?

Section 3: eThekwini Municipality's innovative and intervention strategies on water resource management

3.1 Could you please explain some of the innovative and intervention strategies your organization has employed to minimize the impact of climate change and to improve integrated water resource management in eThekwini Municipality?

3.2 Could you share some of the challenges and opportunities the Municipality has encountered in the implementation of these strategies?

Section 4: Climate Change (Drought and Floods)

4.1 Could you please share your perceptions on the impact of climate change within eThekwini Municipality's water resource management system so far?

4.2 In your opinion, do you think the government has done enough to educate the public about water sustainability measures such as harvesting of heavy rains for irrigation and domestic use and reuse?

4.4 What is the government's plan for the future in managing the excessive water from the floods?

Section 5: Infrastructure adaptability

5.1 In your opinion, what are the eThekwini Municipality's new building techniques in the preservation of water in order to achieve environmental sustainability?

5.2 What are the eThekwini Municipality's strategic measure towards protecting and maintaining the aging of existing water resource infrastructure?