A GIS-BASED APPROACH TO ANALYSE POTABLE WATER ACCESSIBILITY IN LANGELOOP VILLAGE IN EHLANZENI DISTRICT MUNICIPALITY, MPUMALANGA

by

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DEDICATION

I dedicate my thesis to my family, whose unwavering support and love have been my biggest inspiration and motivation throughout this journey. They have been the foundation of my achievements and the driving force behind my perseverance. Their belief in me have shaped me into the person I am today. I dedicate this thesis to them as a token of my gratitude and as a symbol of the profound impact they have had on my academic and personal development. As I delved into the depths of my thesis, I cannot help but acknowledge the profound impact my supervisor Prof Peter Schmitz had, the guidance, influence and constant supervision helped me to overcome any obstacle that came my way of this research.

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Abstract

Potable water accessibility is fundamentally a human right, crucial for sustaining life and ensuring the well-being of individuals and communities. However, in rural areas, people struggle to find enough clean water to cook and drink; they travel or walk long distances to access potable water. Langeloop settlement is a rural area that struggles to access potable water. Therefore, this study aimed to analyse potable water accessibility to the Langeloop community using a GIS-based approach. Langeloop settlement consists of 11 sections/extensions used in this study. The mixed method research approach was used, and potable water sources such as standpipes were captured using a GPS, while observations and a questionnaire were used to conduct a survey. Spatial service area network analysis was performed. The findings of the study are that water accessibility is below average, and many households still do not have access to potable water. This study also found that water availability is a more prominent problem than water proximity. The recommendations of the study include 140 proposed standpipes in the areas where potable water is not accessible. However, it reflects the importance of resource allocation and targeted interventions to improve water access for communities in need.

CHAPTER 1

INTRODUCTION

1.1 Background

The community of Langeloop has a high number of reported cases of protest actions within the Nkomazi Local Municipality as stated in the Nkomazi Local Municipality's Integrated Development Plan (IDP, 2018). The main point of contention is that the community has limited access to water, which has not been resolved over the past five years. The limited access to drinking water for the Langeloop Settlement is an example of the problem rural communities or settlements face.

The Nkomazi Local Municipality, through the Department of Water and Sanitation, and its associates such as Rand Water and donor organisations (IDP, 2018), has been developing, piloting, and implementing several water indicators, such as water availability and water quality, that are meant to measure water accessibility in communities to effectively plan and deliver water services that are accessible to the residents. However, according to Statistics South Africa (STATSSA, 2011) inaccessibility to drinking water for many of the settlements in Nkomazi Local Municipality including Langeloop remains a reality.

Geographical Information Systems (GIS) is well-suited for analysing spatial distribution and accessibility to the basic services such as potable water. Such spatial patterns are essential for community basic services planning. GIS-based accessibility analysis proves to be one method that can be applied to test or examine the accessibility to various resources (Mokgalaka, 2015). This research focuses on determining access to potable water within the different community sections in the Langeloop Village.

The study area is the Langeloop Village, which is within the jurisdiction of Nkomazi Local Municipality, located in Enhlanzeni District Municipality in Mpumalanga Province. Langeloop Village is located about 40km southwest from Komatipoort, and about 14km from the eSwatini border. Figure 1.1. shows the location of the study area.

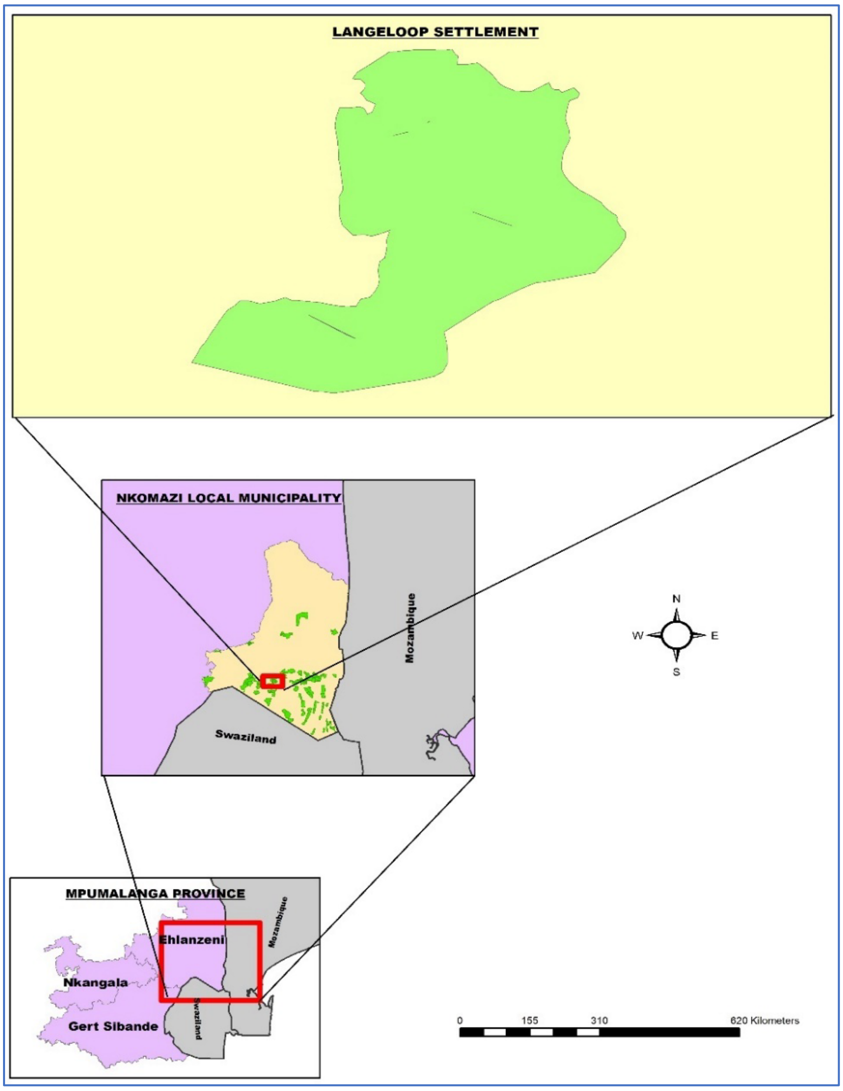

Figure 1.1: Location of the study area

1.2 The research topic

The research topic aims to address a basic service need, namely the access to potable water. Potable water is delivered into a house, a standpipe in the property, a standpipe situated at specific distance from households, a water tank at a street corner, and at water tanker visiting points. Each of these have a geographic location, which can be used to determine accessibility to potable water using GIS.

1.3 Problem statement

This research undertakes a GIS-based approach to analyse potable water accessibility in Langeloop village in Enhlanzeni District Municipality, Mpumalanga. It emanates from the unequal spatial distribution of essential basic services rendered to people in a community, municipality, or country. The need for basic services varies within space and time (Mwamaso, 2015). Therefore, it is of interest to community services planning and human settlement studies.

Effective water service planning has been a problem in South Africa with regards to basic services delivery. Different organisations have researched poor basic services delivery to communities in South Africa (Dempsey, 2012). One of the research studies conducted by the Department of Forestry, Fisheries and the Environment (DFFE) identified common findings in accessing basic services in a community such as that:

- Most rural or semi-rural municipalities have little or no information on the actual population numbers in their areas and their water usage to inform effective essential service delivery.
- Water meters are missing in some areas, leading to municipalities losing revenue that would help maintain and repair the water infrastructure.

- Groundwater is an essential water source, but not utilised in some areas because of the high costs of extracting the groundwater or drilling a borehole.
- Shortages in funds and skills, specifically in rural areas, such as Langeloop.
- Lack of proper management and institutional capacity within municipalities to deal with illegal water connections might lead to inaccessibility to safe drinking water (DFFE, 2013).

Accessibility proves to be an essential aspect of basic services planning. It is crucial for water service authority planners or the local municipality to provide water services efficiently and equitably for the improvement and maintaining of adequate or high-quality living standards (Maposa *et al.*, 2012). The supply of potable water services in the Langeloop settlement constitutes a need, owing to adverse community developments, including slow economic growth, accompanied by high unemployment, and the swift expansion of settlement sectional areas and the resultant increase in the number of residents (IDP, 2018). Therefore, efficient basic services delivery to a growing community proves essential. Currently, the Langeloop Settlement is characterised by a rapidly growing community, which impacts on water service provision.

The accessibility and equitable distribution of essential water services within the Langeloop settlement are spatial in nature, as they involve spatial location, distribution, and variation. Access to water is determined by distance. The distance to water in this study excludes the provision of water within a residence or yard. The provision of water in a residence or yard is the ultimate aim of optimal water provision. However, in absence of the aforementioned, the accessibility study aims to optimise water provision for the community in the context of relevant constraints. Furthermore, the research aims to contribute to the Nkomazi Local Municipality and its water service agents towards improving the provision of water services in the Langeloop Settlement.

1.4 The research aim

Geographical Information Systems (GIS) are powerful tools for collecting and analysing spatial information, including data on various types of water sources. This data is utilised to map existing water sources and provides input to the model for assessing water sources and determining their optimal placement within the Langeloop settlement. The aim of the study is to analyse potable water accessibility in the Langeloop community using a GIS-based approach.

1.5 The research question

What is the current level of accessibility to safe drinking water in Langeloop, and how can it be improved?

1.6 The research sub-questions

The following sub-questions needs to be answered to answer the research question:

1. What type of water provision is available, and where is it located?
2. What is the satisfaction level of access to potable drinking water within the Langeloop Settlement?
3. Where are the areas that need urgent attention to the provision of potable water?

1.7 The objectives of the research

The objectives of this research are:

- To map the spatial distribution of currently available water sources to answer research sub-question 1.
- To quantify and map the level of satisfaction of community members with regards to potable water accessibility in Langeloop to answer research sub-question 2.

- In answering research sub-question 3, the sections that are under-resourced with regards to safe water sources are identified using accessibility analysis methodologies.

1.8 Theoretical paradigm and relevance of this study to the discipline of Geography

Settlement planning and development provide a well-organised spatial construction of land-use and service provision (Polat, 2009). A settlement planning and development system commonly addresses a geographical perspective, environmental sustainability, liveability, spatial equity, and accessibility issues.

Considering this research study and its relevance to the broader discipline of Geography, the most suitable theoretical paradigm of positivism involves using the already existing scientific theory of spatial studies. There are no intended variances in the logic of the investigation across related geographical accessibility studies (Rafeedalie, 2018). Hence, the methodology includes the selection of samples, indicators, measurement standards, analysis, the setting of assumptions where required and the reaching a quantifiable solution to the research problem. A positivistic paradigm is realised through the fact that water accessibility exists within space and time, thereby presenting spatial distribution patterns, measurable indicators, and national standards (Rafeedalie 2018). Water accessibility also offers a spatial relation component by means of which to investigate any spatial distribution of basic services.

Human settlement studies point to water accessibility as one of the essential core needs of a community that sustains the livelihood environment. Maposa *et al*. (2012) acknowledge that geographers recognize the vital importance of water access, stating that no life or meaningful development can occur in a community without it. Maposa *et al.* (2012) further state that worldwide, each person consumes between two and four liters of water every day. However, most of the drinking water is embedded in the food that people eat, since producing 1 kilo of beef, for example, consumes about 15,000 liters of water. In comparison, a single kilo of wheat consumes 1,500 liters (Dempsey, 2012). However, the fundamental tools to understand water movement from primary to tertiary products can be presented in spatial patterns (Polat, 2009). Therefore, the spatial components that water accessibility encompasses make this research fundamentally geographical in nature.

The spatial reality and complex dynamics of the fluctuating population with varying spatial water needs require frequent systematic and logical measures to evaluate and improve essential water service provision (Mwamaso, 2015). So far, quantitative accessibility indicators at the local municipality level as indicated in their municipal integrated development plans have been frequently used to assess and plan water services delivery. Therefore, this research study anticipates utilising some of the readily available data in the Nkomazi Local Municipality's integrated development plans. Meanwhile the GIS's abilities towards integrated services mean that spatial data improve the effectiveness and increase the potential for equity within the essential spatial planning of water services, as indicated by Samuel and Adagbasa (2014). This research study also contributes to the planning of water service delivery. Hence, it focuses on planning essential service provision relative to the actual demand and the actual service usage by improving the access to water services to the areas with demand for water services.

1.9 The concept of access

The term or word "access" is broadly defined as a means or opportunity to approach or enter a place (Oxford English Dictionary, 2015). The concept of "access" is used by a diversity of research study fields that include rural and urban planning, environmental sustainability, human settlement, marketing, and transportation. The word "access" is defined by planners/geographers when referring to the simplicity or difficulty of reaching services within a particular context (Mokgalaka, 2015). Morojele *et al.* (2001) state that the concept of “access” has prospective implementation within urban and rural planning stretching from detecting or finding the best accessible route or location for a retail place. The concept of access is conceptualised as the proximity of one place (whether zone or point) to other specified locations (Maritz, 2008). Among civil engineers focused on road networks, the concept of ‘access’ is regularly cited in relation to adjacent road infrastructure. For people concerned with transportation and time, access refers to the level by which transportation systems assist people in reaching some activities or their destination by using transport types within a given space in time (Mwamaso, 2015).

According to Mokgalaka (2015), these related definitions have formed an area of complexity; hence, access-associated terminology tends to be used incoherently from one research study to another, therein complicating the mission of reaching resonant conclusions. However, Green *et al.* (2016) have demonstrated that accessibility analysis proves to be a valuable tool to locate any facilities in a way that integrates principles of access distance, service threshold, and centrality. For example, though not all residents have the exact travel needs or behaviour, the assessment of individual accessibility measures attempt to understand the question of accessibility on the part of the individual (Maritz, 2008).

The concept has been well thought out to take on an assortment of implications, including a place, but not limited to the amount of strength an individual may have to reach particular destinations or the quantity of some activities that are reachable or accessed from a particular location (Mokgalaka, 2015). According to Mokgalaka (2015), access is a common concept that sums up more precisely the extent of acceptability amongst the residents, and the facility service system. However, Cromley and McLafferty (2012) consider the idea of access to be a multi-dimensional notion that portrays individuals' capacity to utilise services, such as when and where they are required. Thus, the meaning of access relies upon the researcher's objective or study considering its unique context.

With regards to this research, access to a service is within a particular geographical area, Mokgalaka (2015) indicates accessibility as an aggregated measure of how accessible a particular geographical location may be. Accessibility in this context is taken as a performance measure whereby a basic service delivery system is assessed or evaluated.

Based on the above discussions on access, the residents' access to safe water has two sides, namely: the supply or delivery side; and the demand side. The supply side is mainly limited to the ruling government's role-part, organisations, and donor organisations providing water service delivery. In contrast, the demand side refers to clients or consumers of the service. Within the supply side, access to water is objectively well-defined, utilising service coverage or physical access. Emphasis is placed on measuring infrastructure supplies with less consideration of the supplied infrastructure's actual use (Mwamaso, 2015).

Water service consumers or community residents characterize access to water through physical access by considering what is agreeable or satisfactory to them, resulting from the actual use of the water service delivered. Kayaga *et al.* (2009), articulated that usage can be measured precisely within their research study. In South Africa, STATS SA’s General Household Survey (2002 to 2015) and the Community Survey (2016) data define access to water at about 25 litres per person per day. The anticipated maximum distance to a safe drinking water source is around 250 meters (DWS, 2017). Consumers satisfaction is regarded to be one of the best indicators of access. Hence, the water supply or delivery benefit can only accumulate when the water sources are being used. Consequently, the perception that can be mentioned or observed here is “actual use”.

1.10 Defining accessibility in a GIS

Accessibility in a GIS system refers to space and time, and the core questions a GIS can answer include: what, where, and when? Amer (2007) identified these core questions that GIS can respond to as the components of spatial analysis. Green *et al.* (2008) further indicates that GIS is used to answer the questions regarding who has access to what, where, and how.

Four questions characterise the constituents that make up the concept of accessibility, viz.: ' who', 'what', 'where', and 'how' (Amer, 2007). For example, ‘Who gets what (water), where, when, and how, forms the keywords to perform spatial analysis of accessibility. The important aspect in respect of facility locations is the people that the facility will serve, or the “who”, as well as a good understanding of “where” these people live, how they are spatially distributed, and what their profile is (Green *et al,.* 2016).

As indicated by Mokgalaka (2015), the entire descriptions of access or accessibility consist of several references to the following points:

- The questions of ‘who’ or ‘where’ are generally referring to accessibility as an attribute of people and places. Green *et al.* (2016) indicate that the “who” is meant to identify a specific group based on specific criteria, and by examining “where” the demand is located relative to facility supply locations.

- The question of ‘what’ it considers the opportunity that is reached or accessed. For example, land-use activities, supply point, or resource, including people who allow people and places to fulfil their basic needs.

- The question ‘how’ refers to accessibility, which includes the aspects that distinguish the people or places from the supply point, such as costs, distances, information, time, and related elements such as the acts of restrictions or obstructions to accessibility. For instance, in the study of Mwamaso (2015), the "how" in the travel distance determined how far the water facility is from the residents, and considered how the water was collected such as through water tankers or wheelbarrows.

Mokgalaka (2015) states that accessibility is mainly about the ease with which a particular person or group can reach opportunities or any definite set of prospects. Halden *et al.* (2005), define accessibility by referring to the fact that when looking at service delivery agencies, accessibility refers to the ease with which a particular place can be reached from any starting point or kind of origin.

Halden *et al.* (2005) define accessibility according to Mokgalaka (2015), as destination accessibility, catchment accessibility, or facility accessibility. Two fundamental perspectives are recognised from the individual's point of view, viz.: the user or consumer and a service provider providing the service. Other researchers make their viewpoint a universal understanding. Bergh *et al.* (2019) argue that access indeed relates or is being equated to the potential admission into a particular space or usage of a water service system.

According to Gulliford *et al.* (2002), access is understood to refer to the prospective or definite admission of a particular population group or individual within the water service system or scheme. The degree to which the population groups or individuals gain access is based on regular aspects, including availability, accommodation, accessibility, acceptability, and affordability (Mokgalaka, 2015). The accessibility dimensions have been recognised to speak to firmly related water accessibility by more than a few water-related researches conducted by Samuel and Adagbasa (2014); Mwamaso (2015); Bagheri *et al.* (2005); Mokgalaka (2015); Black *et al.*, (2004); Maponya *et al.* (2013); Ruiters and Matji (2015); Mothetha *et al.* (2013) and Maposa *et al.* (2012).

1.11 Brief overview of the chapters

The research outline is as follows: Chapter 1 presents an introduction chapter that provides an overview of the research including a description of the study setting, research question and its sub-questions, aim, objectives, the theoretical paradigm, and the definition of terms and concepts that guides the study. Chapter 2 outlines the literature review, provides a comprehensive understanding of existing studies in water accessibility to identify gaps and limitations that the current study can address, the chapter further critically evaluates existing relevant research literature related to the research question. Chapter 3 presents the research methodology, including details of the study's design, sample criteria, data collection and analysis methods. Chapter 4 of the study presents the results, and data analysis, with attention to maintaining methodological rigour, while also discussing the findings, including a discussion of how they relate to existing literature and theoretical models. Additionally, Chapter 4 addresses the implications of the findings for practice and policy. Chapter 5 presents a conclusion of this research, which includes the summery of all the chapters and suggestions for future research.

1.12 Conclusion

The study considers the Langeloop Village in terms of the community’s limited access to water, which has not been resolved over the past five years. The research in the study area therefore focuses on determining access to potable water within the different community sections or extensions in the Village. Hence, the aim of the study is to analyse potable water accessibility to the Langeloop community using a GIS-based approach. GIS is well-suited for analysing spatial distribution and accessibility to the basic services such as potable water. A GIS-based accessibility analysis is one method that has been applied to determine, test or examine the accessibility to basic water services or resources. Hence, effective water service planning has been a problem not only in Langeloop Village, but more generally in South Africa, towards basic services delivery. Looking at this research, and its relevance to the discipline of Geography more generally, the most suitable theoretical paradigm is positivism, which involves using the already existing scientific theory of spatial studies. The spatial reality and complex dynamics of the fluctuating population with varying spatial water needs require frequent systematic and logical measures or a positivism paradigm analysis to evaluate and improve essential water service provision (Mwamaso, 2015).

The word “access” is defined by planners/geographers when referring to the simplicity or difficulty of reaching services within a particular place (Mokgalaka, 2015). However, Cromley and McLafferty (2012), view the idea of access as a multi-dimensional notion that portrays individuals' capacity to utilise services in terms of when and where they are required. According to Mokgalaka (2015), access is the common concept that sums up more precise extents of acceptability amongst the residents and the facility service system. An alternative term, namely accessibility, refers to an aggregated measure of how accessible is a particular geographical location. Accessibility in a GIS system is always in space and time. Four questions characterise the significant constituents that make up the concept of accessibility, namely: ' who', 'what', 'where', and 'how' (Amer, 2007). For example, ‘Who gets what (water), where, when, and how, forms the keywords to perform spatial analysis of accessibility. Accessibility is also a concept used to understand the effectiveness of rendered basic services in a local area or in a global perspective.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Water accessibility is a critical issue that affects the well-being and development of communities worldwide. Hence, access to water plays a vital role in the lives of individuals residing in both urban and rural areas. According to Muhangane *et al*. (2017) the increasing population and urbanisation in developing countries are major factors contributing to the lack of access to safe water. It is estimated by the World Health Organization (WHO, 2016) that around 785 million people worldwide lack access to safe drinking water. These statistics emphasise that the lack of clean water access is not limited to specific regions or countries; it is a widespread issue affecting communities globally. This uneven distribution of freshwater resources, combined with climate change, poses a significant challenge, hence the issue of water accessibility in developing countries has also been documented on a global scale. Unfortunately, according to Omarova *et al.* (2019) and Bonetto *et al*. (2021), rural Africans have the lowest level of access compared to other developing areas in the world, such as South America and Asia. Moreover, it is important to recognise that access to clean water ought to be considered a human right rather than a privilege, because the lack of access to clean and safe water in rural areas poses significant risks for sustainability of communities. Goal 6 of the Sustainable Development Agenda addresses the sustainability and quality of water resources, which are essential to human and environmental life. In this study, the Sustainable Development Agenda is further explained in the first paragraph of sub-section 2.2. Understanding these factors can help create a comprehensive picture of the challenges faced by rural communities regarding their water supply, hence this issue extends beyond the specific rural area mentioned as Langeloop.

Furthermore, the local and global perspective of water accessibility is discussed, as well with the implementation of water sustainable management practices. This includes the status-quo of water accessibility, with an understanding that a human's existence can be endangered not merely by weapons, starvation, or disease, but also by a lack of water access. Hence, waterborne diseases such as Cholera remains major public health challenge in many parts of the world, particularly in developing countries. Therefore, strategic water planning and water management strategies that take into account both short-term and long-term needs are critically discussed. However, the significance of the Geographical Information System (GIS) for water accessibility is also discussed as a vital tool. Hence, the use of GIS to strategically plan for public facilities has been effective in developed and developing countries, through approaches to measure spatial accessibility. Meanwhile, Geertman *et al*. (2003) state that GIS tools are continually used in several ways to collect, store, process, manage, scrutinize, and present spatial or geographical data. Therefore, there are indicators to measure water accessibility that are further discussed here in order to assess and monitor water access around the world, where various indicators have been developed to measure different aspects of water accessibility.

2.2 The global perspective of water accessibility

Water is a fundamental human need worldwide, proving crucial for sustaining life and ensuring the well-being of individuals and communities. Ensuring that every individual has access to safe, reliable and sufficient quantities of water is a critical component of sustainable development, as recognised by the United Nations Sustainable Development Goal 6, which aims at achieving universal access to safe and affordable drinking water for all by 2030 (WHO, 2016). Sustainable Development Goal 6 is not just about ensuring access to clean water and sanitation; it serves to promote human rights, improving living conditions, and safeguarding the environment for present and future generations. The 2030 Agenda for Sustainable Development recognises the crucial role of clean water, effective sanitation, and adequate hygiene in influencing other sustainable development goals related to health, nutrition, education, and gender equality. Hence, the demands placed on societies by the SDGs require strong institutions and partnerships between public, private, and civil organisations. In this regard, addressing water provision for all, while considering interactions and trade-offs with other global challenges such as climate change, renewable energy, food, and health, calls for a holistic and integrated approach.

However, despite progress made in recent years, a significant portion of the world's population still lacks access to basic drinking water sources. Moreover, the issue of water accessibility is inherently complex and multifaceted, incorporating dimensions such as environmental sustainability, economic viability and social equity. These imply that efforts to address global water accessibility must be grounded in a comprehensive understanding of these complexities, and involve collaborations between governments, NGOs, private entities and local communities. Furthermore, data analysis plays a crucial role in identifying regions and populations that lack access to safe water sources. To this end, the United Nations has established a set of indicators for monitoring progress towards SDG 6 targets, which take into account physical and socio-economic factors affecting water accessibility (Kim *et al*., 2018). Despite these efforts, challenges such as climate change and population growth continue to strain water resources across the globe.

The implementation of sustainable management practices and continuous monitoring of progress towards water accessibility targets are crucial in ensuring that every individual has access to safe drinking water, regardless of socio-economic status or geographic location. Furthermore, it is important to recognise that water accessibility challenges are often closely intertwined with issues of poverty and inequality. For example, evidence suggests that people with disabilities face significant challenges in accessing safe water, sanitation and hygiene on an equal basis with others (Akale *et al*., 2018). Therefore, addressing water accessibility challenges must also involve efforts to address broader socio-economic issues such as income inequality, gender disparities, and social exclusion.

The embeddedness of water accessibility efforts in networks that provide access to globally transferable knowledge about sustainability challenges and practical solutions is crucial for their success. However, progress is impeded by a lack of adequate and reliable data. Therefore, there is a need for continual data collection and analysis to better understand the issues surrounding water accessibility and progress towards meeting global targets. In recent years, there has been an increased focus on the issue of global water accessibility. According to Lulesa *et al*. (2022), by 2015 the World Health Organization indicated that approximately 785 million people still lack basic drinking water services, while over 2 billion people do not have access to adequate sanitation. However, there has been some progress in improving water accessibility. In 2012, 89% of people had access to water suitable for drinking globally (Lulesa *et al*., 2022).

Both developing and under-developed countries face great challenges in terms of water accessibility. According to Spagnolia *et al*. (2020), related challenges vary in each country based on socio-economic factors and life expectancy, and it includes the trends in technology. For example, the COVID-19 pandemic exposed many challenges that are faced by under-developed countries within the socio-economic, health and technology factors. The COVID-19 pandemic has further highlighted the importance of water accessibility, particularly in developing countries, where access to basic sanitation remains a challenge. The pandemic has made it clear that access to clean water and proper sanitation facilities is crucial in reducing the spread of infectious diseases (Zelka *et al*., 2022). Various initiatives have been undertaken to improve water accessibility in response to COVID-19. For instance, UNICEF and the WHO have collaborated to provide clean water and soap to communities in need (Appiah-Effah *et al*., 2020).

The World Health Organization (WHO, 2016) has a point of view about accessibility as the basic element towards any efficient human services delivery. The global perspective on water access is viewed by the WHO (2016) as the fundamental need to improve people's quality of life. The point of view that the WHO has about water accessibility is evident through its progress reports of implementation of the UN MDGs. One of the major targets of the MDGs has been to reduce the number of the world's population that are without access to safe drinking water by the year 2015. Through implementing the target, the percentage of the people who had access to safe drinking water services has grown from 81% to 89% from 2000 to 2015 (Omarova, *et.al*. 2019).

According to the WHO (2016), by 2015, about 785 million people still had no access to safe drinking water, meaning 1 in 10 people lacked access to safe water, with a high possibility of obtaining drinking water from unimproved sources. An unimproved water source is identified as drinking water from an unprotected dug well or unprotected spring (WHO, 2016). The 785 million people without water access globally, as indicated by WHO (2016), reflected significant inequalities between and within countries. Sub-Saharan Africa is characterised by inequalities. It is evident through the report of the WHO (2016), as it indicates that almost half of the people drink water from unimproved water sources, and that is because 8 in 10 people live in rural areas characterised by the low quality of life, reflecting significant gaps between the richest and the poorest countries.

The WHO (2016), in Figure 2.1, indicates that most individuals in their respective countries worldwide at least a proportion of 10 or less than 10, are collecting water from unimproved drinking water sources. In Figure 2.1, it also reflects that in Sub-Saharan Africa a proportion of more than 20, is collecting water from unimproved drinking water sources. It also reflects the inequalities that are characterized by sub-Saharan African countries. The WHO (2016) report stated that in some areas, particularly Sub-Saharan Africa, most of the public spend far more than a minimum of 30 minutes, and others spend more than 60 minutes, on one trip to collect water from an unimproved water source. The amount of time spent collecting water depends on the source of water supply used by households and the time required to transport water from a source to a house (WHO, 2016).

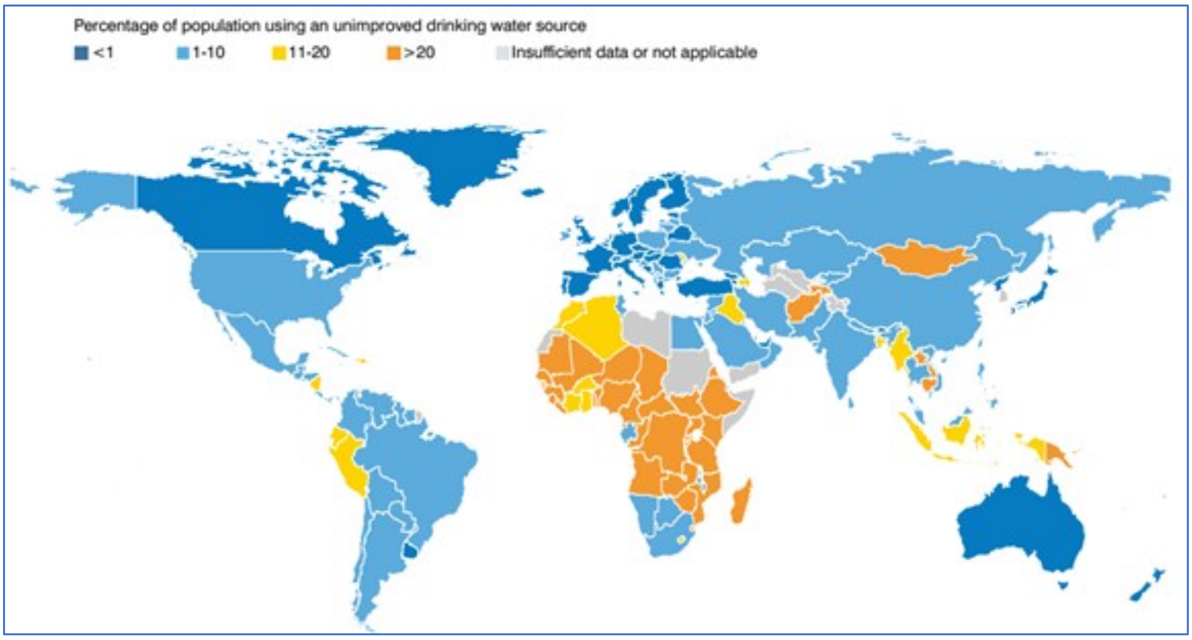

Figure 2.1: Proportion of population using an unimproved drinking water source in 2015 (WHO, 2016).

The implementation of the Millennium Development Goal is one of the strategies that caused the WHO to realise the extent of global inequalities as well as the extent of a lack of monitoring safety of water sources, where it became apparent that there was insufficient attention given to water safety on the part of some countries. By the end of 2015 when the WHO received the report of the implementation of the Millennium Development Goal it was determined that there is a greater need to improve safety to water sources and improved monitoring systems for water supply (Omarova *et al.,* 2019). Achieving the improvements would mean improved water accessibility. According to Slawson (2017), the accessibility of safe water has currently been given greater importance in the new Sustainable Development Goals, with the aim of achieving an improvement in water sources.

Accessibility of sustainable and safe drinking water proves a massive challenge for nearly all countries in the world. As stated in the sustainable development goals, the assurance to "leave no one behind" necessitates a concentration on rural areas, which are stereotypically neglected in receiving essential services. Hence, Omarova *et al.*

(2019) indicated that about 785 million of the people on Earth remain without adequate access to basic water supplies, where about 79% of this population live in rural areas. Meanwhile, 2.1 billion people have no safe drinking water, which means that approximately 14.9% of the urban population and 45.2% of the rural population require improved basic services (Omarova *et al.* 2019).

Omarova *et al.* (2019) further indicated that the higher percentage of 45.2% in rural areas without safely managed drinking water and in need of improved basic services also reflects the vast inequalities between urban and rural areas. According to the WHO (2016), these inequalities mean that rural populations typically live in terrible economic situations than urban populations, which also has an impact on the volume of water use; for example, approximately 90% of the urban population have access to safely managed drinking water, and they consume a larger amount of water than in the rural areas (Omarova *et al.* (2019). As a result, rural areas pose the greatest difficulty in ensuring that everyone has access to potable drinking water.

An example of this is a case study project in Rwanda referred to as Managing Rural Water Supply Systems. This project aims to strengthen the operation and maintenance of rural water supply systems, which began in April 2015 and ended in December 2019. When the project started, according to Dusabe and Igarashi (2020), the government of Rwanda targeted to reach 100% of water access by 2020 for the community of Kigali Settlement. Still, it was difficult to achieve at least 70%, due to limited to resources to efficiently enable the execution of their planned projects (Dusabe and Igarashi, 2020).

However, they gained 70% because they experienced difficulties mainly in knowing and finding the water assets in the rural areas, and conducted a comprehensive data collection of water sources similar to Scott *et al.* (2002). The data collected included boreholes, water tankers, reservoirs, water bulk, and reticulated standpipes. The Rwanda water access project engineers collected data using the SW Map, which is a GIS app for collecting, presenting, and sharing geographic information for mobile phones and tablets, and they also used Garmin GPS devices and undertook their analysis using a GIS open-source software called Quantum GIS (QGIS). The SW Map for data collection did not work correctly, especially in hilly areas, and the inaccessibility to other water sources in remote areas Dusabe and Igarashi (2020), meanwhile, water tankers were excluded from the GIS analysis because they were mobile and had a temporal spatial location (Dusabe and Igarashi, 2020).

One of the successful projects in ensuring that everyone has access to safe drinking water in rural areas is evident in a case study undertaken in Paraguay. According to Slawson (2017), Paraguay is a developing country, which had accomplished access to potable water for more than 94% of its rural population by 2015, compared to 51.6% in the year 2000. As a result, it has advanced further than any other nation. Paraguay addressed the problem of water access in rural areas by integrating its Sanitation and Water Agency into the Health Ministry, ensuring that access to water is treated as a public health priority, and the model worked in rural communities by delegating responsibility for water and sanitation to volunteer-run boards (Slawson, 2017).

The volunteering boards also recover maintenance and operating costs by ensuring that the water service costs a rural household $3-5 per month, which is often paid in cash to the members of the volunteering board (Slawson, 2017). The distinction between Paraguay and other countries was that Paraguay prioritised the monitoring and evaluation aspect of water safety as one of the major components towards sustainable development, and other countries emphasised mainly the construction of infrastructure. Consequently, the Paraguayan government has developed one of the virtuous methods for working with rural communities by creating volunteering boards, training these to operate, maintain, and run the system at the administrative level, primarily through its sanitation and water agency. Meanwhile, technical support is still being provided to them, which is not usually the case in other countries, and constitutes one of the reasons the entire system has been sustained up to date by Paraguay (Slawson, 2017).

2.3 The status-quo of water accessibility in South Africa

South Africa is a country with complex water resource challenges due to its arid and semi-arid climate, variable rainfall patterns, and increasing population growth rates. Water management in South Africa is a difficult task, due to severe water shortages in most regions of the country, where exploiting alternative sources would need to be done at significantly higher costs. This has resulted in a situation where the water supply no longer meets the demand in many catchment areas (Macharia *et al*., 2021). As a result of the country's water shortage, there has been an unsustainable allocation of potable drinking water for activities such as irrigation, or general cleaning.

This jeopardises the economic growth and development of South Africa in addition to endangering the quality of drinking water. Moreover, the water scarcity issue in South Africa is further complicated by climate change. As climate change continues to worsen, the supply of water in South Africa is expected to decrease further, thereby exacerbating the water crisis (Lumborg *et al*., 2021). Efforts towards addressing the water security challenge in South Africa include data gathering and evaluation, impoundment creation, and exploration of alternative sources. However, exploiting alternative sources of water in South Africa may not be sustainable, due to the high costs involved (Aikowe and Mazancová, 2021).

Water accessibility proves to be a critical issue that affects multiple aspects of economic and social development in the country. According to various sources, such as Naz *et al*., (2022), Roux *et al*., (2018), Gumbo *et al*., (2016), and Alhassan *et al*. (2015), water management in South Africa is confronted by multiple challenges that include severe shortages and interruptions of water supply, due to insufficient electricity supply (loadshedding) to the water treatment works plant and entire bulk water supply to community reservoirs. Additionally, a high variable climate change also have an impact. These challenges have resulted in increasing demand for water resources that are almost fully developed, and limited accessibility to alternative sources, such as groundwater, at significantly higher costs than before.

As a result, South Africa is predicted to face water supply deficits by the year 2025 (Assan, 2022). In addition to insufficient water supply, the quality of water in South Africa is also an essential factor that has a significant impact on economic growth and development. The chronic water shortage in South Africa is attributable to climate change, as well as industrial and population expansion. According to Roux *et al*. (2018), given the rate of increase in population, urbanisation, and industries, South Africa's water shortage may persist for a longer time. Therefore, it is essential to develop an approach that will address the usage of all available water resources effectively and economically.

Furthermore, ad hoc efforts towards water security have involved data gathering and evaluation, creation of impoundments, and water infrastructure development. Hence, the current status of water accessibility in South Africa highlights the need for urgent action in order to prevent a full-blown crisis. Such action should involve implementing strategies that will ensure efficient and sustainable use of water resources in South Africa. According to Aikowe and Mazancová (2021), this includes improved water resource management, investment in modern technologies to monitor and manage the distribution of available water resources, and a concerted effort by government and stakeholders to promote water conservation practices. Moreover, there have been various policies by the government to improve access to clean water, such as the Water Services Act and the Free Basic Water Policy. However, these policies have not entirely solved the problem (Lumborg *et al*., 2021).

In light of the ongoing challenges related to water accessibility in South Africa and its potential impact on economic growth and development, a responsible sustainable water conservation strategy is crucial to ensuring the long-term availability of clean water resources, and promoting sustainable economic development in the country.

The chronic water shortage in South Africa is a multifaceted problem that requires an urgent and concerted effort by the government and stakeholders to find sustainable solutions. As a water-scarce country, South Africa continues to face persistent challenges in ensuring reliable and equitable access to clean water (Lumborg *et al*., 2021). Despite ongoing efforts to improve water accessibility in the country, many rural settlements continue to face significant challenges in accessing safe and reliable water sources. Limited infrastructure, inadequate funding for water projects, and lengthy bureaucratic processes are among the hurdles that impede progress towards ensuring universal access to clean drinking water in these areas (Mwamaso, 2015).

It is therefore imperative for South Africa to take a proactive approach to addressing its water scarcity challenges, such as investing in alternative sources of water and improving infrastructure and technologies for water collection, treatment, and distribution. In addition, South Africa needs to focus its efforts on addressing the issues of poverty and inequality as they are closely tied to water insecurity. A majority of poor households in South Africa lack access to reliable water supply services (Loo *et al*., 2021). Therefore, implementing pro-poor policies that prioritise equitable distribution of clean water resources will go a long way towards eradicating poverty and promoting social development.

On the one hand, Giddey *et al*. (2015) argue that water scarcity in South Africa is not a pressing issue affecting rural settlements, but rather, an urban problem where lifestyle changes have led to increased demand. It is further argued by Ngxabi *et al*. (2021) that providing access to water in rural areas may stretch their limited resources even further, and be too costly, given their dispersed populations. Moreover, it is suggested by Giddey *et al*. (2015) that focusing on agricultural irrigation can lead to decreased food security concerns for urban dwellers who rely heavily on imported food. However, this perspective ignores the fact that rural settlements are disproportionately affected by water scarcity, as they lack basic infrastructure and services compared to urban areas. According to Mwamaso (2015), many communities still rely on untreated surface water sources.

While water scarcity is indeed a critical issue in South Africa, Gumbo *et al*. (2016) state that the country's current approach to strategic water planning is not effective. The government is criticised for failing to invest adequately in building and maintaining the necessary infrastructure, resulting in leakages and wastage of large amounts of water. Moreover, corruption has sometimes led to suboptimal allocation of resources and delayed the implementation of important projects that could increase access to water supply. While it is true that factors such as population growth and climate variability have put pressure on South Africa's water supply, Gumbo *et al*. (2016) question whether enough emphasis has been placed on demand management strategies that can reduce the lack of water accessibility.

According to Wrisdale *et al*. (2017), there has not been enough emphasis on this matter, because most of the challenges remain extant. Hence, Gumbo *et al*. (2016) state that water scarcity is not solely due to these factors alone, but note that it arises due to inefficient and ineffective government policies and management. For instance, the lack of investment in the maintenance of the infrastructure for the distribution and storage of water has led to significant losses in the system. In addition, Mwamaso (2015) also mentions that corruption and mismanagement have resulted in inadequate maintenance of existing infrastructure, or even a complete failure to construct new ones. Moreover, while the question of water accessibility is not unique to rural areas alone, it remains a major challenge faced by people living in rural settlements. The majority rely on traditional sources such as rivers or boreholes, which are often contaminated or overexploited due to poor sanitation practices (Gumbo *et al*., 2016).

Giddey *et al*. (2015) and Gumbo *et al*. (2016) argue that water scarcity ought to be addressed by finding alternative sources of water, and that a more effective approach would be to focus on the sustainable management of existing water resources.

Advocates for finding alternative sources of water believe that this approach is necessary due to severe shortages in many catchments throughout South Africa. However, Ngxabi *et al*., (2021) indicate that exploiting these sources will come at significant cost, and may not provide a long-term solution. Moreover, developing new sources can also lead to ecological damage and social justice concerns (Gumbo *et al*., 2016). On the other hand, those who advocate for sustainable management measures argue that they are essential to addressing increasing water shortages primarily caused by population growth and lifestyle changes.

A human's existence can be endangered not merely by weapons, starvation, or disease, but also by the lack of water. The South African' constitutional human rights acknowledge access to water as a fundamental human right. As Maina and Haji (2017) state, water makes life possible; hence, without water, life and civilisation cannot be possible, because for human livelihood and economic development, there is a need for water. Therefore, water as a fundamental human right implies that it should be accessible, that is, reachable, translating into accessibility to safe drinking water. Water accessibility is one of the legislated obligations of local municipalities in South Africa, who must formulate integrated development plans (IDP) to endorse amalgamated and well-informed development along with effective service delivery. Hence, it is well recognised that having access to clean and safe water within a household constitutes one of the primary stages towards reducing or eradicating poverty and further improving quality of life or living standards, specifically in underprivileged communities (Maposa *et al.*, 2012).

Poor communities usually suffer from a single common problem, namely the inadequate supply of water, or no water supply at all, within a settlement. However, the Department of Water and Sanitation entrusts the Water Services Authorities and Water Services Providers with the duty of ensuring that every person in the country including the poor or underprivileged households should have access to at least a basic level of service. The basic level is defined as 25 litres for each person per day, at no cost (Mothetha *et al.*, 2013). Over the past few years, water provision programmes and projects have been implemented to address the inaccessibility of potable drinking water for many communities across South Africa. However, Statistics South Africa still shows that several people have no access to potable water (STATSSA, 2011).

For example, based on Statistics of South Africa (2011) census data, at Langeloop Settlement, there are 2 657 households with an average household size of 4,2 persons per household, with 23% of households demonstrating access to piped water inside dwelling/institution, and where the water source is a 61,6% from regional or local water scheme. Even though a new census was carried out in 2022, the information was not locally accessible at the time the thesis was finished. However, the STATSSA 2011 data indicates a backlog or a gap within the accessibility to potable water within the Langeloop settlement. Maposa *et al.* (2012), once advised that five million South Africans are still without adequate safe water for domestic use. Hence, the inaccessibility to safe water has not significantly reduced over the past few years despite continued financial investment into some mushrooming settlements, accompanied by water sector and water supply technology development.

Maponya *et al.* (2013), emphasise that, even though there is substantial improvement in water services delivery, 4.5 million South African citizens still experience little or no access to a drinking water supply. Many of these citizens live within rural communities. Hence, the framework intended for water infrastructure funding models was designed to meet some of these challenges presented by the current and increasing imbalances that exist between the supply and demand of water in South Africa (Ruiters and Matji, 2015)

Green *et al.* (2009) argues that equitable access to basic services including water in South Africa is still not a reality, owing to the legacy of apartheid-era policies. These policies favoured the suburban areas primarily occupied by Europeans or 'Whites' over those inhabited by Africans (‘Blacks’) or other race groups, so far as public investment was concerned. These policies left a considerable amount of the country’s citizens deprived of proper access to essential services, including access to water. Maponya *et al.* (2013,) indicates in this regard that some local municipalities struggle to provide adequate services and safe water to communities, due to a lack of skills and resources.

In order to address the provision of adequate basic services by local municipalities, the municipalities ought to obtain data in line with their spatial development frameworks (SDFs) or the IDPs. Abbott *et al.* (2008:4) note that, while attention has been given to policy and the regulatory framework, the implementation is fragmented. There is a lack of current, consistent and standardised information, and in many cases, a lack of adequately trained capacity to support the implementation processes. Green, *et al.* (2019) emphasise that an integrated spatial plan can be extremely useful for effective and accessible service delivery. Hence, the necessity and the value of developing merged rural service towns that are well-provided with essential social services to perform as anchors, and emphasise rural and semi-rural development are crucial to support spatial development or transformation in the SDF (Green, *et al.*2019).

2.4 Lack of water accessibility in Langeloop Settlement

Langeloop is a rural settlement located in South Africa that has been facing a significant water access problem for years. This lack of water accessibility in Langeloop has had severe consequences on the lives and livelihoods of its residents. To begin with, water is critical for both agricultural activities and human consumption. As noted by Wrisdale *et al*. (2017), South Africa has to contend with water shortages, and Langeloop is no exception. In Mpumalanga, where Langeloop is located, water is considered scarce, exacerbating the situation (Nkomazi IDP, 2018). As highlighted by Wrisdale *et al*., (2017), access to safe and adequate water is integral to the wellbeing of rural communities. Wrisdale *et al*. (2017) further highlights the negative implications of not having access to reasonable water for up to weeks at a time. This accelerates adverse effects on health, hygiene, and the ability to carry out daily activities such as cooking and cleaning.

Rural communities often use different sources of water for agriculture, but the availability of these sources is significantly limited in Langeloop, due to its location in a water-scarce region. Additionally, the quality of available water resources in Langeloop is poor, as reported by the Nkomazi IDP (2018). The lack of clean and safe water also directly affects crop yield, ultimately affecting the food security and income generation opportunities for the community. Lack of water also limits opportunities for income diversification and hampers the growth of small businesses. Families in Langeloop use different sources of available water resources for agricultural production and food processing. However, these sources are often substandard, with poor quality, that harms not only human health but also livestock (Nkomazi IDP, 2018).

Langeloop's rural nature often means limited financial resources, both at the individual and community levels. This lack of financial capacity hampers the ability to invest in water infrastructure, maintenance, and necessary equipment, perpetuating the cycle of inadequate water accessibility. Women and girls are disproportionately affected by the lack of water accessibility in rural areas. They bear the burden of walking long distances to fetch water, often multiple times a day, taking time away from education, economic activities, and personal development. This perpetuates gender inequalities and restricts the empowerment of women within the community (UN Special Rapporteur, 2014).

2.5 Strategic water planning

Strategic water planning refers to the process of developing comprehensive water management strategies that take into account both short-term and long-term needs

(Hove, *et al*., 2022). Strategic water planning is a vital component of effective water resource management. According to Li *et al*. (2020), the process involves forecasting and assessing future water demand, identifying potential water supply sources, evaluating existing infrastructure and systems. The strategic water planning process assists to identify areas for improvement, designing new infrastructure and systems to meet future water demand. Furthermore, to assist in developing policies and strategies to optimize water allocation within a management context. Furthermore, the approach to strategic water planning should involve stakeholder engagement and participation from relevant government agencies, industry partners, and other organisations involved in water management (Hove *et al*., 2022).

Julius and Okech (2021) define strategic business planning, suggesting that strategic water planning should be comprehensive and involve various aspects such as capital investments, water treatment research, customer services, and governmental and community affairs. Moreover, it should answer questions about where the water utility wants to be positioned in terms of sustainability in both near and long-term scenarios (Muthathi and Rispel, 2020). In regions with limited water resources, such as South Africa, strategic water planning ought to focus on improving water use efficiency and ensure that withdrawal from rivers, lakes or aquifers is done in a way that maximises sustainability (Hove, *et al*., 2022). To achieve successful and sustainable water management, it is necessary to assess the variable aspects of sustainability in a comprehensive system. Evaluating these variables will aid in identifying strategies that promote sustainable integrated water resource management. Sustainability assessments must be evaluated based on a country's situation, which can then be used as a foundation in developing policies and strategies to optimise water allocation within the context of resource management.

For instance, as stated by Fedulova *et al*. (2020), a framework can serve as the initial step in strategic water planning by identifying stakeholders, providing baseline assessments, and setting long-term goals and priorities, resulting in follow-up actions that promote sustainable integrated water resource management. Hence, organisations ought to incorporate long-term water management into their strategic concerns and policies. Additionally, as traditional water supply solutions may have negative consequences on freshwater ecosystems and marginalised communities, who lack a voice in water planning, strategic water planning should prioritise governance and sustainability in water use, as well as utilising both "hard" infrastructure and multiple responses to mitigate water insecurity.

Despite the potential benefits of strategic water planning, some argue that it may not be necessary or feasible in certain contexts or it may not necessarily be suitable for all regions. Hence, the results of a sustainability assessment depend on the country's situation and can vary based on their unique challenges, environmental factors, political landscape, and socio-economic conditions. For example, Neto *et al*. (2017) indicate that, in regions with abundant water resources and low population density, traditional water management methods may suffice. Additionally, strategic water planning may be expensive and time-consuming to undertake in certain contexts where there are more pressing issues such as sanitation or drought response. Consequently, limited financial and technical capacities might constrain the ability to undertake comprehensive SWP processes (Julius and Okech, 2021).

The preparation of water demand forecasts, identification of potential supply sources and infrastructure assessment may require significant investments in resources such as expertise, technology and funding. Additionally, planning may not always lead to implementation due to political or financial constraints that may arise during the planning phase. Moreover, Fedulova *et al*. (2020) argue that strategic water planning tends to prioritise technological solutions, instead of focusing on governance approaches and social considerations. For example, large-scale engineering projects such as dam construction or inter-basin transfers may have a negative impact on local communities' livelihoods or ecosystems.

Furthermore, Muthathi and Rispel (2020) state that a strategic water planning usually involves a top-down approach, where decision-making power lies with a few individuals who may not accurately reflect community needs and interests. In many cases, these planning methods prioritise the interests of large industries or water utilities over marginalised communities, who rely heavily on these resources for their livelihoods (Muthathi and Rispel, (2020). Neto *et al*. (2017) stated that such planning strategies only perpetuate existing disparities in terms of access to clean water and contribute to social inequalities related to water availability. Moreover, there have been instances where strategic water planning has led to unintended consequences or negative outcomes, despite initial good intentions. For example, due to a construction of a dam, there could be an adverse ecological impact.

Li *et al*. (2020) argue that strategic planning may be too rigid and inflexible to adapt to an ever-changing water environment. They suggest that setting long-term goals and priorities can lead to a lack of flexibility in responding quickly to changes or emergencies in the short term. This view characterises strategic water planning as being ineffective in areas with rapidly changing climates or water resource availability. Furthermore, others suggest that there is a tension between long-term planning goals and short-term political priorities. For example, policymakers may prioritise immediate concerns such as economic development over sustainability considerations for future generations. There can also be resistance from stakeholders based on conflicting interests like industry sectors' profitability versus preserving freshwater ecosystems or securing drinking water quality (Li *et al*., 2020).

Julius and Okech (2021) further argue that strategic water planning is unnecessary, as markets can naturally allocate water resources through price mechanisms. In a market-based approach to water allocation, the pricing mechanism works by allocating scarce resources to those who are willing to pay for them at the prevailing market price. Julius and Okech (2021) therefore state that in other regions strategic water planning also imposes significant regulatory requirements on businesses and stakeholders, leading to higher costs in the long run due to extensive regulatory compliance procedures. Hence, local governments and water utilities often do not have the resources needed to implement comprehensive planning processes (Neto *et al*., 2017). Moreover, in some areas where water is abundant, there may be little motivation for authorities and businesses to undertake a long-term investment in infrastructure or policy changes. Muthathi and Rispel (2020) point out that the potential benefits of implementing strategic water planning can sometimes be overstated. The results of sustainability assessments are heavily dependent on specific conditions in each country, which means that it is difficult to guarantee success without thoroughly evaluating every unique situation (Hove *et al*., 2022).

It is important to note that those critics or opposing statements regarding a strategic water planning does not necessarily mean disregarding the importance of responsible water management. It may involve seeking alternative solutions or engaging in dialogue to address concerns and find common ground. Ultimately, the acceptability and effectiveness of opposing strategic water planning depend on the specific context, local circumstances, and the validity of the arguments presented. Hence, concerns are highlighted about the potential for excessive government control and bureaucracy associated with strategic water planning. They argue that centralised planning may lead to inefficiencies, delays in decision-making, and lack of responsiveness to local needs and conditions. Furthermore, some critics express concerns about the potential negative environmental impacts of certain aspects of strategic water planning. They argue that large-scale infrastructure projects, such as dams or diversion schemes, may disrupt ecosystems, alter natural water flows, and harm biodiversity.

However, the goal of a strategic water planning is to ensure the availability of clean and reliable water supply for various uses, such as drinking water, agriculture, industry, and the environment, while evaluating current and future water demands based on population growth, economic development, and changing consumption patterns. Identifying potential risks and vulnerabilities to water resources, such as water scarcity, pollution, infrastructure failures, and extreme weather events or climate change. Involving relevant stakeholders, including government agencies, water utilities, communities, industries, and environmental organisations in the planning process to ensure diverse perspectives and collaboration. This results in implementing strategies to promote water conservation and efficiency, including public awareness campaigns, leak detection, water-saving technologies, and efficient irrigation practices, thereby further developing systems for monitoring water resources, tracking progress towards goals, and evaluating the effectiveness of implemented measures.

2.6 South Africa’s Strategic Water Planning

South Africa has diverse levels of water planning services. Water planning in South Africa starts from the national to the local level, whereby residents access water from different sources. For instance, in Figure 2.2., the DEA (2013) presents a water resource planning framework of South Africa, whereby the vertically wording from the left in Figure 2.2. indicates that planning is consistent with legal requirements. It also specifies the delegation of responsibilities from the national level cascading down to the local and sub-catchment levels. The horizontal wording at the bottom in Figure 2.2. indicates that there is cooperation amongst the three broad water sector areas. Water resource planning is mainly policy-driven, meant to guide, manage, and improve primary water service access. In section 2.2. there are certain discussed frameworks or strategies that are meant for water management, and includes recommended solutions towards water management.

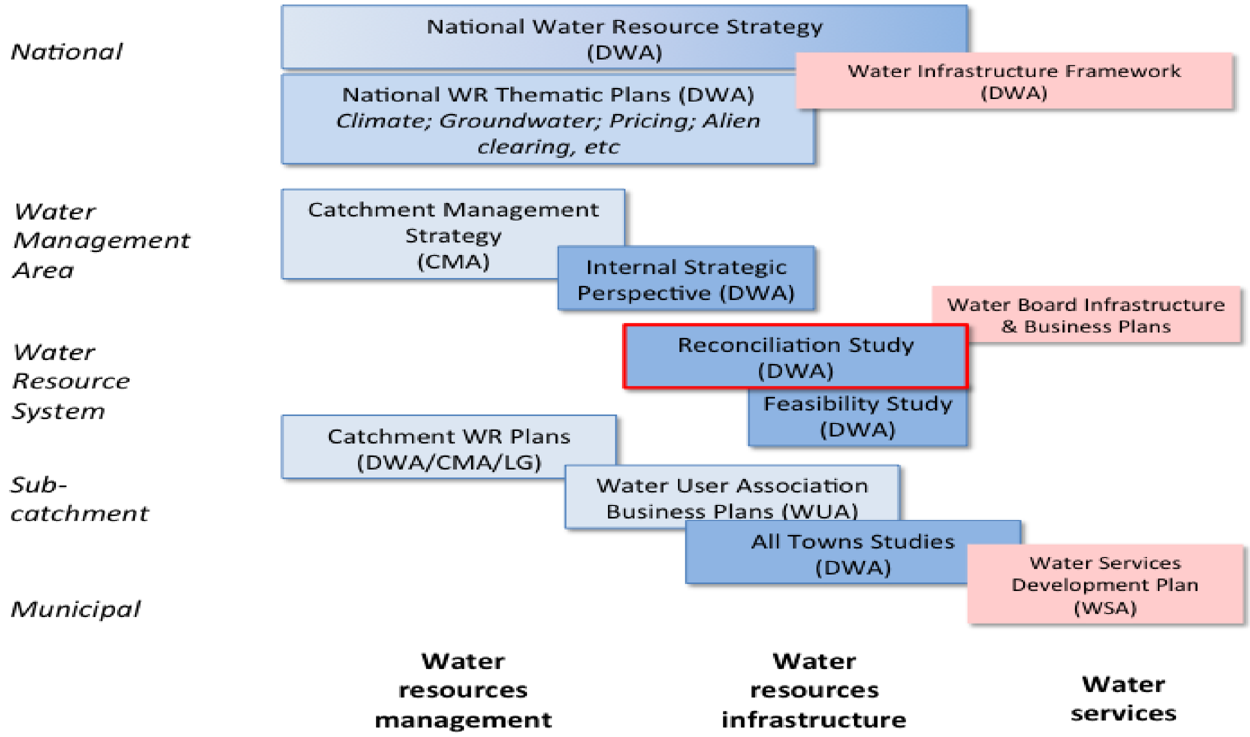

Figure 2.2: South Africa’s water sources planning framework (DEA, 2013).

2.7.1 National water strategic planning

National strategic planning provides the strategic framework for local or municipal water planning. Strategic planning encompasses water resource management, and includes the National Water Resource Strategy. The National Water Resource Strategy characterises the vital strategic direction for water management in South Africa. It emanates from the crucial need to manage water sources and promote equitable access to water as urged by the South African National Water Act (Act 36 of 1998). There are many national thematic plans within the National Water Resource Strategy, including the National Climate Change Strategy for Water sources and the Groundwater Management Strategy (DFFE, 2013). There are seven points below, that explain further the framework and strategies that are meant for water management. Meanwhile, the national water services planning is progressively centred around financing, monitoring, and furnishing a framework with standards and norms for the local administration sphere to enable water service as far as its constitutional obligation.

a. Water for Growth and Development Framework

The Water for Growth and Development Framework, in version 7, was initially released during the year 2009. It is still relevant and generally known as one of the long-term tools for the water sector to address or deal with environmental and climate change occurring in South Africa, as a component towards inaccessibility and availability of safe drinking water within communities. The framework identifies and describes the current water sources as ineffective and inadequate to satisfy the growth in water demands. It further proposes several high-level recommendations to address the identified water sources problems. The DFFE (2013) recommended increasing the water supply by differentiating the water mixture using desalination at the seaside areas and recycling within the inland areas. It encourages recycling water within communities with resources to carry out a recycling plan, even though there are struggling communities without resources to recycle water at a larger scale. The DFFE (2013) further states that this is a recommended strategy to increase South Africa's water security.

b. National Water Resource Strategy

The second or updated National Water Resource Strategy (NWRS) was first conducted during July 2012, and is continuously updated based on public input. As required by the South African National Water Act (Act 36 of 1998), the strategy document describes the strategic implementation or direction for water management in South Africa over the next 30 years (DFFE, 2013). Still, it also concentrates on water priorities over a five-year interim period, while monitoring its implementation impact over a full two decades (DFFE, 2013).

The National Water Resource Strategy 2 is described as one of the strategic documents that outline the short-term response to water resource changes and the

Water for Growth and Development Framework 2030 that is perceived as the medium to long-term responses. The priority of this strategy is to achieve water access equity, infrastructure planning, water allocation reform, conservation of water, and water demand management. The plan also identifies the impact of climate change on water sources, where the DFFE (2013) further states that the effects of climate change increase the pressure on the already strained water sources requiring effective management, use, allocation, and reallocation of available water sources.

c. Climate Change Strategy for water sources

The Department of Water and Sanitation has recently been working on a climate change strategy for South Africa's water sources between 2016 and 2019. This includes the drafted National Climate Change Adaptation Strategy that was published in May 2019. The first such undertaking was a strategy that examined the status quo of water sources in South Africa and the additional dimension or impact that climate change adds to various aspects of managing water sources (DFFE, 2013). For example, water scarcity levels in South Africa are due to climate change, which leads to short-term unfavourable weather conditions, such as a lack of rainfall or drought, and flash floods. The strategy also focuses on the impact that weather conditions have on water sources infrastructure.

According to DFFE (2013), the first point of observing the water impacts of climate change and the strategical response is that we are already facing a highly stressed and damaged water system in South Africa. Therefore, higher water demand and elevated contamination levels from various water sources have further burdened the high-risk water/hydrological system. Climate change adds a layer of expanded pressure onto an already stressed system. One of the clear messages from the strategy is that there are significant moves that need to be undertaken as quickly as possible to manage the available water better, irrespective of the long-term effects of climate change.

d. Groundwater management strategy

The National Groundwater Strategy, completed in 2010, recognises the importance of groundwater as an underutilised water resource (DWAF, 2010c). However, groundwater might be over-utilised depending on the specification of where it is used and for what purpose, since there are areas where groundwater is used for domestic livelihood and agriculture that remain unknown by the Department of Water and Sanitation. Consequently, the strategy aims to quantify groundwater as a resource from the areas where groundwater data is available, and to provide direction for groundwater management (DFFE, 2013).

STATS SA (2016) states that about 10% of South Africa’s water sources are groundwater sources. This value is derived from the number of utilised boreholes in domestic use and agriculture. The agriculture sector uses more groundwater for irrigation than it does for domestic uses (Bonetto *et al*., 2021). However, the strategy does not simply perceive the need to guarantee that groundwater ought to be secured. It should however shape some of the climate change adaption and environmental change adjustment so as to ensure water supplies' coherence.

This strategy recognises the necessity for additional research into the special effects of water resource management on technical matters, for instance, groundwater recharge. This was informed by the findings within the strategy that there is some limited understanding regarding the origin, recharge, and groundwater availability, especially in rural and semi-rural areas (DFFE, 2013). Limited understanding was caused by the lack of both skills and infrastructure for monitoring groundwater on the part of local municipalities. One of the strategy's primary focuses is to assist the local municipalities in recognising groundwater as an alternative water source for communities and managing groundwater sustainability.

e. Incorporating uncertainty of bulk water supply

The occurrence of drought or the irregular long-term dry seasons and resultant expanded periods of low stream flows are characteristic of South African catchments' natural climatic and hydrological variability. According to DFFE (2013), after approximately 30 years in South Africa, the uncertainties of climate change have caused significant variations in water availability, and have hampered the supply of bulk water services to communities. This has resulted in the delay of bulk water supply planning by local municipalities. This is because it the uncertainty poses a challenge to the reliability of decision-making processes.

With uncertainty to supply bulk and reticulated water services, some local municipalities have adopted water supply modelling systems to assist in decision-making regarding the sustainable provision of water. The water modelling systems address insufficient water supply and the probability of an effective water system for futuristic water demand. DFFE (2013) further elaborates that the critical avenue for incorporation of this uncertainty has been the operation of a set of modelling systems that enable a probabilistic analysis of a specific resource system or water scheme's chronological behaviour when subjected to a particular scenario of water demands. Therefore, several local municipalities and water service providers have adopted the techniques they could rely on to supply and monitor water regularly due to the uncertain water supply. According to the DFFE (2013), the modelling system requires long-term naturalised streamflow data from various catchments upstream of a dam to determine the quantity of water available to satisfy a specific demand. These systems are designed to reduce uncertain water supply, understand water demand, and manage water sources.

f. The Concept of Yield

The concept of yield speaks to the certainty in the sustainability of available water within different sources. The yearly water volume that a bulk water supply system can reliably supply is commonly denoted by the notion of system yield or scheme yield

(DFFE, 2013). The water modelling systems further assists in yield, where weather conditions vary between similar seasons in years. For this reason, modelling the water yield assists in understanding the futuristic water availability and demand. According to the DFFE (2013), system yield refers to the determined annual volume of water that can be constantly supplied over the long term, as the annual recurrence interval of failure in approximate terms. The concept of ‘annual recurrence interval of failure’ is, from time to time, interchangeable with the concept ‘annual assurance probability’, which refers to an annual volume of water supplied from a specific system or scheme.

The quantity of water that is expected annually is known through the concept of yield. This includes identifying almost all the water sources that are available within a village or settlement, even though some settlements use rain water, underground water, and mountain water. Mountain water is water that emerges from mountain springs, and it is often used by settlements that do not have any water infrastructure (Ruiters and Matji, 2015). The concept of yield for mountain water is usually known to be equivalent to a borehole water volume (Mukheibir and Sparks (2003). Local authorities are in better position to plan for future water demand. Knowing the annual water volume of their entire water sources further helps them to budget and implement water service delivery efficiently within communities.

Yield analysis is achieved by modelling a water resource system or scheme (DFFE, 2013). During drought or irregular stream-flows, some water sources are modified to preserve water or mitigate famine. Therefore, it follows that any amendment to the deficient water-flow patterns during erratic rainfall or drought in water surface resource systems turn to manifest changes to the water yield volumes and guarantee of delivery or supply.

g. Development approach (water sources planning)

Water resource planning requires considering the components or key drivers of water demand, noting how various future developments will impact water resource availability and use (DFFE, 2013). In local municipalities and communities, infrastructure development constitutes one of the key drivers that enhance the quality of life for the people, and those infrastructure developments come with water demand. Therefore, the availability of water facilitates infrastructure development, but the unavailability of water hinders it. One of the greatest collective approaches towards integrating diverse future development in water sources planning is to initially comprehend the developing trends in the current water usage and quantify the existing water sources, and therefore, to account for the future demand underneath diverse scenarios.

The most crucial drivers for water usage are identifiable when there is a data link between demographics or the population growth rates in an area and the water usage in a particular sector such as an industry, and other further domestic water uses, agro-processing, and related farming irrigation systems. DFFE (2013) states that in South Africa, the rapid growth in urbanisation, combined with economic development, intensifies water demand.

2.7.2 Water resource management

The following water management examples have been identified by Schulze and Perks (2000), and Mukheibir and Sparks (2003) as the recommended solutions to water management.

a. Resource management – planned and coordinated use of river basins

Water resource management requires a comprehensive approach to planning through a river basin to allow collaborative solutions to water quality and water supply problems. Schulze and Perks (2000) further state that this comprehensive approach planning is effective, and addresses the effects of water demand on population and economic growth. Extensive coordinated river basin resource management helps the national department of water and sanitation to guide and monitor water sources effectively. For example, according to DWAF (2002a), manufacturing industries are already obligated to develop and submit a clear understandable water management design or strategy on how the industry would collect water from the river or any primary water sources in a sustainable manner.

The national department of water and sanitation puts forward regulations to condemn water resource exploitation and irresponsible usage. The regulations include the streamflow regulation through storage dams and controlling abstraction and the release to deliver sufficient quantities of water precisely at a given time and location to meet consumers' water necessities. For example, according to Mukheibir and Sparks (2003), groundwater is likely to be most severely affected by exploitation, and with the groundwater table dropping due to reduced recharge. Therefore, according to DFFE (2013), stringent ground-water management systems ought to be in place with early warning mechanisms to report reserves nearing exhaustion of groundwater.

b. Conservation of water and management of water demand

The conservation of water is a sustainable strategy for the use of water. It also encourages water recycling and reduces water pollution. In most countries, including South Africa, there is a challenge to conserve water while there is a developing demand for more economic activities that require large quantities of water usage. Schulze and Perks (2000) emphasise that water conservation is a challenge by stating that the main challenge for sustainable development in South Africa will be a reconciliation of water demand and supply both for the medium and long-term.

Therefore, sustainable conservation assists in balancing water demand and supply. Although there is planning for future water supply resources, it appears as if the demand side of the equation has been ignored (Artmann *et al*. 2019). Meanwhile, reducing the demand can increase excess supply, creating a better margin of safety for future weather conditions such as droughts (Schulze and Perks, 2000). The conservation of water might be observed over various measures that inspire effective water use, such as voluntary compliance, education, legal restrictions on water usage, pricing policies, limiting of water, or the nuisance of water conservation standards on technology (Macharia *et al*., 2021).

It is crucial to conserve water by implementing any available action plan from government water management strategies. According to Macharia *et al*. (2021), conserving water proves to be one of the ways to reduce water demand levels. For example, water from the rooftop is traditionally saved within buckets, basins, and containers when it rains. These traditional forms of conservation reduce the water demand for basic needs such as irrigating subsistence farming, cooking food, washing, and bathing. Sometimes there are other means of conserving water, such as through dams that are designed to hold water from infiltration, where this water can be used for domestic needs and commercial uses, or even for the generation of electricity, depending on the size of the storage dam (Fedulova *et al*., 2020). Water demand is manageable in many ways, especially in communities that value the little water they receive (DFFE, 2013).

c. Reduction in water services expenses

The treatment of water from an unimproved water source is notably expensive, while treatment of water from an improved water source can prove less so. According to DWS, (2017), the treatment of water at low cost is an efficient approach towards water resource management, because it is one of the solutions to conserve water and supply water sustainable for domestic uses. Goldblatt *et al.* (2002) state that water sustainability in South Africa for the household sector accounts for about 15% of total national service, and has the highest expected growth in demand. Yet the statistical level of water unaccounted for in urban distribution systems has been between 15% and 20%, which is regarded as high by national standards (Goldblatt *et al.* 2002). Therefore, the well-organised use of water decreases treatment and distribution expenses for domestic use.

Producing clean water for the community involves costs of treatment, infrastructure such as pipes, and electricity costs used by the water pumps, as well as other related water expenses. This means that there are also high costs spent to supply or meet the demands if there is a high-water demand. Meanwhile, if water is conserved, it also reduces the expenditure costs of producing clean water, and according to Mwamaso (2015), some people opt to use boreholes to minimise water expenses.

d. Reduction of water losses due to agriculture

Water losses are predominantly caused by various economic activities, including agricultural activities. However, agriculture in most countries, including South Africa, is the catalyst to economic growth. STATSSA (2016) have stated that irrigation accounts for almost 60% of the water used in South Africa. This means that irrigation has a significant impact on water sources. There are substantial losses in water supply and irrigation systems, along with considerable evaporation losses. In this instance, sustainable agricultural water use is advisable. This includes alternative irrigation methods and water loss research practices.

Agriculture is a main contributor to water losses, alongside with mining and other industries. According to DWS (2017), most of the mining activities, as they produce raw materials, are also considered to be the leading activities contributing to water losses, because most of the water that is used in mining is not recycled. The water from most mining activities contains hazardous chemicals in such a way that the water cannot be reused or returned to a river or dam.

e. Reuse and recycling of water

To promote sustainable use of water, it should be recycled as far as possible. This may be either by returning the used water to the river for re-use within the water scheme or system from which it was first taken, particularly for industrial and domestic users. Industrial uses sometimes might return the water in a polluted state. It is an industry best practice to recycle and ensure no toxic chemicals before returning the water to the entire water scheme (Lumborg *et al*., 2021). According to Mukheibir and Sparks (2003:11), coastal towns specifically may consider recycling as a potential source of additional water before discharging wastewater to the sea.

Reusing or recycling water reduces water supply costs and maximises sufficient water supply opportunities to meet people’s water demand. The process of reusing and recycling water conserves it and opens up an employment opportunity in a society with high unemployment rates (Higgs, 2004). By rendering a water recycling business, there is a possibility of 80% profit; hence, the 20% is an expenditure for machinery, supplies, and human resources (Ruiters and Matji, 2015). In other words, the benefit of water conservation in this manner is economically viable.

f. Control of water pollution or water quality

Water pollution is one factor that degrades people’s quality of life. People cannot survive in good health while using polluted water. According to Mukheibir and Sparks, (2003), polluted water that is unfit for drinking or other uses can have a similar effect as reduced water supply because a reduced water supply also hinders a person to access safe drinking water. Polluted water cannot be consumed, and therefore there is no point in demanding polluted water or supplying contaminated water that poses a threat to a person’s life. Reducing water pollution efficiently increases water reserves, which in turn increases the safety margin for maintaining water supplies during droughts (Mukheibir and Sparks, 2003).

Water that is polluted not only threatens human life, but it also endangers animals' lives. For example, polluted water quickly causes death to aquatic life forms, including the vegetation that lingers within water sources such as rivers or dams. This is why industries are encouraged to recycle water before they discharge it into the natural environment. Some pollutants can cause undetected diseases (Higgs, 2004). Reducing water pollution can be done in many ways, including water recycling and the government issuing penalties to those who deliberately pollute the water table. Therefore, water pollution control constitutes one of the primary water management approaches to accessing safe quality water.

g. Allocation of water supplies to market-based systems

Water supply to market-based systems refers to the supply and usage of water within the economy of an area. The supply and use of the water ought to be protected and water regulations enforced. The safeguard of water quality presents a significant challenge to water policy in South Africa. Most of the policy papers dealing with natural resources management in South Africa recognise the need for economic instruments and market mechanisms for efficient utilisation and the allocation of natural resources such as water and other environmental resources (Mukheibir and Sparks, 2003). In this instance, it is advisable for industries or companies contributing to the country’s economy to adhere to regulations on water use. For this reason, there should be a balance between company income from production and water used for that production (Mukheibir and Sparks, 2003). In some industries or companies, the moment excessive water is used, pollution is guaranteed, and the more the industries make money at the expense of water pollution.

2.7 Water-borne diseases impact on water accessibility

Waterborne diseases continue to be a major public health challenge in many parts of the world, particularly in developing countries. In such regions, poor access to safe drinking water proves to be a significant contributing factor to the spread of waterborne diseases, which are responsible for causing physical and economic hardships to communities (Collins and Duffy, 2018). For instance, the consumption of contaminated drinking water can be linked to severe life-threatening diseases, such as cholera. According to Afangideh and Udokpoh (2021), these diseases pose a significant burden to human health, particularly among vulnerable populations such as children under the age of five. While various chemical and physical treatment processes have been implemented so as to minimise the risk of waterborne diseases, developing countries still face challenges in ensuring adequate access to clean and safe drinking water. According to Shukrullah *et al*. (2020), as a result of the inadequate access to clean water in developing countries, various waterborne diseases such as typhoid and hepatitis A and E are on the rise, with over 1.8 million deaths occurring annually due to cholera alone.

Cholera is a serious bacterial infection caused by the bacterium vibrio cholerae (Hntsa and Kahsay, 2020). The impact of cholera has been significant worldwide due to its ability to spread through contaminated water and poor hygiene practices. Cholera can cause severe diarrhoea and vomiting, leading to dehydration and even death if left untreated (Thakur and Chauhan, 2021). According to the World Health Organization, as cited in George *et al*. (2016), there are an estimated 3-5 million cholera cases worldwide annually, leading to around 95,000 deaths. It is particularly common in rural areas in developing countries, where poor sanitation and inadequate access to clean water is limited or non-existent, contribute to its spread (Afangideh and Udokpoh., 2021). Hence, studies of Agensi *et al*. (2019) have reported a higher incidence of cholera in rural areas compared to urban areas, due to the lack of basic sanitation infrastructure and poor access to safe water.

Furthermore, for instance, Oguttu *et al*. (2017) also highlight that the high incidence of cholera in rural and suburban areas can be traced back to the absence of proper sanitation infrastructure. On the other hand, studies by Hntsa and Kahsay (2020) have reported a higher prevalence of cholera in urban areas due to overcrowding and unsanitary living conditions. However, a study conducted in Kano State by Ngwa *et al*. (2021), indicates that the incidence of cholera is not significantly higher in urban settings compared to rural areas. These authors cite the Rural-Urban Differential Survey, which found only a small difference (10.8 per 100000 inhabitants) between the infection rate of rural and urban populations, with a slightly higher cholera mortality rate observed in rural areas (Ngwa *et al*., 2021). This finding corroborates similar observations made by Gidado *et al*. (2018) in other parts of Africa, such as in Guinea-Bissau, Zimbabwe, Mozambique and Malawi, where high cholera risk was associated with rural rather than urban settings. In South Africa, cholera has been reported by the Department of Water and Sanitation as a major health concern, with outbreaks occurring frequently in semi-rural areas where access to clean water and sanitation facilities is also limited.

Addressing the issue of waterborne diseases requires a multi-faceted approach that focuses on improving access to safe and clean drinking water, as well as ensuring that the quality of water at the point of consumption meets acceptable standards. Efforts geared towards promoting safe water practices, such as handwashing, proper sanitation, and raising awareness of the importance of clean drinking water are also essential in mitigating the impact of waterborne diseases on water accessibility. For this reason, the economic cost of waterborne diseases cannot be overlooked. According to Odonkor and Addo (2018), these diseases impose a considerable economic burden on individuals, households, and communities in terms of lost productivity, medical services utilisation and treatment costs. Governments and other stakeholders need to prioritise investment in providing clean water infrastructure and improving access to safe water sources (Amer, 2011). Moreover, innovations in technology could play a significant role in helping to mitigate the impact of waterborne diseases on water accessibility (Rainbow *et al*., 2020). The prevalence of waterborne diseases in developing countries can therefore be significantly reduced by implementing control measures such as water purification, vaccination, and treatment of infected individuals. According to Rainbow *et al*. (2020), such strategies have proven to be effective in reducing the spread of these diseases and have been successful in controlling outbreaks.

On the other hand, Levy *et al*. (2008) argue that addressing waterborne diseases through access to safe drinking water and sanitation facilities proves insufficient. Hence, Kim and Kim, (2014) also indicate that, while such measures are necessary in reducing disease transmission, they fail to address deeper underlying issues such as poverty and social inequalities that contribute to poor health outcomes among vulnerable populations. Furthermore, Pande *et al*. (2018) also indicates that the use of control measures such as water purification and vaccination are sufficient to reduce the spread of waterborne diseases but note that comes at a high cost for rural communities and local authority or municipalities. However, these measures have proven effective in reducing cases of waterborne diseases, where their success relies on a consistent supply of clean and safe drinking water. In developing countries where access to clean water is still inadequate, relying solely on control measures may not be sustainable or cost-effective in combating the problem (Varalakshmi, *et al*., 2020).

Furthermore, Abegaz and Midekssa (2021), argue that waterborne diseases do not necessarily have a significant impact on water accessibility. They claim that, while contaminated drinking water is undoubtedly a health hazard, it does not directly affect the availability or accessibility of water resources. While it is true that the existence of waterborne diseases may not immediately limit access to an available source of water, it hinders its usability for human consumption. In addition, according to Afangideh and Udokpoh (2021), the fear and negative perception people develop towards consuming potentially infected sources will eventually lead to reduced accessibility, since individuals will seek alternatives. This could result in overuse or depletion of other available resources such as groundwater or surface waters, which would make finding clean and safe water difficult and inaccessible (Mukheibir and Sparks, 2003). This highlights the urgent need not only to improve access, but also to ensure high-quality standards at the point of water consumption, where many illnesses are associated with consuming or using poor quality water, particularly in developing countries, where susceptibility to outbreaks proves to be higher, due to poor sanitation and water infrastructure, poverty, and socio-economic challenges.

2.8 Citizens' water access strategies

In the context of water inaccessibility, scarcity and increasing demand for clean and safe water sources around the world, citizens have developed various strategies to ensure their access to this essential resource. These strategies can be broadly categorised into two main groups, namely: demand mitigation measures; and supply enhancement strategies (Mauck and Winter, 2021). Demand mitigation measures include practices such as water conservation and improved efficiencies. Supply enhancement strategies, on the other hand, seek to increase the availability of water resources through means such as seawater and brackish water desalination technologies. Therefore, citizens have employed various strategies to certify their access to clean and safe water. The common strategies include: conservation and efficient water use, whereby citizens can conserve water by adopting practices such as fixing leaks, using water-efficient appliances and fixtures or fittings, and practicing mindful water use (Banihabib *et al*., 2020). For example, simple actions like turning off the tap while brushing teeth or using a bucket instead of a hose for watering plants can make a significant difference.

Another common strategy is rainwater harvesting, whereby citizens can collect and store rainwater for various uses like watering plants, cleaning, and even drinking, especially after proper filtration. Rainwater harvesting systems can range from simple rain barrels to more complex setups that include storage tanks and filtration systems (Hari *et al*., 2022). Another productive strategy is community-based water management, whereby citizens can collaborate within their communities to develop and manage local water resources. This can involve establishing community water systems, constructing small-scale water treatment facilities, and collectively implementing water conservation measures (Mauck and Winter, 2021). The conservation measures further include a water recycling and reuse strategy; whereby citizens can explore ways to recycle and reuse water within their households or communities. This can involve treating and reusing greywater (wastewater generated from sources like sinks and showers) for irrigation or toilet flushing. Additionally, implementing systems like decentralised wastewater treatment plants, which can enable safe reuse of water on a larger scale (Van Wyk, 2010).

It is important to note that citizens' water access strategies may vary depending on the specific circumstances, geographic location, and available resources. Collaborating with local authorities, water management agencies, and environmental organisations can provide valuable guidance and support in implementing effective water access strategies. For example, D'Odorico *et al*. (2019) state that citizens have also adopted other strategies to address water scarcity and access issues, and these strategies include importing virtual water, reallocating water from agriculture to industry and basic services, creating a water market, promoting urban and agricultural water management practices, and determining optimal crop patterns and growing industries in the community or region. Additionally, Shunglu *et al.* (2022) state that enhancing law enforcement and coordinating integrated management for a water basin has also been identified by citizens as a conservative strategy to respond to natural or imposed pressures, to maintain the water system in both short and long-term contexts.

However, it is important to note that there are limitations and challenges associated with some of these strategies. For instance, supply enhancement strategies such as desalination can be both costly and energy-intensive, and may pose a challenge for communities with limited resources (Heidary *et al*., 2019). Similarly, creating water markets or reallocating water from agriculture to industry may have unintended consequences on the environmental and social well-being of local communities. Furthermore, Hou *et al*. (2019) state that citizens' strategies such as the reallocating water from agriculture to industry may result in the displacement of smallholder farmers who rely on agriculture for their livelihoods. This can lead to rural-urban migration and food insecurity, which exacerbates existing inequalities (Mdoda *et al*., 2022). Additionally, adopting a market-oriented approach may prioritise the needs of more economically powerful actors at the expense of marginalised communities (Bark, 2021). It is therefore important to consider these challenges when implementing water access strategies.

Furthermore, Geressu *et al.* (2020) state that it is imperative to acknowledge that these strategies may also face resistance from stakeholders with conflicting interests. For instance, farmers may resist reallocation of water from agriculture to another sector or changing crop patterns, as this could affect their livelihoods and income (Geressu *et al*., 2020). In light of these challenges, it is essential to adopt a coordinated and integrated approach towards addressing water scarcity and access issues. Hence, Mdoda *et al*. (2022), highlight that a focus exclusively on technological solutions such as desalination can create a false sense of security and divert attention away from addressing larger societal issues that contribute to water scarcity. For example, affluent citizens tend to consume more water per capita than low-income citizens in many countries, which highlights the need for policies aimed at promoting equitable access to clean water (Bark, 2021). Another challenge associated with citizen-led water access strategies is the need for effective implementation and enforcement of policies to ensure compliance. This requires a strong legal and institutional framework, as well as collaboration and partnership among different stakeholders such as governments, NGOs, and civil society organisations.

Despite these challenges, citizens have a crucial role to play in addressing water access and scarcity issues. These citizen-led water access strategies are vital in ensuring sustainable and equitable water management in the face of increasing demand and scarcity around the world. The concept of integrated water management has also emerged as a potential solution to address collective-action problems and promote sustainable water use practices. For example, by adopting diverse strategies, such as efficient use of existing resources, promoting sustainable practices, and coordinating integrated management approaches, whereby communities can ensure equitable distribution of water resources (Mauck and Winter, 2021). It is important for governments and other stakeholders to support citizen-led efforts by providing funding for research and development, generating awareness about the importance of water conservation practices, facilitating cooperation among multiple sectors to promote integrated management measures. Moreover, it is essential that the environmental aspects be considered while implementing these initiatives. For instance, implementation of desalination technologies must include measures that offset the associated carbon emissions or reduce ecological damage, hence, this strategy requires substantial investment in research and development.

2.9 Rural Water Access Measurement Practices

Rural water access measurement practices are crucial to the efforts to understand and address global water scarcity challenges. Accurate measurement practices are particularly important in rural areas, where access to clean water is often limited and inequality in resource distribution can exacerbate existing challenges (Squire and Ryan, 2017). Currently, there is a lack of standardisation in rural water access measurement practices globally (Nori, 2020). This makes it difficult to accurately estimate the water needs of rural populations and to implement effective policies and programs to address these needs. As noted in a study of Bergh *et al*. (2019) on water scarcity, policies and programmes aimed at addressing rural water access challenges must take a comprehensive approach that addresses multiple layers of inequality within local areas and allows for a more even distribution and efficient utilisation of remaining resources.

Additionally, competition for limited water resources and overexploitation of agriculture in rural areas also present significant challenges to achieving sustainable water access. Furthermore, Squire and Ryan (2017) state that the proliferation of rural-urban water transfers in the context of growing urban demand for water has become a key source of conflict, exacerbating existing inequalities in water access between rural and urban areas. Rural water access measurement practices must account for these complex challenges and inequalities to develop effective policies and programmes addressing global water scarcity. To address the lack of standardisation in rural water access measurement practices, there is a need for increased collaboration between researchers, policymakers, and practitioners to develop a consensus on best practices for measuring and monitoring water access in rural areas (Bergh *et al*. 2019). Inequalities in water, sanitation, and hygiene access persist between urban and rural regions and at sub-national levels (Muthathi and Rispel, 2020). Moreover, the studies of Nori. (2020) have demonstrated a national correlation between asset wealth and access to water, as well as how caste, gender, and class inequities which continue to shape water access in local and regional contexts. Therefore, standardisation of rural water access measurement practices ought to take into account not only the physical infrastructure and availability of clean water, but also social and cultural factors that contribute to inequalities in access.

According to Squire and Ryan (2017), this requires a multi-disciplinary approach that incorporates sociological, political, and economic factors into the measurement practices. Moreover, reliable and comprehensive data on rural water access is essential to assess progress towards achieving Sustainable Development Goal 6, which aims to ensure the availability and sustainable management of water and sanitation for all by 2030. Hence, it is crucial to establish rigorous and standardised methods for measuring rural water access that takes into account the complex challenges and inequalities that exist within local and regional contexts. The lack of standardised measurement practices for rural water access has resulted in underreporting of disparities between urban and rural areas, as well as intra-regional inequalities (Bergh *et al*. 2019). To address this issue, there is a need for increased attention towards subnational disparities in water access measurement practices.

This will enable the identification of specific areas, where greater investment and attention is required. Furthermore, standardised measurement practices will enable policymakers and practitioners alike to develop more targeted policies and programmes that consider the unique challenges posed by different regions. Hence, the global population continues to grow and climate change leads to increasingly severe weather patterns, ensuring access to clean water in rural areas has become a significant challenge (Jin *et al.*, 2018). To further address this challenge, researchers such as Mourad *et al*. (2013), Baiyegunhi, (2014), Yulistyorini *et al*. (2018), and Zhou *et al*. (2022), have been investigating the water conservation behaviour of rural residents, where the findings point to the lack of water conservancy infrastructure, with a huge gap in the water quality between urban and rural areas. Furthermore, scarce water supply has made it increasingly necessary to conduct an overall assessment of the actual status of water supply in rural areas, and to propose effective solutions to meet water supply targets set by national strategies for clean water supply and environmental sanitation.

Rainwater harvesting is among those holistic approaches being implemented to develop, augment, protect and conserve water resources (Yulistyorini *et al*., 2018). Additionally, the percentage of rural populations that have access to standard-level water remains low in certain areas, leaving no alternative but to purchase water from distant locations at high prices Kurniawan *et al*. (2022). As such, it is crucial to adopt appropriate measurement practices and water access indicators as part of strategic water planning in rural areas. These practices and indicators will help in monitoring the water supply systems, identifying areas that lack proper water infrastructure, and proposing effective solutions to increase access to clean water better than rain water harvesting. Hence, the implementation of rainwater harvesting techniques in rural areas has proved useful in solving the water supply problem, as evidenced by its success in countries such as South Africa, China, Thailand, Philippines and Jordan (Baiyegunhi, 2014).

On the other hand, while rainwater harvesting techniques may be useful in solving the water supply problem, according to Xu *et al*. (2018), it is not a manner of ‘silver bullet’, hence, it should be noted that rainwater harvesting techniques may not always be a sustainable solution depending on the climate, rainfall patterns, geographical conditions of the area and availability of suitable infrastructure. In arid regions, for example, there may not be enough rainfall to sustainably meet water demands solely through harvested rainwater. Additionally, while individual households may choose to treat their own water prior to consumption in rural areas, this practice is less common in rural areas, due to limited access to financial and water infrastructure implements a as well as knowledge of such practices (Iwuala *et al*., 2020). Rainwater harvesting systems require regular maintenance and monitoring to ensure that they operate efficiently and provide safe drinking water (Hari *et al*., 2022). For example, it is important to note that rainwater harvesting requires proper infrastructure, such as gutters and storage tanks, which may not be available or affordable for certain rural communities.

However, Mourad *et al*. (2013) state that it is important to note that decades of engineered water infrastructure solutions have improved water access in rural communities. However, poor planning and implementation strategies have resulted in nearly a quarter of these water schemes being non-functional. Additionally, while some engineered water infrastructure solutions that have indeed improved water access in certain rural communities, this approach may not be feasible or sustainable, given the cost constraints faced by many governments or local municipalities and organisations operating in low-and middle-income countries (Baiyegunhi, 2014). As such, it is crucial to adopt a holistic and sustainable approach towards rural water access measurement practices and water access indicators when planning for clean water supply and environmental sanitation in rural area (Kurniawan *et al*., 2022).

Hence, the complexity of achieving reliable rural water access is influenced by various interrelated technical, social, economic and environmental factors (Jin *et al.*, 2018). These factors work in dynamic concert to promote or inhibit sustainable service delivery outcomes (Macharia *et al*., 2021). For this reason, it is necessary to consider the unique characteristics of each rural area and tailor water access solutions according to their specific needs, because some technical water treatment solutions may fall outside of the financial reach of many rural communities (Naz *et al*., 2022). The provision of clean water must be viewed as an essential basic public service and should be addressed through an integrated strategic water planning involving all stakeholders, because, while measuring practices and water access indicators are crucial for monitoring the effectiveness of clean water supply systems in rural areas; their effectiveness may also depend on the level of knowledge and understanding among local communities.

2.10 Approaches to determine spatial accessibility

Spatial accessibility is a widely used methodology in geography and urban planning to evaluate the ease with which individuals may access services and amenities based on their location (Wang and Zhou, 2022). Spatial accessibility allows for the identification of areas with inadequate access to essential public facilities such as healthcare, education, or transportation and water. According to Gülhan *et al*. (2014), spatial accessibility is a powerful tool that can help policymakers and planners make informed decisions to improve access to public facilities, reduce spatial inequalities, and ensure social inclusion for all members of society. Hence, it can be used to evaluate the effectiveness of different spatial planning policies, such as Spatial Planning and Land Use Management (SPLUMA), zoning ordinances, or public transit systems.

When determining spatial accessibility, quantitative methods such as gravity models or network analysis can be used to calculate spatial accessibility metrics, such as travel time, distance covered, and costs involved in accessing public facilities (Kim and Lee, 2021). Determining spatial accessibility helps to identify underserved areas that require additional investments in public infrastructure. Hence, it can also be used to assess the impact of changes in infrastructure, such as the opening or closing of a public facility with regards to accessibility. Moreover, spatial accessibility can help to predict the behaviour of populations concerning accessibility and aid in the targeting of resources towards areas that need them the most (Wang and Zhou, 2022). According to Gülhan *et al*. (2014), determining spatial accessibility is a valuable tool for ensuring equitable access to essential public facilities and services.

It is also important to note that spatial accessibility has its limitations, such as the fact that it assumes equal utilisation of available services by all individuals, regardless of their socioeconomic status, and it does not account for non-spatial barriers such as cultural, linguistic or psychological factors that may hinder individuals in accessing services (Moyo *et al.,* 2021). Similarly, Gondlach *et al.* (2019) criticise that it does not take into account all relevant factors when evaluating spatial accessibility. One such criticism is that spatial accessibility focuses solely on travel time or distance as a measure of accessibility, disregarding other important dimensions, such as affordability or cultural appropriateness. For example, low-income individuals may face significant financial barriers in accessing public facilities, even if their physical proximity to these facilities is relatively close. Similarly, communities with historically marginalised identities may require services that are culturally appropriate and meet their specific needs beyond mere geographical proximity.

Another critique of determining spatial accessibility is related to its potential to perpetuate existing spatial inequalities. Moyo *et al.* (2021) state that, although spatial accessibility measurement identifies underserved areas based on distance or travel time to public facilities, it does not account for the quality or quantity of services available at a given location. In addition, spatial accessibility measurement may prioritise highly populated areas over rural or remote regions that also require adequate access to essential services (Gondlach *et al.*, 2019). Furthermore, Moyo *et al.* (2021) emphasise that which was highlighted earlier by Do *et al*. (2019), who note that this is because spatial accessibility measurement relies heavily on quantitative metrics that overlook individual experiences and preferences when accessing public facilities, and does not adequately account for qualitative factors influencing accessibility. Qualitative research methods, such as focus groups or stakeholder interviews, are better suited for examining the way in which people use public facilities and their perspectives on accessibility barriers. This includes factors such as personal safety concerns, cultural barriers and social stigma associated with basic services. Furthermore, even if quantitative data is available, its accuracy may be limited, due to a lack of granularity in demographic information, or inaccuracies in service location data (Gondlach *et al.*, 2019).

Furthermore, studies by Freitas and Costa (2021) have shown that lower-income groups and pedestrians often experience a relatively low degree of accessibility to public facilities. To overcome these gaps in spatial inequality and ensure equitable access to essential services for all members of society, scholars have consistently called for more accurate measures of spatial accessibility. One such approach uses a complex measure of spatial accessibility pioneered by Ngamini-Ngui and Vanasse (2012). Furthermore, Freitas and Costa (2021) indicate that spatial accessibility measurement requires data on population distributions and service locations to accurately calculate accessibility metrics. The authors, Ngamini-Ngui and Vanasse (2012), used a complex measure combining geographical accessibility and availability indices to calculate a comprehensive spatial-accessibility index for mental health services accessibility.

The research by Ngamini-Ngui and Vanasse (2012) has highlighted the importance of taking a more in-depth approach when measuring spatial accessibility. For instance, they have emphasised the need to consider location equity and accessibility, rather than solely evaluating geographical centres. They have also drawn attention to the relatively lower accessibility levels among vulnerable populations such as low-income classes and pedestrians. Given these concerns, there is an increasing need for approaches that account for socio-demographic factors that impact users' ability to access public facilities. One such example of a comprehensive approach used in assessing spatial accessibility was demonstrated by Ngamini-Ngui and Vanasse in their 2012 research.

GIS tools have been used for many years to measure accessibility to various essential basic services. Geertman *et al.* (2003) state that GIS tools were used in several ways to collect, store, process, manage, scrutinise, and present spatial or geographical data. These GIS tools have been flourishing since the early years of 1990. Therefore, this has been increasing with new developments in multiple studies as an effective technology tool to handle spatial data, including water management planning data. Hence, it is relevant to measuring accessibility to water services to plan for better-quality essential service delivery.

GIS technology provides the platform to test different scenarios for service delivery. The scenarios are based on varying standards or indicators. By comparing the outputs from the different scenarios, possible service provision standards could be determined through the appropriate planning process (Baloyi *et al*., 2017). GIS technology is one of the best spatial planning tools used to deliver support in decision-making for essential basic services desperately needed in communities because spatial patterns of inadequate basic services are easily recognised within a GIS. Those patterns also serve as a solution in providing a service to the exact or approximate affected area.

GIS-based accessibility analysis, as a tool of spatial accessibility, provides a practical approach to support locational planning for rural and urban settlements. Many studies that have supported the use of a GIS-based analysis approach over the past ten years have consistently been sensible and well-balanced within the spatio-temporal framework. Hence, Mokgalaka (2015) states that refined measures of accessibility are continuously being advanced by computing the data measures of spatio-temporal information. Spatio-temporal data analysis is done to support decision-making in addressing the problems of accessibility to basic services, such as water services. Mokgalaka (2015) indicates that measuring spatial accessibility to water is done by computing the data using different travel modes, trip purposes and time spent, demographics such as race, sex, age, and work-related groups, and specific activity types at each destination. Spatial accessibility analysis has proved to be a robust approach for locating and planning social facilities (Green, *et al.* 2016).

The old-fashioned approach towards measuring access has been to determine the number of facilities to a population number as a measure of service availability (Mokgalaka, 2015). However, there are certain obstacles related to the quality of the service facilities. For example, water sources might indicate water availability, but should that facility be damaged, where water availability is compromised. In some instances, people need to walk substantial distances to collect water in rural areas such as Langeloop. Mokgalaka (2015) states that this kind of measuring accessibility based on several service facilities, without knowing how the functional state of the facility inappropriately impacts the use of services in other communities, where for example, the failure to use the nearest facility in one community leads to overlapping and crowded service coverage as well as to redundant facility services.

Talen (2003) has defined various measures used towards measuring accessibility like the coverage area, the volume of quantity, gravity or slope, the distance between demand and supply, and the time spent. According to Higgs (2004), one of the ultimate basic coverage and volume measures is where comparison can be drawn between a facility service supplier with a potential service demand within a particular area. An illustration of this measure might focus on the ratio of water points/taps per hundred populaces in a specified area. According to Mokgalaka (2015), such an accessibility measure is suitable for quantifying accessibility or representing the possible accessibility of a prevailing or prospective water facility, assuming no cross-boundary movement of the people from neighbouring settlement sections or areas. Therefore, this could miscalculate the supply of water services to the people, or vice-versa. Meanwhile, the efficiency of a service is dependent on the anticipated demand of the service at varying areas of a settlement, based on minimum population numbers for the service to be feasible, equitably distributed, and optimally utilised (Green, *et al.* 2016).

The measures of spatial accessibility have improved over the years, and research studies dedicated to the measures of access to basic services include studies by Green *et al.* (2014); Talen (2003); Morojele *et al.* (2003); Green, *et al.* (2008); Tanser *et al.* (2006); Rosero-Bixby (2004); Green *et al.* (2016); Lou and Wang (2006); Higgs (2004); Lovett *et al.* (2002); Mwamaso (2015); and Mokgalaka (2015). These studies have also proved that GIS is a valuable tool used to measure spatio-temporal direct access to basic services effectively. According to Green *et al.* (2016), the GIS-based approach used by studies is meant to advance GIS technology and add knowledge of a spatial logic for the efficient and more equitable allocation of different social facilities, and further advance the principles that are applied in the GIS-based accessibility planning.

Physical accessibility to water service impacts many living conditions, such as health, education, and economic status. According to Maritz (2008), the importance of accessibility is not disputed. Hence, it is essential to the individual, the family, and the economy (to name a few). Tanser *et al.* (2006) state that, importantly, approximating physical water access remains unknown in other developing nations or countries, where GIS tools are frequently not used to inform decision-making in the planning of basic services. Morojele *et a.,* (2003) state that GIS tools and other related spatial pattern analysing tools have been utilised to distribute the movements from the demand source to the supply or delivery centre to address the deficiencies of basic services. Morojele *et al.* (2003) further make an example, that GIS has been used to demarcate supply centres in catchment regions and evaluate the activities that are associated with supply centres.

Green *et al.* (2016:439) state that using measures of spatial accessibility addresses spatial quantification and fairness, and enables other basic services related analysis across space to reflect patterns of efficiency. Preceding research studies of Higgs (2004) and Mokgalaka (2015), emphasise the critical part of efficient basic services by indicating that spatial features always have to reflect patterns based on service demand and service delivery. According to Green *et al.* (2008), there are three comprehensive arrangements of spatial elements on accessibility. Higgs (2004) and Mokgalaka (2015), identified these as: (i) the spatial pattern and features of the water basic delivery system alongside a comprehensive variety of quality measures related to specific services; (ii) the function of the pattern movement system and the relative importance of private and public pattern movement in various socio-cultural contexts; and (iii) the behaviours or attributes of citizens who frequently use water services or more other services. This indicates that, using relevant census or demographic data, the three comprehensive arrangements explain how the spatial features and services of the places in which they are located connect to one another. According to Green *et al*. (2016), there is a correlation between the difficulty and expense of providing basic community services in areas with lower population densities.

Bagheri *et al.* (2005) used GIS pattern network analysis to produce the main route based on standards for the least or shortest time spent starting from the suburban neighbourhood to the service facility within the Otago region of New Zealand. Mokgalaka (2015) argues that an alternative to a general geometric centroid of the settlement sections or the mesh blocks, using the mean centre of population distribution within each mesh-block polygon, is one of the best practices to measure accessibility. Mokgalaka's (2015) research indicates that attention should be given to non-geographic aspects, such as ethnicity, poverty indexes, age, gender, housing, income, education, and transportation when assessing the accessibility of basic service facilities such as primary healthcare. Setting any accessibility attributes such as service availability or service affordability might vary, but the approach might be similar in assessing water accessibility. According to Maritz and Maponya (2010), experience has indicated that certain spatial modelling systems often fail due to incomplete design, or simply not taking local realities sufficiently into account.

2.11 The significance of GIS for water accessibility analysis

GIS accessibility analysis empowers more effective service delivery, service management, and further monitoring of the publicly provided essential services and facilities. GIS-based research has remained valuable in demonstrating the accessibility of existing and potential community services in different local municipalities (Green *et al.*, 2016). Mokgalaka (2015) states that spatial analysis has delivered a good foundation for planning essential community services worldwide. GIS provides a versatile and advantageous way of testing the implications of demand scenarios and standards relating to service delivery factors, thereby contributing to better-informed decision-making (Baloyi *et al.*, 2017).

Since GIS is a general purposeful technology meant for handling spatial or geographical data in a digital system, its capabilities include pre-processing data into a suitable form, supporting spatial decision-making and modelling (Maina and Haji, 2017). Therefore, when it comes to delivering water services to a community, different spatial datasets are vital in allocating resources to it. For example, safe drinking water planning requires spatial data on water sources, population, utilisation, and water demand. Hence, GIS has been used extensively in South Africa to strategically plan for public facilities over the past 15 years, allowing for the modeling of spatial accessibility using population, road network, and facility location data (Baloyi *et al.*, 2017).

GIS-based accessibility analysis is a suitable tool for analysing gaps in public facility provision, testing the effect of different provision standards indicators, and testing the facility's location and capacity concerning identified consumer groups' location (Baloyi *et al.*, 2017). By using advanced GIS spatial allocation models, it is possible to undertake from a strategic perspective a national or regional analysis of demand (population distribution) and potential supply points (town points) linked via the transport network. Such models prove highly beneficial for balancing and planning facility capacity within a region or an area to attain spatial equity and social justice (Green, *et al.* 2016:437).

Therefore, planning for essential service delivery requires accurate and precise spatial data at all times. All detailed empirical planning approaches, such as service access planning, rely on good data (Green, *et al.* 2009). Effective essential services are influenced by the population's spatial distribution based on their primary service's needs. According to Mwamaso (2015), such spatial datasets are frequently unobtainable or given at a different spatial scale that does not reflect the actual basic need. Mokgalaka (2015) agrees that this is primarily factual, especially for South Africa. On that note, Scott *et al.* (2002) also consider the limits of available data sources. For example, STATS SA is in place to cater to demographics, yet is mainly used by municipalities to inform basic service delivery needs. Sometimes, that data is not enough to identify the extent of areas affected by service. Maritz *et al.* (2017:3) further identify that unavailable or incomplete data impacts service delivery planning. A core problem is the widely differing analysis units and scales used for different sectors or scientific disciplines (Naude *et al.*, 2008).

Since STATS SA’s smallest area unit is the enumerator area, it does not show access to safe water at a residential unit level. It is thus difficult to determine which residences do not have access to water. Almost all the data outcomes in their system are aggregated into a ward or sub-place level, decreasing its significance for an in-depth accessibility analysis based on the citizens' location. Without this, any improvements regarding the availability and quality of data input, the possibility of having adequate and reliable spatial data analysis approaches that support water resource planning, might stay untouched within local municipalities (Singh *et al*., 2014).

Many research studies in South Africa have delivered or added valuable knowledge towards spatial planning for essential services over the past years, such as Maposa *et al*., (2012), Gumbo *et al*., (2016), Roux *et al*., (2018) and Jacobs-Mata *et al*. (2018).

However, it seems not enough has been done to improve determining or investigating essential services' demand. Basic services planning is primarily a demand-driven process; municipalities' service delivery should respond effectively to the existing and potential demand (Green, *et al*. 2016). Therefore, the research study anticipates further additional GIS abilities to integrate spatial data of basic services to improve spatial planning effectiveness for essential services.

According to Amer (2007), a GIS-based accessibility analysis compromises a valuable method that might be suitable for fully supporting and maintaining locational planning in a settlement. Mokgalaka (2015) adds that, over the past ten years, planners and geographers have thoroughly examined and employed a plethora of studies that fully support utilising a GIS-based approach. Therefore, it is significant that GIS should be included in planning services that require decision-making in terms of services accessibility. However, because water accessibility consists of complex accessibility indicators, it requires a more dynamic approach and strategies. It is also essential to recognise and integrate the effective strategies of managing water accessibility from the environmental and government institutional perspectives. GIS technology is not a comprehensive solution or answer to understanding all the matters of access to services. However, it is one of the valuable tools that serves to support planning by spatially categorising where interventions are most needed, particularly in the presence of exact locational data. Furthermore, a GIS cannot be a solution in the absence of precise or accurate geo-referenced information (Mans *et al*., 2014).

GIS has revolutionised the field of water resource management and planning. Through the use of spatial data, GIS can provide valuable insights on water distribution patterns, quantify water availability and usage across different regions, and identify areas with issues related to water quality and accessibility (Ouyang *et al*., 2019). According to Won *et al.* (2015), GIS enables us to model and simulate different scenarios regarding water management practices, consequently allowing us to make informed decisions about the most efficient allocation of resources for water accessibility. GIS technology can be used to develop comprehensive solutions for water resource-related problems, including assessing water quality, preventing flooding, and managing natural resources on a regional or local scale. In addition, GIS-based water quality indices are essential tools for quickly and accurately transferring information on the status of water resources (Won *et al.,* 2015).

Furthermore, recent advancements in GIS technologies have led to the development of web-based GIS systems for water resource management. These spatial tools provide real-time data and accessibility to water quality information, pollution sources, and water supply and demand information (Twumasi and Merem, 2007). The significance of GIS for water accessibility lies in its ability to integrate and analyse spatial data from various sources, leading to a better understanding of water resources and more effective management strategies. GIS has played a critical role in enhancing decision-making processes related to water accessibility through the utilisation of spatial data for monitoring and managing water resources (Twumasi and Merem, 2007). The utilisation of GIS for water resource management and planning is a significant development in today's rapidly changing world.

GIS technology further provides a powerful tool to developing countries for efficiently managing water resources, making it an essential component in current solutions addressing water resource problems, including in South Africa. The GIS ability to collect spatial data from vantage points above the Earth's surface through remote sensing techniques has helped in observing large-scale changes in relevant water bodies, such as depletion rates and assessing natural disasters affecting them (Twumasi and Merem, 2007). GIS has been used widely to model and simulate scenarios related to water management because of its effectiveness in storing, organising and visualising different types of geospatial information leading to more informed decision-making on the optimal allocation of resources for improved accessibility (Won *et al.,* 2015).

This technology has brought forth a new wave of efficient solutions to water accessibility problems, which were previously difficult to analyse and address. The applications of GIS have extended beyond just monitoring water distribution patterns; it is now used in modelling and simulating scenarios for optimum utilisation of resources and developing feasible solutions (Batsuuri *et al*., 2020). According to Won *et al.* (2015), this powerful tool can assess the availability of different types of water sources across regions, quantify the usage patterns, identify areas with insufficient or poor-quality water supply, and prevent flooding. Moreover, with easy access to web-based GIS systems on various devices, any individual concerned with water management can gain real-time information regarding the status of their local water resources.

GIS-based technologies enhance decision-making processes by providing real-time information on a wide array of variables such as precipitation rates, soil moisture levels, flow rates in river systems, among others. According to Singh *et al*. (2014), GIS indeed has an ability to collect diverse spatial data on critical factors such as topography, land use/land cover types, climate/weather patterns, and hydrological systems, in order to create predictive drought models and simulate different scenarios regarding crop yield, livestock production, disease spread from polluted sources, water supply and demand trends at different scales. This implies that GIS tools have revolutionised not only our understanding, but also our response to issues related to water accessibility, hence the storage, management and display of information regarding water resources are facilitated by GIS technology. Henceforth, it enables professionals working in this field to gain critical insight into issues relating to water quality, availability, accessibility, and usage patterns.

2.12 Challenges and Criticisms of Using GIS Technology in Water Resource Management

However, while GIS has significantly contributed to the efficient management of water resources, it is essential to acknowledge its possible limitations, such as the acquisition and processing of spatial data that can be costly and time-consuming, making it difficult for some regions with limited resources and expertise to utilise GIS effectively (Batsuuri *et al*., 2020).

Sturiale and Scuderi (2018) argue that there are limitations to GIS technology regarding water management. One such challenge is related to the quality and reliability of spatial data used in GIS-based models for water resources. Data accuracy issues can arise due to incomplete databases and errors during data collection, which can result in either misinterpretation or bias (Sturiale and Scuderi, 2018). Another limitation is that not all regions have access to advanced GIS technology or expertise, especially those in developing countries, where information systems may not be efficiently managed. According to Haakana (2017), this uneven distribution of technological access could lead to unequal representation and information gaps, resulting in inaccurate modelling and decision-making processes.

One possible criticism is that GIS technology often requires complex data inputs and analysis, making it inaccessible for many small-scale water resource management applications. This can be challenging in areas lacking high-resolution spatial data or limited resources to purchase expensive equipment. Additionally, some experts such as Batsuuri *et al*. (2020), argue that relying solely on GIS-based solutions ignores the human aspect of water management issues, such as social dynamics and cultural barriers. On the other hand, Sturiale and Scuderi (2018) argue that GIS technology may not be suitable for all water accessibility issues, stating a concern that in developing countries with limited resources and infrastructure, where implementing sophisticated GIS systems can prove challenging due to financial constraints, technical expertise requirements, and access to GIS or spatial related equipment. Such a concern is related to the cost and infrastructure needed to implement GIS technologies fully, where any discrepancies or inaccuracies in the collected data can lead to unreliable analysis outcomes and potentially undermine any decisions made based on such results. Furthermore, there are potential challenges related to data quality management when dealing with large quantities of spatial data from various sources.

Additionally, since GIS technology rely primarily on satellite imagery data for observation at large scales or remote sensing techniques requiring certain weather conditions or specific physical attributes such as high spectral resolution. It may present efficiency challenges in managing water resources in regions that lack such conditions or topography (Twumasi and Merem, 2007). In spite of these challenges, the benefits of GIS for water accessibility outweigh its limitations. Therefore, efforts should be made to ensure that there is access to this technology in regions where its application could lead to significant improvements in the management of water resources.

2.13 GIS and actual accessibility to water services

The utilisation of GIS in case studies or research has become increasingly prevalent in various academic disciplines, due to its many benefits. One such benefit is the availability of sophisticated methods that allow for the capture and analysis of a wide range of spatial data for multiple individual point locations. Moreover, many GIS water-related studies have shown that GIS is suitable for deriving quantitative information regarding spatial and temporal water catchment changes. In addition to this benefit for water catchment studies and analysis including land cover changes through remote sensing and GIS techniques is tremendously advantageous across multiple fields. GIS technologies have been found to be useful for generating thematic maps and regular monitoring of various parameters, as well as the analysis of temporal changes in them.

The application of GIS techniques in hydrology enables the examination of hydrological variables and morphological changes for small, medium, and large regions at different scales, both spatial and temporal (Khatami, and Khazaei, 2014). Furthermore, GIS significantly enhances the value of spatial analysis in land use administration by providing valuable datasets for automatic delineation of drainage systems and fundamental catchments (Khatami, and Khazaei, 2014). According to Schuster-Wallace and Sutherland (2019), another use of GIS in water access related case studies is its ability to aid in water accessibility, whereby the use of GIS tools for water resource management facilitates the implementation of appropriate schemes for the construction of drainage structures and agricultural water management aspects, including irrigation water management.

Alcaraz (2016) states that tools for water resource management using GIS can function on various platforms with separate software applications. For example, data management platforms such as 3D visualisation surfaces used in hydrological modelling allow relevant stakeholders to obtain easily accessible information about potential threats related to a particular area's groundwater system's contamination source (Alcaraz, 2016). Through data management platforms using separate software tools, GIS can provide relevant information on water resources that aid decision-making processes. Furthermore, the incorporation of remote sensing data analysis tools has led to effective investigations into practical problems, such as poorly gauged catchments, or detecting crucial features regarding water.

GIS analysis tools have been found to be effective for investigating practical water accessibility problems and detecting important features of water resources. According to Du *et al*. (2016), many methods can be applied to extract valuable information on water bodies from satellite imagery data. Open-Source Web GIS software systems are also increasingly being utilised for enhancing the accessibility of water resources through efficient management, monitoring, conservation, and planning policies. GIS-related studies on water accessibility have provided valuable insights into the distribution of water sources, identifying areas with limited access to safe drinking water.

Some GIS-related studies on water accessibility, such as Cassivi *et al*. (2019), Deshpande *et al*. (2020), Bo *et al*. (2021), Berihun. *et al*. (2022), Schuster-Wallace and Sutherland (2019), Sairam *et al*. (2019), and Bergh*et al*. (2019), have some key findings that includes: spatial disparities; whereby GIS analysis has revealed spatial disparities in water accessibility, with certain regions or communities facing greater challenges in accessing clean water. These disparities have been found to be influenced by factors such as geography, infrastructure, socio-economic status, and population density. Another key finding includes: distance to water sources, whereby GIS studies have highlighted the distance people must travel to access water sources by mapping the proximity of water points to populated areas, and researchers have identified regions where people have to travel long distances, often on foot, to fetch water.

Such findings highlight the need for improved water infrastructure and services in those areas, hence another key finding includes: water quality variations; whereby GIS has been used to assess water quality across different locations, by overlaying water quality data with population data, and researchers have identified areas where water sources are contaminated or have poor water quality, potentially posing health risks to communities. These findings help prioritise water treatment initiatives and monitoring efforts. Another key finding includes: identifying vulnerable populations; whereby GIS has helped identify vulnerable populations that are disproportionately affected by water accessibility challenges, by mapping socio-economic data, such as poverty rates or marginalised communities, researchers have identified and highlighted areas where access to clean water is limited, helping target interventions, as well as aid to those most in need.

One more important discovery includes the impacts of climate change; whereby GIS have been used extensively to explore the impact of climate change on water accessibility, by integrating climate data, such as rainfall patterns and water availability, with existing water infrastructure and population distribution, researchers have identified regions at risk of water scarcity or changes in water availability. Such findings can inform adaptation strategies and water resource management plans. Additionally, it improved infrastructure planning; whereby GIS analysis has informed infrastructure planning for water supply systems, by mapping existing infrastructure and population growth projections, researchers have identified areas where new water infrastructure is needed to meet the increasing demand. This helps guide investment decisions and resource allocation for improving water accessibility.

Furthermore, in effective emergency response; whereby during emergencies or natural disasters, GIS has played a crucial role in mapping water sources and coordinating relief efforts, by rapidly assessing the availability of clean water sources and overlaying this with affected areas, where emergency response teams have prioritised aid and resource distribution so as to ensure access to safe drinking water for affected populations. These findings from GIS-related studies have provided valuable evidence for policymakers, water management authorities, and development organisations to develop targeted interventions, improve water infrastructure, and ensure equitable access to safe drinking water for communities around the world.

Geospatial accessibility analysis can help find suitable locations for facilities to serve the inhabitants (Ragoasha *et al.*, 2018:52). Amer (2007) states that when observing various accessibility measures mostly used in water analysis, many publications bring forward study research on potential water accessibility. Although measuring the possible water accessibility has remained an old-fashioned method, actual water accessibility might be a more practical approach. Hence, GIS analysis is based on the assumption of rational choices, such as the notion that a person will always go to the closest facility (Mans *et al.*, 2014:1). However, research studies incorporating actual water access and consumption into GIS analysis are relatively rare. McLafferty, 2003; Maheswaran *et al.* (2003); and Mwamaso (2015), have realised the spatial aspect concerning the location of potential residents and in-depth patterns of utilisation within developed nations or countries.

Developed countries began to create most of the GIS software, while trying to solve the question of accessibility. Amer (2007) notes that it is evident that most GIS software applications used in the water field originate from developed or wealthy countries. In contrast, practical implementations of that software are done within developing countries in Sub-Saharan Africa. The performance of this software implemented in developing countries are mostly disadvantaged by the shortage of datasets, which result in a significant delay. McLafferty (2003) further observes that water planning requires data on water sources, the water demand status (demographics), usage, water treatments or water quality status, and infrastructure network. However, then again, such datasets are frequently unobtainable, or if these are available, they are provided at diverse temporal-spatial scales.

The difficulties that have been identified thus far are also related to the selection of indicators and the custom of water access standards with regards to elements such as understanding the definition of water access between the stakeholders in the industry, the process of developing and selecting water indicators, and the method used to measure citizens' access to water. For that reason, this study examines the methodology of water indicator selection, procedure, and practice on measuring citizen’s access to water as generally accounted for by water service suppliers along with water service consumers.

The decision support that can come from a GIS-based analysis of spatial accessibility to determine accessibility to safe drinking water is being improved due to trends in technology. Advanced GIS systems make spatial analysis quicker and better decision support outcomes, especially when more data is available for analysis. The availability of data begins with a clear direction of what kind of data is needed, or a selection of crucial water accessibility indicators. Some water indicators are influenced by changes or improvements in GIS technology. Gine-Garriga *et al.* (2013), make an example by stating that in constructing and operationalising water access indicators, the methodology to that end is still a paradox among researchers and practitioners because some lack the GIS skills and are left behind by GIS technology trends, particularly in local municipalities. According to IDP (2018), this is evident in Nkomazi Local Municipality, where there are limited GIS capabilities for measuring the residents' access to water in Langeloop and other areas.

Through the mapping of water access indicators, this research study advances knowledge about the application of the GIS approach. Consequently, the authorities of the Nkomazi local municipality may receive valuable recommendations that will help them make more informed decisions about the provision of equitable and dependable water supply services.. Hence, in South Africa, the current norms or standards for levels of water services have, over the past few decades, inadvertently concentrated on addressing water services for equitable and efficient water services to all residents, taking into account: financial challenges, availability of water sources, geographical or spatial placement matters, addressing the backlog, servicing the vulnerable groups, and especially in rural areas (Duncker, 2015).

2.14 Service area spatial analysis

A service area spatial analysis is a GIS process that can be used to model or simulate spatial reality to access basic services in an area or settlement. It is also known as a service area network (SAN) analysis. A SAN analysis is a method used to assess the availability, accessibility and reliability of network services within a specific area (Ekanayaka and Perera, 2018). According to Ouyang *et al*. (2019), this analysis involves modelling the network infrastructure of an organisation, identifying critical services and their associated dependencies, assessing potential points of failure or vulnerability, and developing strategies to improve service accessibility, availability and performance. SAN analysis is also a geoprocessing tool that is commonly found within a GIS such as ArcGIS (ArcMap) software. For instance, Khashoggi and Murad (2021), indicates that to carry out a SAN analysis, the network analysis tool in ArcGIS is usually utilised as it aids in finding the shortest distance between different locations and identifying the service coverage areas of service facilities.

Moreover, the network analyst extension is a valuable tool that can solve various routing problems spatially (Ouyang *et al*., 2019). Hence, network analysis provides a comprehensive picture of the network infrastructure's performance and helps to identify areas where improvements are needed. Furthermore, Aminigbo and Omogunloye (2022) indicate that it assists in resource allocation and streamlines decision-making processes by providing an accurate understanding of the network's performance. Service area network analysis typically involves measuring and analysing variables such as network speed, downtime frequency and duration, service quality, data transfer rates, response times or latency values, and other key performance indicators (Ekanayaka and Perera, 2018). The SAN analysis is a complex but vital process used to ensure that network services are reliable and available at all times (Parsakhoo *et al*., 2017). Therefore, a SAN analysis provides an integrated and systematic approach to network infrastructure evaluation that is critical towards ensuring that organisational network services are efficient, reliable, and meet the needs of its users.

Furthermore, Haque *et al*. (2020), state that a SAN analysis is a widely used technique in transportation service planning, health services mapping, ecosystem service assessment, and urban service facility assessment. While SAN analysis aids in identifying critical services that must function optimally for the network as a whole to work correctly. Koike *et al*. (2016) indicates that to facilitate this process, experts use various spatial tools within ArcGIS network analyst extension, such as route optimisation, location-allocation analysis and service area determination. Route optimisation involves determining the most efficient path from one location to another based on factors such as road speed limits or traffic volumes (Haque *et al*., 2020). Location-allocation analysis helps determine optimal locations for facilities by maximising coverage of surrounding population areas (Ouyang *et al*., 2019). For instance, in studies done by Parsakhoo *et al*. (2017), the location-allocation tool within the ArcGIS network analyst was used in several studies to locate waste bins, assign users to these bins considering typical footpaths of citizens in specific areas, or even determine the appropriate number of anthropogenic GAPs required to cover maximum population within a specified walking distance. To perform a network analyst analysis effectively, it is necessary to have an in-depth understanding of the network infrastructure and the critical services that it provides. This involves collecting relevant data regarding the service delivery process, identifying potential failure points or vulnerabilities within the network structure, and determining strategies to address these concerns proactively.

However, SAN analysis has been criticised by Brún and McAuliffe (2018), stating that running an analysis is time-consuming and resource-intensive. Hence, the process requires a large amount of data to be collected and analysed, which can be difficult to obtain in some cases. Moreover, the analysis is heavily reliant on accurate input data as well as properly built network models which may not always reflect actual usage patterns resulting in biasness in results (Oliveira *et al*., 2018). Furthermore, one of the limitations of a SAN analysis, as highlighted by Murad (2018), is that it overlooks the qualitative aspects of network performance, such as user satisfaction or user experience, such as quality service, which cannot solely rely on quantitative metrics like speed or latency alone. Hence, these are critical measures and attributes to determine whether an end-users will accept any proposed improvement. Brún and McAuliffe (2018), further highlight the limitation that the analysis may not fully consider user preferences and needs when assessing service areas. This pertains, for example, to personal choices in terms of where a person seeks medical attention might vary from what location-allocation algorithms recommend as optimal for maximising coverage (Murad, 2018).

Although SAN analysis is a helpful tool, it should not be the sole basis for determining service coverage and performance. Many factors can influence network performance, such as user behaviour, external environmental conditions like weather patterns that may affect network equipment or infrastructure, and other unpredictable events like natural disasters (Yuan *et al*., 2022). Additionally, relying solely on software analyses may fail to take into account physical factors of network facilities, where varying geographies make routing strategies less reliable, since terrain structures, such as road potholes and damaged bridges, can lead to interruption points in communication lines (Oliveira *et al*., 2018). Hence, Service Area Network analysis seems to assume that the network is stable and static. Yuan *et al*. (2022) highlight that this assumption may not hold in real-world scenarios, where network outages or other disruptions occur regularly. Therefore, in such cases, the results of a SAN analysis may not accurately reflect the performance of the network during abnormal conditions, leading to ineffective resource allocation and decision-making processes.

Hence, Guerrero and Kao (2013) states that inaccurate or incomplete data could generate erroneous output from Service Area Network analysis models leading to poor decision-making processes. Moreover, carrying out a successful SAN analysis requires specialised skills and knowledge that might be lacking within an organisation (Koike *et al*., 2016). Hence, performing accurate data collection and cleaning processes before building a model using these tools pose significant challenges to many rural local authorities or municipalities (Parsakhoo *et al*., 2017). For instance, investing in training individuals or hiring outside professionals to carry out these analyses can result in additional costs which might exceed expected benefits. However, Guerrero and Kao (2013) stated that implementing this method requires skilled personnel with expertise in network engineering, geographic information systems, cartography, statistical modelling or machine learning techniques, hence there are many benefits of acquiring accurate data and skilled personnel to perform SAN analysis. In such case, the benefits outweigh the limitations.

2.15 Identifying indicators to measure water accessibility

To assess and monitor water access around the world, various indicators have been developed to measure different aspects of this important issue. Indicators provide valuable information about the availability, quality, and reliability of water supply in different regions (Ingram and Memon, 2020). They help to identify areas where improvements are needed, and can guide policymakers in their decisions about how best to allocate resources to address water access challenges. According to Komatsu *et al*. (2019), examples of water access indicators include measures of water availability and resource variability, such as annual precipitation and water resources per capita. Other indicators focus on access to safe and reliable drinking water, such as the percentage of the population with access to improved water sources or the proportion of households that meet a minimum basic water requirement (Nunes and Machado, 2021).

Efforts to map and measure water access indicators have been undertaken by international organisations, governmental agencies, and NGOs. Furthermore, Zhao *et al*. (2021) note that good governance indicators, such as voice and accountability, as well as the rule of law may also have a significant impact on improving access to water, as these indicators are closely associated with institutional effectiveness in addressing this issue. Hence those governance indicators such as voice and accountability may have a greater impact on improving water access than legal frameworks alone. Through the use of water access indicators, it is possible to gain a more comprehensive understanding of the challenges and opportunities related to water access around the world (German *et al*., 2020). Moreover, the information obtained through these indicators can facilitate the development of effective programmes and policies that promote universal access to sustainable water resources.

German *et al*. (2020), Komatsu *et al*. (2019), Ingram and Memon (2020), and Zhao *et al*. (2021), provide insights into the different types of indicators used in mapping and measuring water availability, resource variability, reliable drinking water, and good governance. It is notable that while physical water resources may be abundant in some regions, low quality or unimproved access can hinder its availability for drinking and other purposes. Water access indicators provide qualitative and quantitative measures aimed at tracking progress towards meeting basic human needs related to water availability and quality.

It is important to note, however, that while water access indicators provide a useful tool for assessing and monitoring water access globally, they are not without their limitations. According to Lohano and Marri (2020), these indicators are often based on limited data availability and may not fully capture the complexities of water access challenges in different contexts, such as those related to cultural and social norms, as well as political and economic factors. Therefore, it is essential to complement water access indicators with context-specific information and qualitative data so as to gain a more nuanced understanding of the challenges involved in achieving sustainable water access in different regions (Gine-Garriga *et al*., 2013).

Hence, despite the potential benefits of using water access indicators to address challenges related to water resources, Zhang *et al*. (2020) have raised concern about their effectiveness. One argument against the use of water access indicators is that they may be oversimplified and fail to capture nuances specific to different settlements or regions. For instance, an indicator measuring access to improved sources of drinking water might indicate success in one settlement or region, while not taking into account the cost associated with providing such a source. Another argument against relying on indicators is that they may incentivise short-term thinking, rather than long-term planning (Lohano and Marri, 2020). Caution must therefore be exercised when interpreting results obtained from these indicators, particularly in terms of cross-country comparisons or making generalisations about specific communities or regions.

Furthermore, it is important to recognise that the development and use of water access indicators should involve diverse stakeholders, including local communities and indigenous groups. Meaningful engagement at the community level can help ensure that data collection processes are sensitive to cultural norms and practices related to water use and management. These stakeholders may also provide valuable insights into the social, economic, environmental, and political factors that influence water access challenges at the local level. Furthermore, it is crucial to recognise that water access is an essential prerequisite for achieving other development goals, such as food security and energy production (Nunes and Machado, 2021).

Therefore, indicators related to these outcomes can also be integrated with water access indicators in order to develop a more comprehensive set of measures that reflect the complex interconnections between different aspects of development. Komatsu *et al*. (2019) have suggested that effective policies addressing water access must take into account wider development goals related to poverty eradication, health promotion as well as gender equality. For instance, Komatsu *et al*. (2019) have highlighted the importance of considering different scales and perspectives when measuring water access in order to ensure that local-level experiences are adequately captured.

Access to safe drinking water is measured by the standards brought forward by the South African government and other global institutions in dedicating themselves to fulfilling potentially the most central constitutional right, namely access to sufficient water. Suitable standards or established guidelines facilitate service delivery and the backlog determination procedures, and make basic services delivery needs easier to be quantifiable and transparent to decision-makers (Green, *et al.* 2009). These are used to determine the optimum location for new services or facilities (Green, *et al.* 2008).

The South African government stresses water access, while emphasising aspects such as proximity, water quantity, quality, reliability, and affordability (Mwamaso, 2015). The standards defining water accessibility have been readily available as set by the government, where local authorities or municipalities also know these standards. However, the challenge is with the implementation of these standards. The Department of Water and Sanitation (DWS, 2017) states that full water service is the highest level of water supply service, satisfying people's demand for water for all kinds of uses, such as business, domestic, industrial, and agricultural.

The water access measures being emphasised are the indicators that define access to safe drinking water, and there are different datasets and statistics for these indicators. The indicators have to be in a GIS dataset to analyse and understand the pattern impact of the indicators in the lives of the people/citizens. Martinez (2015) indicates that by having the indicators in a GIS or digital spatial form, it becomes easy to recognise the patterns of the indicators that need to be improved and identify where some of the indicators are excelling. Six indicators receive explanation below.

a. Proximity or physical access to a water point

A proximity indicator is generally the key in pattern spatial distribution analysis for effective service delivery. A water source's proximity is usually determined by a distance such as a walking time from a consumer's household to the source. Mwamaso (2015) states that it is one of the most commonly used access indicators to measure physical access or coverage levels, although proximity is diverse in context and conditions, where the optimal standard distance differs from one country to another depending on a country's government water institutions. For example, in South Africa, the standard distance to access water is less than 250 meters, and the access or delivery point be at least a yard connection (DWS, 2017). An essential supply of water means 25 liters for each person per day and is easily accessible within 200m of the household (Jacobs-Mata *et al.*, 2018).

According to Mwamaso (2015), the WHO supports that water sources have to be within 1,000 meters from the consumer's house. The time to collect water must not exceed 30 minutes. Tanzania's national water policy has set 400 meters as a maximum distance to access a water point and not more than 30 minutes for collection time, including going, waiting, collecting, and returning. Worldwide, access to water has a proximity standard that is acceptable by the government and the people in their communities. The UN Special Rapporteur (2014) states that the human right to access sufficient water includes distance, cost, and time, taking into account persons with disabilities, along with their age, and number of children. Furthermore, the facilities need to be located in safe areas to ensure the water user's physical security.

b. Water quantity

Water quantity involves the container or volume of water available to supply or meet the required needs effectively. The UN Special Rapporteur (2014) elaborates by stating that it entails enough uninterrupted water for domestic and personal use and personal hygiene, house sanitation, laundry, drinking, and cooking, supplied per capita per day. The WHO (2008) states that an individual, irrespective of being in rural areas or semi-urban settlements, is regarded to have optimal access to essential water in terms of the water quantity they use between 50 and 100 liters each day. According to Mwamaso (2015), in rural areas of Tanzania, a measure of water access, in terms of quantity, considers optimal water access when each dwelling uses a minimum of 25 liters of water per capita for each day through the water points that are located within 400 meters from the furthest household. In South Africa, the quantity of water an individual is able to access or uses per day is similar to that in Tanzania. However, the general standard of water quantity in South Africa is not less than 25 litres for each person per day (DWS, 2017). Jacobs-Mata *et al*. (2018), also emphasised that the current standard of 25 litres per day must be easily accessible within 200m of the household.

c. Affordability

The affordability indicator looks at the economic status of a household to be able to afford water. This includes households that are declared indigent, because each household deserves to have access to water, regardless of economic status. Hutton (2012) states that affordability is a global indicator for almost any rendered services; for any individual to access those services, they have to afford it in any way of payment. Affordability, as a universal indicator, in terms of water access, compares the yearly residential water expenses with the annual income (Jacobs-Mata *et al.*, 2018). However, the indicator does not consider particular basic household financial persistent costs that include water treatment. Mwamaso (2015) states that the affordability standard is based on the residents' monthly water costs and disposable revenue and expenses. The implication is that the amount paid for the water services should not limit individuals' capacity to purchase other essential services guaranteed by other human rights. Langford and Winkler (2014) elaborate that in a superficial sense, residential households should not be mandatory to do payments concerning essential water services, and include other additional necessities, such as healthcare costs or food consumption.

According to Mwamaso (2015), the affordability index used in other countries is three to four percent of the disposable income for low-income families. In contrast, in South Africa, the affordability index ranges between 2.8 percent for median families and 7.5 percent for low-income families. There are other affordability indices based on a country's gross domestic products and market trades. According to Mwamaso (2015), based on the index that some global agencies establish, the UNDP uses three percent, the World Bank five percent, and then the African Development Bank five percent of water services expenditure. In South Africa, the DWS requires a free essential water supply of a minimum of 25 litres per person per day to be provided to registered indigent households (DWS, 2017). Therefore, water affordability is based on the costs associated with water treatment, storage, distance to collect water, and the quantity of water usage, for example, the more water a person uses is the more that person should pay.

d. Service availability and reliability

The availability of water services is important; hence it is the basis of accessibility of water, because if the water is not available, there is nothing to access. Water service availability and reliability means supplying enough water every day so as to ensure that people's water needs are met, both present and in the future. Water availability enhances the quality of life of the people, since people use water constantly. Mwamaso (2015) states that the United Nations handbook for essential water service provision as a fundamental human right indicates that water should be available and reliable at home, schools, work, etc. According to DWS (2017), water should be made available 365 days per year and not interrupted for longer than 24 consecutive hours. Water should furthermore be made available at a high pressure that is not exceeding 9 bar/ 9kPa. Mwamaso (2015) stated that a water policy in Tanzania gives directions that water should be available in an adequate quantity of at least 25 litres for each person every day. Although on the other hand, he stated that the implementation of the policy is still complex, due to the rapid population growth concerning the current resource capacity limitations.

e. Quality and safety

Water quality and safety means that water should be in a state or standard of being free from pollution or free from toxic contamination. Water quality is generally matched or defined through its use. For example, the best quality water for domestic services is mainly used for drinking and cooking. More inferior quality water, such as grey or muddy water, is primarily used for irrigation and flushing of toilets (Van WyK, 2010). The UN Special Rapporteur (2014) further elaborates by stating that water needed for people or individuals for domestic use should be safe and free from chemical substances, bacteria-free, and radiological hazards that create a threat to an individual's health system. The DWS (2017) states that the water provided should comply with the SANS 241 quality standards. This means that the water provided should be clean, with no odour, but safe, and drinkable. According to the UN Special Rapporteur (2014), the WHO has guidelines for potable water quality. It gives a clear guideline for developing national criteria that should be implemented, guaranteeing water consumption safety.

According to Mwamaso (2015), water is safe merely when drawn or collected from an improved source. However, water could be contaminated within the pipes before it emerges from the tap. Therefore, according to Mwamaso (2015), owing to the various perspectives and circumstances across nations or states, measures to guarantee the delivery of water quality are commonly well established by the national and local standards, but subject to the safety of a country's water infrastructure situations. For example, in South Africa, local water service providers or local municipalities are responsible for determining water quality at the point of water production, while benchmarking the government's national water quality standards.

f. Acceptability

The acceptability indicator looks at perception standards in terms of the user’s ideal about the accessibility of a water source. Masanyiwa *et al.* (2014), elaborate that acceptability is fundamental in defining residents' access to essential water in user-friendly water infrastructure for all citizens. Hence, a water facility might not be user-friendly to people in society's social and cultural norms standard for the people it is intended to serve or supply. This ought to show that all water service facilities ought to be suitable to socio-cultural standard and delicate to femininity. For example, Mwamaso (2015), stated that gender suitability of water sources could be about the technological designs of the water sources or another access dimension, for instance, in the secure positioning of the water sources. This aspect led the DWS (2017) to state that the water access/delivery point should be at minimum a yard connection. Furthermore, water should be of good taste, colour, and odour, so as to ensure acceptability for all domestic and personal usage.

The water access indicators discussed in this section are summarised in Table 2.1 with their measurement standards. If these criteria are met, a local authority's provision of the water services can be deemed accessible and equitable (Green, *et al.* 2008).

Table 2.1: Water access indicators and standard measure

Indicator	**A measure of indicator standard**
Proximity or physical access to a water point	Less than 250 metres
Water quantity	25 litres of water per day
Affordability	Citizen's income status to be able to pay for water access service.
Service availability and reliability	Water is available 24 hours a day.
Quality and safety	Water clean, with no odour or contamination, but safe to drink.
Acceptability	Respect for cultural and social factors of the local area.

These indicators are the key to collect water accessibility information from the residents using a questionnaire. Green *et al.* (2008) state that the questionnaire process is a community consultative process that serves to ensure better decision-making by local municipalities or authorities and develop better services provision policies. Hence, the outputs support planning facilities where they are needed and where people live irrespective of ward boundaries and political processes (Green, *et al.* 2009).

2.16 Thematic map assumptions

Thematic maps are a type of cartography designed to display spatial distribution and variations of data across geographic regions (Krzysztofik *et al*., 2021). The effectiveness of thematic maps is dependent on the use of symbols that accurately convey the contents of the map and enable good communication between map makers and users. According to Zhao *et al*. (2020), the design of symbols on thematic maps should adhere to certain assumptions. He *et al*. (2019), and Pham., (2020), indicate that, firstly, symbols should be simple and easy to draw while still being sufficiently comprehensive. Secondly, symbols must be clear and easy to read or understand for map users. Thirdly, the modulations of marks and symbols utilised on thematic maps must work together graphically to evoke the overall form of a distribution. Finally, the design and production of thematic maps should take into account specific themes connected to a geographic area, such as cadastral maps, legal land use map design, population density maps, and agricultural productivity maps (He *et al*., 2019). Furthermore, the well-established data symbolisation techniques used in choropleth maps to make their design and production relatively streamlined (Zhao *et al*., 2020).

Thematic maps have gained prominence in visualising geographic information due to the popularisation of map systems for the internet, which has turned the use of maps into an everyday practice (Beitlova *et al*., 2020). According to Dąbrowski *et al.* (2021), the objective of thematic maps is to express geographical information through graphic representations designed to present relations of data similarity, ordering and quantification. Nevertheless, when designing a thematic map, it is crucial to create symbols that accurately represent the point being conveyed, while still maintaining simplicity. Through proper symbol design and presentation on a map, they can communicate spatial patterns and relationships across various geographic areas.

However, it is important to consider opposing arguments when discussing the assumptions underlying thematic maps. Jílková and Janata (2019) argue that the design of symbols on thematic maps can be overly simplistic and may not accurately convey complex data. Additionally, while well-established data symbolisation techniques may streamline production (Zhao *et al*., 2020), they can also lead to a lack of creativity and innovation in map design (Jílková and Janata, 2019). Furthermore, some scholars critique the focus on visual representations in thematic mapping and argue for a more comprehensive approach that incorporates other sensory modalities, such as touch or sound (Zeng *et al*., 2015). This requires developing new methods of designing tactile or auditory symbols, which can effectively communicate spatial data to individuals with disabilities.

One argument by White (2018) suggests that symbols can be ambiguous and not clearly understood by all map users. This arises due to the different interpretations people may have towards similar symbols used on diverse geographical locations or scales. Additionally, some people may have little knowledge about what specific symbols represent and hence misinterpret them (Zhao *et al*., 2020). However, Zeng *et al*., (2015) question the effectiveness of thematic maps in providing comprehensive information about a particular location without considering other factors such as historical context and cultural diversity. For instance, population density maps may provide misleading data if important aspects like migration patterns and local customs are not observed or taken into consideration (Zeng *et al*., 2015).

White (2018) indicates that the use of thematic maps they oversimplify complex phenomena, and can lead to misinterpretations or misunderstandings, where thematic maps are limited by their reliance on two-dimensional representations of data, which may fail to capture spatial relations and dynamics accurately. Furthermore, certain themes may be difficult to represent cartographically, leading to a biased representation of geographic regions (White, 2018). Another critique by Dąbrowski *et al.* (2021) is that thematic maps can perpetuate stereotypes about places or people, hence, the association between certain themes and specific regions may result in stigmatisation or marginalisation of individuals belonging to those areas. This implies that, while the assumptions for designing symbols on thematic maps are well-established, it is important to acknowledge or recognise that they may not be applicable in all contexts. For instance, the assumption that symbols should be simple and easy to draw may not hold true when representing complex datasets with various variables across a large geographic area. In such cases, according to Krzysztofik *et al*. (2021), using more intricate symbols or multiple coordinated symbol sets may be necessary to accurately convey information.

2.17 Conclusion

Water is a fundamental human need worldwide, crucial for sustaining life and ensuring the well-being of individuals and communities. As Maina and Haji (2017) state, water makes life possible; hence, without water, life and civilisation cannot be possible, because for human livelihood and economic development, there is a need for water. According to the WHO (2016), by 2015, about 785 million people still had no access to safe drinking water, which meant 1 in 10 people still did not have access to safe water, and suffer a high possibility of accessing drinking water from unimproved water sources. Challenges such as climate change and population growth continue to strain water resources across the globe. Furthermore, the WHO (2016), report states that in some areas, particularly Sub-Saharan Africa, most of the public spend far more than a minimum of 30 minutes and others spend more than 60 minutes on one trip to collect water from an unimproved water source.

Langeloop is a rural settlement located in South Africa that has been facing a significant water access problem for years. Additionally, the quality of available water resources in Langeloop is poor as reported by the Nkomazi IDP (2018). The COVID-19 pandemic has further highlighted the importance of water accessibility, particularly in developing countries, where access to basic sanitation remains a challenge. Hence, the consumption of contaminated drinking water can be linked to severe life-threatening diseases, such as cholera. The implementation of sustainable management practices and continuous monitoring of progress towards water accessibility targets are crucial in ensuring that every individual has access to safe drinking water, regardless of socio-economic status or geographic location. Hence, Langeloop's rural nature often means limited financial resources, both at the individual and community levels.

However, despite progress made in recent years, a significant portion of the world's population still lacks access to basic drinking water sources. Maponya *et al.* (2013), emphasise that even though there is substantial improvement in water services delivery, millions of South African citizens have little or no access to a drinking water supply. According to various sources, such as Naz *et al*. (2022), Roux *et al*. (2018), Gumbo *et al*. (2016), and Alhassan *et al*. (2015), water management in South Africa is confronted by multiple challenges that include severe shortages and interruptions of supply, due to a highly variable climate. It is therefore imperative for South Africa to take a proactive approach in addressing its water scarcity challenges, such as investing in alternative sources of water and improving infrastructure and technologies for water collection, treatment, and distribution. The envisaged proactive approach should include GIS to support decision-making in analysing and implementing improved water infrastructure. Hence, GIS spatial data accessibility analysis empowers more effective service delivery, service management, and further monitoring of the publicly provided essential services and facilities (Green *et al.*, 2016).

Furthermore, data analysis plays a crucial role in identifying regions and populations that lack access to safe water sources. For example, safe drinking water planning requires spatial data on water sources, population, utilisation, and water demand. Therefore, planning for essential service delivery requires accurate and precise spatial data at all times. Currently, almost all the demographic data outcomes in Statistics South Africa system are aggregated into a ward or sub-place level. However, the aggregated ward or sub-place data pose a risk of inaccuracy by decreasing its significance for an in-depth accessibility analysis based on the citizens' household location. This is evident in thematic maps presentations, whereby in a ward/sub-place unoccupied land/space would be represent with a classified figure similar to the settlement occupied land/space. However, GIS still it is one of the valuable tools to support planning by spatially categorising where interventions are most needed, particularly in the presence of accurate or exact locational data.

Despite the utility of GIS, the technology often requires complex data input and analysis, making it inaccessible for many small-scale water resource management applications. This can be challenging in areas lacking in high-resolution spatial data or limited resources to purchase expensive GIS equipment. The concern is related to the cost and infrastructure needed to implement GIS technologies fully, where any discrepancies or inaccuracies in the collected data can lead to unreliable analysis outcomes and potentially undermine any decisions made based on such results. A GIS-based accessibility analysis as a tool of spatial accessibility provides a practical approach to supporting locational planning for rural and urban settlements. GIS analysis tools have been found to be effective for investigating practical water accessibility problems and detecting important features of water resources. Mokgalaka (2015) indicates that measuring spatial accessibility to water is done by computing the data using different travel modes, trip purposes and time spent. Using a GIS and GPS technology in the field, or in other spatial-related research, is an efficient way to capture data for mapping various facilities, such as water standpipes. A SAN analysis in a GIS is a method used to assess the availability, accessibility, and reliability of network services within a specific area (Ekanayaka and Perera, 2018).

While GIS is an excellent supportive decision-making tool, strategic water planning constitutes a vital component of effective water resource management. The DEA (2013) outlines a water resource planning framework of South Africa. However, the goal of a strategic water planning is to ensure the availability of clean and reliable water supply for various uses, such as drinking water, agriculture, industry, and the environment. It further consists of strategies that empower local government and communities to access water sustainably. In this regard, citizens have employed various strategies to certify their access to clean and safe water. For example, the common strategies include: rainwater harvesting, water recycling and reuse strategy, conservation and efficient water use; whereby citizens can conserve water by adopting practices such as fixing leaks, using water-efficient appliances and fixtures or fittings, and practicing mindful water use (Banihabib *et al*., 2020).

Rural water access measurement practices are crucial in the effort to understand and address global water scarcity challenges. However, access to safe drinking water is measured by the standards brought forward by the South African government and other global institutions in their dedication to fulfil the constitutional right of access to sufficient water. The emphasised water access measures constitute the indicators that define access to safe drinking water, namely: proximity or physical access to a water point, water quantity, affordability, service availability and reliability, quality and safety, and acceptability. These indicators are commonly used to measure water accessibility, and they are the key to collect water accessibility data or information from the residents or households using a questionnaire.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

GIS-based analysis of spatial accessibility to essential community services research tends to utilise a mixed methods approach, analysing both qualitative and quantitative data. Bryman (2012) indicates that implementing a mixed-method approach in a study is determined or acceptable by the nature of the research questions and objectives. Bryman (2012) further discusses that the mixed research method is used to verify outcomes as a validation process. With regards to this research, the methodology used includes GIS models, identified water accessibility indicators and adopted standards, and designing questionnaires to collect data from the residents within the study area. Additionally, using a global positioning system (GPS) and GIS software were used to perform spatial analysis and visualise the data or results.

Spatial analysis is one of the GIS-based methods to analyse the accessibility of distributed essential services. Mokgalaka (2015) states that GIS-based accessibility analysis is a logical method that can be applied to test or examine accessibility to resources. Therefore, the research focus was to determine the access to drinking water within the community in the Langeloop settlement, determine improved accessibility measures towards water services and support and enhance current water sources provision and resource planning.

According to Bryman (2012), quantitative and qualitative research methods may be joined to double-check outcomes so that they might be commonly substantiated. Hence, objective and subjective indicators are equally significant in measuring residents' access to water, even though they give extra prominence to water quantity, reliability, quality, affordability, and proximity. A study by Fukuda-Parr *et al.* (2014) further maintained that access to sufficient water as a human right calls for objectives and indicators that are both qualitative and quantitative, which can reliably quantify critical aspects of water access. Therefore, this research used a mixed research methodology, whereby both the research methods, namely qualitative and quantitative methods, were used for data collection or assembly and analysis, so as to improve the rationality and reliability of the research results based on the research question and objectives.

The basic methodology and analysis stages used based on Mwamaso (2015) and Mokgalaka (2015) were:

Stage 1: To gather the required spatial data, such as Langeloop demographics, road network, imagery, and water infrastructure, from various sources. This includes collecting other readily available water-related information at different levels of aggregation, and cleaning and organising each dataset that can be used as inputs into the analysis.

Stage 2: To conduct a water accessibility survey in the community using a questionnaire.

Stage 3: To map the data in a GIS, apply the data from the water accessibility survey, and draw accessibility analysis. This stage includes a SAN analysis. The accessibility analysis indicates the areas that need the installation of water sources to address the backlog.

Stage 4: The discussion of the results of the analysis and make relevant recommendations.

3.2 A GIS-based analysis method

GIS-based analysis in the assessment of spatial accessibility has emerged as a logical and effective method for evaluating the extent to which equitable access to services and facilities is achieved. This methodology involves utilising advanced GIS tools to measure distance and supply factors for assessing spatial accessibility. Typically, it uses GIS software to create spatial networks and analyse various factors affecting accessibility, such as distance, transportation routes, and demographic characteristics (Stentzel *et al*., 2016). Several steps are typically followed to conduct a GIS-based analysis of spatial accessibility. Artmann *et al*. (2019) state that a primary network is initially constructed using GIS software, which includes identifying spatial locations of facilities or services, and creating a network structure to simulate different levels of transportation routes. According to Yaagoubi *et al*. (2022), the network structure includes nodes representing road intersections and connections representing different road levels. These nodes and connections form the basis for calculating access to services or facilities via SAN analysis (Ouyang *et al*., 2019).

The next step in the analysis is to calculate the accessibility to services or facilities based on the created network. This is done by considering factors such as travel distance, transportation modes such as walking, motorised traffic and cycling, and impedance or resistance of the transportation routes (Haque *et al*., 2020). Statistical analysis is also often employed in order to further refine the assessment of spatial accessibility. The final step in the methodology involves evaluating the spatial accessibility of services or facilities based on the calculated measures (Iraegui *et al*. 2020). This can be accomplished through various approaches, such as generating descriptive statistics in order to characterise accessibility based on the distance to each type of service, creating geographical representations that visually depict the spatial entry of the studied phenomena, and employing hierarchical clustering to identify critical trends at the neighbourhood level (Thiam *et al*., 2015). These steps allow for a comprehensive spatial accessibility analysis and provide valuable insights into the distribution and availability of services and facilities. Overall, GIS-based spatial accessibility analysis helps evaluate equitable access to services and facilities, especially with accurate data input.

The mixed methodology of the study is reflected within the identified Mwamaso (2015) and Mokgalaka (2015) basic methodology and analysis stages. The quantitative method includes more of stage 1 and 3, hence the number of service/facility location data is captured and quantified. The demographic information or households' statistics and the spot building count data analysed is reflective of quantitative method. Furthermore, the characterised water accessibility based on the distance to each of the water facilities also reflect a quantitative method. Additionally, the use of SAN analysis using the distances in meters, and quantifiable interpolated standpipes are part of the quantitative method. The qualitative method includes more of stage 2, whereby the questionnaire interviews were done to gather individual experiences and preferences when accessing water facilities. The results of the questionnaire reflect their true perspectives on water accessibility. Hence, according to Gine-Garriga *et al.*, (2013), the qualitative results assist to gain a more nuanced understanding of the challenges involved in achieving sustainable water access in different regions.

3.3 Data input for analysis

Stage 1 of the research was to gather the required spatial data. The data contains the community water service points, namely standpipe taps, reservoirs, water tanker service points, and other water sources, such as a river. Households with taps inside a house and in the yard are excluded from the study, as this constitutes the ultimate goal of service provision. This study aimed to assess the accessibility of water provision for the selected residents using the standards listed in Table 2.1 and the average convenient walking distance identified by the community until the local authority can provide yard taps or connect houses to the water network. The indicator data in Table 2.1 was used in a questionnaire to establish the distances to the various water service locations in Langeloop. The location of water sources allows for an accessible water source or supply point. Hence, the water demands are the selected households in Langeloop (Mans *et al.*, 2014:1).

Location data in Langeloop was not available at Nkomazi Local Municipality, which resulted in the use of a GPS to create the data. A GPS device captured water sources' locations where water networks or infrastructure spatial data prove unavailable. Water source attribute data, such as water source type and operational status, was also collected (Green *et al*. 2009). A Trimble Nomad GPS was used for the captured standpipes, and a data file dictionary was created in the GPS to capture the data accordingly. The captured data was further processed in a Trimble pathfinder software through a differential correction process. Lewis *et al*. (2019) indicated that it is essential to post-process the raw GPS data with Trimble Pathfinder Office software, using nearby Continuously Operating Reference Stations to obtain more accurate data.

Individual structures in the Langeloop Settlement showed an average household of 4.2 persons. Stats SA census data were used to sample several households with water demand. The location of the individual structures was sourced from Eskom's SPOT-building count points dataset. The spatial data was received as a shapefile for use in a GIS, and the metadata indicated that the data was created on the 30th September 2017. SPOT-building count data refers to collecting and analysing information regarding the number of buildings within a specific area (Zhang *et al.*, 2018). This approach utilises technologies such as big data, artificial intelligence, and machine learning to automate the classification of land use and building typologies, making capturing and extracting building parameters spatially explicitly easier and more cost-effective (Fan *et al.*, 2020). This data is essential for various purposes, such as urban planning, infrastructure development, accessibility assessment survey planning and resource allocation. However, the areas that have buildings that were erected after the SPOT data are rare in many sections, except in Mountain View, where the only expanding section in Langeloop, and they were addressed or catered for though the administered questionnaire survey of the study. Consequently, responses from the sampled households were aggregated into a thematic representation of the settlement sections.

3.4 Questionnaire survey

Stage 2 of this research involved the collection of data using a questionnaire in addendum A. The Langeloop study area consists of 11 sections/extensions, where a questionnaire was administered to 22 randomly selected households per section. This sample size has been determined using the sample calculator from Qualtrix on the Internet (Qualtrix, 2020). Qualtrix offers an online sample size calculator that can help determine ideal survey sample size quickly, by insetting the confidence level, population size, margin of error, and the perfect sample size is calculated. The number of households based on the Stats SA 2011 Census is 2657. Using a 90% confidence interval and a 5% error, the sample size is 246 households. It has been reduced to 242 households for ease of use, equating to 22 households per section.

The study utilised a structured questionnaire to obtain information on the nature of water accessibility. Only persons above 18 years of age were interviewed. The questionnaire was prepared in English to accommodate local and foreign people living in Langeloop. When a respondent could not read, speak, write, or understand English, the researcher explained the questionnaire to the respondent in their vernacular. A base map or Google image of the study area was first prepared and inserted into the survey questionnaire form, informing the respondents about the extent of the study area, and giving them a quick overview of it.

The questions based on the water access indicators were constructed and contained a five-point Likert scale to measure or rate the respondent's access to safe drinking water. Maritz (2013) states that in order to measure the perceived value of accessibility, a questionnaire is applied with the participants and a five-point standardised Likert scale, ranging from strongly agree to strongly disagree. Addendum A, the questionnaire's five-point Likert scale was measured from extremely poor to excellent. The questionnaire showed similarities with the questionnaire used by Maritz (2013) to collect a respondent's access to essential services.

Personal information, such as a respondent's age and the number of years of residence in Langeloop, was determined at the beginning of the survey for descriptive purposes. For the respondents with neighbours, the researcher determined if they have consistent interactions with their neighbours by verbally posing a question to the respondent, "Do you sometimes discuss your water access status with your neighbour ?" For the respondents with neighbours, the researcher determined whether or not they have consistent interactions with their neighbours by asking: "Do you sometimes discuss with your neighbour about your water access status?"

A question regarding the rating of their current access to safe drinking water in Langeloop was asked as part of the written questionnaire at the beginning and at the end of the survey questionnaire in order to determine the answers' consistencies. Responses at the start of the questionnaire were meant to state or determine their intuitive access to water rating. Ultimately, their more coherent and considered rating of access to safe drinking water was answered after knowing the considered indicators in the study.

A column of a priority scale was added to the questionnaire in addendum A in order to determine all the indicators' relative importance. According to this priority scale, the respondents scaled the indicators that they would like improved in their space/location before the others. This priority scaling provided the weightings to map access to safe drinking water in Langeloop. It gave a general view of what most residents would like to be improved in order to improve their access to safe drinking water in Langeloop considerably.

Lastly, a question within the questionnaire asked whether the respondents needed to walk to fetch water from a water facility source, as well as what would be a convenient distance they could walk. The distances are 100m, 150m, 200m, and 250m, respectively. The latter is the standard distance listed in Table 2.1., where based on Google Earth images, 100m represents roughly a street block in Langeloop.

While administering the questionnaire, some neighbouring residents took interest in responding to the questionnaire survey, however it was explained to them that the sampling size for the representative collective response had been reached.

3.5 Software

As part of Stage 3 (analysis), the software used for this research is Flowmap version 7.4.2 and ArcGIS 10.6. Flowmap software has been used to conduct the accessibility analysis by, amongst others, Ragoasha *et al.* (2018), Mokgalaka (2015), and Green *et al.* (2014). It proves to be one of the best suitable to measure access to facilities, and it is an open software with no license fees (free to download and to use). Flowmap has a series of functions that are not present in ArcGIS software (Green *et al*., 2014), and it has not been developed as a complete GIS package (Liu and Zhu, 2004). Geertman *et al*. (2003) state that Flowmap is a computer software well-suited to be integrated into a GIS-based planning support system, such as facility planning and accessibility analysis, owing to its ability to model and analyse geospatial interaction and network flows.

ArcGIS software was used to organise data for the analysis and visualise the analysis results. ArcGIS 10.6 is a software capable of performing geo-spatial analysis, geocoding, geo-processing, relational data management, and map production. The collected fieldwork data was used in ArcGIS for preprocessing and analysis. The GPS points showing the locations of the water sources included attribute data such as water source type and water facility functional status. The spatial attribute tables within ArcCatalog in ArcGIS 10.6 Version presented the water source attributes. They formed part of the data analysis informing decision-making regarding replacing or allocating water sources.

3.6 Data analysis

Stage 3 represents the analysis section of the methodology. Access to potable drinking water is modelled using the respondent's convenient walking distance to access water, as asked from the questionnaire and the indicator's standard of 250m. The analysis begins with the residents' perception of water quality and provision and determines the convenient walking distance to a water service point. The first data analysis was done in MS Excel to quantify counts of satisfaction and dissatisfaction, average convenient walking distance, and other water-related statistical counts. The latter was fed into the accessibility analysis using ArcMap. Using standard analysis methods such as standard deviation that are already available in MS Excel is anticipated, and it is not necessary to use sophisticated statistical software such as R and SPSS.

The GIS was used to prepare the data in Flowmap and ArcMap. The following datasets were required for modelling:

1. Destination data: water sources such as standpipes and water tanker locations, was collected using a GPS.
2. Origin data: The households in each section, determined using GeoTerraImage's building point dataset or Eskom SPOT building count dataset.

3. Road network: The local roads that people use to collect water. Langeloop's road network was obtained from Nkomazi Local Municipality, and it was cleaned in Flowmap through removing footpaths and clipped towards the study area.
4. Tessellation set: The tessellation set represents the analysis's demand and supply surface. This unit (hexagon) proves particularly useful for spatial analysis and visualisation, due to its equal size and fine resolution (Maritz *et al.*, 2017:6). The analysis units, which are the hexagons, are considered adequate for measuring access equally; meanwhile, they give more precise and accurate distance measurements than other uniformly shaped tessellation types (Ragoasha *et al.*, 2018). The tessellation was created in Flowmap, it was made up of 50 meters in length per side, making it 6495 square metres.

Spatial analysis:

1. Once the data has been prepared, ArcMap determined the currently served areas, namely households collecting water within a distance of 250m or less and unserved areas, which are households collecting water within a distance of above 250m or more.

2. Unserved households within 250m walking distance from a water source are those that depend on water sources whose capacities, such as JoJo tanks, are insufficient to meet the demand.

3. The SAN tool in ArcMap was used with the average convenient 250m walking distance to a service point to determine the areas served by the standpipes. The GIS SAN tool primarily analyses the service scope of the service facility, by modeling or calculating the approximate distance back from the road centerlines that is considered reachable from the road. Therefore, polygons are created, and those polygons are a network service areas or regions that

encompasses all accessible streets. This process is like creating a traditional buffer zone. However, it is different because it uses the local road network to calculate the distances, rather than using a point with a constant distance. According to Mwamaso (2015), road length should always be used in order to establish accessibility, rather than a ‘crow’s flight’ distance from the source.

4. Creating the link of households served or unserved into the tessellation surface, was done through ArcMap using a geoprocessing tool called spatial join to aggregate the households that exist within the served or underserved areas. An assumption was made that a hexagon without a household is regarded as an area where there is no population, or no water demand.

5. The final step was to determine new optimal locations for water sources to serve the demand from established unserved areas using interpolation in ArcMap. After determining which places are served and which are not, the sites of the proposed standpipes were established. As a result, proposed standpipes were manually simulated or interpolated within the map, and positioned in the unserved areas where households are represented. After the proposed standpipes were placed where there are households, a Service Area Network analysis was conducted several times on the proposed stand pipes until it was determined that the entire areas with households are served.

The results are used as part of the discussions and recommendations. Meanwhile Figure 3.1. illustrates the abovementioned data analysis methodology.

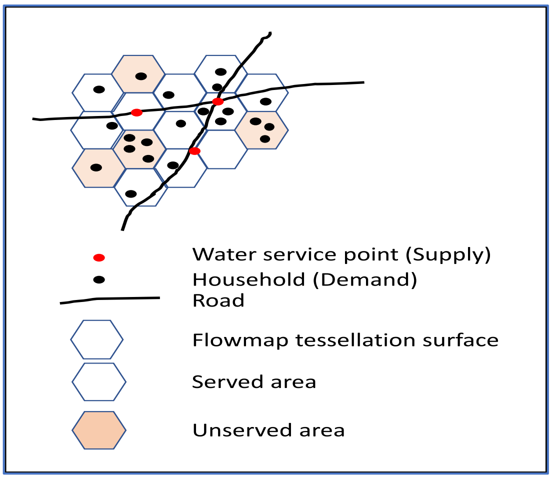

Figure 3.1: Determining served and unserved areas using ArcMap and Flowmap

One challenge encountered while analysing the standpipes for water accessibility was that while conducting the survey, some of the standpipes were captured as non-functional, because water was not available in those standpipes during the facility capturing. This resulted in technical problems for several weeks, and it was a concern to use those standpipes on the accessibility analysis. However, based on Mwamaso (2015), it is stated that a water point or standpipe is considered to be functional even though water is only available seasonally, or where there were no long-term technical issues on the standpipe. On the contrary, a water point or standpipe is considered non-functional if it does not supply water for more than six months consecutively (Mwamaso, 2015). Thus, because the captured standpipes that were recorded were non-functional, the residents mentioned that those standpipes did function periodically, and in cases where they experienced technical problems, they were fixed within two months. They were then regarded as functional standpipes and were considered or used in the accessibility analysis.

3.7 Results, discussions, and recommendations

This is Stage 4 of the methodology. Once the various analyses had been conducted, the results were discussed in Chapter 4, and recommendations were made to improve water provision in Langeloop. Maps were used where applicable to substantiate the results and suggestions.

3.8 Ethics

Since the research involved interviews with selected residents from Langeloop, UNISA's standard ethical procedures were followed, and UNISA granted ethics approval, refer to addendum B. The ethics reference number is 2022/CAES_HREC/033. This included the obtained consent letter from the relevant authorities to conduct the interviews in Langeloop, an informed consent letter from UNISA that needed to be signed by the participant, and strict adherence to COVID-19 regulations. Furthermore, the researcher used local guides to assist the researcher in entering Langeloop, conducting the interviews and mapping the water sources.

3.9 Conclusion

This research used a mixed research methodology, whereby both the research methods, namely qualitative and quantitative methods, were used for data collection and analysis in order to improve the rationality and reliability of the research results based on the research question and objectives.

The following essential descriptive practice and GIS-based analysis stages were used.

Stage 1

The data containing the community water service points, such as standpipe taps, reservoirs, and water tanker service points, was collected. Households with taps inside a house and in the yard were excluded from the study. A GPS device was used to capture water sources' locations and were used as water-accessible or supply points. Furthermore, Eskom's SPOT building count point dataset was collected and used as water demand or household points.

Stage 2

Data was collected using a questionnaire in addendum A. The Langeloop study area consists of 11 sections/extensions. A questionnaire was administered to 22 randomly selected households per section. This sample size has been determined using the sample calculator from Qualtrix on the internet (Qualtrix, 2020). The number of households based on the Stats SA 2011 Census is 2657. Using a 90% confidence interval and a 5% error, the sample size is 246 households. It has been reduced to 242 households for ease of use, equating to 22 households per section. Only persons above 18 years of age were interviewed. The questionnaire was prepared in English in order to accommodate local and foreign people living in Langeloop, and the researcher explained the questionnaire to the respondents in a vernacular language to those who did not speak or understand English.

The questionnaire had a five-point Likert scale to rate water accessibility indicators based on their experience with water accessibility in Langeloop. The questionnaire's five-point Likert scale was measured from extremely poor to excellent. The questionnaire had similarities with the questionnaire used by Maritz (2013) to collect respondent’s access to basic services. A question regarding the rating of their current access to safe drinking water in Langeloop was asked in the written questionnaire at the beginning and at the end of the survey questionnaire to determine the answers' consistencies or correlation. A column of a priority scale was added to the questionnaire to select all the indicators' relative importance. In this priority scale, the respondents scaled the indicators that they would like to be improved in their space/location before the others.

Stage 3

At this stage, data analysis was done, where the first data analysis involved the counting and mapping of the captured water sources. The second analysis was done from the questionnaire in MS Excel to quantify counts of the rated water accessibility indicators, indicating satisfaction and dissatisfaction, average convenient walking distance, and other water-related statistical counts. Furthermore, for analysis, the software used for this research is Flowmap version 7.4.2 and ArcGIS 10.6. However, Flowmap software was used to organize data for the analysis, and ArcMap for analysis and to visualise the analysis's results. For the analysis, a tessellated surface was created. The tessellation set was used to determine the demand and supply surfaces.

Several steps are typically followed to conduct a GIS-based spatial accessibility analysis, as stated by Artmann *et al*. (2019). After the data had been prepared, spatial analysis was performed as the last analysis. For this reason, a SAN analysis tool in ArcMap was used with the average convenient 250m walking distance to a service point to determine the areas served by the standpipes. This was accomplished through various approaches, such as generating descriptive statistics to characterise accessibility based on distance to each type of service, creating geographical representations that visually depict the spatial entry of the studied phenomena, and employing hierarchical clustering to identify critical trends at the neighbourhood level (Thiam *et al*., 2015). ArcMap determined the currently served areas, households collecting water within a distance of 250m or less, and unserved areas, which are households collecting water within a distance above 250m or more.

Stage 4

At this stage, the results were used as part of the discussions and recommendations in Chapter 4. UNISA's standard ethical procedures were followed while implementing the methodology, especially in data collection.

CHAPTER 4

RESEARCH DATA ANALYSIS RESULTS AND FINDINGS

4.1 Introduction

This chapter consists of the findings/results and a discussion of the practically implemented data collection, data processing, and data analysis. The administered questionnaire in addendum A was analysed, and the statistical analysis was done in line with the objectives of the study and in relation to the standards of the water access indicators on how people as water service consumers rate/rank their accessibility to safe drinking water. The chapter goes into great detail about the spatial coverage of water sources, and it explicitly reveals the mapped water source patterns, citizens' perceptions, and SAN analysis output, which revealed pockets of under-served and well-served areas. It also covers the spatial statistics of the population that is well-served or under-served and the level of service provided for each water access indicator in the study area. Hence, there is a comprehensive and comparative evaluation of all indicators of water accessibility.

4.2 The spatial distribution of currently available water resources

Accurate information on the spatial distribution of currently available water resources is crucial for ensuring effective management and planning of water use. The available water sources were accurately captured using a GPS. Understanding the spatial distribution of available water resources in Langeloop is essential for the implementation of the Nkomazi IDP water projects. This spatial knowledge is necessary for various applications, including water resources planning and management at both river basin and local level scales, which includes water reticulation, surface water allocation for agriculture practices and the design of water supply and irrigation systems. Additionally, comprehension of the temporal and scalar variability of water resources is important when analysing and establishing sustainable management practices. Furthermore, inadequate planning and management of water resources can lead to inefficient actions and contribute to the unbalanced spatial and temporal distribution of water resources in a settlement. Another crucial aspect is understanding the anticipated demand for water resources. This information can be used to ensure an equitable allocation of water resources.

Regarding the question of what type of water provision is available, and where is it located, as per the study sub-question, the objective of establishing the spatial distribution of currently available water resources in Langeloop has been accomplished. According to Scott *et al.* (2002), a comprehensive data collection of water facilities is very important to illustrate the patterns of water service distribution. Additionally, the water data ought to mostly consist of all water points, which include boreholes, water tankers, reservoirs, water bulk, and reticulated standpipes. At Langeloop Settlement, there are 100 currently available water points or resources, and they were determined by capturing their location and coordinates with a GPS, as Green *et al*. (2009) and Dusabe and Igarashi (2020) have done in their studies.

In Figure 4.1, the map displays the captured 100 water points. Within the 100 water points, there are 93 standpipes, two reservoirs, and five privately-owned water tankers. Two boreholes were excluded since they have been non-functional for more than 15 years.

In Figure 4.1, there is another potential water source north of the Gomora and Sidzakanini section, which is the Mlumati River. The river is mostly used by the neighbouring farms for crop irrigation, and the community usually use the river to perform rituals, which makes it difficult for the community to use the river water as their source of daily drinking water. The river consists of some pollutants from the performed rituals, and those pollutants are dangerous in that they can cause undetected diseases (Higgs, 2004). In this study of accessibility to safe drinking water, the river is therefore discarded as a safe source of water to the community; hence, the community also does not want to use the river water for any cooking or drinking. Figure 4.1 further illustrates the spatial distribution of the functional 100 water points whereby the community can access safe drinking water.

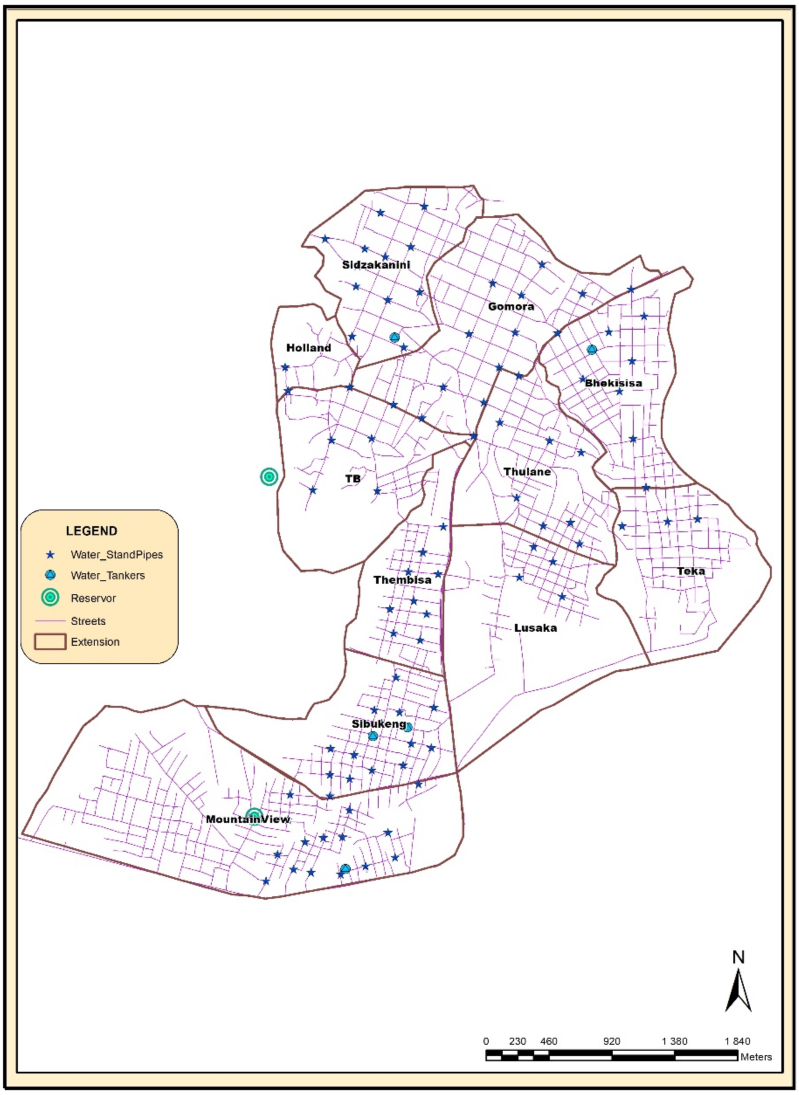

Figure 4.1: Spatial distribution of available water points.

The water points distribution depicts spatial patterns; the patterns illustrate spatial inequality; hence, the topic of the study emanates from observing the unequal spatial distribution of essential services rendered to people in communities within South Africa (WHO, 2016). The two reservoirs, as illustrated in Figure 4.1, are meant to serve the entire Langeloop Settlement by supplying the water to the standpipes and for the water tankers to fetch the water and supply it to the community. There are five water tankers, and they fetch the water from the reservoirs at a cost to the community members who requested them. Community individuals with a water container below 2500 litres are not permitted to fetch water directly from the Langeloop reservoirs. The location of the water tankers operational in Langeloop is illustrated in the map presented in Figure 4.1, and the location is based on the residential location of where they are stationed. Therefore, it is impossible to quantify or categorise the distribution of the reservoirs and water tankers based on which extension or section they are providing a service to, since, in this case, the reservoirs and water tankers service the entire Langeloop Settlement. Meanwhile, water tankers were excluded from the GIS analysis because they were mobile and had a temporal spatial location (Dusabe and Igarashi, 2020).

The 93 standpipes are those water sources that are quantifiable or identifiable based on which sections they are servicing. In Figure 4.2, a map illustrates the spatial distribution of the standpipes per extension, and the spatial inequality distribution is highly visible. There are some extensions with many standpipes compared to other extensions; for example, in Figure 4.2, Mountain View has 15 standpipes, and Teka has three.

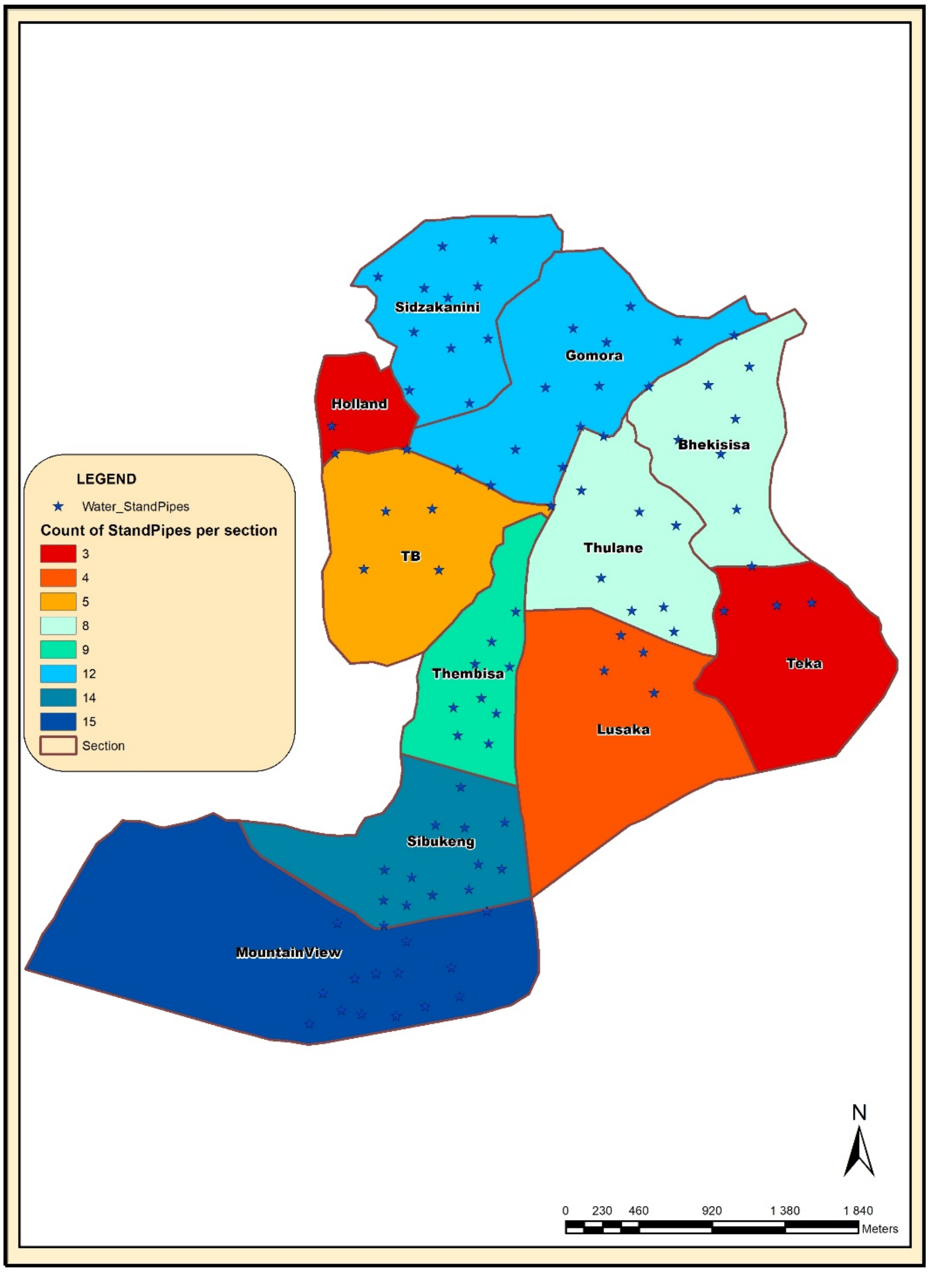

Figure 4. 2: Map of the number of water standpipes per section.

The count of standpipes per section in Figure 4.2 is displayed as a thematic map. Thematic maps are an essential tool for visualising spatial data and conveying complex information effectively. According to Zhao *et al*. (2020), the use of symbols plays a central role in the creation of thematic maps, allowing map makers to communicate information clearly and efficiently to users. It was, therefore, important to make the thematic map or design symbols that are simple yet comprehensive. The design and production of choropleth maps, in particular, have become streamlined due to well-established data symbolisation techniques (Zhao *et al*., 2020). The thematic map depicted in Figure 4.2 was created using ArcGIS software (ArcMap). The creation of the thematic map began by importing the water standpipes and settlement extensions/sections into ArcMap, and then making a spatial join. The spatial join was made from the settlement extension with the water standpipes. The spatial join features tool is designed to transfer and append information from one layer to another, and the information that is transferred is based on the type of spatial relationship defined or based on a common attribute that is shared between the two datasets. Optionally, statistics can be calculated for the joined features. Therefore, the spatial join of standpipes into the settlement extensions was done with the spatial relationship of the location-based option of the standpipes within the settlement extensions layer, along with a statistical option to sum the standpipes per section.

Furthermore, a joint settlement extension layer was then created, consisting of the aggregated number of standpipes per section. In ArcMap, the joint settlement extension layer was symbolised categorially in the symbology tab, and the aggregated count of the standpipes field was used on the unique value category to symbolise the counts; the unique value renderer option allows the user to symbolise features in a layer based on one or more matching attributes. The lowest count per extension is three standpipes, and the highest count is 15 standpipes per extension, as illustrated in Figure 4.2. The map further illustrates the water infrastructure invested by the local municipality in Langeloop, which proves insufficient to fulfil the needs of the community. According to Dąbrowski *et al*. (2021), the purpose of a thematic map is to communicate quantitative and qualitative data through the use of visual representation, and thematic maps provide researchers with a means of conducting spatial analysis and exploring complex relationships within an area. However, the thematic map in Figure 4.2 does not reflect the complex relationship of water accessibility; for instance, it cannot be assumed that the areas with more standpipes have greater access to water than those areas with fewer standpipes. At this stage, further spatial analysis is required to determine the spatial water access relationship that exists in Langeloop.

4.3 The level of satisfaction of the residents' access to safe drinking water

To determine the level of satisfaction with the residents' access to safe drinking water, a questionnaire in addendum A was designed and administered to the 242 sampled households. Maritz (2013) indicated that to measure the perceived value of accessibility, a questionnaire is applied to the participants, and a five-point standardised Likert scale ranges from strongly agree to strongly disagree. The water accessibility indicators were scaled in the questionnaire in addendum A as follows:

Extremely Poor	**Below Average**	**Average**	**Above Average**	**Excellent**
Mark = 1	***Mark = 2***	***Mark = 3***	***Mark = 4***	***Mark = 5***

A statistical average calculation of the residents' responses as per Green *et al*. (2008) and Maritz (2013) was done, and the observations are discussed. There were two identical questions, but they were positioned differently within the questionnaire. One question was positioned at the beginning of the questionnaire and the other at the end of the questionnaire. The question was: "Considering all aspects of accessing water, how do you rate your access to safe drinking water in Langeloop?" The water accessibility responses at the start of the questionnaire were meant to state or determine their intuitive access to water rating, and ultimately, proved to be a more coherent and well-thought rating of access to safe drinking water, since the latter (for consistency) was answered after knowing the considered indicators in the study.

Figure 4.3. presents a bar graph that indicates the comparison of the residents' responses to the question. The observation of this bar graph indicates that the residents' intuitive response to their accessibility to safe drinking water is below average in all of the settlement extensions. The observation of these results further indicates that, within the community, there is a perception that access to safe drinking water is compromised, and the community is aware that there is a lack of access to clean and safe drinking water in a certain area or the entire community. This perception is caused by a variety of factors, such as lack of infrastructure, natural disasters, or economic and political issues. For example, according to the Department of Forestry, Fisheries and the Environment (DFFE) (2013), the lack of proper management and institutional capacity within municipalities to deal with illegal water connections also leads to inaccessibility to safe drinking water. Thus, according to Mokgalaka (2015), the GIS-based accessibility analysis is a logical method that can be applied to test or examine the degree to which access is obtained.

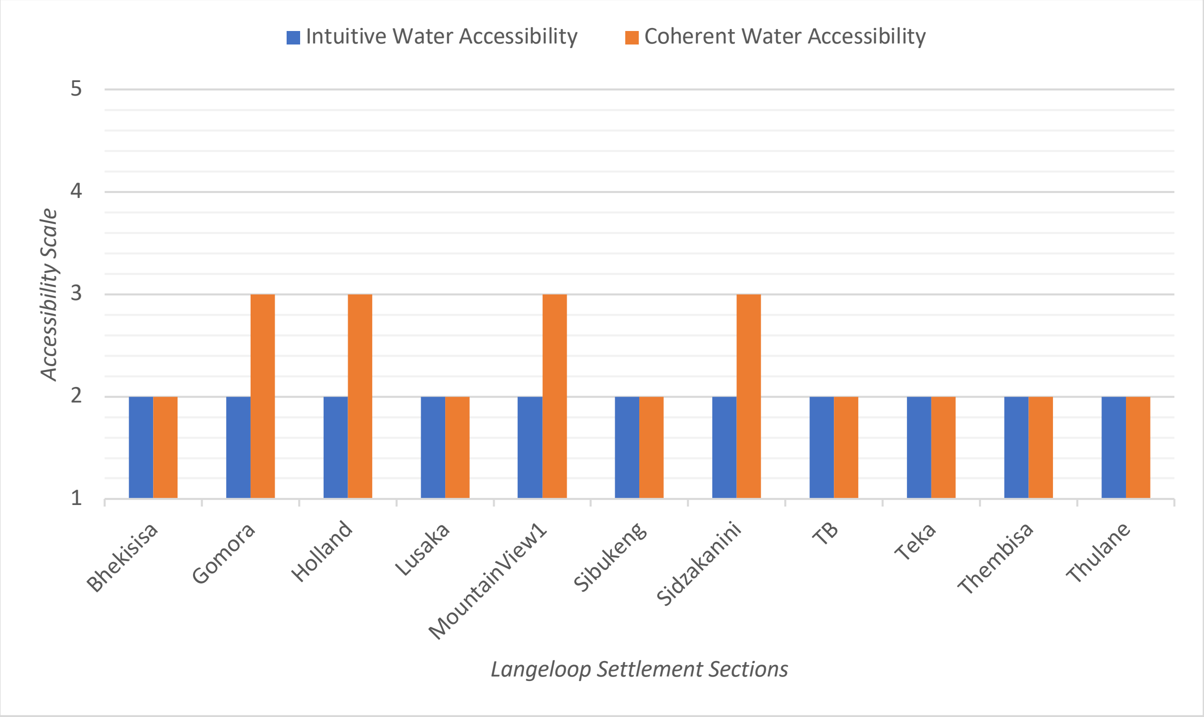

Figure 4.3: Intuitive and coherent current water accessibility per section

The coherent water accessibility results in Figure 4.3. also indicate that most of the settlement extensions' accessibility to water is below average. The observation that four extensions (36%) are on average accessible and seven extensions (64%) are below average correlates with the observation of Statistics South Africa (STATS SA) (2011), which indicates inaccessibility to drinking water for many settlements, including Langeloop with 23% accessibility to drinking water.

4.4 The current sources of clean and safe drinkable water in Langeloop

The community currently sources clean, safe, and drinkable water from the standpipes and from the water tankers. The results of the questionnaire in addendum A indicate that the majority of the households in Langeloop source clean water from the standpipes, and only a few households source their clean water from the water tankers. Figure 4.4. indicates that within the 11 sections, ten (10) sections mostly rely on standpipes rather than water tankers to access clean water, whereas one section mostly relies on a water tanker to access clean water.

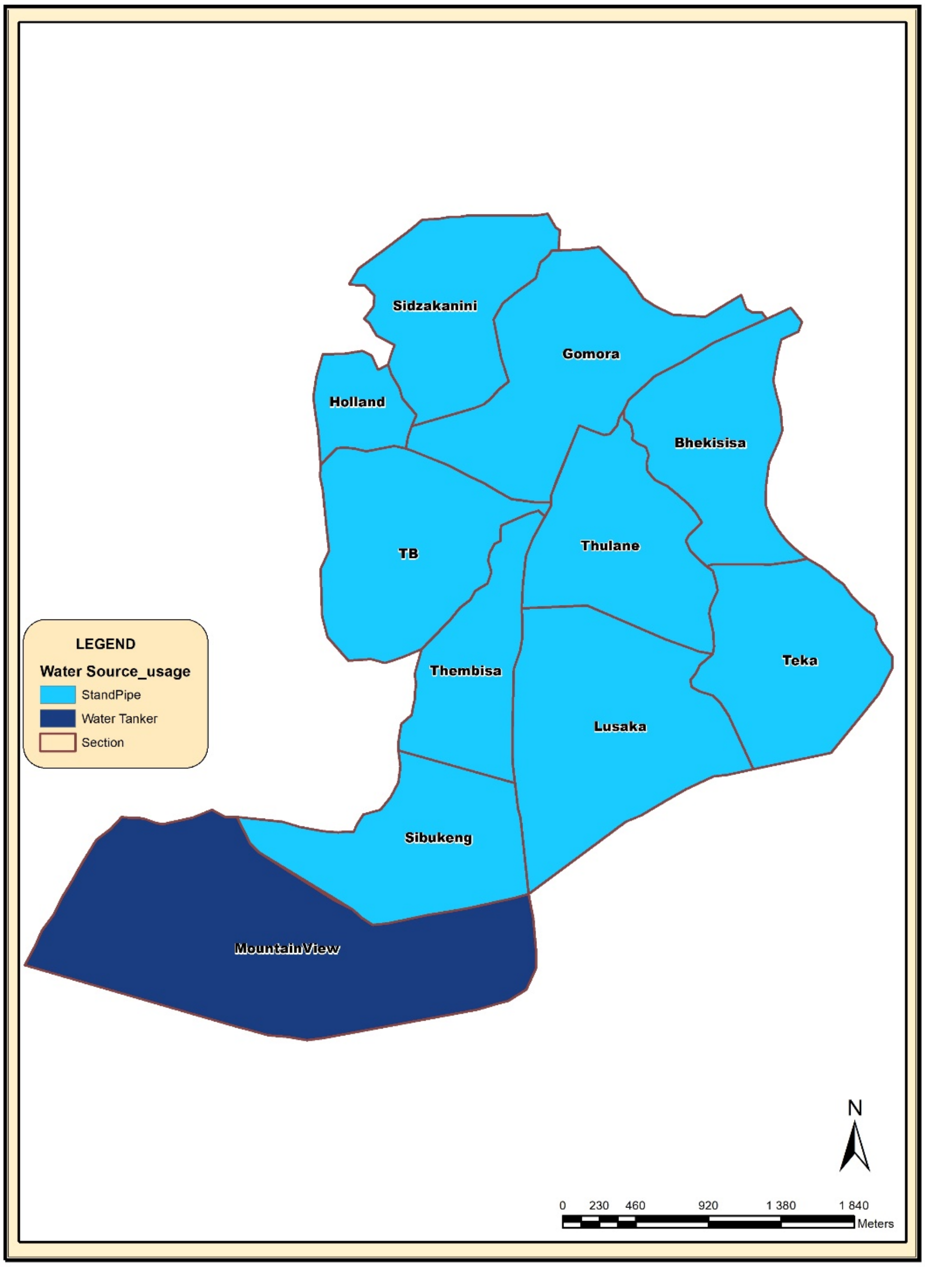

Figure 4.4: Standpipes and water tanker usage

Based on the observation in Figure 4.4, the Mountain View section is the one section that is more reliant on using water tankers to access clean water. However, the observation in Figure 4.4 in relation to the previous observation in Figure 4.2, the common obvious observation in Figure 4.2 and Figure 4.4 is that Mountain View Extension had the highest number of water source infrastructure access, such as the standpipes and the higher water tanker usage, which implies that there is high-water demand in that section, or that there is a higher number of households that are in need of water access than other sections. This bears itself out when observing the Langeloop local traditional chiefs allocating residential plots of land. The Mountain View section has more densely populated households than the other extensions. Furthermore, the Mountain View section is expanding or developing with new households since the local traditional chiefs continue allocating plots of land. The expansion of this section implies that water demand is also expanding, and that water accessibility will continue to be a challenge.

4.5 Measured water accessibility indicators in Langeloop Settlement

The measured water access indicators are those indicators that define access to safe drinking water in a standardised manner (Mwamaso, 2015). The indicators are water proximity, water quantity, quality, availability/reliability, and affordability. The addendum A questionnaire results for those indicators are shown in Figure 4.5 Water Accessibility per section. The results in Figure 4.5 show that water proximity is rated below average in all the 11 sections in the Langeloop Settlement. The respondents collectively consider themselves to be collecting water at a walking distance above 250 metres since, according to DWS (2017), the standard distance to access clean water is 250 metres.

Figure 4.5: Water Accessibility per section

One of the reasons why the respondents are perceived as getting access to water beyond a walking distance of 250 metres is because they indicated that some of the water standpipes are not reliable; as indicated in Figure 4.5, the availability of water indicators is below average in eight of the sections, which means there are interruptions in receiving water daily, with some standpipes partially functioning, causing water not to be available daily. However, according to DWS (2017), water should be made available 365 days per year, and not interrupted for longer than 24 consecutive hours.

When conducting the survey, respondents indicated that when water is not available in a standpipe, they therefore walk a further distance to collect water on another standpipe, where some prefer hiring a water tanker to collect and deliver the water to them. Additionally, the majority of the respondents indicated that they prefer to walk from one standpipe to another, because they cannot afford to pay for a water tanker. This reason is supported by the results of the affordability water indicator, as indicated in Figure 4.5. It is below average in 10 sections. Access to safe, drinkable water in rural areas is usually not affordable to the residents because the majority of the people in rural areas are unemployed and economically disadvantaged (Mwamaso, 2015). The affordability of water access is also dependent on the water infrastructure affordability of reservoir construction and maintainance of the installed water pipes (Hutton, 2012). Meanwhile, when the community does not have enough money to pay for the rendered services, this leads to a decay of service infrastructure.

According to Figure 4.5, water quantity, quality, and acceptability indicators for water access appear to be performing better. This means that, when respondents access water, the majority notice that no matter which standpipe or water tanker they use, they receive 25 litres of water per day regardless of distance, even though some of them pay water tankers to bring the water to them. In so doing they still receive the 25 litres of water daily, but the affordability indicator is compromised. Meanwhile, the basic water quantity level is defined as 25 litres for each person per day at no cost (Mothetha *et al.*, 2013). However, the results of the survey in Figure 4.5, when observing the quality and acceptability indicator, show that the respondents obtain clean quality water in a sensible way, and that the quality of the water is acceptable to the respondents. According to Masanyiwa *et al.* (2014), the acceptability indicator is meant to identify clean quality water accessibility in a user-friendly water infrastructure for all citizens.

Furthermore, the observed detailed results in Figure 4.5 are reflected in aggregated results in Figure 4.6. The water accessibility indicators in Figure 4.6 reflect what the respondents of the Langeloop Settlement collectively perceive about their water accessibility. What is observed in the results is that three of the water access indicators, namely proximity, availability and affordability, performed below average and those indicators are most critical for water accessibility. Hence, the entire settlement indicated that they currently lack water availability, and they struggle to fetch the little available water while they also cannot afford to pay for the water or the water tankers. The other three indicators, namely quantity, quality, and acceptability, have performed average or better since, according to Omarova *et al*. (2019), those indicators are secondary critical indicators. However, they also reflect existing water access inequalities in the settlement, where some of the residents are tolerant of how they currently access water, with the hopes that their water accessibility will be improved over time (Omarova *et al.,* 2019). The observation of the results in Figure 4.6 indicates that the standards of water access indicators have not been met in the whole settlement, which implies that there is very poor water accessibility. Meanwhile, according to Green *et al*. (2008), when the standards are met, a local authority's provision of water services can be deemed accessible and equitable.

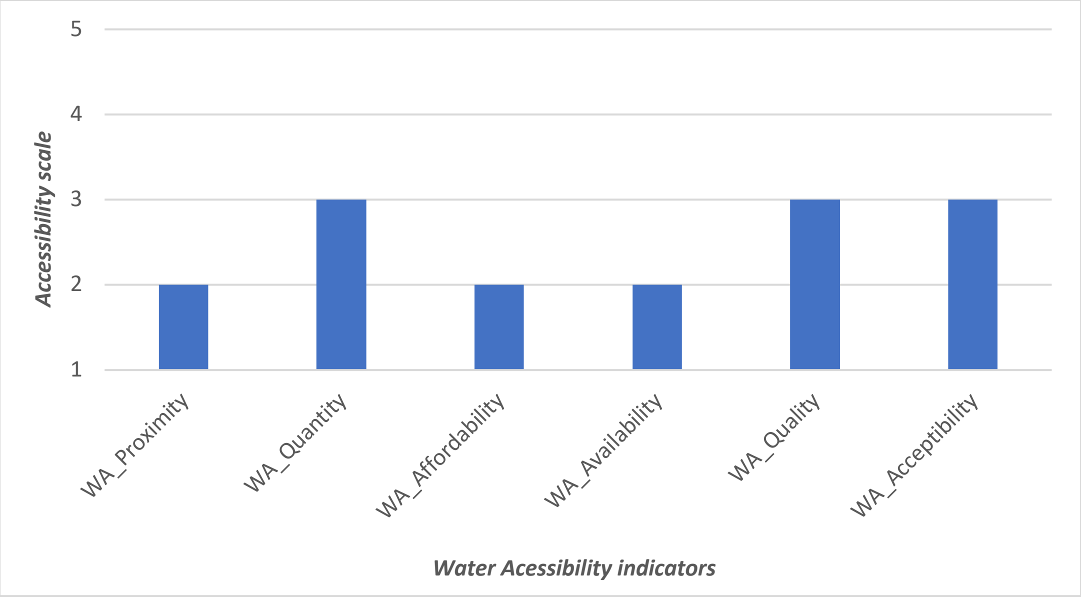

Figure 4.6: Langeloop Water Accessibility Indicators scaled

4.6 Priority indicator ranked to be improved

A column of a priority scale was added to the questionnaire in addendum A to determine all the indicators' relative importance. For this priority scale, the respondents scaled the indicators that they would like to be improved in their space/location before the others. The scale ranked from 1 to 6, and the ranked number 1 is the urgent or most prioritised indicator to be improved, while the ranked number 6 is the lowest/last indicator to be improved for water access in Langeloop. Figure 4.7 shows the results, where the entire Langeloop Settlement have prioritised water availability as their first indicator to be improved. This also points to the need to improve water infrastructure to ensure that water is always available at a convenient distance for the residents. The proximity indicator was ranked second because, in Figure 4.6, a majority of the community already felt they were collecting the available water at a distance above 250 metres. Quality came third, and quantity fourth, because the community deemed it appropriate to have access to clean and safe water that is available at the nearest place.

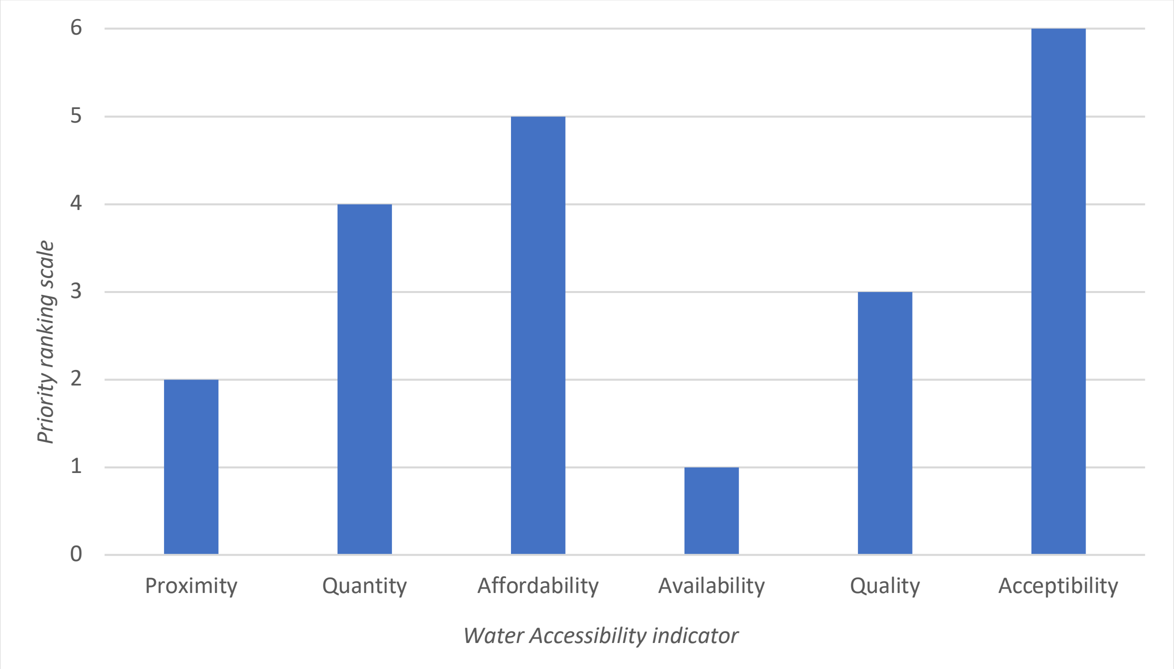

Figure 4.7: Prioritised indicator to be improved before the other

4.7 Sections that are under-resourced with safe water facilities

Mokgalaka (2015) indicates that measuring spatial accessibility to water is done by computing the data using different travel modes, trip purposes and time spent.

Settlement sections that are under-resourced with water infrastructure are regarded as water-unserved areas (Maposa *et al.*, 2012). This is because, where there is water infrastructure, it is expected that water facilities will serve the intended areas. To determine the served or under-served areas, a GIS was used through a SAN analysis tool. A SAN analysis is a method used to assess the accessibility of network services within a specific area (Ekanayaka and Perera, 2018). Therefore, in the SAN analysis tool, the standard proximity of 250 metres was used to identify served and unserved areas. Standpipes were the point of origin/facilities used to determine the proximity of 250 meters accessibility; this excluded reservoirs and water tankers, because the reservoirs are fenced and gates locked; people are not allowed to walk directly and collect water from the reservoir. The water tankers were excluded because they are mobile, and only those who can afford to pay can access water from them.

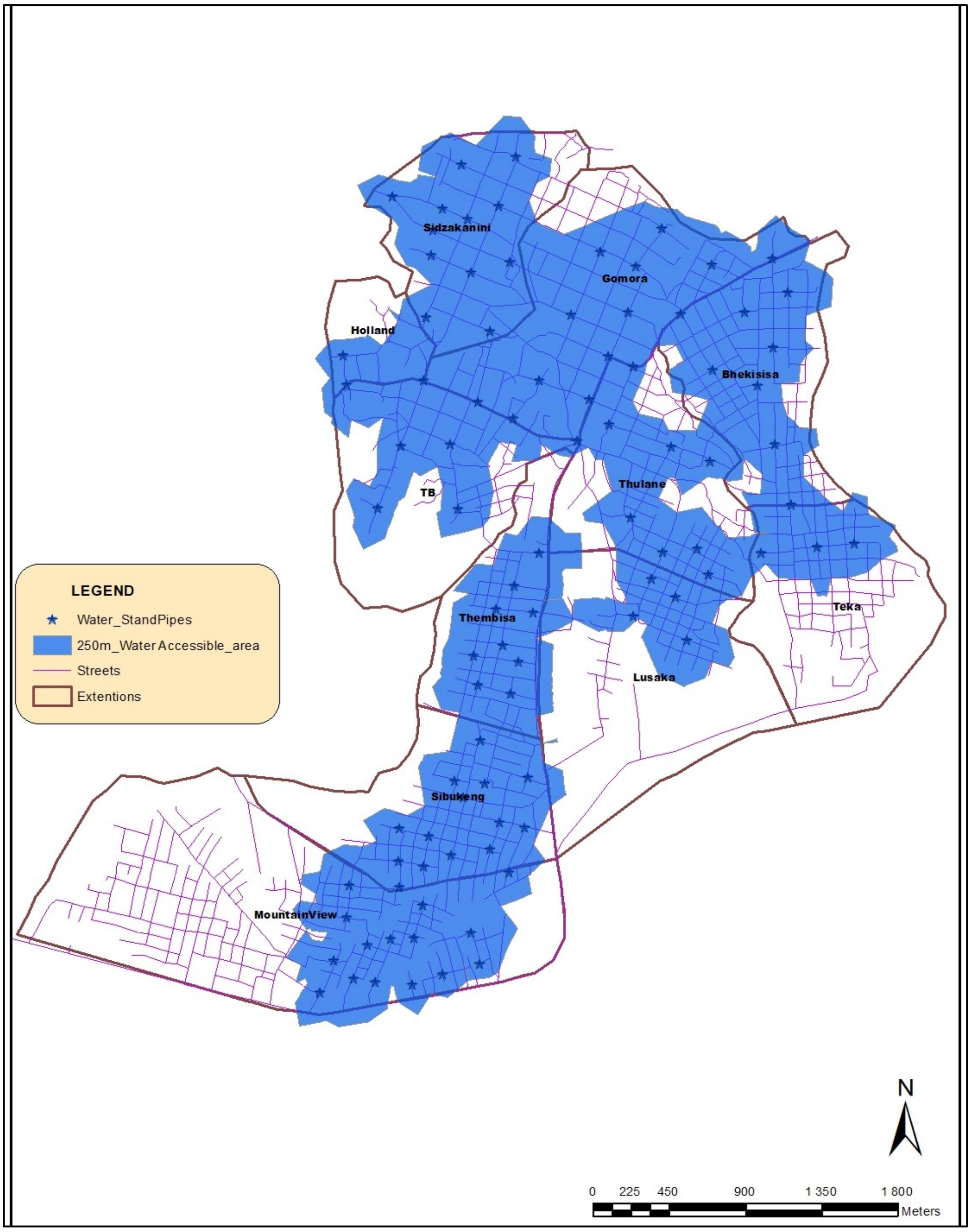

Figure 4.8: Water-served areas

In Figure 4.8, the results indicate areas that are served by the standpipes, and the areas outside the identified served area are unserved. The observation of these results in Figure 4.8 shows that the served areas are central to the settlement. By observing

Figure 4.8, the areas that are not served include most parts of four sections, namely Teka, Lusaka, TB and Mountain View sections. These results are consistent with the results in Figure 4.5, where the residents rated the proximity indicator to be below average, which means they acknowledge that there are some areas that access water, but the majority of the residents observe that water is only accessible to certain portions or certain standpipes, which require the residents to walk a further distance to access a functional standpipe. In Figure 4.8, there are patches of unserved areas in all the settlement sections.

The tessellated map view in Figure 4.9 proves particularly useful for spatial visualisation due to its equal size and fine resolution (Maritz *et al*., 2017). Figure 4.9 is the tessellated view of the served and unserved areas. The tessellation is made up of 50 metres in length per side, making it 6495 square metres. The tessellation made it more possible to view the areas that are served, and those underserved within an equal surface distance of each hexagon, because they give more precise and accurate distance measurements than other uniformly shaped tessellation types (Ragoasha *et al*., 2018).

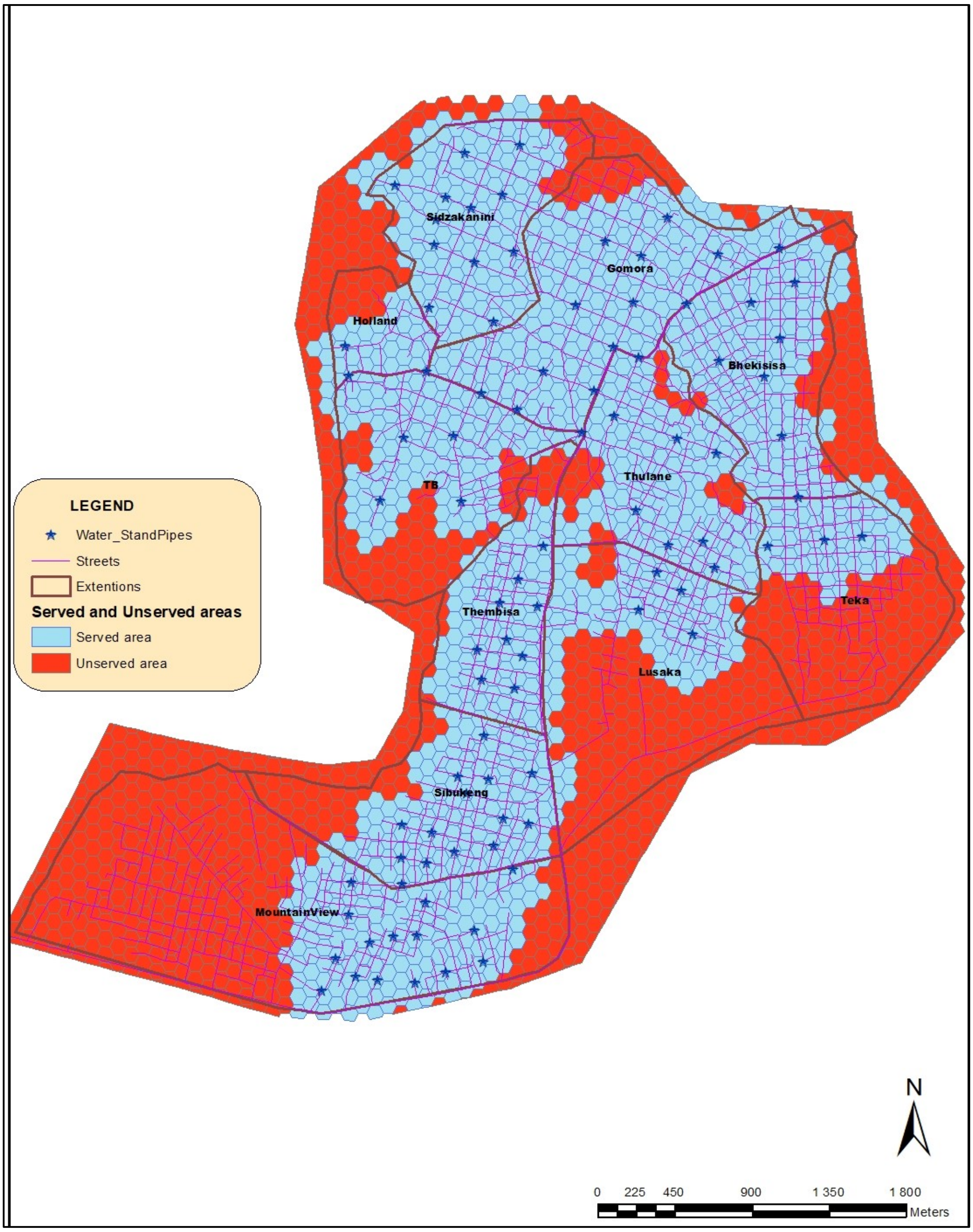

Figure 4.9: Tessellated water served and unserved areas

In the areas where the water is served or unserved, there are households experiencing daily inequalities that exist in the settlement. The creation of the tessellated surface has made it possible to increase the number of households that are served or under-served. In Figure 4.10, the map indicates tessellations with embedded or linked households; the households are the 2017 SPOT building count data provided by Eskom. The tessellation has a minimum of one household and a maximum of eight households, and they are reflected by their respective colours in Figure 4.10. The households that are served are visible within the light-blue shaded area, which indicates where the water standpipes are serving the households, while those outside the blue shade are not served. According to Mans *et al*. (2014), water demand is determined by the number of consumers, and in this study, the water demands are the households in Langeloop. By observing the map in Figure 4.10, there is a high number of households not served in Teka, Lusaka and Mountain View sections.

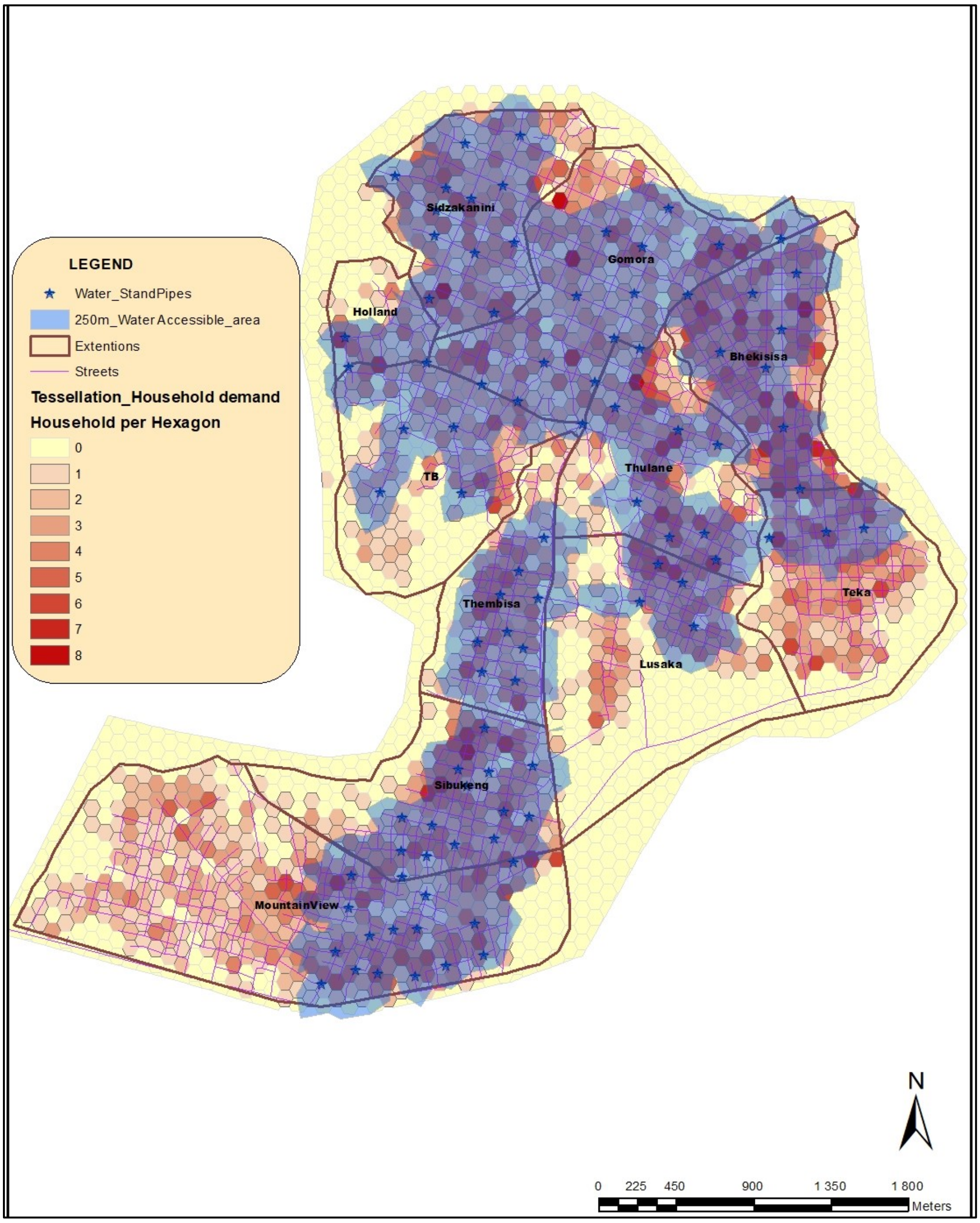

Figure 4.10: Tessellated households with water accessible areas

4.8 Recommendations to improve access to safe water in the under-resourced sections

The households that are not served, as per Figure 4.10, are households that need to be also prioritised equally with those that are served. Accessibility to safe drinking water is one of the fundamental human rights that should not discriminate or display any spatial inequalities. According to the WHO (2016), inequalities exist, where rural populations typically live in worse economic situations than urban populations, and one of the terrible economic situations is evident in Figure 4.6, whereby the observation of the affordability of water has been ranked below average by the residents of Langeloop Settlement.

Therefore, to address the spatial inequality to access safe water within Langeloop, it is recommended that additional standpipes should be installed within the areas that are not served, as indicated in Figure 4.9 in which are shown areas that are not served by the current standpipes. The proximity and availability indicators in Figure 4.6 were ranked below average, and by installing additional standpipes while making sure water is always available in all the standpipes, accessibility to safe water at Langeloop will be addressed or solved. In Figure 4.11, there are 140 proposed standpipes that can be installed in the Langeloop Settlement. The proposed standpipes in Figure 4.11 are proposed, based on the areas or patches that are not served within the settlement, and these are placed strategically within each section to serve safe water to the households.

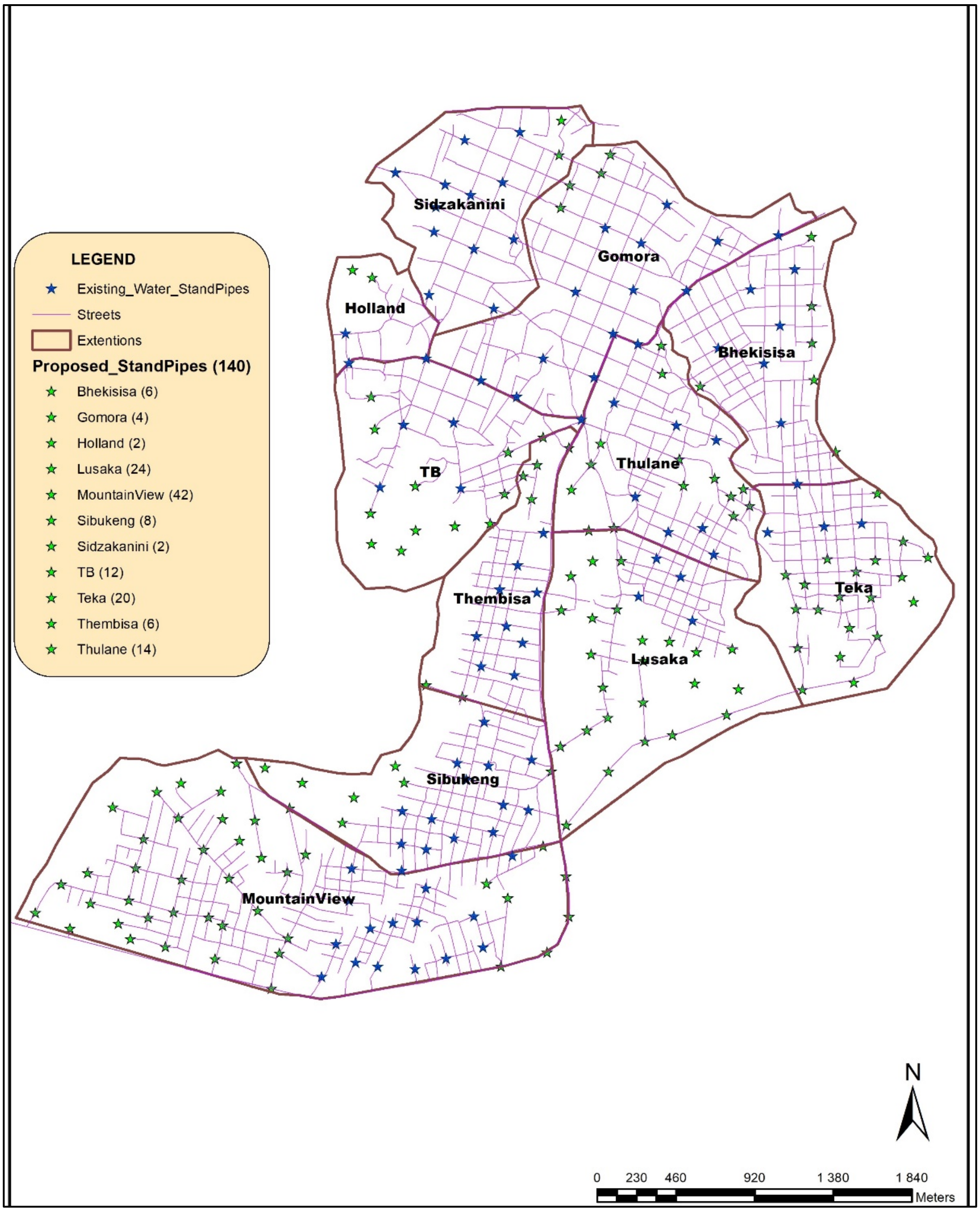

Figure 4.11: Proposed water standpipes

The proposed standpipes will be highly beneficial to the community because they are one of the ways in which to improve access to safe drinking water within the settlement. In Figure 4.12, it is evident that the additional standpipes can serve the households that are currently not served in Figure 4.10. Through the proposed standpipes, a 250 metre proximity indicator distance was used in the service area network analysis in Arcmap. This is done in order to determine whether the proposed standpipes will indeed make an impact to improve accessibility to safe drinking water (Slawson, 2017). Therefore, in Figure 4.12, the hexagonal surface area was imbedded or spatially joined with the served and unserved area data, along with similar spatial join with the households. The areas that were previously not served are currently served as indicated in the map, and all the sections' households are served with safe, drinkable water because they are within 250 meters of proximity. The areas that are not served in Figure 4.12 are the areas where currently there are no households. It would be a waste of resources to install standpipes in those unserved areas in Figure 4.12.

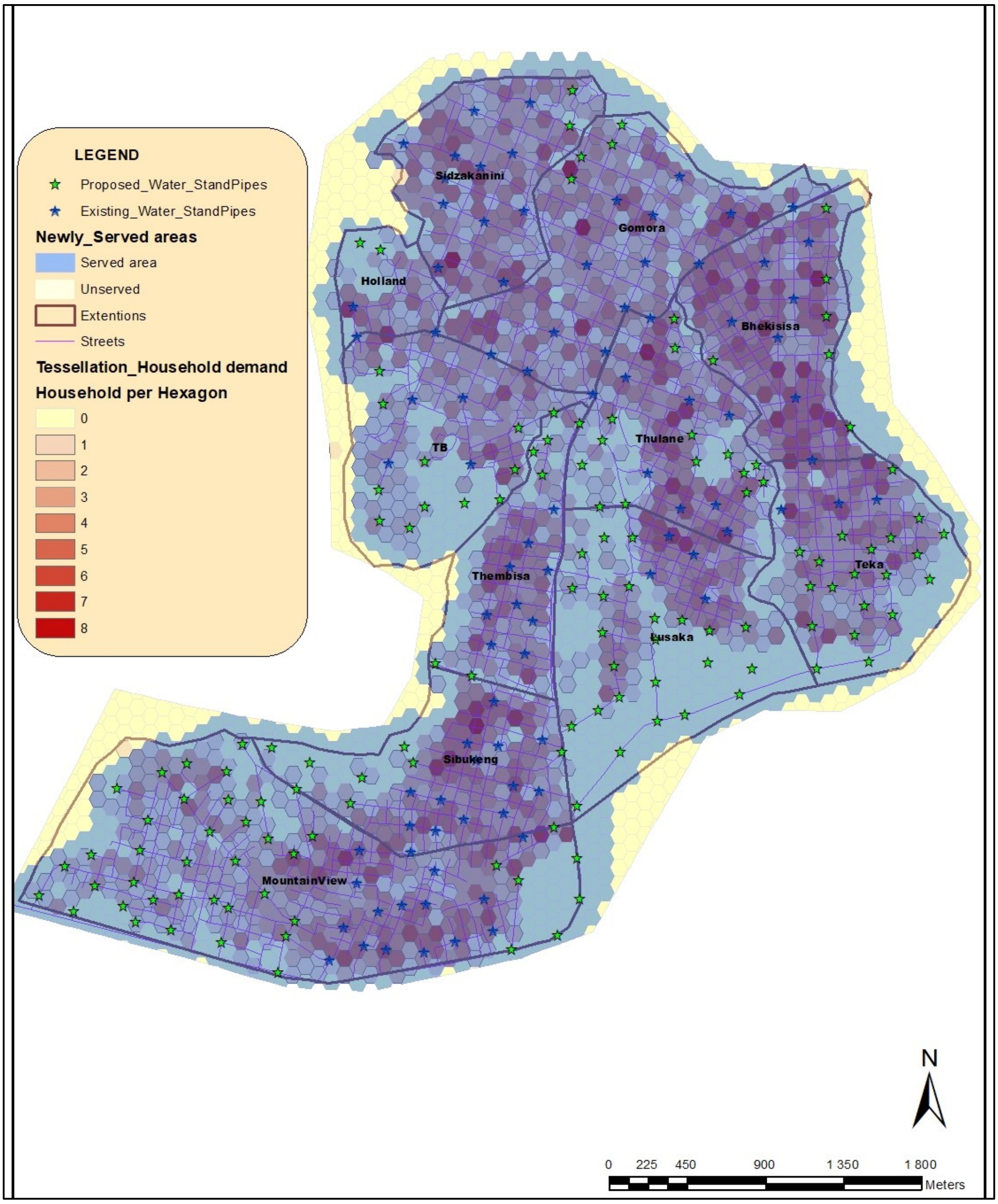

Figure 4.12: Water-accessible areas by the proposed water standpipes

There are several recommendations to improve access to safe water in the Langeloop Settlement, including constructing and maintaining the proposed and existing standpipes. Hence, according to Slawson (2017), in order to ensure sustainability, it proves critical to ensure that standpipes are properly placed, operational, and maintained. Upgrading water supply networks and distribution systems can help to ensure that water is delivered more efficiently and reliably to standpipes. According to Omarova *et al.* (2019), as standpipes often rely on a centralised water supply, water treatment technologies can be implemented at the source to improve the quality of the water and improve the availability of safe water. According to DWS (2017), the treatment of water at low costs constitutes an efficient approach towards water resource management. It therefore proves itself to be one of the solutions to conserve water and supply water sustainably for domestic use.

Investing in infrastructure while implementing low-cost water treatment solutions, such as affordable water treatment technologies that include chlorine tablets, ceramic filters, or bio-sand filters, can be effective in removing contaminants from water sources and improving their safety. According to Mukheibir and Sparks (2003), contaminated water that is unfit for drinking leads to a reduced water supply, and both conditions make it difficult for people to acquire safe drinking water. Reducing water pollution efficiently increases water reserves, which in turn increases the safety margin for maintaining the water supply (Mukheibir and Sparks, 2003). Using technology such as remote sensors and other digital tools can help to monitor water quality and identify potential problems before they arise. Hence, there is a greater need to improve the safety of water sources and improve monitoring systems for water supply (Omarova *et al*. 2019).

Promoting community engagement: engaging with communities to understand their needs and concerns is essential for successful water access projects. Community members can also be involved in the planning, implementation, and maintenance of water infrastructure and treatment systems, because this ensures the community that water is acceptable and creates awareness of safeguarding the water infrastructure. Masanyiwa *et al.* (2014) elaborate that acceptability is fundamental in defining residents' access to essential water in user-friendly water infrastructure for all citizens.

Overall, a multifaceted approach that includes a combination of the recommended options will be effective in improving access to safe water in the Langeloop Settlement, and these are likewise important to considering the specific needs and challenges of the community, and to work collaboratively with community members to develop further sustainable solutions. Some sustainable water solutions include:

- Leak detection and repair: Regular inspection and repair of the standpipe and its components will help prevent water losses and ensure a sustainable water supply.
- Rainwater harvesting: Collecting and storing rainwater in buckets.
- Greywater reuse: Using water from showers, sinks, and washing clothes for non-potable purposes can reduce the demand for freshwater and then ease the pressure on water treatment facilities.
- Install solar-powered pumps: Using solar-powered pumps to draw water from the source and distribute it to the standpipe will reduce energy consumption and costs, and help ensure a reliable and sustainable water supply.
- Drilling boreholes where there are no standpipes and maintaining them will also be a sustainable water solution.

4.9 Conclusion

The results and findings were discussed in line with the objectives of the study. To begin with, the sub-question is in relation to what type of water provision is available and where it is located. As per the study, it is found that in the Langeloop Settlement, there are 100 currently available water points or resources. These were captured using a GPS, as done by Green *et al*. (2009) and Dusabe and Igarashi (2020). In Figure 4.1, the map displays the 100 captured water points. Within the 100 water points, there are 93 standpipes, two reservoirs and five privately owned water tankers. The location of the water tankers is based on the residential location of where they are stationed, as well as the reservoirs.

The 93 standpipes are the water sources that are quantifiable or identifiable based on which sections they are servicing. In Figure 4.2, a map illustrates the spatial distribution of the standpipes per extension/section. However, it was impossible to quantify or categorise the distribution of the reservoirs and water tankers as to which extension or section they are providing a service to because, in this case, the reservoirs and water tankers are servicing the whole Langeloop Settlement. Meanwhile, water tankers were excluded from some of the GIS analyses because they were mobile and had a temporal and spatial location (Dusabe and Igarashi, 2020). The count of standpipes per section in Figure 4.2 is displayed in a thematic map. There are some extensions with many standpipes compared to other extensions; for example, in Figure 4.2, Mountain View has 15 standpipes, and Teka has three. However, the map assists in identifying the spatial inequality distribution of water infrastructure invested by the local municipality into the community of Langeloop.

A questionnaire in addendum A was also administered to determine residents' water accessibility experience and statistical average calculation of the residents' responses. One of the questions was asked twice at the beginning and at the end of the questionnaire to determine a given respondent's intuitive access to water rating, and in the end, the more coherent and well-thought (after considering the water access indicators standards) rating of access to safe drinking water. The question stated, "Considering all aspects of accessing water, how do you rate your access to safe drinking water in Langeloop?" Figure 4.3 presents a bar graph that indicates a comparison of the residents' responses to the question, revealing residents' intuitive response to their accessibility to safe drinking water as below average in all of the settlement extensions, where the coherent water accessibility results also indicate that most of the settlement extensions' accessibility to water proves itself to be below average. This indicates that within the community, there is a perception that their access to safe drinking water is compromised, and the community is aware that there is a lack of access to clean and safe drinking water in a certain area, or the entire community.

Furthermore, the results of the questionnaire indicate that the majority of the households in Langeloop source clean water from the standpipes, and only a few households source their clean water from the water tankers. Figure 4.4 indicates that within the 11 sections, ten sections mostly rely on standpipes rather than water tankers to access clean water, whereas one section mostly relies on a water tanker to access clean water. However, the one section from the 11 is the Mountain View section, which is observed to be more reliant on water tankers than it is on standpipes. The observation in Figure 4.2 (map of water standpipes per section/extension) and Figure 4.4 (standpipes and water tanker usage per section) is that the Mountain View extension has the highest number of standpipes and water tanker usage, which implies that there is high-water demand in that section, or there is a high number of households that are in demand of water access than the other sections.

Additionally, the questionnaire results on the water access indicators standards are indicated in Figure 4.5. In Figure 4.5, the results indicate that water proximity is rated below average in all the 11 sections in the Langeloop Settlement, the availability of water indicator is below average in eight of the sections, where the affordability water indicator is below average in 10 sections, and the water quantity, quality, and acceptability indicators appeared to be performing better because they are rated on average. Furthermore, the results of all the sections were aggregated to a settlement point of view, and the results in Figure 4.6 indicate that three of the water access indicators performed below average, and the other three indicators performed average or better. However, the collective observation is that the standards of water access indicators have not been met in the entire settlement, where there is a high degree of inequality in water accessibility. Hence, when the standards are met, a local authority's provision of water services can be deemed accessible and equitable (Green *et al.*, 2008).

Furthermore, in order to improve water accessibility, residents were required to rank the water access indicators that they would like to be prioritised for water accessibility improvement in the Settlement. Figure 4.7 shows the results, and the whole Langeloop Settlement has prioritised water availability as their first indicator to be improved. This also points to the need to improve water infrastructure to make sure that water is always available at the resident's convenient distance because the proximity indicator was ranked second. The water quality indicator came third and quantity at fourth place because the community deemed it appropriate to have access to clean and safe water that is available at the nearest place or at a convenient distance.

In order to determine the served or under-served areas, a GIS was used through a Service Area Network analysis tool. The standard proximity of 250 metres was used to identify served and unserved areas. In Figure 4.8, the results indicate areas that are served by the standpipes, and the areas outside the identified served area are unserved. By observing Figure 4.8, the areas that are not served include most parts of four sections, namely Teka, Lusaka, TB and Mountain View sections. These results are consistent with the results in Figure 4.5, where the residents rated the proximity indicator below average. In Figure 4.10, the map indicates tessellations with embedded households; the households are the 2017 SPOT building count data provided by Eskom. The tessellation has a minimum of one household and a maximum of eight households. By observing the map in Figure 4.10, there is a high number of households not served in the Teka, Lusaka and Mountain View sections. Therefore, in order to address the spatial inequality to access safe water within Langeloop, it is recommended that additional standpipes be installed within the areas that are not served. By installing additional standpipes while making sure water is always available in all the standpipes, accessibility to safe water at Langeloop will be addressed or solved.

In Figure 4.11, based on the areas or patches that are not served within the settlement, there are 140 proposed standpipes that can be installed in the Langeloop Settlement. Therefore, in Figure 4.12, the areas that were previously not served are currently served as indicated in the map, and all the sections' households are served with safe, drinkable water; hence, they are within 250 meters of proximity. However, there are several recommendations to improving access to safe water in the Langeloop Settlement, including constructing and maintaining the proposed and existing standpipes. According to Omarova *et al*. (2019), as standpipes often rely on a centralised water supply, water treatment technologies can be implemented at the source to improve the quality of the water and improve the availability of safe water. Additionally, with regards to promoting community engagement, engaging with communities to understand their needs and concerns is essential for successful water access projects and to effectively implement sustainable water access solutions.

CHAPTER 5

CONCLUSION

5.1 Introduction

This chapter presents a conclusion of this research, which includes a summary of all the chapters. Moreover, the objectives and responses to the research questions presented in Chapter 1 are used to summarise the findings to further help demonstrate a solid understanding of the research topic and its implications. Hence, the research also offers practical recommendations and implications for stakeholders or practitioners in accessibility studies or within the field of basic community services planning. Additionally, the research has real-world applicability and can contribute to improving practices or addressing existing challenges in the Langeloop Settlement, while suggesting avenues for future or further study.

5.2 Conclusions

The research topic is a GIS-based approach to analyse potable water accessibility in Langeloop Village in Enhlanzeni District Municipality, Mpumalanga. This study emanates from the spatial distribution patterns of people and their variable need for basic services, which is a stretched attentive interest within the field of basic community services planning. It divulges a challenge that is well suited for GIS analysis. Thus, water resource planning has long been a problem in South Africa, hindering effective service delivery, including in Langeloop Settlement. However, the full level of basic service delivery is targeted, and anticipated to satisfy people's demand for water for various uses such as business, domestic, industrial, agricultural, and mining. Additionally, satisfying people's water demand is done in an integrated manner where there are water consumer stakeholder engagements, while making the most efficient and sustainable use of available water sources.

Water is a fundamental human need worldwide, crucial for sustaining life and ensuring the well-being of individuals and communities. The GIS-based accessibility analysis is a logical method that has been applied to test or examine the degree to which access is obtained (Mokgalaka, 2015). This research has used a mixed research methodology, where both qualitative and quantitative research are used for data collection or assembly and analysis, so as to improve the research results' rationality and reliability. The study's mixed approach is evident in the fundamental methodology and analysis stages indicated by Mwamaso (2015) and Mokgalaka (2015). Stage 1 and 3 activities such as capturing and quantifying the service facilities, are the quantitative method. The data analysis of the spot building count and the demographic information or household statistics are indicative of the quantitative approach. Additionally, the quantifiable simulated or interpolated standpipes and the characterised water accessibility based on the distance to each water facility both exhibit a quantitative approach. The questionnaire interviews conducted in stage 2 to collect individual experiences and preferences when accessing water facilities is the qualitative method.

The integration of GIS technology in water resource management has led to a more precise evaluation of available water resources, facilitated effective data management and analysis, and improved decision-making capabilities. However, this multidimensional approach allows for the identification of areas in need of improvement and informs decision-making regarding water resource management policies and infrastructure development strategies.A GIS-based approach to analysing potable water accessibility involves assessing the proximity, quantity, quality, and availability of water sources to ensure that people have reliable access to safe drinking water. Here are some summary steps that were considered when analysing and mapping potable water accessibility:

i. Data collection: collect relevant data such as households, road networks, and imagery, including locations of water sources such as standpipes and other water-related infrastructure from a diversity of sources, or physically capture data in the field using a GPS device.

ii. Define water access indicators: determine the indicators that will assess water accessibility. Common indicators include proximity, which is the distance to the nearest water source; water quality; water quantity; water availability; water affordability; and acceptance.

iii. Designed a questionnaire form: the questionnaire is inclusive of the water access indicators and prepared to conduct a water accessibility survey in the community or study area.

iv. Stakeholder engagement: engage with local communities, water management authorities, and other relevant stakeholders to gather additional insights and feedback. Hence, local knowledge can provide valuable information about water sources, accessibility challenges, and potential solutions.

v. Perform geospatial analysis: utilise GIS software to analyse and visualise the data. GIS software allows the overlay of various layers of information, such as water sources, population distribution, and infrastructure, to identify patterns and gaps in water accessibility.

vi. Execute a SAN analysis: GIS calculate the distance from populated areas to the nearest water sources using road network data. This analysis helps identify areas that have access to water or where people have to travel long distances to access water. This helps to prioritise areas for intervention.

vii. Interpolate interventions: this includes interpolating water standpipes to the areas that have no access to potable water. It predicts the proximity coverage of water accessibility where people have to travel long distances to access water.

viii. Make further water access recommendations: The local context or regional sustainable water management strategies are applicable. Furthermore, it includes continuous monitoring of water accessibility in the study area; hence, water accessibility is dynamic and changes over time. For instance, establish a monitoring system to track changes in water availability and proximity. However, regularly updated data and indicators used in analysing and mapping accessibility ensure the accuracy and relevance of the information and recommendations.

Following these steps leads to a comprehensive understanding of water accessibility in a given area, which guides decision-making, resource allocation, and targeted interventions to improve water access for communities in need.

5.3 Summary of the research findings

- **Located the available water provision in Langeloop.**

For the entire Langeloop Settlement, there are 100 currently available water points, and these were determined by capturing their location and coordinates with a GPS. There are 93 standpipes, five privately owned water tankers, and two reservoirs among the 100 water points. At the moment, the community gets its drinkable, safe, and clean water from water tankers and standpipes. The spatial patterns shown by the distribution of water points depicts spatial inequality, such as the uneven distribution of standpipes within the Langeloop sections.

- **Satisfaction of access to safe drinking water within the Langeloop Settlement**

A questionnaire containing water accessibility indicators was created and administered to 242 sampled houses in order to ascertain how satisfied the locals were with their access to safe drinking water. The measured water access indicators as indicated by Mwamaso (2015), are the indicators that define access to safe drinking water in a standardised manner. Based on the results of the questionnaire, the majority of the settlement sections have below-average water accessibility. According to these results, there is a collective perception in the community that not everyone has equal access to clean, safe drinking water, and people are aware that some parts of their community, if not the entire settlement, lack that access to safe water. Therefore, the community is dissatisfied with the current water accessibility. Hence, the entire Langeloop community decided to rank water availability as their first priority indicator to be improved. This also points to the need to improve water infrastructure to make certain that water is always available at a convenient distance for the residents. However, the proximity access indicator was then ranked second priority indicator to be improved, where the water quality indicator came third, and quantity at fourth place to be prioritised for improvement, because the community's responses determined that it is appropriate to have access to clean and safe water that is available at their closest location and convenient distance to regard them satisfied with their access to safe water.

- **The areas that need urgent attention to the provision of potable water**

A SAN analysis tool within ArcMap was used to identify the areas that are served or underserved with safe drinking water. To determine which locations are served and which were not, a standard proximity of 250 metres was used in the service area network analysis tool. The results indicate that the areas that are not served include most parts of four settlement sections, namely Teka, Lusaka, TB and Mountain View sections. However, the areas that needs urgent attention to the provision of potable water are all the sections in the settlement, because all sections have patches of unserved areas, and the current access to safe drinking water is below average. These results correlate with the results in Figure 4.5, whereby the residents rated the proximity indicator below average due to the fact that many residents access water above 250 metres. Furthermore, in figure 4.10 the GIS tessellation surface makes it easier to visualise the areas and the households that are served and those underserved within an equal surface distance in the Langeloop Settlement.

5.4 Recommendations

The households suffering from a lack of water accessibility or are currently not served, as per Figure 4.10 need to be prioritised to promote equality of access. Thus, it is recommended that 140 more standpipes be installed in the unserved parts of

Langeloop in order to alleviate the geographical imbalance of access to clean water. There are proposed standpipes in Figure 4.11, and are proposed based on the areas or patches that are not served within the Settlement, which are placed strategically within each section to simulate that they serve safe water to the households. Assuming that water is available or delivered to the standpipes, a 250-meter proximity indicator distance was used to assess whether the planned or proposed standpipes would, in fact, improve accessibility to clean drinking water. Consequently, as shown in the map in Figure 4.12, the areas that were not previously serviced are currently simulating as served, and all of the households in the sections are supplied with safe, drinkable water. According to Slawson (2017), to warrant sustainability on safe water accessibility, it proves critical to ensure that standpipes are properly placed, operational, and maintained. Thus, it is recommended to invest in infrastructure while implementing low-cost water treatment solutions, such as chlorine tablets and ceramic filters. Furthermore, it is recommended to promote community engagement and sustainable water solutions, which include rainwater harvesting, water recycling and reuse strategy, and leak detection and repair regularly.

5.5 Limitations and future research

The study could not conduct a scientific water quality assessment, such as contamination levels and the presence of pathogens in the water that the community of Langeloop are currently accessing. This information can be obtained from future water testing research and reports or proposed local water quality monitoring programmes, because scientific water quality assessment data can be overlayed with the population distribution to identify areas where water safety may be compromised. Thus, poor water quality has an impact on a person’s water accessibility, because a person would travel a long distance to access quality or safe water. The water quality data would also further help to determine the safety of water supplied by water tankers and the water tankers that collect potable water from a safe source to the community to have water collection licenses or be recognised by the community through the licenses to ensure accessibility to quality water.

Another limitation of this study is the assessment of the condition of the road, which looks for potholes or gully streets, that could delay or limit water accessibility. Hence, some standpipes might not be accessible due to flooded roads or streets, because when there are heavy rains, the roads get flooded, the ground gets saturated, and wheelbarrows cannot move or the water tankers cannot supply water to the residents who depend on or access water through water tankers. However, further research could be conducted on road usability under damaged conditions or rainy seasons. Hence, water accessibility is also limited by those circumstances.

In summary, the issue of water accessibility is a critical concern for community sustainable development and requires collaborative efforts on multiple levels to ensure that every individual has access to safe drinking water sources. Moreover, such efforts must be informed by comprehensive research and understanding of the complex dimensions and factors associated with water accessibility, including environmental sustainability, economic viability and social equity.

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Addendum: A

A SURVEY QUESTIONNAIRE

A GIS-based approach to analyse potable water accessibility in Langeloop village in Ehlanzeni District Municipality, Mpumalanga, South Africa.

(This document is confidential and for research purpose only)

Questionnaire:

General information of the head of the household:

Gender	Female:		Male:		Age:	
How long have you been staying in Langeloop?			Years:			

Access to safe water:

Scale definition:	😡	🙁	😐	🙂	😃
	Extremely Poor *Mark = 1*	**Below Average** *Mark = 2*	**Average** *Mark = 3*	**Above Average** *Mark = 4*	**Excellent** *Mark = 5*

Considering all aspects of accessing water, how do you rate your access to safe drinking water in Langeloop?	😡	🙁	😐	🙂	😃

Type of water access:

Tap in the house	Tap in yard	Stand-pipe	JoJo tank next to house	Water tanker	Dam	Hand pump (yard)	Hand pump (communal)	JoJo tank (communal)	River	Other

Please indicate the “other” access to water: …………………………………………………………

If your water access is other than “Tap in the house”, “Tap in yard”, and “Hand pump (yard)” – Rate the following water access indicators.

Assessment of water access indicators:

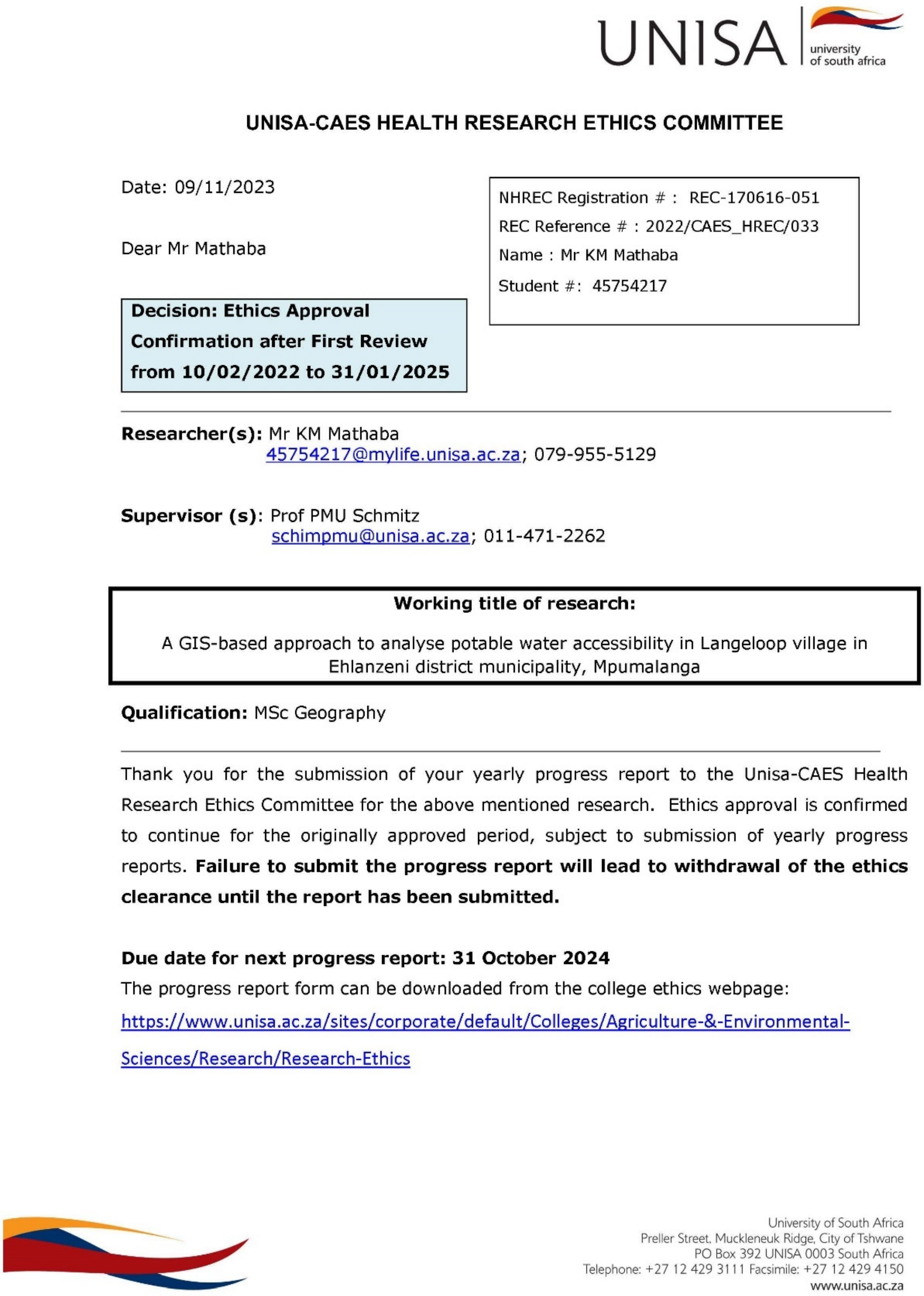
Indicator	**Indicator standard description**	☹	🙁	😐	🙂	😃	**Scale of Priority (1-6)**
1. Proximity or physical access to water point	Rate your access to water, distance Less than 250 meters.						
2. Water quantity	Rate your access to at least 25 litres of water per day.						
3. Affordability	Rate your contribution to water services/Paying to access water service.						
4. Water availability	Rate the water availability within 24 hours a day (24/7).						
5. Water Quality and safety	Rate the water being clean, no odour, safe and drinkable.						
6. Acceptability	Rate the physical conditions to access water. Consideration of landscape and cultural factors of local area.						

- **From the above questions (1 – 6), on the far right column please give your priorities, 1 being the urgent indicator to be improved and 6 being the lowest/last indicator to be improved for water access.**

Considering all aspects of accessing water, how do you rate your access to safe drinking water in Langeloop?	☹	🙁	😐	🙂	😃

THANK YOU FOR YOUR PARTICIPATION.

Addendum: B



UNISA university of south africa

UNISA-CAES HEALTH RESEARCH ETHICS COMMITTEE

Date: 09/11/2023

NHREC Registration # : REC-170616-051
REC Reference # : 2022/CAES_HREC/033
Name : Mr KM Mathaba
Student #: 45754217

Dear Mr Mathaba

Decision: Ethics Approval Confirmation after First Review from 10/02/2022 to 31/01/2025

Researcher(s): Mr KM Mathaba
45754217@mylife.unisa.ac.za; 079-955-5129

Supervisor (s): Prof PMU Schmitz
schimpmu@unisa.ac.za; 011-471-2262

Working title of research:

A GIS-based approach to analyse potable water accessibility in Langeloop village in Ehlanzeni district municipality, Mpumalanga

Qualification: MSc Geography

Thank you for the submission of your yearly progress report to the Unisa-CAES Health Research Ethics Committee for the above mentioned research. Ethics approval is confirmed to continue for the originally approved period, subject to submission of yearly progress reports. **Failure to submit the progress report will lead to withdrawal of the ethics clearance until the report has been submitted.**

Due date for next progress report: 31 October 2024
The progress report form can be downloaded from the college ethics webpage:
https://www.unisa.ac.za/sites/corporate/default/Colleges/Agriculture-&-Environmental-Sciences/Research/Research-Ethics

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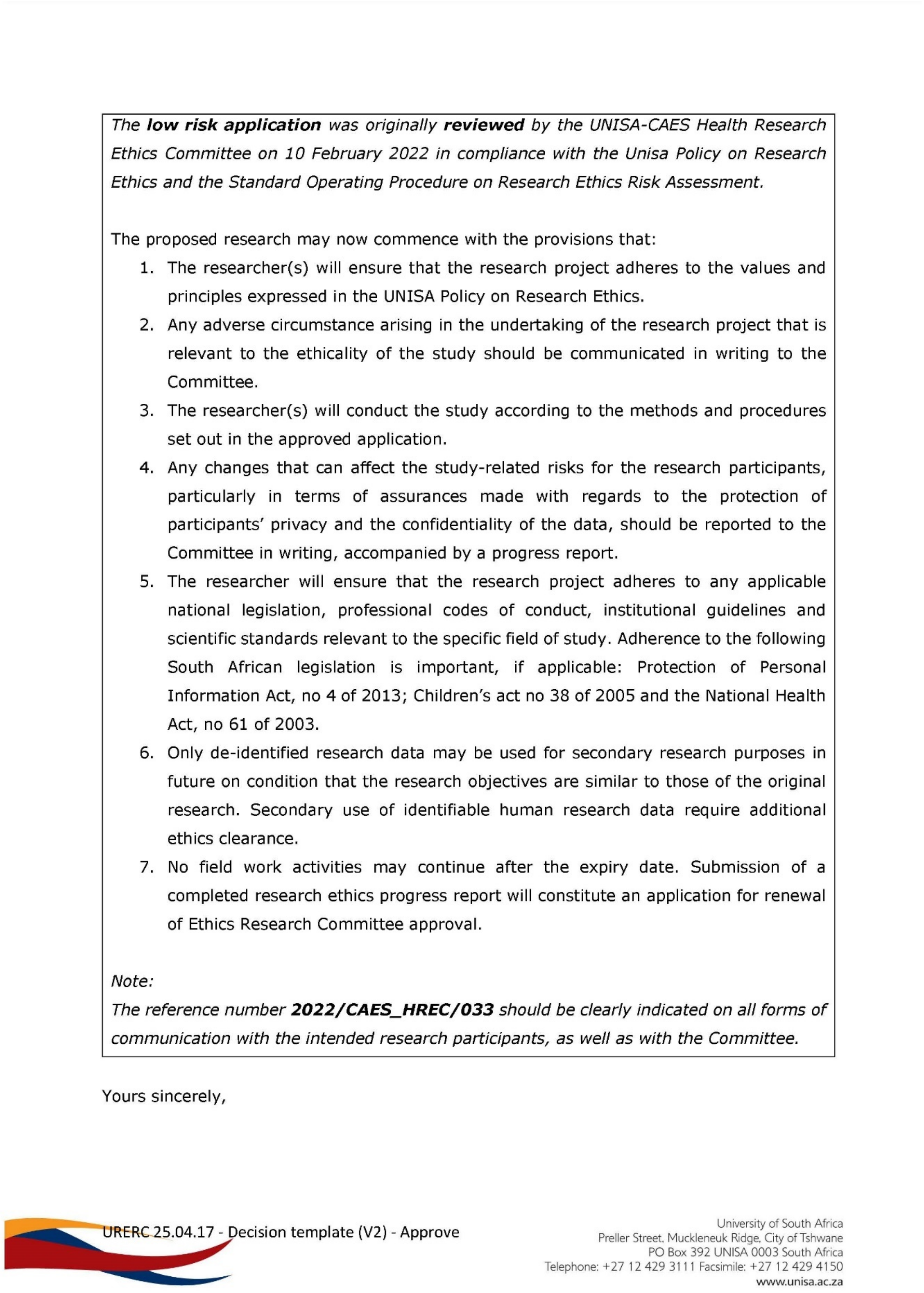

The ***low risk application*** *was originally* ***reviewed*** *by the UNISA-CAES Health Research Ethics Committee on 10 February 2022 in compliance with the Unisa Policy on Research Ethics and the Standard Operating Procedure on Research Ethics Risk Assessment.*

The proposed research may now commence with the provisions that:

1. The researcher(s) will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.
2. Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study should be communicated in writing to the Committee.
3. The researcher(s) will conduct the study according to the methods and procedures set out in the approved application.
4. Any changes that can affect the study-related risks for the research participants, particularly in terms of assurances made with regards to the protection of participants' privacy and the confidentiality of the data, should be reported to the Committee in writing, accompanied by a progress report.
5. The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study. Adherence to the following South African legislation is important, if applicable: Protection of Personal Information Act, no 4 of 2013; Children's act no 38 of 2005 and the National Health Act, no 61 of 2003.
6. Only de-identified research data may be used for secondary research purposes in future on condition that the research objectives are similar to those of the original research. Secondary use of identifiable human research data require additional ethics clearance.
7. No field work activities may continue after the expiry date. Submission of a completed research ethics progress report will constitute an application for renewal of Ethics Research Committee approval.

Note:

The reference number ***2022/CAES_HREC/033*** *should be clearly indicated on all forms of communication with the intended research participants, as well as with the Committee.*

Yours sincerely,

Prof MA Antwi
Chair of UNISA-CAES Health REC
E-mail: antwima@unisa.ac.za
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Prof M Ntwasa
Acting Executive Dean: CAES
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A GIS-based approach to analyse potable water accessibility in Langeloop village in Enhlanzeni District Municipality, Mpumalanga

PARTICIPANT INFORMATION SHEET

Ethics clearance reference number: 2022/CAES_HREC/033
Research permission reference number:

<date>………………………..

Title: A GIS-based approach to analyse potable water accessibility in Langeloop village in Ehlanzeni District Municipality, Mpumalanga

Dear Prospective Participant

My name is Knowledge Mathaba and I am doing a research with Professor Peter Schmitz, an Associate Professor of Geography/GIS in the Department of Geography towards an MSc Geography degree at the University of South Africa. We are inviting you to participate in a study entitled A GIS-based approach to analyse potable water accessibility in Langeloop village in Enhlanzeni District Municipality, Mpumalanga.

WHAT IS THE PURPOSE OF THE STUDY?

This study is expected to collect important information that could determine the spatial distribution and number of functional and non-functional water sources, determine the level of satisfaction of the residents' access to safe drinking water, and identify which water sources needs improvement/replacement to further enhance accessibility to safe drinking water.

WHY AM I BEING INVITED TO PARTICIPATE?

You are invited to participate because you are a resident of Langeloop and you are above 18 years of age. You are one of the randomly picked household out of the 20 households that participants are required to participate in this settlement section.

WHAT IS THE NATURE OF MY PARTICIPATION IN THIS STUDY?

The nature of your participation is to answer a questionnaire that is based on your experience of water accessibility. The study involves a questionnaire survey interview that seeks to get your view on the level of water accessibility. Answering the questionnaire will take less than 5 minutes of your time to be completed.

CAN I WITHDRAW FROM THIS STUDY EVEN AFTER HAVING AGREED TO PARTICIPATE?

Participating in this study is voluntary and you are under no obligation to consent to participation. If you do decide to take part, you will be given this information sheet to keep and be asked to sign a written consent form. You are free to withdraw at any time and without giving a reason. Hence, it will not be possible to withdraw once you have submitted the questionnaire.

WHAT ARE THE POTENTIAL BENEFITS OF TAKING PART IN THIS STUDY?

There is no financial benefits/loss or any direct livelihood benefit to the participants, hence participants that are interested in the findings of the research will get to understand the existing patterns of water accessibility within their community.

ARE THERE ANY NEGATIVE CONSEQUENCES FOR ME IF I PARTICIPATE IN THE RESEARCH PROJECT?

There are no negative consequences for you to participate in the research project.

WILL THE INFORMATION THAT I CONVEY TO THE RESEARCHER AND MY IDENTITY BE KEPT CONFIDENTIAL?

You have the right to insist that your name should not be recorded anywhere and that no one, apart from the researcher and identified members of the research team, will know about your involvement in this research OR your name will not be recorded anywhere and no one will be able to connect you to the answers you give. Your answers will be given a code number or a pseudonym and you will be referred to in this way in the data, any publications, or other research reporting methods such as conference proceedings.

Your answers may be reviewed by people responsible for making sure that research is done properly, including the transcriber, external coder, and members of the Research Ethics Review

Committee. Otherwise, records that identify you will be available only to people working on the study, unless you give permission for other people to see the records.

However, your anonymous data may be used for other purposes, such as a research report, journal articles and/or conference proceedings. Hence, your name and other personal information will not be captured in the official database of the research participants.

HOW WILL THE RESEARCHER(S) PROTECT THE SECURITY OF DATA?

Hard copies of your answers will be stored by the researcher for a period of five years in a locked cupboard/filing cabinet in the researcher's resident for future research or academic purposes; electronic information will be stored on a password protected computer. Future use of the stored data will be subject to further Research Ethics Review and approval if applicable. After the five years storage of the data, electronic records will be permanently deleted, and hard copies be burnt.

WILL I RECEIVE PAYMENT OR ANY INCENTIVES FOR PARTICIPATING IN THIS STUDY?

You will not receive payment or any incentives for participating in this study, hence it is voluntary to participate.

HAS THE STUDY RECEIVED ETHICS APPROVAL

This study has received written approval from the Health Research Ethics Committee of the College of Agriculture and Environmental Sciences, Unisa. A copy of the approval letter can be obtained from the researcher if you so wish.

HOW WILL I BE INFORMED OF THE FINDINGS/RESULTS OF THE RESEARCH?

If you would like to be informed of the final research findings, please contact Knowledge Mathaba on 0799555129. The findings are accessible for 3 years.

Should you require any further information or want to contact the researcher about any aspect of this study, please contact 0799555129 or E-mail: 45754217@mylife.unisa.ac.za.

Should you have concerns about the way in which the research has been conducted, you may contact Prof Peter Schmitz, on 0114712622 or schimpmu@unisa.ac.za. You can further contact the research ethics chairperson of the CAES Health Research Ethics Committee, Prof MA Antwi on 011-670-9391 or antwima@unisa.ac.za if you have any ethical concerns.

Thank you for taking time to read this information sheet and for participating in this study.
Thank you.

Knowledge Mathaba

Nkomazi
Local Municipality

9 Park Street - Malalane
Private Bag X101
Malalane,
1320
Tel: (013) 790 0245
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OFFICE OF THE SPEAKER: PUBLIC PARTICIPATION SECTION

Enquiry: S.P MDLULI

Mr Knowledge Mbongeni Mathaba
P.O Box 196
Uthokozani
1346

LETTER OF AUTHORIZATION TO CONDUCT A RESEARCH SURVEY AT LANGELOOP SETTLEMENT

The above subject refers

Upon a review of the letter sent to us by yourself requesting permission to do an academic research survey at Langeloop settlement, as Nkomazi Local Municipality we are glad to offer you an opportunity to conduct the study in our jurisdiction.

This letter serves as authorization of Mr Knowledge Mbongeni Mathaba, a UNISA student, with student number: 45754217, to conduct the research project entitled A GIS-based approach to analyse potable water accessibility in Langeloop village in Enhlanzeni District Municipality, Mpumalanga

All interviews, field surveys, observations around the settlement and the distribution of questionnaires are approved and will be duly supervised by our public participation personnel to protect members of the community and the researcher.

Communication of the research survey date should be provided to the Office of the Speaker three weeks before the research survey initial date. This will allow our office to schedule a meeting and also facilitate it between the community members or community stakeholders and the researcher a week prior the commence of the research survey.

I trust you will find the above-mentioned in order and any further queries can be directed to the manager of the Office of the Speaker.

Kind regards

....
Mr. SP Mdluli
Mananger: Office of the Speaker

NKOMAZI MUNICIPALITY
P.O. BOX 101 MALELANE 1320
2021 - 12 - 14
OFFICE OF THE MUNICIPAL MANAGER
MALELANE CIVIC CENTRE

BETTER LIFE