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Assessing the feasibility and effectiveness of Rooftop Rainwater Harvesting in Winnie Mandela Madikizela Local Municipality

A thesis submitted in fulfilment of the academic requirements for the degree of

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DECLARATION

I, Abongile Ongezwa Nakin declare that

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V. A section of this thesis has been published as an abstract at the frontiers in hydrology meeting, 2022 as "Nakin, O., Ikegwuoha, C., Ngubane, Z., & Walker, M. (2022). Assessing Water Quality from Roof Rainwater Harvesting Systems Aimed for Potable Use: A Case Study in the Eastern Cape Province, Nomlacu Rural Area, South Africa. https://doi.org/10.1002/essoar.10511285.1 ".

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ABSTRACT

South Africa's primary source of water is surface water. The potability of this water is doubtful especially in rural areas. Evaluation of rainwater quality from various roof materials is crucial. Additionally, there is a need to evaluate the quantity and the economic viability of Rooftop Rainwater Harvesting (RRWH). Winnie Madikizela Mandela Local Municipality (WMMLM) of Nomlacu currently has 73.6% municipal water supply backlog. With the current challenges, it is important not only to explore ways to save water but also to generate own sources of water. This makes RRWH systems as a viable water resource, an option for alleviating water scarcity. The study aims to assess the feasibility and effectiveness of RRWH for domestic use in WMMLM.

The target is to determine the potential of rainwater harvesting as a potable water supply and conservation alternative. Hydrological data was obtained from the Weather SA to facilitate the calculation of the quantity of rainwater that can be harvested per household. Moreover, catchment areas were obtained through QGIS to determine size and materials of the roof types. Thus, to analyse the impact of roof materials on water quality for human consumption and irrigation.

According to the results obtained in this study, Turbidity and *E. coli* produced non-compliant results of (0.8 – 2.8 NTU) and (0 - >2420 MPN /100mL) respectively. Although within limits, Aluminium, Colour, and Zinc concentrations present higher values on zinc metal roof compared to tiled roofing material. This is due to the high radiation and good heat conducting capacity of the metal. Results also showed higher pH levels on tiled roofs (7.05 – 7.39) compared to zinc roofs (6.27 – 7.19), which is in line with the nature of concrete. The most significant and immediate threat to health that roof collected water poses is bacterial contamination. Therefore, it is important to regularly clean the system, use disinfection solutions like chlorine tablets and boiling water before consumption.

Overall, Nomlacu area receives relatively high amounts of rainfall which is greater than country's annual rainfall. The study showed that RRWH can meet the annual demand of rainwater and have an overflow of roughly 7211L/year which is equivalent to an approximate potential annual harvest of 124% when utilized to its optimal potential and at worst case scenario can alleviate the pressure from the municipal water supply system by at least 81%. Results showed that optimal rainwater harvesting can be

achieved by using more than two storage tanks per household. This then makes it possible for the system to alleviate pressure from the municipal water supply. On the economically aspect, installing a RRWH system is financially feasible, it would spare the municipalities approximately 48.8% of the municipal water supply spend to supply water to the municipality should this project be a government initiative.

ACRONYMS AND ABBREVIATIONS

ANDM	Alfred Nzo District Municipality
DHS	Department of Human Settlement
DWA	Department of Water Affairs
DWS	Department of water services
EC	Eastern Cape
E. coli	*Escherichia coli*
ECSECC	Eastern Cape Socio-economic Consultative Council
GI	Galvanized Iron
IDP	Intergraded Development Plan
IODSA	The Institute of Directors South Africa
MIG	Municipal Infrastructure Grant
MLM	Mbizana Local Municipality
MLM DIDP	Mbizana Local Municipality Draft Integrated Development Plan
NAAQS	National Ambient Air Quality Standards
NWA	National Water Act
pH	Potential of Hydrogen
PVC	Poly vinyl chloride
QGIS	Quantum Geographic Information System
RC	Runoff Coefficient
RWH	Rainwater harvesting
RRWH	Rooftop rainwater harvesting
SA	South Africa

SANS	South African National Standards
SAWS	South African Weather Service
SS	Suspended Solids
STATS SA	Statistics South Africa
TDS	Total Suspended Solids
WHO	World Health Organization
WMMLM	Winnie Madikizela Mandela Local Municipality
WSA	Water service Act
WSDP	Water Service Development Plan
WTW	Water Treatment Works
WWF-SA	World Wide Fund for Nature South Africa

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CHAPTER 1 : INTRODUCTION

1.1 Background

Rooftop rainwater harvesting (RRWH) is a technique of collecting rainwater runoff from impermeable roof surfaces, known for providing an inexpensive source of water. Rainwater harvesting structures consist of three basic components. The catchment area which is the roof is used to capture the rainwater. A collection device to store water and a conveyance system through gutters and pipework to transfer water from the catchment area to the collection device and taps (Juliana *et al.*, 2017). Rainwater can either be collected by temporary facilities such as pots, buckets and drums or by permanent structures such as water storage tanks. Water is stored in waterproof tanks and is later used for multiple agricultural and domestic household uses. Harvested rain water may be used temporarily, seasonally, or permanently depending on the amount of rainfall harvested (Dwivedi and Bhadauria, 2009; Rahman *et al.*, 2014). Approximately 96% of all rooftop rainwater harvesting systems installed in South Africa are located in rural areas with the aim of providing an alternative water supply (Mwenge Kahinda et al., 2010). The application of RRWH for domestic use through allocating storage tanks to households can assist in reducing the municipal water distribution system (Mwenge Kahinda et al., 2007).

Water scarcity is one of the growing problems in many parts of the world. The world's population is increasing, and so is the water demand. Some countries have physical water scarcity due to lack of or not enough water resources to supply the increasing demand. Other countries have an economic water scarcity which translates to enough resources but lack of investment, due to poor governance, poor management and other problems that lead to unavailability of water and infrastructure for the population.

South Africa (SA) is a semi-arid to arid country, and it is ranked the 30th driest country in the world (DWS, 2017), it is predicted to approach physical water scarcity by 2025 due to recent droughts (Rodrigues et al., 2012). Water demand in SA is forecasted to exceed supply by 1.3% (IoDSA, 2012). Rainfall is the main source of water, yet SA receives a low average rainfall of 490mm per annum WWF-SA, (2017) which is below the worlds average rainfall of 860mm per annum. Rainfall in SA is highly seasonal and varies significantly from East to West (Botai et al., 2018).

Many rural parts of the country have little or no access to potable water supply. According to Stats SA, (2019) 11.9% of the population have no access to piped water. Eastern Cape is the second most affected and under-serviced province with 26.1% of the population with no access to tap water, compared to Western Cape and Gauteng having only 1.5% and 2.4% respectively. Water security has become an increasing concern due to droughts, climate change, low water quality and the ageing infrastructure (WIN-SA, 2013).

Since surface water is the primary source of water in SA couples with the fact that the Eastern Cape receives more rainfall per annum, there is a greater potential demand for RRWH systems. As the demand for water increases, it becomes crucial to challenge the perception that only one model/method can meet people's water needs. Appropriate technologies and methods such as RRWH need to be investigated and evaluated as possible solutions to the crisis (Bwapwa, 2018). Recent statistics show that only 1.4% of the population have access to domestic rainwater harvesting systems. Approximately 5% of the population still depends on untreated water from rivers, dams, springs and other stagnant water sources (Stats SA, 2019), which justifies the importance of RRWH to alleviate the surge of water scarcity. The efficient use of local water resources such as RWH may conserve domestic potable water usage and augment efforts to meet the basic water needs of the rural and under-serviced areas.

For many years, untreated water from roof rainwater harvesting has been used for consumption purposes with only a few recorded serious health problems. However, researchers like Ahmed *et al.*, (2011); Chidamba and Korsten, (2015) have reported that rainwater harvesting may cause health risks than understood when consumed prior to treatment because of its potential to carry microbial pathogens. Various studies have shown that harvested rainwater used for consumption should be evaluated to assess the presence of bacterial pathogens and other faecal indicators (Shanks *et al.*, 2016; Stewart *et al.*, 2016; Friedler *et al.*, 2017; Hamilton *et al.*, 2019). Moreover, the quality of water from roof runoff depends on both environmental conditions and the roof type. The quality of rooftop rainwater harvesting can be improved through effective maintenance and better tank design (Lee *et al.*, 2012).

1.2 Research Problem Statements

Water is one of the most essential resources of human life. Without water, human beings can only survive for a few days, and lack of water supply leads to a spread and exacerbation of diseases (WHO, 2020). Nevertheless, many countries are still affected by water scarcity, where freshwater resources are insufficient to meet domestic, economic and environmental needs. The lack of access to safe drinking water and sanitation causes a constraint on human health and productivity (Cosgrove and Loucks, 2015). Only 64% of the South African population have access to reliable water supply (Viljoen and van der Walt, 2018). Hence, it is important to evaluate the water quality of harvested rainwater that can be used for human consumption.

South Africa is currently facing challenges with physical water scarcity and is expected to face a water deficit of 17% by 2030 based on current usage trends such as population growth, industrial developments, and climate change (Rodrigues *et al.*, 2012; Viljoen and van der Walt, 2018). In the Eastern Cape, Winnie Madikizela Mandela Local Municipality (WMMLM) previously known as Mbizana Local Municipality (MLM) is currently at 73.6% (45 178 households) backlog of water supply which means that majority of its population depends on untreated and unreliable sources of water. Of this population, only 4.6% have access to a rainwater harvesting system (MLM, 2020). With the current challenges, it is important not only to find ways to save water but also to generate own sources of water. Although the RRWH method has been used for decades in South Africa, it is still debatable whether this method is being utilized to its full potential. In many cases the quality of water from rivers, streams and dams is unsatisfactory or has not been accessed.

Much as there is a current water supply, the availability of water in communal taps is not guaranteed as some communities occasionally experience dry water taps. Approximately 25.8% of the South African households have reported dysfunctional municipal water supply service where households occasionally experience interruptions that last two days or more at a time. Currently, RWH in South Africa is practised without structured guidelines and regulations (Mwenge Kahinda *et al.*, 2007; Macnamara, 2018). Figure 1-1 shows the municipalities that has the lowest access to improved water supply. Mbizana now known as Winnie Madikizela Mandela Local Municipality is shown to be one of those municipalities.

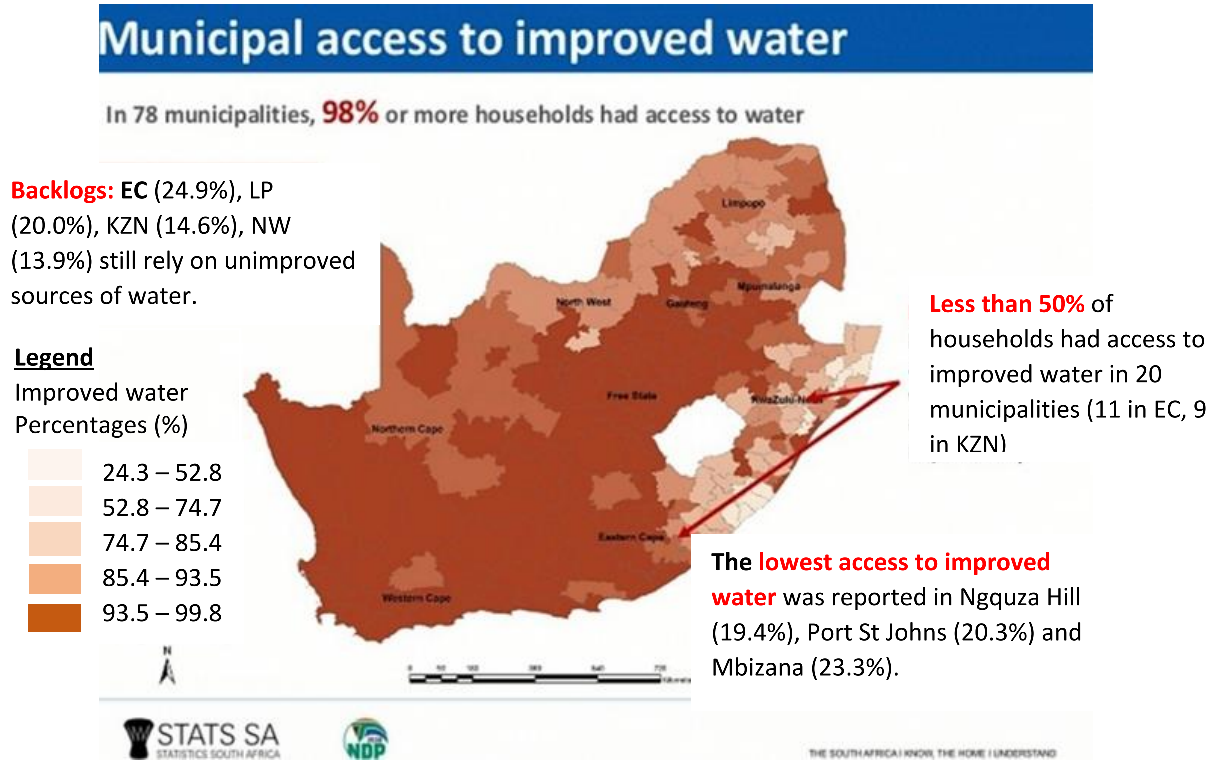

Figure 1-1: The State of Basic Service Delivery in South Africa (2016) (Lehohla, 2017)

1.3 Research Aim

The aim of this study is to assess the feasibility and effectiveness of RRWH for domestic use in Winnie Madikizela Mandela Local Municipality (WMMLM). The target is to determine the potential of rainwater harvesting as a potable water supply and conservation alternative.

The feasibility study aims to focus on the technical, legal and the economic aspects of rooftop rainwater harvesting.

Technical aspect - The technical aspects aim to focus on the appropriate methodologies for maximising good quantity and quality of the harvested water.

Legal aspect - Reviews the water regulations and status of rooftop rainwater harvesting in South Africa as well as to determine the social acceptance of the concept by the community.

Economic aspect - To evaluate the economic viability of rooftop rainwater harvesting system versus the construction of the municipal reticulation system.

1.4 Objectives

- ❖ Quantify the potential volume (L/month) of RRWH that can be harvested in a typical household along with the monthly rainwater availability after usage.
- ❖ Evaluate the factors that affect the quantity of RRWH.
- ❖ Analyse the effect of different roof materials (Zinc metal and tiles) on water quality based on physical and biological properties of potable water.
- ❖ Provide water treatment methods to convert RRWH to potable water.
- ❖ Evaluate the cost variation between the implementation costs of RRWH vs the construction of municipal water supply.

1.5 Research Questions and Hypothesis

1.5.1 Research Questions

- ❖ Can the quantity of rainwater harvesting be an effective solution to Winnie Madikizela Mandela Local Municipality?
- ❖ Is the quality of rainwater harvesting suitable for human consumption?
- ❖ Does roof material have an effect on the outcome of the quality of harvested water?
- ❖ Is rainwater harvesting an economically viable solution for the community of Nomlacu?

1.5.2 Hypothesis

- ❖ Assuming a daily consumption rate of 91.2l/day per household, the potential rainwater harvest per year could be approximately 55% - 60% per household.
- ❖ Roof material will have an impact on water quality based on the physical properties of the roof and environmental contaminations however, minimal treatment will be required to convert this water to potable standards.

1.6 Limitations

Although there are many types of rainwater harvesting systems and treatment methods, this study will only focus on rooftop rainwater harvesting and domestic treatment methods to convert the harvested water to potable domestic water use. This research will only focus on the rural administrative area of Nomlacu, Mbizana. Only zinc metal and tiled roof materials will be considered for analysis of water parameters. Although the whole spectrum of the SANS 241:2015 Edition 2 consists of forty-six parameters, only eleven parameters were taken into consideration in determining the impact of roof materials quality of RRWH. Looking at the quantity of RRWH, the estimated average area of the household was taken into consideration for the whole community, abstracted form QGIS. Financially, the prices obtained from the service providers are subject to change and applicable for 2022 and price increase. The CPI inflation rate is also variable and may need to be updated monthly.

1.7 The Significance of the Study

This research will provide further knowledge of rainwater harvesting and its potential to combat water scarcity in remote areas. It will help provide a comprehensive understanding on reducing water demand for the local municipalities as well as assisting for water management reforms. The study will generate a more heightened awareness to the community about the benefits of using free rainwater to increase their domestic water supply and promote the principle of community-based water resource management. The information of the study can also be useful to hydrologists and policymakers for suitable legislation considerations in the integrated water resource sector.

1.8 Ethical Considerations

Before the commencement of the research study, the researcher had to do a research ethics training program in order to understand and have knowledge on what is expected when conducting a research study concerning people, see Appendix A. There was no hidden information about the intention of the study and participants were not deceived in any way. Participants operated under an informed consent and were not asked to perform any acts that would harm or put them at risk. Participants participated voluntarily and had an option to choose to pull out at any given time without a negative impact towards them. Privacy of the participants was respected and kept anonymous, no identifying information was published, and all information provided was treated with confidentiality. Participants were given a letter of information detailing all the information pertaining the study and their participation, see Appendix B. Authority to conduct the surveys was requested to participants and only upon their approval the study was conducted, see Appendix C.

Due to the current Covid-19 pandemic, the interviewer and the participants were wearing masks during the course of the questionnaire. The interviewer and the participants always maintained social distancing (2m apart), only two people plus the interviewer were allowed per household. All participants were provided with a hand sanitizer before the commencement of the questionnaire. The survey interviews were conducted outside within the yard. The participants' temperatures were screened using the non-contact infrared thermometers to help reduce the risk of Covid-19 transmission.

1.9 Structure of Dissertation

The structure of this dissertation is divided into six chapters, divided as follows:

Chapter 1 - Introduction

The chapter introduced the topic of the study in terms of the feasibility and effectiveness of using rooftop rainwater harvesting in rural areas, while justifying the use of RRWH in the study area. This Chapter focused on the background of the study, which included the introduction, problem statement, aims and objectives, limitations, significance of the study and ethical considerations.

Chapter 2 - Literature review

This chapter reviewed previous related studies regarding rooftop rainwater harvesting, the effect of roof material on water quality as well as the financial analysis. The purpose of this chapter was to review previous researchers' information regarding the same or related topics.

Chapter 3 - Study area

This part of the study provided statistics of the hydro-climatological characteristics of the area. Demographical information was also described in this chapter.

Chapter 4 - Materials and methods

Discussed the methodologies that were employed in the study in order to obtain the data for the computations required to arrive at the results/findings of the study.

Chapter 5 - Results and Discussion

The analysis, interpretation, and discussion on the findings of the study were conducted in this chapter.

Chapter 6 - Conclusion and recommendations

Presented the summary of the research findings, conclusions and recommendations on the effectiveness and feasibility of the rooftop harvesting system in rural areas.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

This chapter seeks to review/unpack the available literature on the feasibility and effectiveness of rooftop rainwater harvesting. Although water covers 70% of the earth, some countries including South Africa are water scarce. With the current water challenges, it is important to evaluate, assess, and review from literatures, other sources of water in order to alleviate the pressure from the current municipal water supply.

This literature review seeks to provide a comprehensive summary via critical evaluation of previous work that has been conducted pertaining rooftop rainwater harvesting. This review has encapsulated the water demand guidelines in South Africa, water legislations regarding rainwater harvesting and an overview of RRWH. Literature related to the effect of roofing materials on the quality of water, maintenance and treatment of RRWH, factors affecting the quantity of RRWH, advantages and disadvantages of RRWH and the implementation cost of RRWH versus the municipal water supply is also acknowledged in this chapter.

2.2 Water Demand Guidelines in SA

2.2.1 The Constitution of the Republic of South Africa, 1996

Section 27 of the South African Constitution (Constitution SA, 1996) states that “everyone has the right to have access to sufficient water”. This means that adequate water ought to be economically and physically available to the user. Physical accessibility refers to the distance travelled in order to access water. The distance should be accessible even to the disadvantaged people such as senior citizens, children, and those living with disabilities. Sufficient water infrastructure should be provided, there should be effective maintenance of the equipment and facilities even to the under-serviced areas. The term "economic access" refers to the costs associated with obtaining water.

The quantity and quality of water available to satisfy the basic domestic need for potable water is referred to as sufficient water. The “quantity” refers to the bare minimum of water available to meet basic needs, while the “quality” refers to the minimum appropriate drinking water requirements.

2.2.2 Department of Water and Sanitation Services

In clause 5.2 of the Department of Water and Services norms and standards DWA, (2017), it is stated that the minimum standard of services is designed to meet people's survival and basic need for potable water which is a human right. Therefore, provision of these services should be well-organized to ensure it is accessible, financially viable, realistic and sustainable, while maximizing water resource efficiency.

Clause 5.2.3 of the Department of Water and Services norms and standards DWA, (2017) also states that the minimum requirement for free basic water supply services to the indigent is 25 litres per person per day at a minimum cartage distance of 200 meters. Water supply services are to be provided only to the under privileged households. The main goal is to meet the peoples need for basic domestic water supply consistently and at a constant quantity. Water demand guidelines for indigent domestic water supply:

- ❖ A monthly potable water allowance of at least 6000 litres per household.
- ❖ Supplied water must meet the South African National Standard (SANS) 241 quality requirements as listed below in Table 2-1. See Appendix D

Table 2-1: SANS 241:2015 Edition 2 water quality requirements (Drucker and Oster, 2015)

Parameter	Unit	Risk	Standard limit
pH	pH Unit	Operational	≥5.0 - ≤9.7
Conductivity	mS/m	Aesthetic	170
Turbidity	NTU	Operational	1
		Aesthetic	5
Colour	mg/L	Aesthetic	15
Zinc	mg/L	Aesthetic	5
Total Dissolved Solids	mg/L	Aesthetic	1200
Iron	µg/L	Chronic health	2000
		Aesthetic	300
Aluminium	µg/L	Operational	300
E. Coli	cfu/100mL	Acute Health /micro	0
Lead	µg/L	Chronic health	10
Suspended Solids	mg/L		

- ❖ The access/delivery point must be at least a yard connection.
- ❖ Water supply must be available at no less than 350 days per annum, and should not be interrupted for more than two consecutive days.
- ❖ Both water consumption and supply must be metered.
- ❖ To reduce water demand, water loss and leak detection will be introduced.
- ❖ The Water Service Act (WSA) is responsible for maintaining the service's facilities in good working order.
- ❖ The re-use and control of greywater must be promoted.
- ❖ It must be a point that the quality of service is accepted and understood by the users.
- ❖ Users must be taught and trained on how to use water efficiently and how to practice good hygiene

2.2.3 The Neighbourhood Planning and Design Guide

The Human Settlement Planning and designs guidelines DHS, (2019) focuses on the factors to consider when designing and implementing water supply initiatives for current and emerging communities. The guidelines are also useful when a Water Services Authority (WSA) drafts a Water Services Development Plan (WSDP), which is then incorporated into a municipality's Integrated Development Plan (IDP). Water service boards may use these principles to create plans as well as prepare and set goals. During a feasibility study for comprehensive water supply in future designs, these technical guidelines may be taken into consideration and used for water resource planning and future water demand. Water demand assessment is generally focused on historical usage (DHS, 2019). In the absence of historical water use data, current per capita can be calculated by looking at the population. Table 2-2, on the other hand, can be used to predict usage until the system is modified and consumption changes (DHS, 2019). When providing water to a community, key concepts such as sustainability and effectiveness are critical. According to Table 2-2 below, the typical consumption for a community that uses communal standpipes as water supply in a dry sanitation area is 50 l/c/d. The domestic water consumption ranges from 40 to 60 l/c/d for an average of 5 persons. For the purpose of this study, 60 l/c/d will be used because the average persons per household in Nomlacu is more than six persons.

Therefore, a monthly requirement ranges from 8400L to 9300L for domestic water consumption will be needed to serve the particular community.

Table 2-2: Residential AADD(per capita) connections (DHS, 2019)

Land-use		**Persons per unit**	**Typical AADD L/c/d (#1)**	**AADD range L/c/d (#1)**
Standpipe		5	25	10 to 40
Yard connection	With dry sanitation	5	50	40 to 60
	With low-flow (LOFLOs) sanitation	5	60	50 to 70
	With full-flush sanitation	5	70	60 to 80
House connection	Low-income housing	5	90	60 to 120
	Residential	5	230	120 to 400
	Group/cluster housing	3 to 5	120	130 to 120
	Flats	1 to 4	150	250 to 110
(#1) - per capita calculated on persons per unit				

2.3 Water Legislations Regarding Rainwater Harvesting

The South African water legislations gives an ambiguous understanding regarding the implementation of rainwater harvesting. Which therefore makes rainwater harvesting illegal under strict adherence to the rules, with the exception of rooftop rainwater harvesting as discussed below.

There are two water related legislation documents in South Africa that assist in the supply and management of water supply.

- ❖ The National Water Act (NWA) Republic of South Africa, (1998) (Act No. 36 of 1998) - This is South Africa's primary legal document for managing water resources. It emphasizes equitable water resource allocation and justice, as well as productivity, water quality conservation for long-term sustainability, and the need for integrated water resource management.

- ❖ The Water Services Act (WSA) Republic of South Africa, (1997) (Act No. 108 of 1997) – This act focuses on people's rights to access to basic water resources and sanitation. The Act provides national guidelines, rates, and implementation plans for water service providers, as well as financial support to water service providers. It primarily addresses reticulated water supply and sanitation services. It also guides municipalities on how to meet their responsibility to provide water and sanitation services while maintaining the physical, economic, and practical constraints.

Chapter 1, Section 6 of the WSA states that “Without the approval of the water services authority having jurisdiction in an area, no one may use water services from a source other than a water services provider nominated by that authority.” However, if an individual was using a water service source apart from the one designated by the applicable water service authority at the time this act was implemented, that person may continue to use it by following chapter 1, subsection 2. In Chapter 1, Section 4 of the NWA states that water from another water supply can be used for appropriate household water use such as, gardening, animal watering, fire - fighting and other recreational activities, as set out in schedule 1”. However, this section excludes commercial activity. Chapter 4, Part 1, Section 22 (1) further emphasizes on permitted uses of water under schedule 1 and Small-scale commercial planting is expressly prohibited. Roof runoff water can, however, be stored and used, thus, harvesting water from the roof top for domestic use is very legal.

2.4 Overview of RRWH

Rooftop rainwater harvesting is considered one of the simplest techniques of catching and holding rainwater where it falls. This system is known to be economically inexpensive in construction as compared to other water infrastructure such as reticulation systems and dams (Kumar, 2015). RRWH could be an alternative water source for water scarce regions with insufficient ground-water supply, limited water resources and infrastructure to meet the community’s water demand or facing water shortage issue (Siddiqui and Siddiqui, 2018).

Rooftop rainwater harvesting systems can supply water for both potable and non-potable usages (Gayani Karunasena, 2013). Rainwater that is intended for human consumption must be treated to eliminate pollutants. Typical treatment process required for water purification for consumption purposes of rainwater is filtration and disinfection. In cases where the rainwater contains heavy metals, special treatment such as membrane filtration may be required. No treatment is needed for non-potable uses such as flushing toilets, watering gardens and washing (Kumar, 2015).

2.4.1 System Components

Rooftop rainwater systems consist of three major components which will be discussed in more detail in subsequent sections, the catchment area, the conveyance system and a storage device. The Figure 2-1 illustrates the different components of residential rooftop rainwater harvesting.

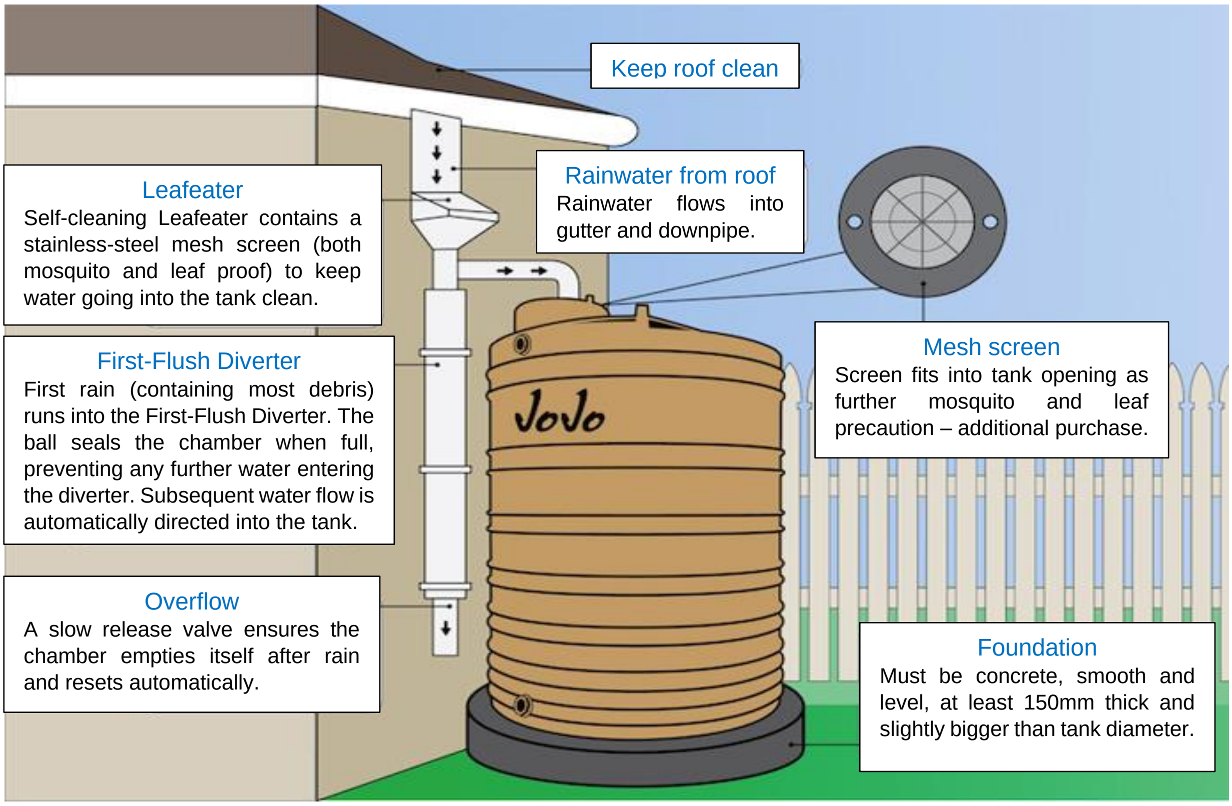

Figure 2-1: Typical RRWH system

Source: https://www.rainharvest.co.za

2.4.1.1 Catchment

The catchment area for domestic rainwater harvesting refers to the roof top surface that receives direct rainfall. Therefore, it should be impermeable and safe for the rainwater harvesting. Hence, the efficiency and water quality of rainwater harvesting is influenced by the roof material and roof area (Finley, 2000; Antonakopoulou *et al.*, 2017). Any roof material may be used for rainwater harvesting. However, it is advisable that water from thatched roofs and asphalt covered roofs may not be collected if the water is intended for consumption purposes (Kumar, 2015). The catchment surface qualities should be smooth, impermeable and should be made from nontoxic materials. Effective rainwater roof catchment materials include galvanized corrugated iron sheets, concrete/clay tiles and slate (Kumar, 2015; Antonakopoulou *et al.*, 2017; Norman *et al.*, 2019).

- Concrete / Clay tiles – Tiles must be painted or coated with a specific sealant to reduce possible water loss and prevent bacterial growth.
- Corrugated iron sheets – The texture of this material is highly recommended because it is smooth enough for optimum water collection and can easily shed contaminations.
- Slate – The smoothness of this material makes it ideal for harvesting.

2.4.1.2 Conveyance System

The conveyance system consists of gutters and pipes that convey rainwater from the roof into the storage tank. These gutters generally hang around the edges of the roof, sloping towards downpipes that receive the water into the storage device. To achieve an effective RRWH system, it is of utmost importance that the gutter system is well designed and carefully constructed (Kumar, 2015).

In a general rule of thumb, it is recommended to have approximately 1 cm^2 of gutter cross-sectional area per 1 m^2 of roof area (Zhu *et al.*, 2015). This becomes essential in optimizing the amount of water that can be collected. Splash guards can prevent spillage during high intensity rain periods that may cause rainwater to shoot over the conventional Gutter, thus resulting in low water harvest.

The most common material used for gutters is poly vinyl chloride (PVC) and metal. Generally, a well-designed and correctly fitted gutter system can deliver approximately 90% into the storage device. Conduits are pipe linings that transport roof runoff from the roof to the storage device and are usually available in galvanized iron (GI) or polyvinylchloride (PVC). Furthermore, filters and/or other cleaning materials are used to prevent the entry of foreign materials such as leaves, stones, insects etc. (Li *et al.*, 2010).

2.4.1.3 Storage Device

The storage device is the container/tank that is used to store the rainwater. Usually, the storage device is the most costly component of the RRWH system (Traboulsi and Traboulsi, 2017). Therefore, it needs to be strategically designed in order to provide optimal storage capacity. Large quantities of water can either be stored in below the ground tanks or above the ground tanks. Above the ground surface storage tanks are most common for RRWH for some reasons discussed in the next paragraph. Storage tanks can be square, rectangular, or circular shaped. Circular shaped tanks are found to be stronger and durable than rectangular or square shaped tanks (Kumar, 2015).

Leakages and damages are easily detectable on above ground tanks compared to below ground tanks due to excavation costs, therefore making it less expensive to maintain tanks above the ground. Water from surface tanks can easily be accessible and conveyed for domestic use through gravity, without the use of a pumping system. Ground water tanks are susceptible to damage caused by tree roots and flood water contaminations. Conversely, above surface water tanks require a lot of space and run the risk of hot temperature exposure.

Inert materials can be used to build tanks. Materials such as reinforced concrete, ferro-cement, wood, metal, fibre glass, plastic polyethylene, brick interlocking blocks, stainless steel, or they could be made of compressed soil or rubble stone blocks. Local material like bamboo and wood may also be utilized as a support alternative for concrete tanks. When the tank is empty, the material used on the walls of underground tanks should be able to withstand soil and soil water pressures from outside.

Storage tanks must be situated at a close proximity to the point of water supply and demand in order to minimize the travelling distance of water, and be impervious to prevent algal growth. Polyethylene tanks are commonly used because they can be cleaned and connected to the piping system with ease. However, the choice of material depends on affordability and on local availability. (Finley, 2000).

As a minimum requirement, all rainwater storage tank designs must include:

- A stable and strong lid
- Coarse inlet filters
- Drain for overflow
- Manhole, drain to ease up cleaning and sump
- A non-contaminating water extraction device, such as a pump or tap

It is recommended that storage tanks be appropriately sized. An undersized tank may be filled and depleted quickly thus failing to provide enough water for households. An oversized tank reduces the water quality due to infrequent cycling and may work out to be unnecessarily expensive (Li *et al.*, 2010).

2.4.2 Factors affecting RRWH quality

Rainwater is considered to be relatively clean; however, universal studies reveal different conclusions regarding the quality of rooftop rainwater harvesting. The rainwater quality is highly influenced by the surrounding climate, tree types and location (Alim *et al.*, 2020a). Other factors that influence the quality of roof runoff include the storage time and maintenance of the system (Struk-Sokołowska *et al.*, 2020). The catchment area introduces contaminations such as pathogens, organic matter, metals, dust, bird droppings, insects and tree leaves. Collectively, various studies found that factors such as roof material, precipitation event, location of the roof, meteorological factors, and physical boundary condition of the roof influence the quality of roof harvested rainwater (Zhang *et al.*, 2014; Friedler *et al.*, 2017; Norman *et al.*, 2019).

Norman *et al.*, (2019) highlights the five major sources of contaminations: roofing conditions, roofing geometry, roofing material, surrounding environment and weather conditions. According to Chidamba and Korsten, (2015), animal faecal droppings are one of the major sources of contamination for RRWH tanks. Concisely, the quality of RRWH largely depends on the design, maintenance, roofing material, roof cleanliness and environment. It is therefore recommended to divert the first few millimetres of roof runoff away from the tank. This process of washing/discarding the initial runoff is called the 'first flush" (Mwenge Kahinda *et al.*, 2007).

It is also recommended to clean the catchment area, conveyance system and the storage tank regularly, at least twice a year to improve the water quality (Korsten *et al.*, 2016). Regular maintenance such as the removal of particles, leaves, insects and other possible substances that might be trapped inside the storage device is important. Thus, minimizing the number of contaminations inside the tank. Likewise as it is important to keep the tank lid properly closed to prevent evaporation, algae growth caused by light as well as water related diseases caused by contaminations inside the storage tank (Daily and Wilkins, 2012).

2.4.3 Water-Related Diseases related to rooftop rainwater harvesting

Good drinking water is an essential fundamental part of life. Lack of water exacerbates the challenges of vulnerable people such as infected children, the elderly, the physically handicapped, those with weakened immune systems (HIV/AIDS) and those exposed to waterborne diseases. In South Africa, many households only have access to little or poor-quality water thus resulting to more cases of patients/casualties due to water borne diseases. Water-borne diseases have a huge impact on South Africa and approximately 43 000 people die yearly due to diarrhoeal diseases (Mwenge Kahinda *et al.*, 2007). The main source of the malaria disease is caused by insects such as mosquitoes bred unwittingly in storage tanks Moglia *et al.,* (2016). Malaria transmission is a multifaceted phenomenon, with climate playing a significant role in its regional and temporal distribution. Regions that are affected by malaria in South Africa are the north-east parts of KwaZulu-Natal, Limpopo, and the low-veld regions of Mpumalanga. As a result, additional precautions must be taken into consideration when RRWH is implemented in these three provinces to prevent mosquito breeding in the storage tanks (Mwenge Kahinda *et al.*, (2007). Roof runoff contaminations are normally introduced into the storage tank through the presence of faecal matter present in the roof and gutters (Ahmed *et al.*, 2011).

According to Mosley, (2005) , acceptable water quality is achieved when:

- There are no bacteria in the water that are faecal in nature that could cause human diarrhoea or other life-threatening illnesses.
- There are no chemical compounds present at levels that would endanger human health.
- Water should not have a foul odour or taste.

Rainwater is relatively free from impurities and it rarely carries microbiological contaminant until it is collected. As previously stated, dust, bird's droppings, insects, leaves and other contaminated debris found on the catchment area are possible sources of contamination of rainwater in storage tanks, this contamination can be exacerbated by the sitting time of the contaminants which may lead to health risks when directly consumed (Shanks *et al.*, 2016; Hamilton *et al.*, 2019). Regardless of the initial good quality of the rainwater, its harvesting process, catchment area and the tank can introduce pollutants that need to be removed before consumption. Poor hygiene practices, designed and poorly managed rainwater system may cause a high health risk. A rainwater tank system can contain a variety of pollutants, as shown in Table 2-3 below.

Table 2-3: Pollutants found in rainwater harvesting tank systems adapted from (Mosley, 2005)

Pollutant	Cause	Possibility of tank entry	Ways to minimize entry
Dust and Ash	Surrounding dirt and tree leaves (Lee *et al.*, 2016)	Moderate	Frequent cleaning of the roof and gutter. Use of first-flush device and tank maintenance.
Pathogenic bacteria	Aninal feaces on the roof (de Carvalho *et al.*, 2018)	Moderate	Tank management and use of a first-flush device
Heavy metals	Material of the roof and dust present (Friedler *et al.*, 2017)	Low	Tanks should be located further away from large-scale industrial activity such as smelters.
Inorganic contaminats (e.g sea-salt seaspray)	Seaspray and unsuitable tank or roof material (Friedler *et al.*, 2017)	Low	Tanks should be located further away from the ocean and large-scale industrial activity
Larvae from Mosquito	Mosquitoe breeding in the tank and in the gutters (Olaoye, R.A, Olaniyan, 2019), (Wan Johor *et al.*, 2017)	Moderate	Clean gutters and the filtration treatment process

According to the research conducted by Stewart *et al.*, (2016), bacterial contamination is considered to be the most and immediate health risk that is associated with roof harvested water used for consumption purposes. Microbiological pollutants found in rainwater harvesting systems are classified into two categories: Pathogenic contaminants which are those that cause diseases and non-pathogenic contaminants which refer to those that do not cause diseases. Non-pathogenic microorganisms include different kinds of protozoa, algae, bacteria, and viruses. Even though these kinds of pathogens do not cause any illnesses, they do however reduce the aesthetic quality of the water and can affect how the rainwater harvesting system operates (White, 2007). The degree of safe drinking water is dependent on eliminating and reducing the entry of pathogens into the RRWH system. Table 2-4 shows that there are three main types of pathogens found in roof harvested water, (parasites, viruses and bacteria). These include pathogens such as *Giardia*, *Cryptosporidium*, *Salmonella*, *Escherichia coli*, *Campylobacter*, and Hantavirus. These organisms are introduced into the rainwater harvesting system through contamination of faecal material from animals such as frogs, reptiles, birds, rodents, cats, rats and insects (Ahmed *et al.*, 2011). Below are some of the pathogens that can enter into a rainwater system if it is poorly designed, operated and maintained.

Table 2-4:Diseases caused by pathogens present in rainwater harvesting(White, 2007)

Type of pathogen	Organism	Source	Diseases caused to humans
Protozoa	*Giardia lamblia*	cats and wild animals	Chronic diarrhoea syndrome (Funari *et al.*, 2011)
	Cryptosporidium parvum	cats, birds, rodents and reptiles	Severe diarrhoea, fever, Abdominal pains (Funari *et al.*, 2011)
	Toxoplasma gondii	cats, birds and rodents	Toxoplasmosis, birth defects(Ramírez-Castillo *et al.*, 2015)
Bacteria	Campylobacter spp.	Birds, rats, poultry, pigs, sheep, cats and dogs	Diarrhoea, Fever, Gastroenteritis (Funari *et al.*, 2011), (Ramírez-Castillo *et al.*, 2015)
	Salmonella spp.	cats, birds, rodents and reptiles	Typhoid fever(Funari *et al.*, 2011)
	Leptospira spp.	Mammals, rodents	Leptospirosis(Levett, 2015)
	Escherichia coli	birds and mammals	Acute and Bloody Diarrhoea(Funari *et al.*, 2011)
Virus	Hantavirus	rodents	hantavirus cardiopulmonary syndrome, haemorrhagic fever with renal syndrome (Brocato and Hooper, 2019)
	Hepatitis A and E	Human faecal matter	Hepatitis, Miscarriage(Ramírez-Castillo *et al.*, 2015), (M.Fazal-Ur-Rehman, 2019)

Pathogenic organisms in small amounts are quite common in rainwater, especially in samples collected after rainfall (Ahmed *et al.*, 2011). High concentration of pathogenic organisms is usually found in the first flush of rainwater; however, the level of contamination decreases as the rain continues. A substantial reduction of contaminations is noticed during rainy seasons due to catchment areas being frequently washed with the rainwater. Pathogenic microbes cause more health hazards to rainwater users than most chemical contaminants, for reasons listed below (White, 2007):

- Pathogens can cause disease after a single exposure, while it may take several months or years for chemical contaminants to cause an effect after exposure.
- Pathogens do not necessarily affect the physical appearance of the water, taste or smell. Most chemical contaminants affect the physical appearance of water, taste and smell, especially if the chemicals that are present in the water have reached levels that would cause a short-term risk.
- Pathogen levels escalate rapidly whereas chemical levels are more likely to remain constant. Subsequently, it is costly yet easy to periodically test for chemical contaminants whereas it is both costly and difficult to continuously test for most pathogens.
- A disease caused by pathogens can be contagious whereas any health effects caused by chemicals only affects those who actually consumed the contaminated water.
- Waterborne illnesses caused by pathogens can cause serious harm and pose a health risk to infants, chemotherapy patients, elderly, and those with a weak immune system.

Certain protozoan parasites, bacteria, and viruses are pathogenic microbiological pollutants. The rate of contamination and virulence may differ depending on the pathogen and the individual's immune system. It only takes just a few pathogen species to cause an illness in people who have compromised immune systems.

2.5 The Effect of Roof Material on Water Quality

Rainwater can be seen as a valuable and safe resource if it is installed and maintained properly. Globally, rainwater harvesting can either be used as the primary water source for households or as a substitute to alleviate the pressure from other sources of water. However, it is critical to evaluate the consistency of rainwater from various roof materials. Among many catchments for RWH, roof catchments are the most commonly used because people use existing roofs, thus resulting to no additional catchment area cost. However, the quality of RRWH depends on the roofing material and environmental conditions such as air pollution and temperature (Lee *et al.*, 2012).

Roof material is crucial in designing RRWH because it has an effect on the quality of the rainwater collected, as well as its intended use for potable or non-potable purposes. Roof material, slope, design, age, and condition may all have an impact on the quality of roof harvested water. Other additional causes of poor roof water quality include; weather conditions, land-use patterns and certain hydrological variables and temporal patterns (Shanks *et al.*, 2016; Norman *et al.*, 2019).

Roofs are made of different materials and most of them are suitable for rainwater harvesting catchment areas. Roofs made from potential toxic materials and grass/reed/thatch are excluded as catchment areas. The most popular roofing materials include metal sheets, rock slate, ceramic tiles and ferro-cement. Metal sheet roofs are fairly smooth and have fewer chances of retaining contaminations such as bird dropping, leaves and dust on the roof unlike the rough concrete tile roofs.

In a comparative study conducted by Chang *et al.,* (2004), to determine the quality of rooftop harvested rainwater in Nacogdoches Texas; roof materials such as galvanized iron, wood shingle, painted aluminium and composite shingle were examined. They concluded that roofing materials has a significant influence on zinc levels, electrical conductivity as well as pH values. The study also concluded that wood shingles produce the poorest quality of roof runoff in comparison to the other examined roofing materials. Steel roof catchment areas provide relatively high quality of harvested water when it comes to total organic carbon, colour, and turbidity as compared to asphalt shingles. Poor quality results from asphalt shingles could result from its material properties (Despins *et al.*, 2009). Various studies have found that concrete and metal roofs yield good roof runoff due to their even surfaces.

Metal roofs are different from other roof materials in that they possess a low percentage of bacteria in their composition, making them ideal for rooftop rainwater harvesting. A study in Ntembeni village of South Africa conducted by Chidamba and Korsten, (2015) concluded that iron sheet roof material may have a sanitising effect on the dust and debris that is accumulated on roof catchment area. This is due to the high radiation and good heat conducting capacity of the metal. According to a study by Lee *et al.*, (2012), galvanized steel roofs revealed higher iron concentrations than clay and concrete tiles, which again could be the atmospheric deposit of the galvanized steel roof. Moreover, galvanized metal roof material presented higher concentrations iron compared to ceramic tiles, concrete and asphalt roofing materials (Mao *et al.*, 2021). Similar to a study conducted by Lee *et al.*, (2012), where a comparison between various roof materials for rainwater harvesting in South Korea was conducted and the results showed that galvanized steel roof material was more suitable for RRWH. This was indicated to be because of the ultraviolet light and high temperature, which served as a bacterial disinfectant. Concrete tiles and cool roofs have also been shown to generate similar quality of collected rainwater as metal roofs, indicating that these roofing materials are appropriate and recommended for rooftop rainwater harvesting (Mendez *et al.*, 2011). Likewise, in a study conducted in China where harvested rainwater quality for concrete and ceramic tile exhibited good results compared to other roofing materials (Mao *et al.*, 2021).

According to Ward *et al.*, (2010) rainwater runoff that comes from metallic internal fittings are subject to soft water corrosion and therefore tend to exhibit high levels of metals such as copper, zinc and aluminium. Although zinc has a low toxicity level on human beings Plum *et al.*, (2010); Chubaka *et al.*, (2018), rainwater from the metallic roofs should not surpass the World Health Organization (WHO) and SANS 241 acceptable zinc level. It is not recommended that lead fittings be used on RRWH systems as they contain hazardous levels of lead that could be harmful for human consumption (Chubaka *et al.*, 2018). Meanwhile, rainwater harvesting from metallic roofs in acidic rain areas have not yet been flagged for caution which therefore means that more corrosion and leaching may occur under such conditions (Okpoebo *et al.*, 2014). In a study conducted by (Mosley, 2005) it is suggested that harvesting under such conditions should be monitored with caution. It is therefore suggested that metal roofs that are visibly corroded be fixed or changed to prevent health issues and degraded colour quality caused by the iron from the corroding roof (Mosley, 2005; Okpoebo *et al.*, 2014).Roofing materials are often supplied with a paint coating or are painted on site. Painted roofs may sometimes be used for rainwater harvesting. However, it is important that nontoxic paint is used to avoid the cause of water pollution (Biswas and Mandal, 2014). Other types of paint can contain hazardous composites that may require suitability tests prior to painting. Paints containing lead, tar/bitumen, fungicides, chromate, or other chemicals should be avoided because they can pose a health risk or give water a bad taste. Once the roof has been repainted, the first roof runoff from the first precipitation occurrence must be prevented from coming into the tank and rather be disposed of and used as non-potable water.

2.6 Maintenance of RRWH System

Storage tanks should be cleaned annually, especially if large amounts of debris have entered the tank. Cleaning helps in the restoration of good water quality. Based on previous studies, raw harvested rainwater has been proven to be ineligible for direct consumption purposes prior treatment due to contamination of microorganisms, heavy metals, organic matter, roof materials, and other environmental contaminations (Owusu-Boateng and Gadogbe, 2015; Friedler *et al.*, 2017). This could be further induced by insufficient maintenance of the RRWH collection system which includes the catchment roofs, gutters, pipes, first-flush tanks or storage tanks. It is therefore recommended that the whole system is cleaned and maintained to restore and improve rainwater harvesting quality.

2.6.1 Roof

The roof catchment area is the biggest part of contamination in RRWH. Usually, the roof can clean itself through first flush runoff, however it is also recommended to manually clean the roof before it starts raining and after a long dry spell. Cleaning the roof is however practical on flat and less steep roof types. Trimming tree branches that are overhanging the roof is important so as to minimize the bird droppings and leaves landing onto the roof (Mosley, 2005).

2.6.2 Gutters

It is essential to clean gutters periodically. Gutters can be swept out with brushes before the rainy season starts and randomly during the rainy season. The frequency of cleaning is however dependent on the overhanging trees and the level of blow dust around the gutters (Korsten *et al.*, 2016).

2.6.3 Filters

To achieve better and improved quality of harvested water, leaves and other debris must be removed and prevented from entering the tank by using coarse filters (Korsten *et al.*, 2016). Filters must be strong, easily cleanable, and replaceable. It is crucial that tank inlets are completely sealed, so as to avoid mosquitoes from entering the storage tank (Mosley, 2005). Dirty filters may cause clogging and may not pass the water efficiently causing them to be the source of contamination. Some filters are self-cleaning but still need to be inspected to ensure that it is working efficiently and correctly. Filters that are non-self-cleaning should be inspected and washed occasionally.

In an event where sand filters become dirty due to an increased obstruction of the flow of water, filters need to be emptied and thoroughly cleaned before placing it back. Cloth filters also get dirty with time but won't obstruct the flow of water but will allow the dirt to go through the filter and into the tank. Cloth filters should be washed whenever they look dirty and can be washed with ordinary household laundry.

Filters that are made from mesh tend to catch larger debris such as leaves and stones. Once they are blocked, they obstruct the flow of water meanwhile they are creating a home for wildlife such as rats. The dirt on these filters may be removed through brushing or tapping out the dirt.

2.6.4 First flush

During dry (April to September) periods and the beginning of the rainy season, impurities such as leaves, and dust gather on rooftops. These contaminants are usually washed into the storage tank in the absence of a first-flush device and inlet screens in the storage tank. In the presence of a first-flush device, the harvested water is much cleaner and safer to drink. The purpose of the first-flush device is to prevent the impurities from coming into the storage device (Korsten *et al.*, 2016).

Systems should be cleared of accumulated sludge after at least every third storm to prevent them from being a source of contamination. First flush systems should be self-cleaning to enable them to be automatically reset.

The amount of first flush water that needs to be eliminated before water can be deemed safe to drink has been found to vary between various studies. In a study conducted by Naqvi *et al.*, (2018), results concluded that around 95 to 114 litres of water ought to be redirected in the first flush. However, this water may not be used as consumable water, due to its turbidity and acidic attributes but can be used for non-consumable purposes at commercial and domestic levels. The first-flush volume indicated is specifically for the 121 to 139 m^3 catchment areas with an average rainfall of approximately 1500 mm/year. Removing the first millimetre of first-flush, total coliforms and *E. coli* can be reduced by approximately 98% and 100%, correspondingly (de Carvalho *et al.*, 2018). The reduction found in these examined parameters guarantees a negligible health hazard for drinking rain collected water; for 1 mm of first-flush which was redirected for the clean security of the storage (de Carvalho *et al.*, 2018).

Doyle and Shanahan, (2012) discovered that diverting the first flush reduced reliability of supply by no more than 8%. According to an analysis study of three existing RWH systems in Rwanda, Bisate, the recommended 1 mm of first-flush diversion can only reduce the number of days the system meets demand by 7 per year. According to Kus *et al.*, (2010), the first flush of roof runoff from an inner-city residential area in Sydney metropolitan, Australia, the quality of the collected water is significantly appropriate for consumption as opposed to the Australian Drinking Water Guidelines (ADWG) after diverting the first 2mm of rainfall. Turbidity and lead contaminants did not meet the ADWG standard which therefore required approximately 5mm of first flush rainfall. When lead and turbidity levels are reduced by treatment, the consumer can save money by avoiding the first 1 to 2mm of rain and increasing the yearly rainwater tank yield. Furthermore, the first flush should not have to be wasted. Although diverted water may not be appropriate for drinking, it may be used for other uses such as irrigation.

2.6.5 Tanks

Cleaning the storage tank is the most common action taken where maintenance of rooftop rainwater harvesting system is concerned. The process of cleaning a storage tank involves the drainage of rainwater from the tank to a temporary storage tank. One litre of household bleach solution can be added into the remaining water inside the tank. The bottommost of the tank together with the walls of the tank can then be thoroughly scrubbed using a brush (Mosley, 2005; Goyal, 2014)

2.7 Treatment of RRWH to Potable Water

There are various inexpensive methods of treating rooftop rainwater harvesting to ensure that the water is of adequate and sufficient quality for consumption. The methods are namely disinfection, slow sand filter, chlorination and pasteurization.

2.7.1 Disinfection

Disinfectants are normally applied to harvested rainwater with the aim of improving its fungal quality. Chlorination is one of the widely known, inexpensive and easily applicable practices in water treatment. Chlorine is used to deactivate most of the micro-organisms found in water which may cause waterborne diseases such as cholera, typhoid, dysentery and hepatitis (Lakshminarayana, 2020). Where contamination is suspected due to the rainwater's colour or odour, chlorination becomes the best treatment option (Satvat *et al.*, 2004).Chlorination is usually applied once the harvested rainwater has been taken out of the storage tank. This is because chlorine could react with organic matter and form unwanted by-products which may settle at the bottom of the storage tank. For considerate and effective chlorination, chlorine should range between 0.4 – 0.5 mg/l (Lakshminarayana, 2020). This can be achieved by applying chlorine gas or tablets. The main limitation of this process is that some parasites can resist low doses of chlorine.

2.7.2 Slow sand Filtration

Sand slow filtration is an inexpensive biological treatment that is used to enhance the bacteriological quality of rainwater harvesting. Filters are constructed using graded sand layers that have fine sand particles at the bottom and coarser sand layers at the top. Filtration can be used to prevent pollutants from entering into the tank and during the extraction of water from the storage tank, through the tap before consumption (Satvat *et al.*, 2004). To achieve effectiveness, it is essential for the water to flow through in a constant manner of 100 to 200 litres per hour per m^2 of the filter area (Lakshminarayana, 2020). An effective slow sand filtration process can remove 98% to 99% of bacteria in the water (Lakshminarayana, 2020). However, if this process is operated at slower rates or in conjunction with preliminary treatment and chlorine, an efficiency of 99.5 to 99.9% may be achieved (Lakshminarayana, 2020). The main limitation of this process is that micro-organisms can only be cleared and not completely cleared.

2.7.3 Pasteurization

Pasteurization is a low-cost water treatment method that can be achieved by combining heat from solar energy and ultraviolet radiation. Harvested rainwater can be pasteurized by pouring it in plastic bags or bottles. This method is more effective when the water is fully oxygenated and the temperature is at least 50ºC (Lakshminarayana, 2020). Pasteurization method is mostly effective when it comes to removing *E. coli* and other pathogenic bacteria. The main limitation of this treatment is that it becomes less effective if the concentrations of the suspended solids are 10mg/l or more.

However, numerous treatment methods can be utilized where one treatment method produces unsatisfactory results in producing improved rainwater quality requirements. RRWH cannot be used for consumption after only one simple water treatment method. If harvested water is intended for drinking purpose, intensive treatment methods need to be implemented to meet satisfactory standards for drinking water. The most common method for achieving satisfactory drinking water standards is combining the disinfection method together with the membrane filtration method. However, according to (Lakshminarayana, 2020), Solar pasteurisation method produces better results than all other purification methods. This method also has no operational cost and also is very effective in removing all impurities in rainwater.

Once water purification methods have been effectively achieved, the obtained treated water may be used for consumption. However, depending on the size of bacteria and viruses, it may be essential to boil the water before drinking (Ahmed *et al.*, 2011; Hamilton *et al.*, 2019). Nevertheless, the cost of this water treatment method is high and high maintenance routines may not necessarily be required except for filters and other industrial operations.

2.7.4 Boiling

Water that has been fully boiled for at least 1 minute is usually devoid of toxic bacteria and pathogens. Since it is not feasible to purify water in this way every day, it is normally only used as a last option (Satvat *et al.*, 2004).

2.7.5 Direct sunlight

By exposing water in clear glass or plastic bottles to direct sunshine for many hours, hazardous bacteria can also be eliminated from the water (Gould, 2010). This method not always feasible. However, to achieve the best results, the water must be clear, there should be good sunny weather and allow water to cool overnight before consumption (Satvat *et al.*, 2004).

2.8 Factors affecting the quantity of RRWH

The success and failure of RRWH greatly depends on the quantity of water that can be collected at a given location. Factors such as tank size, the roof slope, rainfall intensity, the catchment area, and the duration of the rainfall may influence the amount of available water in RRWH (Karunasena *et al.*, 2013; Faza and Suwartha, 2021).

2.8.1 Catchment area

Rainwater harvesting from a wider roof area may result in a larger volume of water. Nevertheless, the quantity of annual roof runoff volume may alternate as a result of other external factors such as the effects of rainfall intensity, the amount of first flush volume wasted, size of the storage tank as well as the slope of the roof (Faza and Suwartha, 2021). The size of the roof catchment area determines the amount of rainwater that can be collected (Norman *et al.*, 2019).

2.8.2 Runoff Coefficient

The volume of captured water is influenced by the Runoff coefficient (RC) which is a dimensionless parameter that ranges from 0 to 1. This is the ratio of the amount of water that runs off a surface to the volume of rain that falls on it. Roof runoff coefficient varies significantly based on the roof material and the slope of the roof. A high runoff coefficient represents a higher percentage of water that can be harvested. Which therefore means that the higher the runoff coefficient, the greater the harvest (Biswas and Mandal, 2014). According to a study done by Ojwang *et al.*, (2017), the RRWH system's evaporation and leakage losses are represented by the runoff coefficient. Great amounts of water flow off on smooth and impermeable surfaces. For example, rooftops or cleared ranges as compared to soil and areas that are not paved. Different types of catchment surfaces retain water in different ways. (Kumar, 2015). Table 2-5 demonstrates typical runoff coefficients for different types of catchment materials.

Table 2-5: Runoff coefficient for traditional roofing material

Type of roof material	Runoff coefficient	Country of study	Reference
Corrugated metal sheet	0.7–0.9	Bangladesh	(Biswas and Mandal, 2014)
	0.81-0.84	Unknown	(Ugai, 2016)
	0.7-0.9		(Davis and Tapia, 2016)

Type of roof material	Runoff coefficient	Country of study	Reference
	0.7-0.9	Pakistan	(Siddiqui and Siddiqui, 2018)
	0.7-0.9	Nigeria	(Mohammed, 2018)
Tiles	0.8-0.9	Bangladesh	(Biswas and Mandal, 2014)
	0.75	India	(Kumar, 2004)
	0.8-0.9		(Davis and Tapia, 2016)
	0.8-0.9	Pakistan	(Siddiqui and Siddiqui, 2018)
	0.85	South Africa	(Armitage *et al.*, 2013)
	0.8-0.9	Nigeria	(Mohammed, 2018)

2.8.3 Type of roof

The type of roof is often differentiated by its shape which may affect the amount of roof runoff that can be harvested. The appropriate roof that may be used in rainwater harvesting is a single-pitch roof capable of draining out the rainwater collected through the guttering. In contrast, flat roof types are exposed to prolonged runoff time which therefore means that evaporation loss make it less efficient. This can be improved by providing adequate finished edges for the water to be retained until it can be drained out through the gutters (Yahya *et al.*, 2019).

2.8.4 Material and Slope

In a research conducted by Farreny *et al.*, (2011), it was determined that roofs with slanted smooth surfaces can collect up to 50% more rainwater than flat roof surfaces. This is because rainwater can shed off quickly on steep roofs, whereas a flat roof causes water to flow slowly. Moreover, The volume of rooftop harvested water is influenced by the gradient of the roof catchment (Ojwang *et al.*, 2017; Norman *et al.*, 2019). Both the quality and quantity of RRWH are primarily determined by the roof material. For example, because of their high runoff coefficients, hard surfaces such as concrete, iron and tiles generate the most roof runoff. (Ojwang *et al.*, 2017). Not only does the roof material influence the runoff coefficient, but it also has an impact on the water quality of the rainfall collected. A roof that is impermeable will provide a large amount of good-quality water that can be utilized for cooking, washing, and drinking (Biswas and Mandal, 2014).

2.8.5 Rainfall

Generally, the primary source of surface water is rainfall and plays a huge role in the hydrological cycle. Hence, rainwater harvesting systems should be carefully installed to provide appropriate results for water supply in any location where the rain falls on earth's surface (Qi *et al.*, 2019). It has been argued that RRWH systems may not necessarily be a viable option for regions that receive low average annual rainfall (Peters, 2016). The environmental feasibility of RRWH systems is highly dependent on the precipitation variations and volume in the specific area, the duration of dry seasons as well as the accessibility of other available water sources. Rainfall patterns may determine whether or not RRWH can serve as an alternative water source against the other water supply systems. Tropical climates that have short dry seasons ranging from one to four months and experience high rainfall intensity and rainstorms are the most ideal regions to provide the most ideal conditions for rainwater harvesting (Gould, 2015). Table 2-6 shows the 10-year historical that was obtained from the South African Weather Services (SAWS).

Table 2-6: 10-year historical rainfall data (mm) obtained from (SAWS,2021)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2010	100.4	56.2	63.6	42.4	8.4	39.4	11.2	0.4	26.4	120	127.2	177	772.6
2011	137.6	6.2	40.6	52.4	216.8	102.4	107	31	8.8	69.2	221	53.4	993
2012	46.2	91.2	383.2	78.2	17.4	14.8	24.4	141	208	234.4	172.6	195.8	1607.2
2013	141.6	96	318.2	122.8	51.2	9.4	99.6	14.2	47.8	180.6	108.6	458.2	1648.2
2014	78.2	89.4	150.4	31.2	26	4.6	6.8	45.6	96	82	72.2	162.4	844.8
2015	51.4	40.8	98.8	135.2	0	4	140.8	28.2	88	36.8	100.8	98.6	823.4
2016	69.2	101	197.6	21.6	58.6	7.6	208.6	47	69.8	107	151.6	45.8	1085.4
2017	122.6	139.2	119	54	223.8	0	14	118.8	80.2	150.4	198.4	89.6	1310
2018	83.2	128	146	42.4	17.8	0	8.4	102.6	40.8	99.2	62.2	117	847.6
2019	121.2	88.6	97.4	549.2	33	21	12	37.6	61.4	66.4	140.8	137.6	1366.2
2020	131.6	142.6	100	142.2	7.4	1.2	15	21	28	147.4	209.8	89	1035.2
Avg. p/m	**98.5**	**89.0**	**155.9**	**115,6**	**60.0**	**18.6**	**58.9**	**53.4**	**68.7**	**117.6**	**142.3**	**157.1**	**1135.5**

2.8.6 Capacity of storage tank

Rainwater harvesting storage tanks are to store harvested water and help reduce peak flow during peak-flow-generating rainstorms. Several studies have shown that the larger the tank size, the more reliable the RRWH system becomes. Thus resulting in higher yield (Teston *et al.*, 2018). The size of the tank that should be used for a roof catchment area is highly dependent on the amount of rainfall in the area. In tank sizing, the volume of the tank is directly proportional to the cumulative demand for a specific household over a specific time period (Abdulla, 2020).

2.9 Advantages and Disadvantages of RRWH

Roof water harvesting is widely known for its ability to provide an inexpensive source of water and alleviating pressure of water demand in water scarce countries. Both new and ancient homes can easily have it installed. In terms of the environment, if the system is put in a significant number of homes, it can help to minimize surface runoff, which invariably reduces flooding and erosion in flood/erosion-prone plains (Kahinda *et al*., 2010). Rainwater harvesting has both advantages and disadvantages. It is imperative to not only look at the advantages and disadvantages of RRWH holistically but rather categorically based on its different uses and services. Table 2-7 below demonstrates the operational advantage of RRWH based on individual, community, government and the environment. While Table 2-8 focuses on the operational disadvantages of RRWH based on individuals, community, government and no disadvantages were found on the environmental issues of RRWH.

Table 2-7:Advantages of RRWH systems(Che-Ani et al.*, 2009)*

Individual	**Community**	**Government**	**Environmental**
The systems are simple to maintain for the owner/user, and the operating costs are minimal. (Goyal, 2014)	It is an independent system and therefore well-suited for disperse and remote communities.	It serves as a vital backup in the event of an emergency or a failure of the public water supply system. (Yusop and Syafiuddin, 2018)	It has very little environmental impacts compared to other water supply systems. (Mohammed, 2018)
Ensures that water is available when it is most needed. It is run and managed by the owners. (Kagabika and Kankuyu, 2021)	Water obtained is of better quality and is safer than that found in rivers and streams. (Kagabika and Kankuyu, 2021)	RRWH system are easy to install, and local people can easily be trained to do so, lowering the cost. (Mohammed, 2018)	Rainwater is friendly to landscape plants and gardens (Abdullah and Mamun, 2020)

Installation, operation, and repair do not require a lot of manpower. (Kagabika and Kankuyu, 2021)	It is built using local materials and labour. (Mohammed, 2018)	Reduces the burden for new and replacement of ageing systems and infrastructures. (Che-Ani *et al.*, 2009)	Reduces floods, stormwater runoff and erosion. (Goyal, 2014)
After adequate treatment, it produces clean drinking water for humans. (Kumar, 2015)	Provides water source for agricultural demands, thus creating job opportunities for the community. (Kagabika and Kankuyu, 2021)		The systems do not require high sources of energy to run. (Kagabika and Kankuyu, 2021)
Reduces water bills (Goyal, 2014)			

Table 2-8: Disadvantages of RRWH systems (Che-Ani et al., 2009)

Individual	**Community**	**Government**	**Environmental**
The success rate of RRWH is determined by the regularity and the amount of rainfall. Thus, making it a non-reliable source of water in dry seasons and during drought eras. (Abdullah and Mamun, 2020). Storage limitations (Abdullah and Mamun, 2020)	In a case where inadequate treatment is performed due to a lack of appropriate knowledge/resources, people may be faced with health risks resulting from mosquito breeding and other contaminations.	Low storage volumes would restrict rainwater harvesting, resulting in the system's inability to provide water during periods of low rainfall. Increased storage capacity raises construction and maintenance costs, potentially rendering the technology uneconomical unless subsidized by the government.	
RRWH deteriorates after some time and therefore requires routine treatment. (Kagabika and Kankuyu, 2021)	It is a selfish solution, destroys the feelings of sympathy and sharing. (Kunt and Çiftçi, 2018)	Rainwater harvesting systems can result in a reduction in revenue for public utilities. (Kunt and Çiftçi, 2018)	
The construction of a new RRWH system may incur high initial costs. This might disadvantage other to low income families who cannot afford high volume storage tanks (Kagabika and Kankuyu, 2021)			

Individual	Community	Government	Environmental
Animal wastes and vegetable matter may contaminate the water, posing a risk to humans if rainwater is not treated before being consumed. (Goyal, 2014)			
Certain roof types might seep chemicals (Abdullah and Mamun, 2020)			

2.10 Economic Feasibility of RRWH

The saving of water is one of the most important considerations in determining the overall economic value of RRWH. The efficiency of water saving depends on populations water demand, household size, rainfall intensity, tank size, design period, catchment area and the economic capability of the household (Akter and Ahmed, 2015). According to a study conducted by Rahman, (2017), the economic analysis of RWH system is a consideration of various issues such as the potential amount of water that can be saved, interest rate, price of water, environmental benefits and the amount of time saved for fetching water which can translate to productivity, the cost of available alternative water supply and maintenance of the RWH system. Liang and van Dijk, (2011) conducted a study in the rural areas of Beijing with the aim of analysing the financial and economic performance of constructed RRWH using the cost benefit analysis method. The results showed that RRWH systems are economically feasible and have a positive effect on society.

The adaption of RWHS can serve an economic benefit reducing water demand from municipal water mains and by decreasing stormwater volumes that might require supplementary drainage system to manage (Alim *et al.*, 2020b; Zabidi *et al.*, 2020). Similarly, Morey *et al.*, (2012) carried out a study regarding the ability of RRWH to meet the domestic water demand. The findings revealed a decrease in reliance on traditional water supply systems, which could result in monthly water bill savings of up to 50%.

In a study conducted to investigate the financial feasibility of RRWH for high water use households in Colombia with the use of historic rainfall data, Oviedo-Ocaña *et al.*, (2018) concluded on a possible 44% of potable water saving which is equivalent to 131m^3/year with an estimated payback period of 23 years. On the other hand, in a study conducted in Mexico City, at a logistics company, the results showed 100% reliability and that RRWH was capable of covering the current water demand of the company. Therefore the implementation of the rainwater harvesting system had an economic benefit to the company with a five year payback period given the size of the establishment (Miguel Ángel López Zavala, 2018).
Globally, rainwater harvesting plays an important part in ensuring the efficiency and appropriate use of rainwater. According to Awawdeh *et al.*, (2012), RRWH has the potential of saving 125% - 145% of potable water supply for domestic use in Jordan. In a case study in Brazil, an assessment of residential, public and commercial sectors was done and found that the potential of potable water saving can vary from 1.7% - 50.5% (Cureau and Ghisi, 2019). Related to the study conducted in Nigeria, an average household can harvest approximately 74 000L of rainwater per year. In Abeokuta, the annual average water demand for flushing and washing is 29 400L and can meet the household monthly demand excluding the months of November to December. With adequate storage, the excess rainwater stored during the peak period can be sufficient to supplement the shortfall (Aladenola and Adeboye, 2010).

Conversely, Armitage *et al.*, (2017) conducted a study in the Cape Town Liesbeek River using the Urban Rainwater/Stormwater Harvesting Model (URSHM) to calculate the viability of RWH. The study concluded that rainwater harvesting is not economically feasible for many residential households because of the cost of installation and maintenance compared to the reduction in water bills but rather economically viable for a minority of households. However, an evaluation of the reliability of rainwater harvesting (RWH) in SA schools was conducted using the Behaviour Analysis method (BAM). The study showed a 90% reliability on RWH supply levels for different schools (Ndiritu *et al.*, 2014).

2.11 Summary

From the literature review, it is clear that there is a demand for water and rainwater harvesting systems can help to alleviate the pressure from municipal water supply. According to the constitution of SA, everyone has a right to adequate water supply. The minimum requirement for sufficient water is 6kl per household. The current legislation regarding rainwater harvesting as a whole is ambiguous and therefore does not give a clear explanation of whether or not rainwater harvesting is permitted in the country. However, with the literature provided, rooftop rainwater harvesting for domestic/household purpose is permitted under authority.

Related literatures allude to the fact that there are many factors that may affect the quantity and quality of RRWH systems. Roof material, guttering, roof storage tank, roof geometry, land use and weather conditions have been listed as one of the most common factors that affect the quality of roof harvested water. Meanwhile factors such as catchment area, runoff coefficient, rainfall intensity, size of the tank and surrounding environment have been listed as factors that may affect the amount of harvested rainwater that can be captured by the system. Although various studies prove minimum number of severe illnesses and diseases caused by roof runoff, it is noted that there are bacteria and viruses present in roof harvested water that may be harmful to human if consumed prior to treatment.

There is a collective agreement from various authors that indeed roof material does have an effect on rainwater quality, therefore system maintenance and treatment is crucial. Routine maintenance includes cleaning of the catchment area, gutters and the storage tank. Disinfection, Pasteurization and Slow sand filter are the most common rainwater harvesting treatment methods. Studies also recommended boiling the water before consumption which helps in killing the bacteria found in rainwater.

Several studies have been conducted about the economic feasibility of RRWH. Many have concluded that economic feasibility is dependent on various aspects such as populations water demand, household size, rainfall intensity, tank size, design period, catchment area, economic capability of the household, environmental benefits and the amount of time saved for fetching water. Based on the studies observed, the payback period can range from 5 – 23 years depending on the demand size.

CHAPTER 3 : STUDY AREA

3.1 Introduction

This chapter provides statistics of the hydroclimatological characteristics (climate, precipitation and air quality). Demographical data such as population and household sizes were addressed in this chapter as well as educational level of the community. Another important aspect that was discussed in this chapter is the status quo of the current water supply along with the government service delivery towards the community. These services include water, sanitation, electricity, roads and other facilities.

3.2 Location and description

Winnie Madikizela Mandela Local Municipality (WMMLM) falls under the Alfred Nzo District Municipality (ANDM) in the Eastern Cape province. The Mbizana town is situated in the Eastern Pondoland and therefore forms part of the Wild Coast region of the Eastern Cape (EC). It is surrounded by the Eastern Cape O R Tambo District municipality on its southeast, Alfred Nzo's Ntabankulu Local Municipality and Umzimvubu Local Municipality covers the north and northwest and lastly the KwaZulu Natal's Ugu District Municipality on its northeast region. The Mbizana town's R61 connects to the South Coast of KZN to the N2 highway that leads to Mthatha in the O R Tambo District Municipality. The WMMLM lies between two rivers, the Mthentu river towards the south and the Mthamvuna river towards the north. These rivers form the northern boundaries of the EC province with KZN. The WMMLM currently consists of 31 wards. Nomlacu is a rural village within the WMMLM and falls on the South West region of ward 26. The population size is approximately 2194 people. Nomlacu lies on latitude -30°50'30.63" and longitude 29°46'46.06" with an estimated terrain elevation of 971 meters above sea level. The average area of this village is approximately 4.2 km^2 as shown in Figure 3-1 and Figure 3-2 shows the close-up aerial view of the study area.

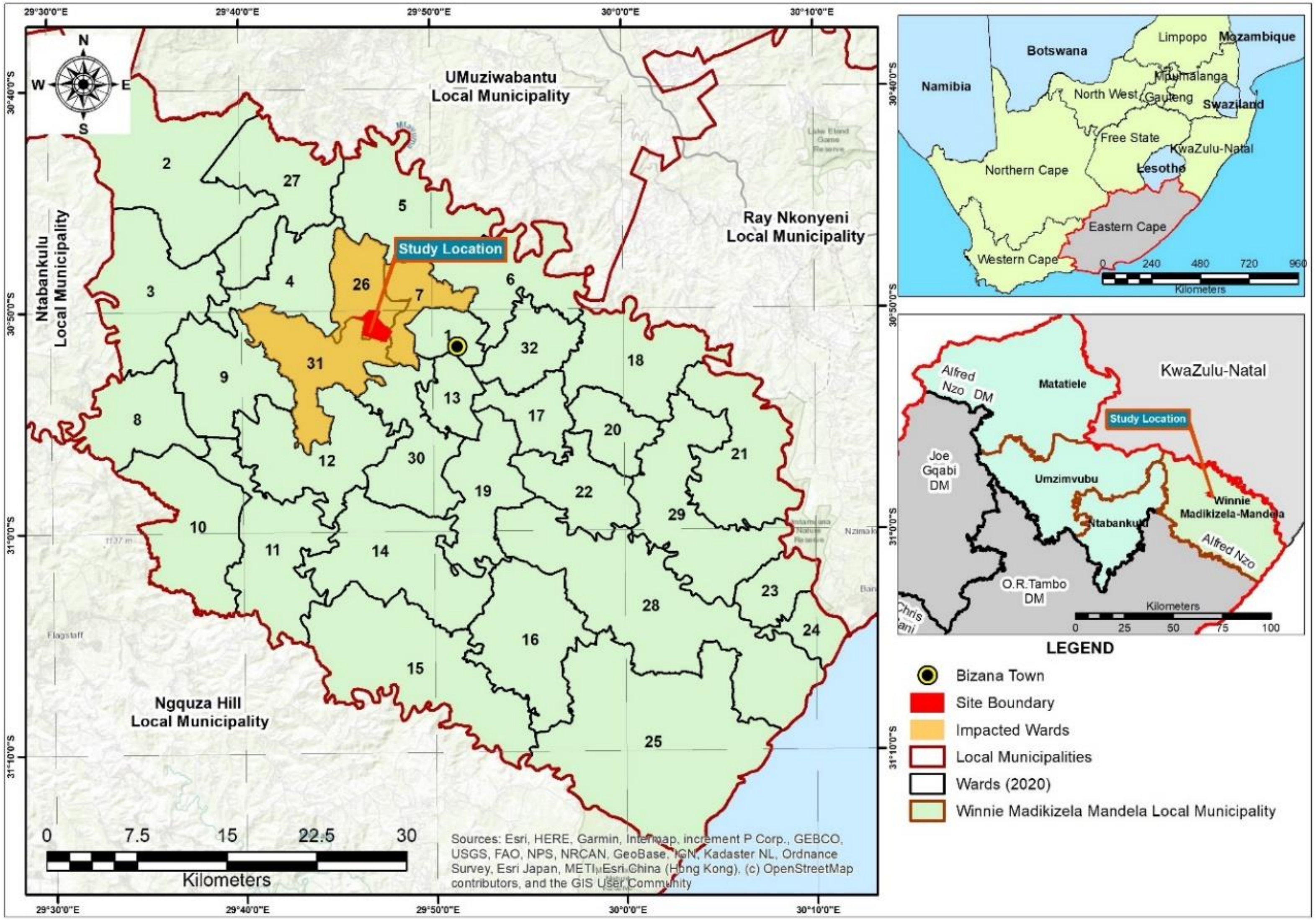

Figure 3-1: Winnie Madikizela Mandela Local Municipality locality plan

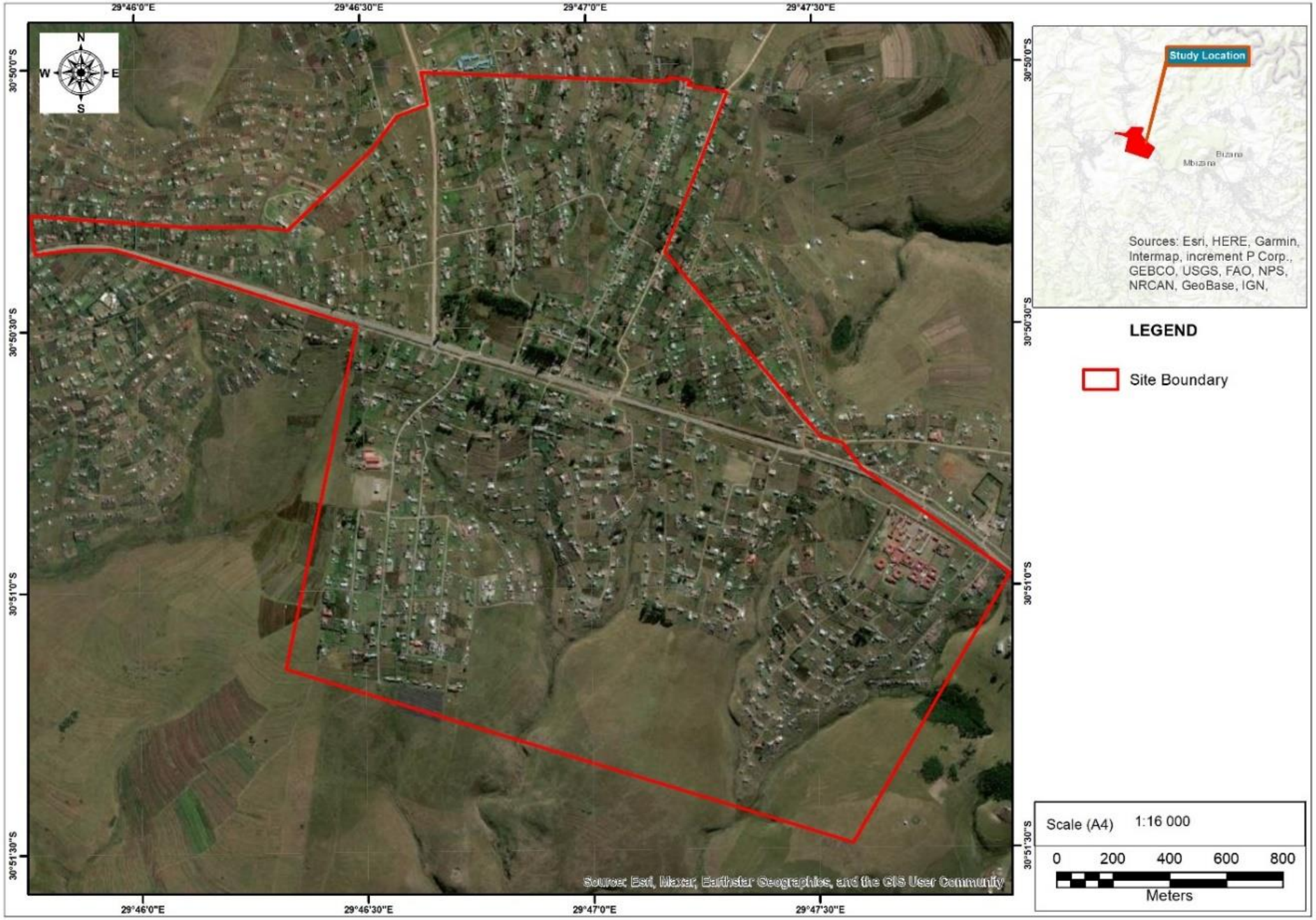

Figure 3-2: Nomlacu aerial view

3.3 Population

3.3.1 Demarcation

According to (MLM DIDP, 2021), The population of WMMLM has an approximate total has an average household size of 5.3 members with approximately 56% of the population being economically active. In a report by (MLM DIDP, 2017) states that WMMLM is a youthful population because approximately 66% of its total population is less than 35 years of age. Although elderly citizens aged 60 years and above, they only occupy 8% of the total population. According to ECSECC, (2017), Mbizana is dominated by females at approximately 54% of the total population as opposed to the 46% of the males. The largest population group in Mbizana is Black Africans at 99.58% of the population. The population is estimated to rise to an average annual rate of 1.3% from “311 000 in 2016 to 332 000 in 2021” (ECSECC, 2017).

3.3.2 Education

Education and literacy levels at Mbizana are generally low. Less than 50% of the population study until high school level and only a few people further their studies at higher educational level after matriculation. Few people pursue post-secondary education, necessitating the government's allocation of sufficient resources to education as a primary factor (MLM DIDP, 2021).

3.4 Climate

3.4.1 Temperature

Like many coastal areas, temperatures in Mbizana usually range from (3°C to above 30°C) with a mean annual temperature of 21°C. Temperatures become slightly wider towards the inlands and ranges from (3°C to above 40°C) with a mean annual temperature of 16°C. Light snowfalls are occasionally experienced during the winter season, melting within one or two days (Dweba *et al.,* 2016).

3.4.2 Air Quality

Mbizana is considered to have ambient air quality which is very good throughout the municipal area. The area does not have a significantly huge amount or sources of air pollution. The air quality in the WMMLM is estimated to be within the limits of the National Ambient Air Quality Standards (NAAQS) and not harmful to health and well-being (Dweba *et al.,* 2016). In some instances, the air quality does become relatively poor at times in areas close to the local source of air pollution, whereby it exceeds the NAAQS air quality compliance limits. Areas such as waste sites, at peak traffic times in Mbizana town and adjacent to busy unpaved roads have been identified to have a potential sources of air pollution. Air quality may be poor in rural areas where communities use wood as the primary source of energy for cooking. In most cases, this is experienced during the winter season where more fuel is used and the atmospheric dispersion potential is not as effective as in the summer season (Dweba *et al.,* 2016).

3.5 Precipitation

Mbizana Local Municipality falls within a temperate climatic region. It has warm humid summers and frost-free winters. Rainfall in Mbizana usually occurs in summer in the form of heavy thunderstorms. The lowest rainfall of the area is generally 8 mm and it occurs around June. The highest rainfall occurs around December and can go up to 104 mm (Dweba *et al.,* 2016; MLM DIDP, 2020) The average rainfall varies depending on the altitude and topography, and ranges between 1 000 mm to 1 300 mm per annum along the coastal areas, to 700 mm per annum in the inlands and up to 1 500 mm per annum along the cliffs. Tornadoes are occasional and rare in this area (Dweba *et al.,* 2016).

Rainfall data obtained from the South Africa Weather Service (SAWS), measured at the Port Edward rainfall station (Station ID 0155394A5) which is the closest rainfall to Mbizana town. The data obtained is from 2010 – 2020.

3.6 Service Delivery

3.6.1 Water

According to the (MLM, 2020), the municipality currently has a relatively high percentage of backlogs where services delivery is concerned. As mentioned in chapter 1, The municipality currently has 73.6% water backlog which equates to approximately 45 178 households without basic water supply. Of this population, only 4.6% have access to a rainwater harvesting system (MLM, 2020). This means that majority of the population depends on stagnant, untreated and unreliable sources of water. However, the situation is different in the community of Nomlacu. Nomlacu has both yard and community taps where they obtain their water. Although there is a current water system, water cut-offs are still being experienced by the community.

3.6.2 Sanitation

Although sanitation backlogs have improved to 73%, there is still 27% of unserved households. For refuse collection, only 3% households and 100% businesses including rural business hubs receive refuse collection from the municipality. It is estimated that 21% of the population do not have means for waste removal while others use their own means.

3.6.3 Electricity

The electricity backlog is approximately 13% which means that 87% of households have access to electricity. The municipality is however estimating a 16000 growth of households due to current housing projects that will still need electricity.

3.6.4 Roads

Mbizana IDP demonstrates that approximately 54.5% of the surrounding villages do not have access to proper roads. The local municipality has been reported to have bad conditioned roads. Roughly, 385.6km of road have been created and 23.6km was targeted for the financial year of 2019/20.

3.6.5 *Facilities*

Nearly 28% of homes lack access to a telephone (MLM, 2020). The majority of homes with telephone connection benefit greatly from cell phone service, which is frequently impeded by inadequate network and signal coverage, especially in rural areas. The performance of the municipality as a whole has significantly improved in areas including infrastructure, community services, education, health, the road system, transportation, and social development services.

3.7 Water Supply

Generally, water supply backlogs are relatively high in the municipality, and there are current projects put in place to provide for such backlogs. “Currently there is no service level agreement between the WMMLM and the ANDM about the provisioning of water” (MLM, 2020). The water services Authority which is the Alfred Nzo District municipality has reviewed many water schemes that are currently present at the rural areas. The Ludeke dam has been built to plan to reticulate water to the rural areas. The capacity of the Ludeke Dam completed in 2014 is 14.5 million cubic metres at Full supply level. The dam is 33.7 m deep and has a surface area of 140 hectares (Bain, Tyler., Udal, Mike., Rennie, 2012).

Upon the connection and completion of the of the Greater Mbizana Regional Bulk Water Supply Scheme, the implementation of the scheme can service 85% of the water supply backlog at the least. However, the dam capacity can serve 100% of the population upon augmentation.

The current Nomlacu Water Treatment Works (WTW) has been designed and built at 10Ml/Day which can later be upgradable to a 20Ml/Day in order to provide service for the whole Mbizana population. At the moment, the 10Ml/Day WTW can only supply 48% of Mbizana community and that is the whole WMMLM population. However, there is currently no bulk pipeline and secondary bulk which therefore means that it still needs to be provided for (MLM DIDP, 2017).

Figure 3-3 show the current water supply and state of water supply system in Nomlacu:

Figure 3-3: a. Yard tap, b. Leaking communal tap, c. Estranged communal tap

3.8 Summary

Nomlacu village is situated in Bizana town under the Winnie Madikizela Mandela Municipality. The village has an approximate area of 4.2km and has an estimated population of 2194 people. According to the IDP, the population of Mbizana is youthful and female dominated with approximately 66% and 54% respectively. Generally, the service delivery around the municipality for roads, facilities, electricity and sanitation are of good standing. However, water cut-offs are still being experienced by the community where water supply is concerned. This gives RRWH as a water supply in Nomlacu an opportunity to bridge the gap and provide water during cut-offs as well as providing water for households that still rely on untreated water. Temperatures around the area ranges from 3°C to 30°C with an annual average temperature of 21°C. The annual rainfall ranges from 1000mm to 1300mm which makes RRWH a possibility.

CHAPTER 4 : METHODOLOGY

4.1 Introduction

In order to determine whether or not rainwater harvesting can be feasible and effective, it is important to consider the water availability, water quality, social acceptance, legality as well as the economic benefits.

In the previous chapters, factors that contribute to the feasibility and effectiveness of rooftop rainwater harvesting were addressed. To examine the hypotheses stated in section 1.5.2, this chapter aims to define the research design and the methodology used during the course of this study. Moreover, this chapter will discuss sampling methods, calculations and the approach used to obtain the results.

4.2 Research approach/design

Methodological approach, or research design, is one of the key factors to take into account while developing any type of study. As a result, it can be claimed that a study design should include comprehensive information regarding the research topic, objectives, concepts and their operational definition, variables, hypothesis, and methods. This includes data collection and processing methods, analysis and interpretation techniques, time-frame considerations for the study, and an estimate of the costs involved (Akhtar, 2016).

Qualitative results obtained from the study may be used as a foundation for the quantitative study. Multi-method approach combines qualitative and quantitative methods, which are used to investigate the research objectives with multiple perspectives, also taking advantage of the strengths of both qualitative and quantitative research methods (Daly *et al.*, 2013).

The below Figure 4-1 is an outline of the research methodology and justification on why and how a multi-method approach was adopted.

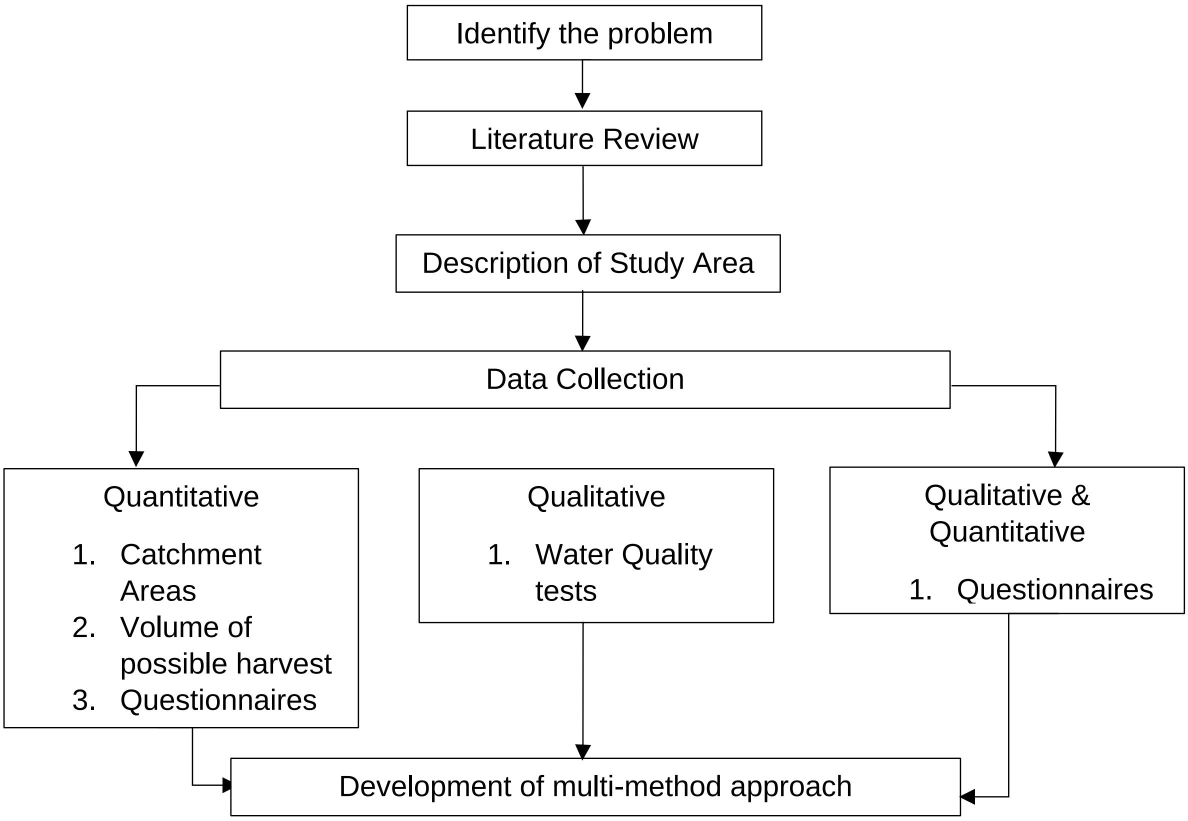

Figure 4-1: An outline of how the research methodology was obtained

4.3 Data collection

4.3.1 Questionnaire survey

A quantitative research approach was adopted in the collection of the survey data. A total of one hundred household questionnaires were conducted for a population of one thousand and forty-four households, see Appendix E. Households were randomly selected within Nomlacu and surety of covering all angles of the area was taken into consideration. Although the terrain was mountainous in some areas, surveys were conducted on all mountainous, levelled ground and along the road. The fieldwork took place on the 26th of June 2021. Local field assistants were provided by the ward councillor to ensure quality response and that the community feels comfortable to cooperate. The questionnaire data was conducted to assess the current water situation in Nomlacu, to establish water trends and water uses of the population, to determine the social acceptance of RRWH and lastly to establish the reasons behind why people do not have RRWH systems installed in their households.

4.3.2 Catchment area

The roof area is one of the most important components of RRWH system, as it is used for capturing the rainwater. Roofs have a potential of providing the best catchment area for RRWH, provided that they are kept clean (Biswas and Mandal, 2014). The roof catchment area may be constructed using many different materials. For the purpose of this study only the existing tile and zinc metal were considered. All the household rooftop areas were digitized and converted into polygons with the use of QGIS 3.22.1 geometric tools and the aid of Google Earth to attain accuracy. The area of each polygon was calculated by the QGIS 3.22.1 database. Roof areas ranged from 4m^2 to 543m^2 with an average of 105m^2 which was used to calculate the potential quantity of RRWH. A total of one thousand and forty-four (1044) polygons were digitized to calculate the roof areas of almost all the rooftops in Nomlacu. Satellite images obtained from Google Earth also helped in the identification of the possible and different roof materials used in the existing households. The Figure 4-2 illustrates how the roof areas were obtained.

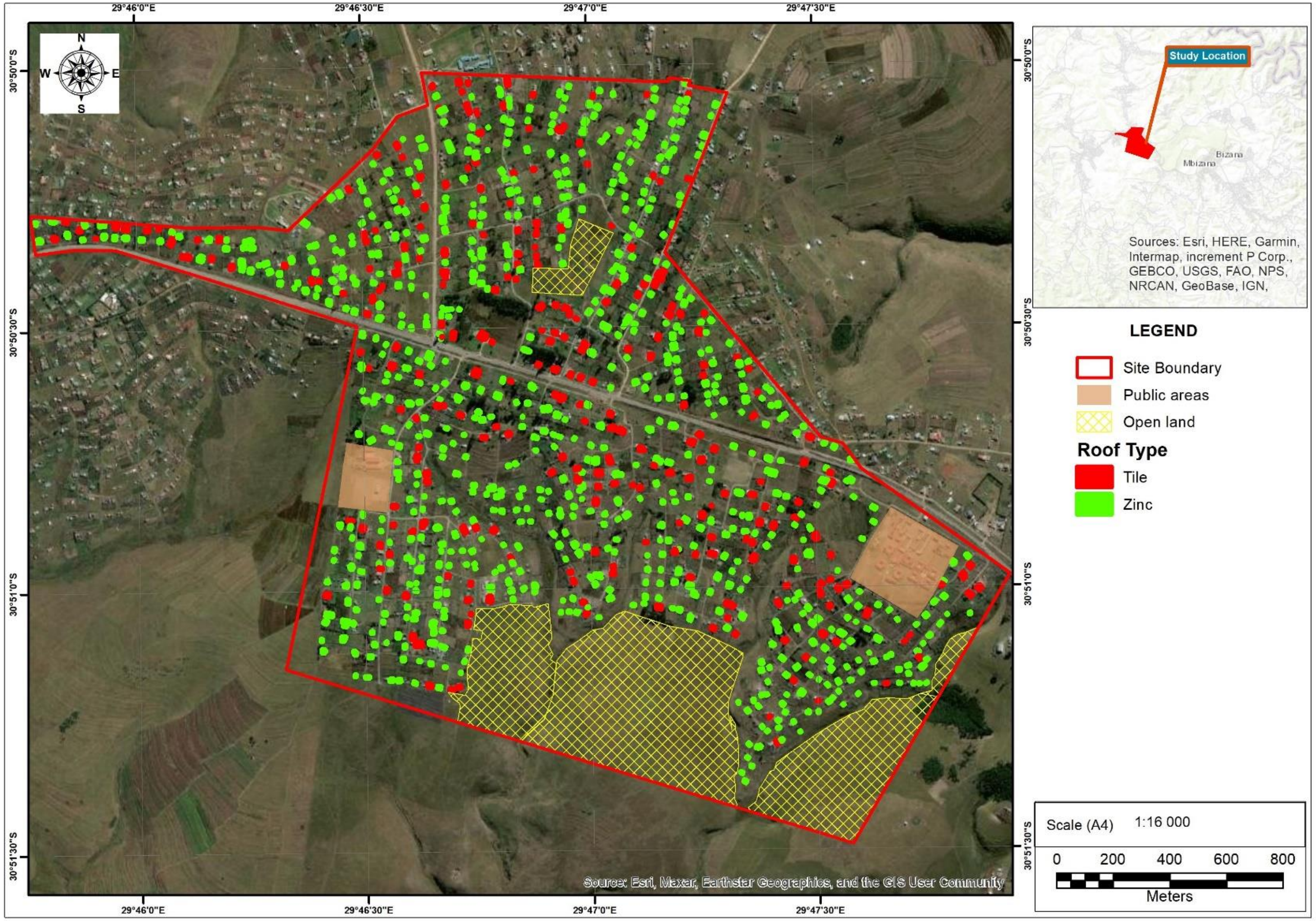

Figure 4-2: Aerial view of the geospatial household areas

4.3.3 Runoff Co-efficient

The ratio of the amount of water that runs off a certain type of surface to the amount of rainfall that falls on it is known as the runoff coefficient for any catchment (Biswas and Mandal, 2014). For example, a runoff coefficient of 0.85 means that 85% of the rainfall will be collected. Therefore, the higher the runoff coefficient, the greater the harvest. In an instance where the roof angle is not considered, the roof material only can be used to determine the coefficient Ojwang *et al.*, (2017). Therefore, due to the absence of the roof angle in this study, the minimum coefficient value of metal sheeting was incorporated for both roof types to account for unconsidered losses. Based on the literature provided, the runoff coefficient adopted for tiled roofs is that of a South African study of 0.85 and 0.7 for metal zinc roofing. The 0.7 coefficient was selected as the worst case scenario of losses for zinc metal roofs.

4.3.4 Rainfall data

Historical data that was obtained from the South African Weather Services. The data obtained was a 10-year historical data from the years 2010 to 2020. Monthly Daily Rain (mm) was measured at 08:00 Data for station [0155394A5] – Port Edward. Figure 4-3 demonstrates the monthly and annual rainfall data of Port Edward which is the closest rainfall station to Mbizana town of Nomlacu area. The maximum annual rainfall occurred in 2013 which was 1648.2mm and the minimum annual rainfall was recorded in 2010 which was 772.6mm. The maximum average monthly rainfall is observed in December. The lowest monthly average rainfall was recorded in June where the years 2017 and 2018 received no rainfall.

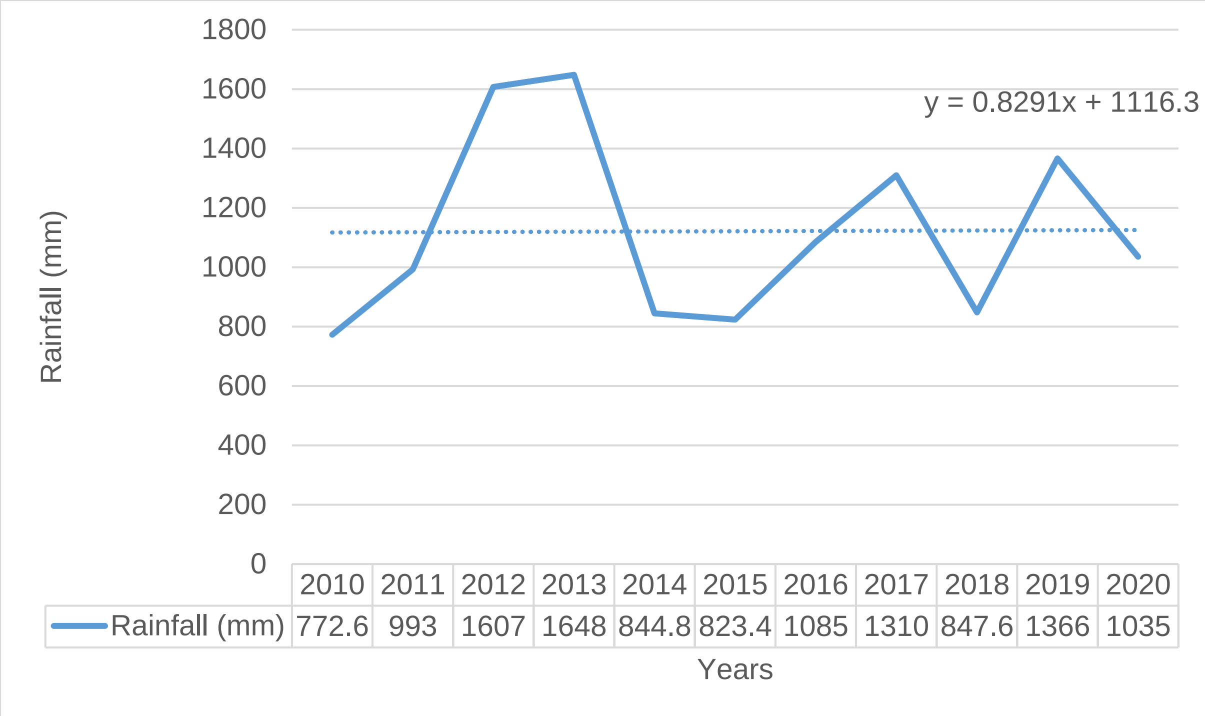

Figure 4-3: Annual rainfall data

The average annual rainfall that was used for calculations for this study was 1121.2 mm as stipulated in Figure 4-4 obtained from the linear formula. According to the data provided by the South African Weather Services, most rainfall is experienced in the months of December and March while the lowest is experienced in June. Rainfall remains low and between May and August and gradually increases from September to December. Another decrease in monthly rainfall is experienced from April to June.

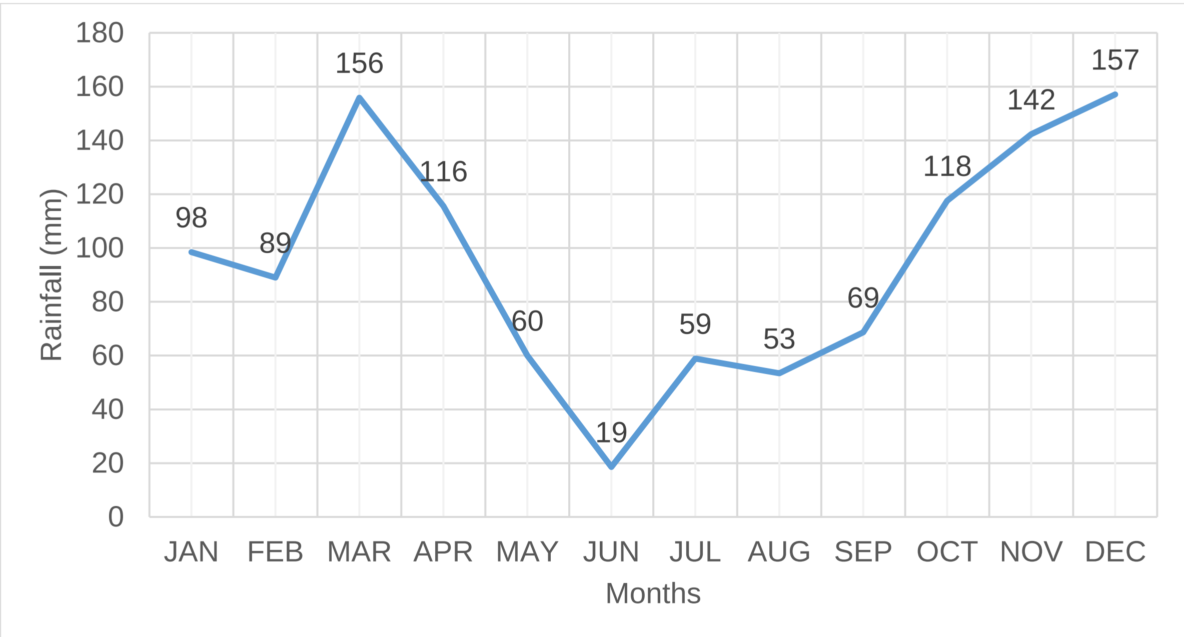

Figure 4-4: Average monthly rainfall

4.3.5 Water sample collection

The water sample collection was performed following the Umgeni Sampling instructions. According to these instructions, samples for microbiological testing were collected, grouped into three categories 1,2 and 3 and stored in sterilised 500mL blue/clear plastic bottles. The bottles contain sodium thiosulphate as a preservative. While for chemistry testing, samples were collected and stored in 2L bottles. All sample bottles were clearly marked and identified to avoid any confusion as shown in Figure 4-5. All bottles were tightly closed and submitted to the laboratory within 6 hours of sampling.

Figure 4-5: Sampling bottles

SAMPLING METHOD FROM A TAP PROCEDURE:

The sampling process that was followed for obtaining water from a tap outlet was to clean the tap with the running water or with a clean cloth where necessary. Other methods of cleaning the tap are to flush the tap with a running water for approximately five minutes, sterilize the tap with a gas burner until the steam appears from the inside and alternatively swab with methylated spirits and then ignite. Once the tap is clean and sterile, it is important to open the tap for approximately one to two minutes to obtain a gentle flow rate. When filling the bottle, it is advisable that one holds the lid facing downwards to avoid contamination with fingers. Air voids in the bottled water should be avoided at all times. Once the sampled water has been collected, it is preferred that the bottle is kept clean, cool and in a dark place. Samples should be kept in a cooler box with ice packs during transportation and should be transported to the laboratory within six hours. To ensure accuracy, it is imperative that the samples are clearly marked and well labelled.

Samples from group 1 were collected on 27 November 2021, which is considered to be the beginning of the rainy season in Bizana. Samples from group 1 can be considered as the first rain because several days had passed without any rainfall. Samples from group 2 were taken on 08 December 2021, which is considered to be the peak of the rainy season. Group 3 samples were taken on 19 January 2021, which is considered to be closer to the end of the rainy season. All Samples were collected six weeks apart.

Samples were tested at Umgeni water laboratories following the South African National Standard (SANS 241:2015) testing methods for drinking water to determine the water quality for potable use. These standards state the minimum requirements for potable water to be considered safe for human consumption. The SANS 241: Edition 2 also indicate the various properties of water that require to be analysed in order to determine if the water is either safe or not for human consumption. Parameters that were tested include Aluminium, Colour, Conductivity, E. coli, Iron, Odour, Lead, pH, Suspended solids, Total Dissolved Solids, Turbidity and Zinc. Parameters were randomly selected but taking into consideration to test parameters that test aesthetics, operational, chronic health and acute health risks of water.

4.3.6 Potential quantity of rainwater harvesting

The implementation of roof rainwater harvesting system depends on the quantity that can be harvested. The potential of RRWH was calculated by using Equation 1. According to a study conducted by Farreny *et al.* (2011); Siddiqui and Siddiqui, (2018); Abdulla, (2020), this is one of the most common, economical and easy formula to use to calculated harvested rainwater.

$$Q = CiA \qquad \textit{Equation 1}$$

The above equation is inspired by the rational method which is well known to estimate the peak runoff rate. Thus, the following equation was used for estimating the potential volume of RRWH.

Where:

Q = is the potential rainwater that can be harvested (m^3/day)
C = is the roof runoff coefficient (dimensionless)
i = is the average runoff intensity (m/day)
A = is the estimated roof area (m^2)

The potential volume of RRWH (Q) was then converted from (m^3/day) to (L/month) in order to compare and relate to the data obtained from the questionnaire. The monthly volume of harvested rainwater was calculated to obtain the potential annual RRWH volume.

The amount of annual rainwater percentage that can be potentially harvested (PHP) can be calculated using Equation 2. The formula was described by (Abdulla ;2020)

$$PHP = \frac{AH}{AD} \times 100$$ *Equation 2*

Where:

PHP = Potential Harvesting Percentage (%)
AH = Annual harvested volume (L/year)
AD = Annual demand volume (L/year)

The water available in the storage tank at the end of each month for the first month of the year was obtained using Equation 3. For the purpose of this study, January was used as the inception month.

$$WA = VC - VU$$ *Equation 3*

Where:

WA = Water available at the end of the month (L/month)
VC = Volume of rainwater collected for the month (L/month)
VU = Volume of rainwater usage for the particular month (L/month)

Thereafter, the following months' accumulative month end water availability was calculated using Equation 4.

$$WA = IV + VC - VU \qquad \textit{Equation 4}$$

Where:

IV = Initial volume from the previous months' volume (L/month)

4.3.7 Economical consideration

Cost analysis of the RRWH is an important factor to determine the economical consideration of possible adaptation of the system. The construction of RRWH system includes the materials for installing, a rain storage structure and labour. Once the RRWH system is installed, it requires maintenance and operating costs. These costs may be minor and may include basic disinfection and periodic cleaning to improve the water quality.

The cost analysis included calculating the cost of constructing a concrete slab that will be used as foundation for the storage tank, cost of the storage tank, collection systems and brass taps. It is important to note that due to the water scarcity and inconsistency, some households already had existing storage tank. However, for the sake of this study, all households were considered as not having a RRWH system in place in order to estimate for the worst-case scenario.

As discussed in Chapter 2, roof areas ranged from $4m^2$ to $543m^2$ with an average of $105m^2$ which was used for the estimation of the cost of construction for a RRWH system per household. Three quotations from three different companies were obtained to estimate the cost of construction of the system per house. See Appendix F. The highest value amount obtained from the quotations was used and multiplied with the number of households captured on QGIS. Therefore, Equation 5 was used to calculate the total cost of rainwater harvesting.

$$RRWH_{cost} = RRWH_{house} \times N \qquad \textit{Equation 5}$$

Where:

$RRWH_{cost}$ = Total cost of RRWH system for the whole community (R)

$RRWH_{house}$ = RRWH cost per household (R)

N = Number of households (units)

The estimated capital costs per household for water supply for the population of 1000 and 5000 people was obtained from Municipal Infrastructure Grant (MIG). Table 4-1 below provides a summary of the provincial unit cost for water supply based on the scheme size and the province. Nomlacu population is approximately 2194 people. Thus, an interpolation method between 1000 and 5000 people was adopted to obtain an approximate figure for 2194 people for the scheme size. Equation 6 was used to interpolate between the two scheme sizes, the below formula was adopted.

$$y = y_1 + (x - x_1) + \frac{(y_2 - y_1)}{(x_2 - x_1)} \qquad \textit{Equation 6}$$

Where:

y = Linear interpolation value

x = independent variable

x1; y1 = values of the function at one point

x2; y2 = values of the function at another point

Table 4-1: Sum of Provincial Capital Cost per Household for Water Supply, including P&G and VAT. Source: (DoCOGTA, 2010)

Scheme size				
Province	Very small	Medium	Large	Larger
	1000 people	5000 people	20000 people	50000 people
EC	R 38295	R 24669	R 22264	R 21428
FS	R 38815	R 23894	R 21248	R 20315
KZN	R 39987	R 25997	R 23564	R 22718
LP	R 37112	R 23099	R 21053	R 20393
MP	R 37618	R 23571	R 21131	R 20316
NC	R 37694	R 23376	R 21509	R 20989
NW	R 36495	R 22790	R 20653	R 19953
WC	R 37495	R 23334	R 21039	R 20313

To determine the financial feasibility of RRWH, a comparison between the installation cost of the RRWH system for the whole community and the total cost of the construction of a municipal water supply system for a population in Nomlacu was considered. Table 4-2 below was abstracted from the (StatsSA, 2021) CPI rates table from 1980 to 2022, see Appendix G. For the purpose of this study, the focus was mainly on the estimated yearly consumer price index (CPI) inflation rate from 2011 to 2022 to provide comparable rates for the 2022 invoices obtained from the material list for the installation of the RRWH systems.

Table 4-2: Historical average CPI rates presented in %. Source: (StatsSA, 2021)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg.
2011	3.7	3.7	4.1	4.2	4.6	5.0	5.3	5.3	5.7	6.0	6.1	6.1	5.0
2012	6.3	6.1	6.0	6.1	5.7	5.5	4.9	5.0	5.5	5.6	5.6	5.7	5.6
2013	5.4	5.9	5.9	5.9	5.6	5.5	6.3	6.4	6.0	5.5	5.3	5.4	5.7
2014	5.8	5.9	6.0	6.1	6.6	6.6	6.3	6.4	5.9	5.9	5.8	5.3	6.1
2015	4.4	3.9	4.0	4.5	4.6	4.7	5.0	4.6	4.6	4.7	4.8	5.2	4.6
2016	6.2	7.0	6.3	6.2	6.1	6.3	6.0	5.9	6.1	6.4	6.6	6.8	6.4
2017	6.6	6.3	6.1	5.3	5.4	5.1	4.6	4.8	5.1	4.8	4.6	4.7	5.3
2018	4.4	4.0	3.8	4.5	4.4	4.6	5.1	4.9	4.9	5.1	5.2	4.5	4.7
2019	4.0	4.1	4.5	4.4	4.5	4.5	4.0	4.3	4.1	3.7	3.6	4.0	4.1
2020	4.5	4.6	4.1	3.0	2.1	2.2	3.2	3.1	3.0	3.3	3.2	3.1	3.3
2021	3.2	2.9	3.2	4.4	5.2	4.9	4.6	4.9	5.0	5.0	5.5	5.9	4.5
2022	5.7	5.7	5.9	5.9	6.5	7.4	7.8	-	-	-	-	-	6.4

The inflation rate for the years 2011 – 2022 was calculated using Equation 7 for each year. Due to the missing data from August to December at the time of data collection, only the average of January to July was considered for the calculation.

$$A = P(1 + rt) \qquad \textit{Equation 7}$$

A = final amount (R)

P = initial principal balance (R)

r = annual interest rate (%)

t = time (years)

Once the 2022 amount for the capital cost had been determined per household, the total cost for the water supply for the population was calculated using Equation 8.

$$Water\ Supply_{cost} = Capital\ Cost_{house} \times N \qquad \textit{Equation 8}$$

Where:

$Water\ Supply_{cost}$ = Total cost of the water supply system for the whole community (R)

$Capital\ Cost_{house}$ = Water supply cost per household (R)

N = Number of households (units)

4.4 Schematic workflow of the study

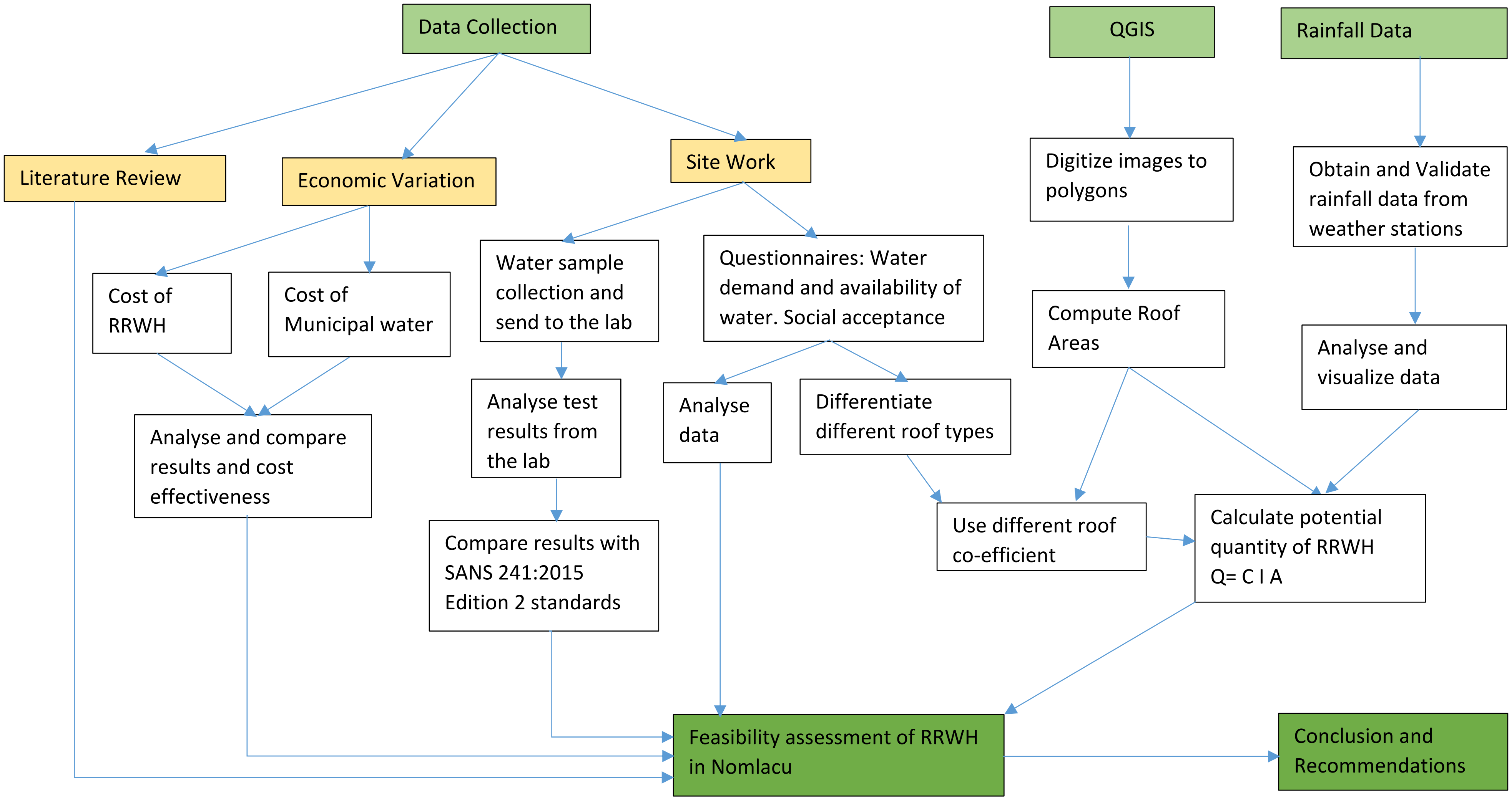

Figure 4-6: Schematic workflow of the study

4.5 Summary

A dual approach methodology was used in this study. Catchment areas were digitised and converted to polygons with the use of QGIS 3.22.1 geometric tools and the aid of Google Earth. This also assisted in identifying the different types of roof material used such as zinc and tile roofing. The importance of obtaining the roof materials from Google Earth was to determine the runoff co-efficient that can be used for different types of roof materials. The rainfall data that was obtained from WSA was used to assess the feasibility of RRWH systems on a quantity point of view.

A qualitative approach was used when conducting door-to-door questionnaires with the aim of investing water usage, management strategies, water supply issues and investigate factors affecting the implementation of RRWH. A quantitative methodology was used to quantify the feasibility of RRWH systems as well as calculating the potential saving from the current water system. Conversely, a quantitative approach was used to determine the cost variation between RRWH systems and the municipal water supply system. Lastly, the schematic workflow diagram displays the work frame and tasks that was taken to complete this study.

CHAPTER 5 : RESULTS AND INTERPRETATION

5.1 Introduction

This chapter presents the analysis, interpretation, and discussion on the findings of the study. Analytical data collected through means of questionnaire survey will be discussed in this chapter. An interpretation of both the questionnaire data and the water quality laboratory results will be analysed and interpreted. Moreover, the potential quantity of RRWH as well as the feasibility and effectiveness of RRWH system in Nomlacu will be discussed.

5.2 Questionnaire data

Below are the results obtained from the door-to-door questionnaire surveys conducted in Nomlacu administrative area on 26 June 2021. In the survey conducted in Nomlacu administrative area, it is found that the average number of persons per house is 4.68 as per arithmetic calculations and was converted to 5 persons per household. Figure 5-1 shows that majority of the households visited had more than six people residing in them.

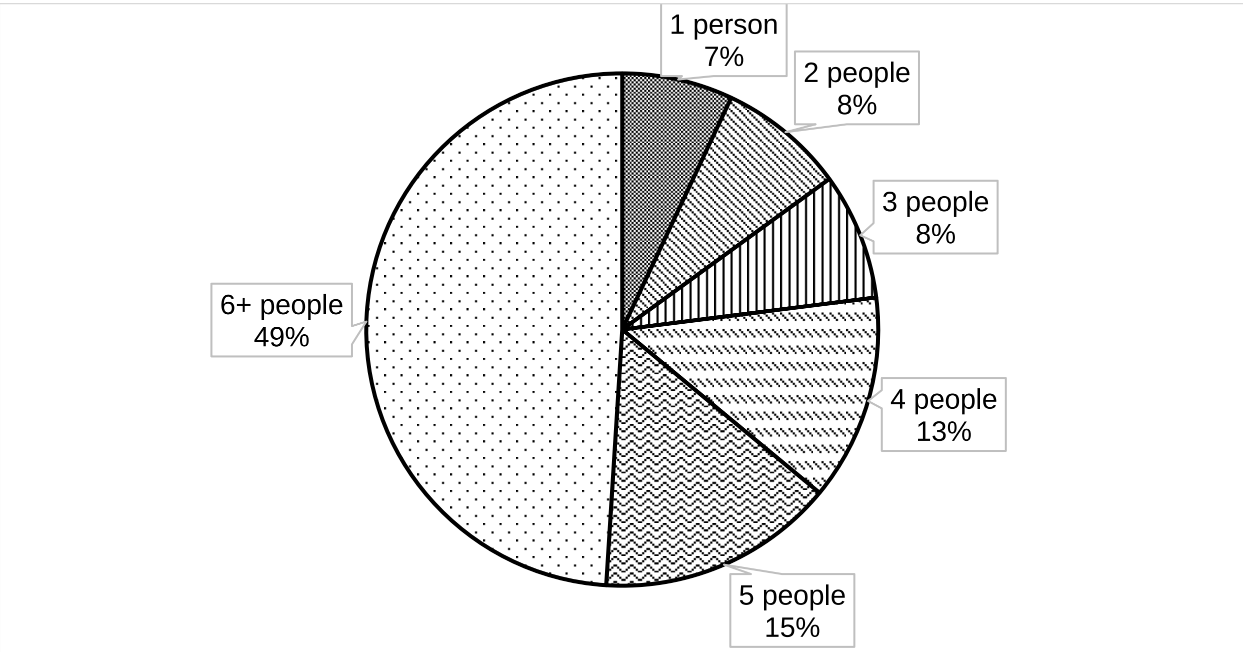

Figure 5-1: Number of persons per household

Figure 5-2 has shown that 45% of the community have yard taps installed in their homes while 51% of the community use communal taps (shared tap). Only 3% of the community relies on solely on rooftop rainwater harvesting while 1% depends on facilities like rivers and dams. Currently, no one depends on the water tanker for water supply. This gives RRWH system installation a probable chance in 55% of the household to provide water at closer proximity.

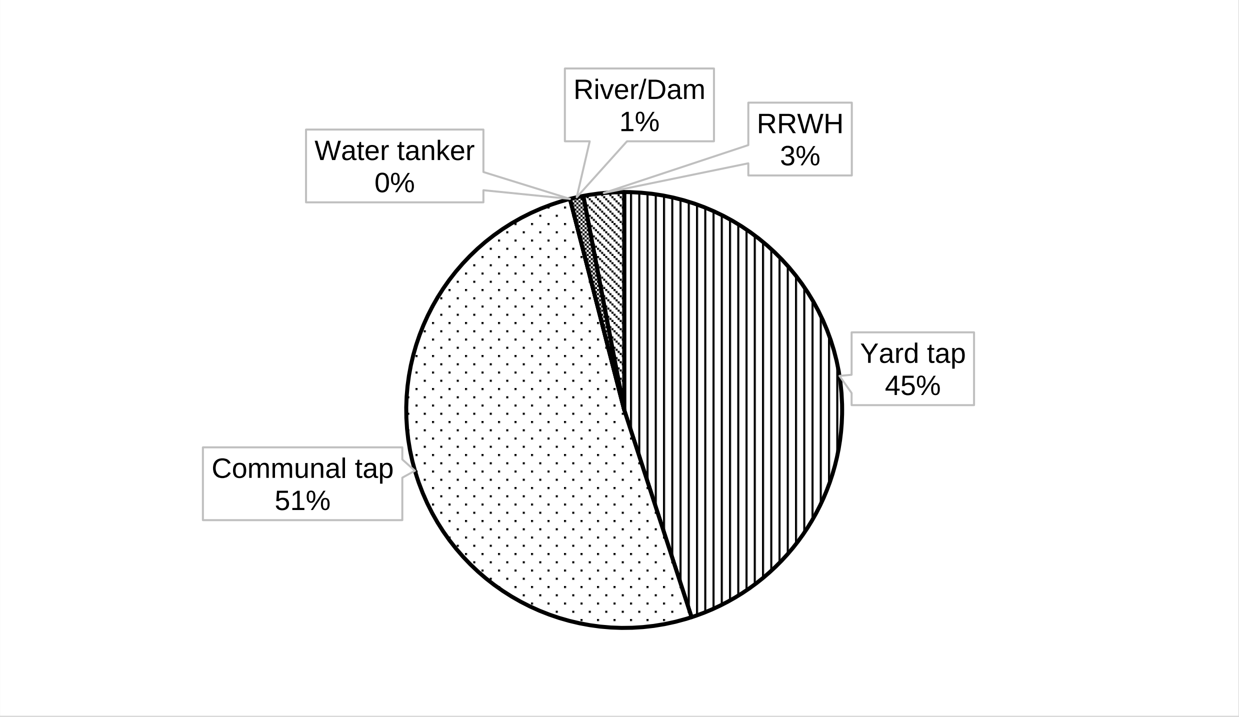

Figure 5-2: Current source of water

Results in Figure 5-3 show that the water supply of the area is good. The results of the participants were based on the taste and aesthetic appearance of the water. The 4% of the population that found the water to be of bad quality could result from the households who obtain their water from rivers, dams, and communal taps. Nonetheless, this could be the result of the bad water quality experienced by the community when the water has been cut-off and returns with a deteriorated quality as well.

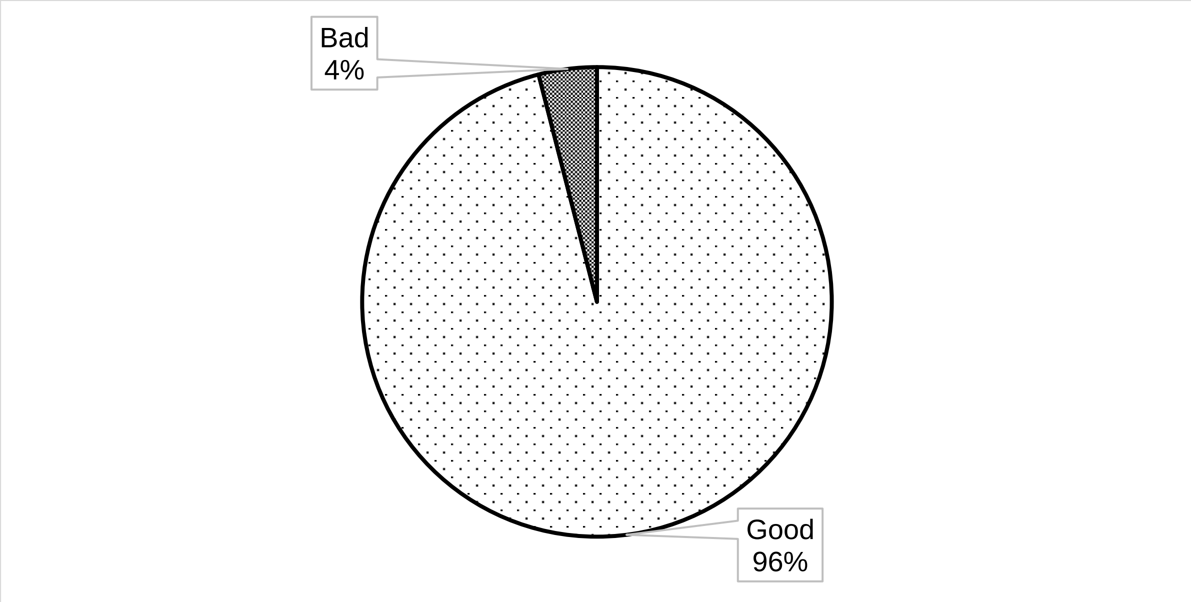

Figure 5-3: Current water quality

According to the data obtained, Figure 5-4 shows that 72% of the population finds water to be available everyday while 1% disagree. However, 27% of the population says water is sometimes available and sometimes not. This could result from cut-offs implemented by the local municipality.

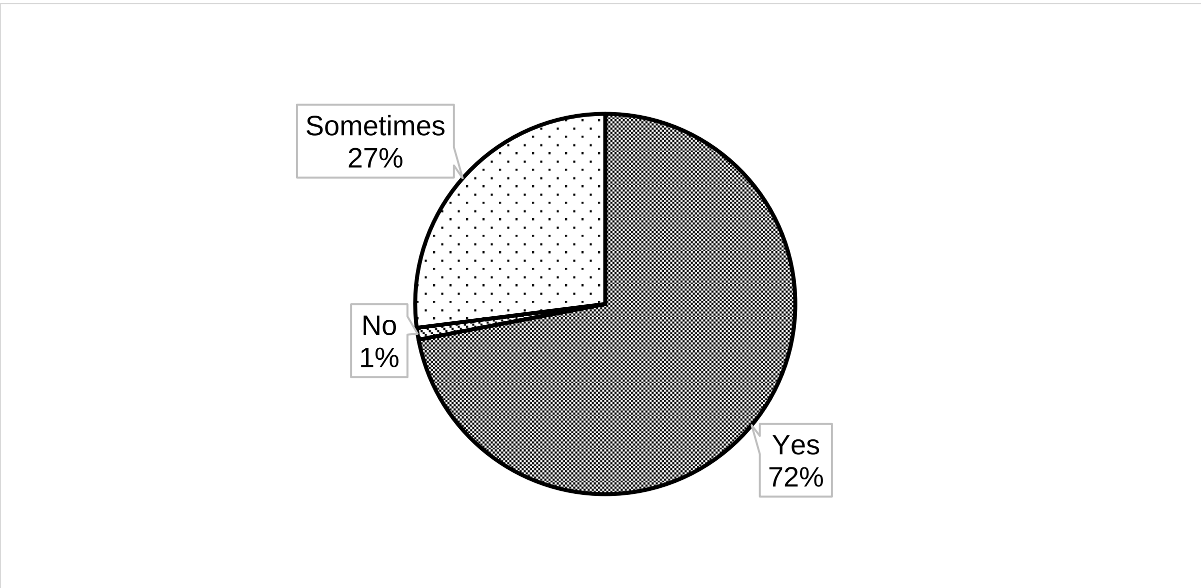

Figure 5-4: Current water availability

The population responded positively to the idea of the implementation of RRWH systems in their yards. Although approximately 38% of the population already has the system in place, it was still a favourable option. However, 14% of the population are not in favour of the RRWH system as water is readily available for use in both yard and communal taps. Only 2% of the population refused to answer to that question as seen in Figure 5-5 below.

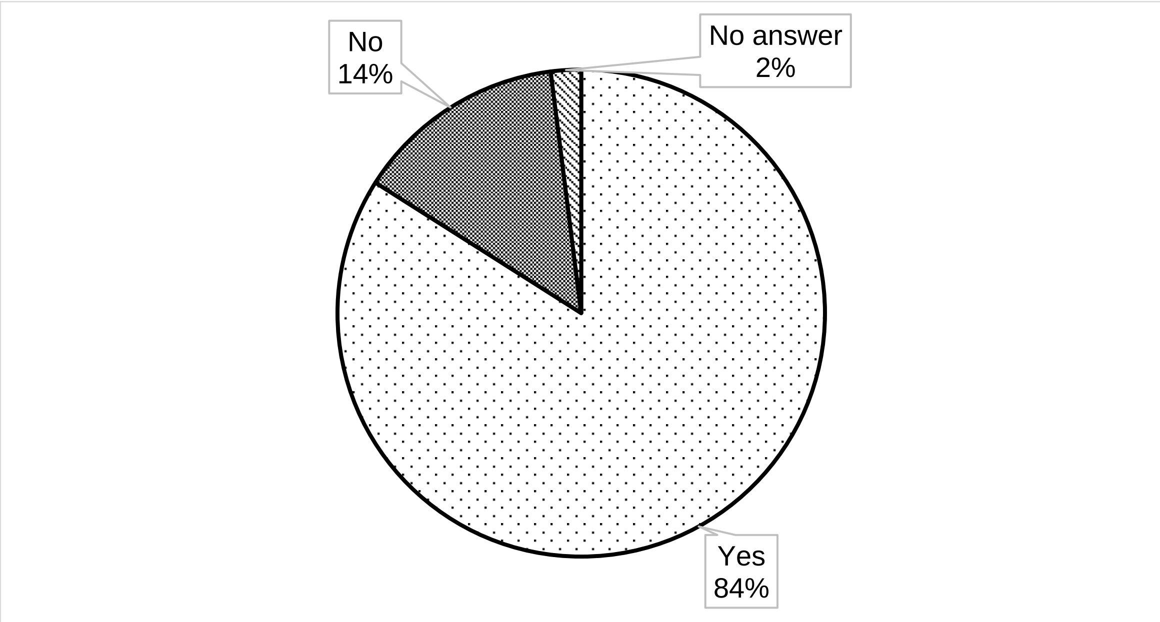

Figure 5-5: RRWH system consideration

According to the sample survey done in Nomlacu, there are various reasons that lead to the acceptance of RRWH system in people's yards. Below is a summary list of reasons why the population would like a RRWH system to be installed in their yards:

- To have access to water during water cut-offs
- To use for watering the garden and wash laundry
- To have an emergency reserve (storage) tank and save water
- To access water at a close proximity as some communal taps are far from other households therefore people have to walk long distances to get water
- Sharing a communal tap is problematic as it occasionally breaks. The community has to then buy and fix the broken part while some of the community members who use the same tap refuse to pay for the replacement and installation of the broken part/s.
- Communal taps are too far especially for the elderly who live with comorbidities such as "knee joint pain and arthritis"

A summary of reasons why they don't want RRWH systems installed in their yards:

- Tank is too expensive
- Water is already available in the taps

The cost of rainwater harvesting tanks for rural homes is a problem, and this is due to affordability. However, if the government may subsidise this component, many households would be appreciative and enjoy the privilege of accessing water at a closer proximity. Regardless of the enjoyment of water at close proximity many households that are headed by children and old age women would benefit from this initiative.

The availability of water plays an important role in the human race. The implementation or subsidizing of rooftop rainwater harvesting systems in homes are less privileged may help increase their quality of life. Although water is available in the area, it is important to save and store water for emergencies as it has been noted that water is not always available.

According to the questionnaire survey data collected, water usage percentage in the community for cooking, gardening, laundry, and bathing & cleaning corresponds to 4%, 16%, 18%, and 62% respectively. The data represented is weekly, thus laundry being done at an average of twice a week and all other water usages on a daily basis have been factored in.

Currently, majority of this household usage is obtained from the existing municipal water supply. The implementation of RRWH systems in households may alleviate the pressure from the municipal water supply. This could be achievable if water used for bathing & cleaning, laundry and gardening can be obtained from the RRWH system. Although water used for cooking can be collected from the municipal water supply, with adequate storage and proper treatment, rainwater harvesting can provide for this usage for efficient water saving practices. Figure 5-6 below shows a graphical representation of the water usage per category.

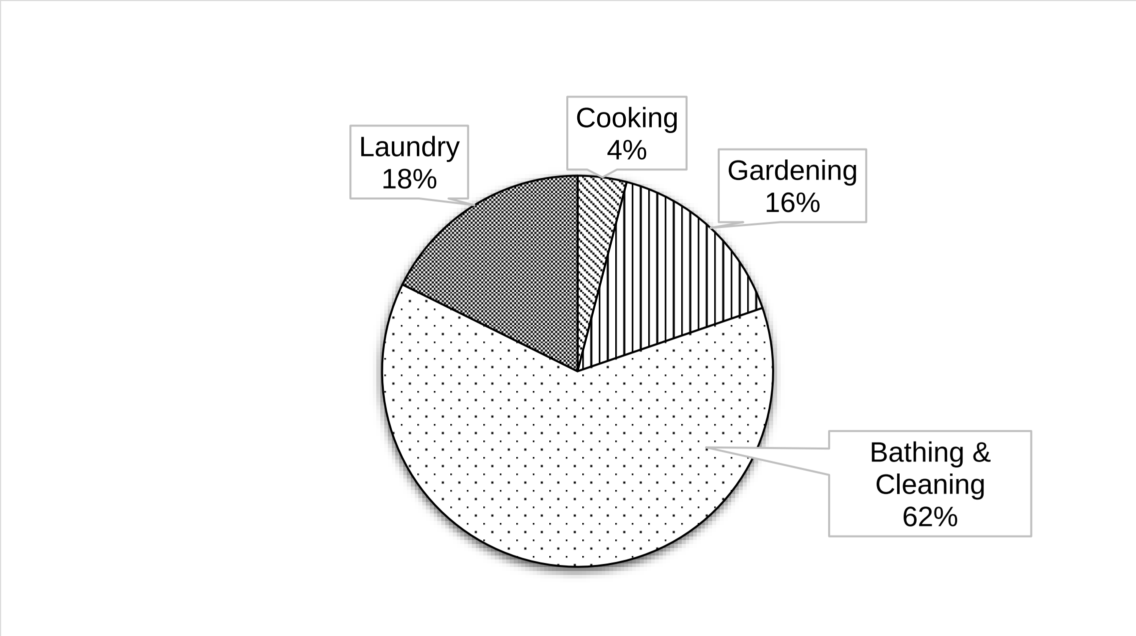

Figure 5-6: Current water usage per category

5.3 Potential Quantity of Rooftop Rainwater Harvesting

With the use of Equation 1 stated in Chapter 4, Table 5-1 shows the approximate potential quantity that can be harvested by each household per month based on the type of roofing material used for the particular household. Tiled roofs produce more harvest compared to the zinc roofs, this is because the runoff coefficient for tiled roofs is much higher than the zinc roof. The minimum harvest made on both roof types is in June and the maximum is December.

Table 5-1: Potential RRWH quantity per household per month

Month	Intensity (m/day)	$C_{zinc\ roof}$ Dimensionless	$C_{tile\ roof}$ Dimensionless	Average area (m^2)	Q_{Zinc} (L/month)	Q_{Tile} (L/month)
Jan	0,003	0,7	0,85	105	7240	8791
Feb	0,004	0,7	0,85	105	7203	8747
Mar	0,005	0,7	0,85	105	11459	13914
Apr	0,004	0,7	0,85	105	8497	10317
May	0,002	0,7	0,85	105	4410	5355
Jun	0,001	0,7	0,85	105	1367	1660
Jul	0,002	0,7	0,85	105	4329	5257
Aug	0,002	0,7	0,85	105	3925	4766
Sep	0,002	0,7	0,85	105	5049	6131
Oct	0,004	0,7	0,85	105	8644	10496
Nov	0,005	0,7	0,85	105	10459	12700
Dec	0,005	0,7	0,85	105	11547	14021

Figure 5-7 shows the different monthly rainfall depths obtained from the SAWS. The highest monthly rainfall depth was observed in December at 12342L/month while the lowest was observed in June at 1461L/month which is below the monthly demand for both the South African basic requirement and the demand obtained from questionnaires. This graph also shows that the winter months (May to August) receive just about enough rainfall to meet the population demand obtained from the questionnaire. However, based on the national basic need demand of 6kL per month per household, the graph shows that the rainwater supply is failing to meet the demand from the middle of April to the beginning of September.

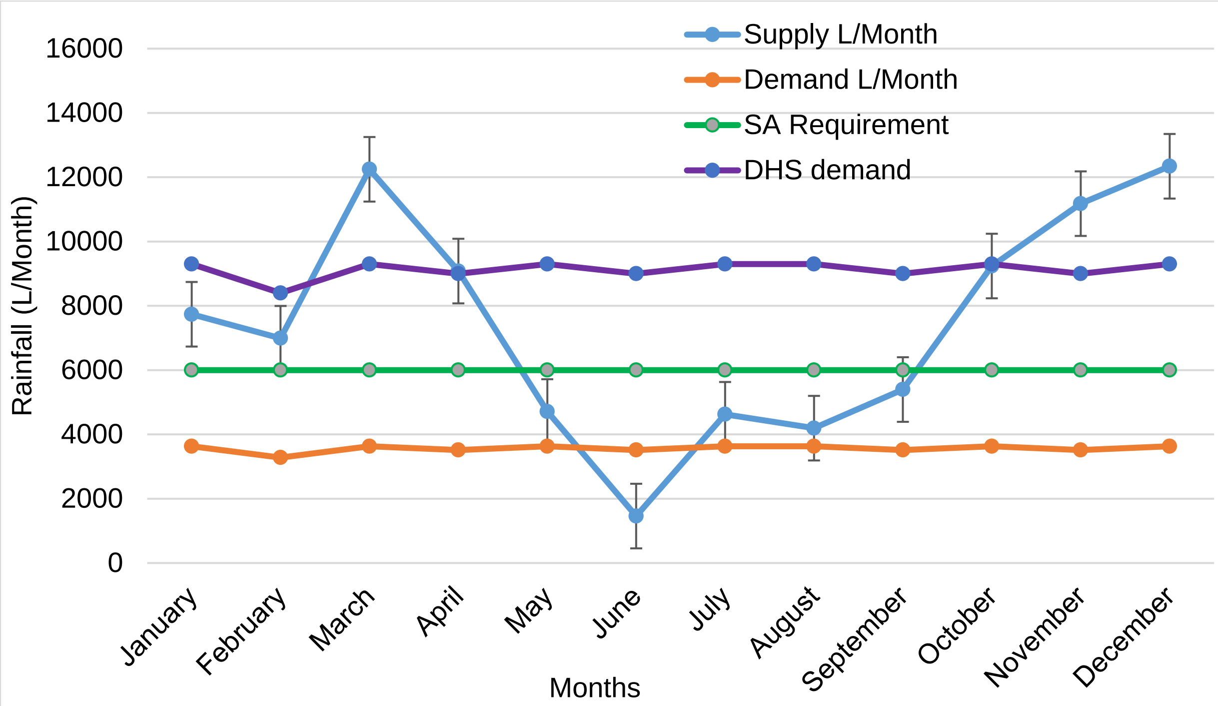

Figure 5-7: RRWH supply vs community water demand vs SA requirement demand vs Typical consumption demand

A very high demand is also observed on the typical consumption demand where only March, November and December seem to be receiving enough rainfall for the harvest. Conversely, a very low water demand is observed on the community demand. This is based on the community's daily activities where water consumption is concerned. Households within this community use pit toilet that do not require constant flushing, washing in basins as opposed to bath tubs and showers, water is never left running on taps as water is always put into a basic use for any kind of wash. Rainfall is lower in the winter months (May to September) and gradually increases after winter in the month of September and reaches its peak in December.

As previously noted in Figure 5-7 that months, May to September, have a deficit and cannot meet the demand as per the South African legislature. It is also noted that months, April and December, have an overflow of harvested rainwater, relative to the tank capacity.

5.3.1 Water availability potential based on SA basic demand

Based on the 6000L demand per household per month, it is evident that rainwater will be sufficient throughout the year. Assuming that the harvest is optimized to its full capacity, harvested rainwater will be a viable solution to supplement the current water supply system. The potential annual rainwater harvesting percentage obtained by using Equation 2 is approximately 124%. This means that the supply of the annual rainwater is greater than the annual demand of the community.

For the purpose of this study, it is assumed that each household will have at least two storage tanks, making the storage capacity at least 10000L. Figure 5-8 is an illustration that shows the availability of rainwater in the tank after consumption at the end of each month. Based on this assumption, it is expected that there will be a spillage of approximately 7211L obtained from April and December, thus requiring at least four storage tanks to avoid spillages. With that being said, it is worthy to note that a third storage tank may be required to optimize on the harvest. Figure 5-8 also shows that there will be sufficient water for each month. According to the calculation obtained by using Equation 3, there will be water available for the first month and Equation 4 proves that there will be water available after usage throughout the whole year. However, it is observed that there will be less water available in the tank after consumption for the months August and September. It is then advisable that the annual tank cleaning happens during this period.

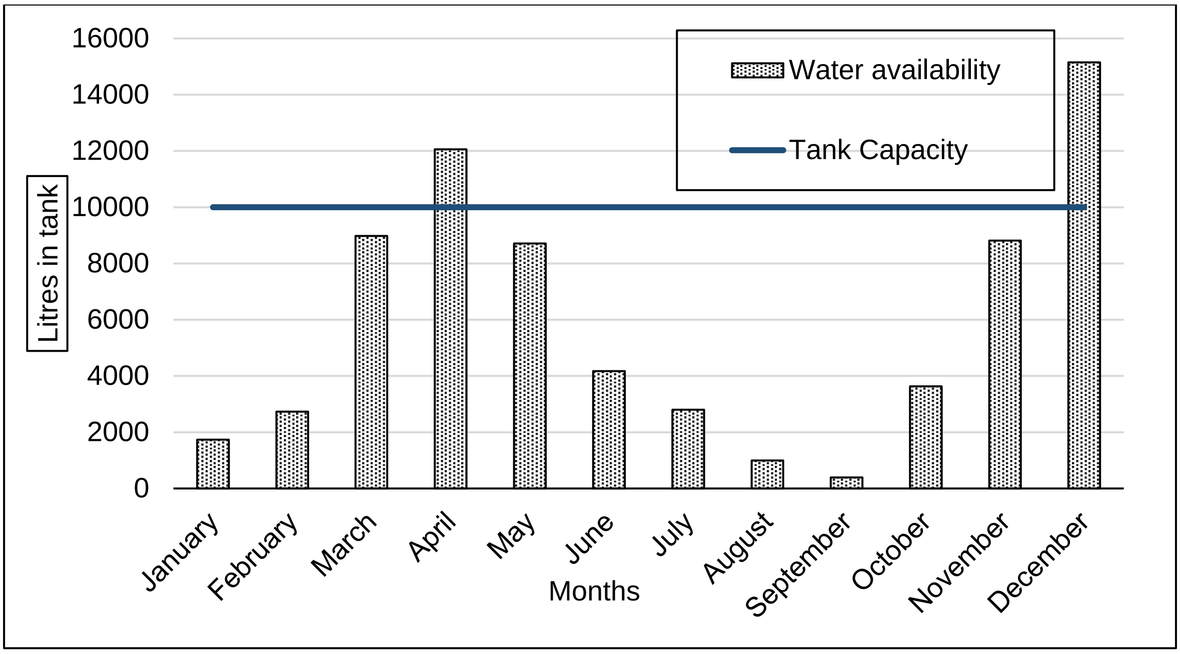

Figure 5-8: Water availability on tank based on SA requirement

5.3.2 Water availability potential based on Questionnaire data demand

According to the data provided in Figure 5-7, June was the only month that couldn't meet the required demand at a deficit of 2053L/month. Therefore, the required amount of harvested rainwater that will be required for that duration is 2053L and it will successfully be met by the previous months' harvest. With the data provided, the annual potential harvesting percentage of 209% per household can be calculated using Equation 2. This means that the supply of rainwater is double the demand required by the demand obtained from the door to door household questionnaires.

Figure 5-9 is based on the average of 3563L demand per household per month that was obtained from the questionnaire. Figure 5-9 also shows that there will be rainwater available in the storage tank at the end of the inception month, proven by Equation 3. Equation 4 was used to calculate the recurring months' month end water availability. There is an estimated total surplus of 36450L accumulated between the months March to May and September to December. Understanding the maximum storage capacity of 10000L, which is two storage tanks of 5000L each, it is quite obvious that harvested rainwater will be sufficient for all months. However, an approximate of ten storage tanks will be required to prevent spillages.

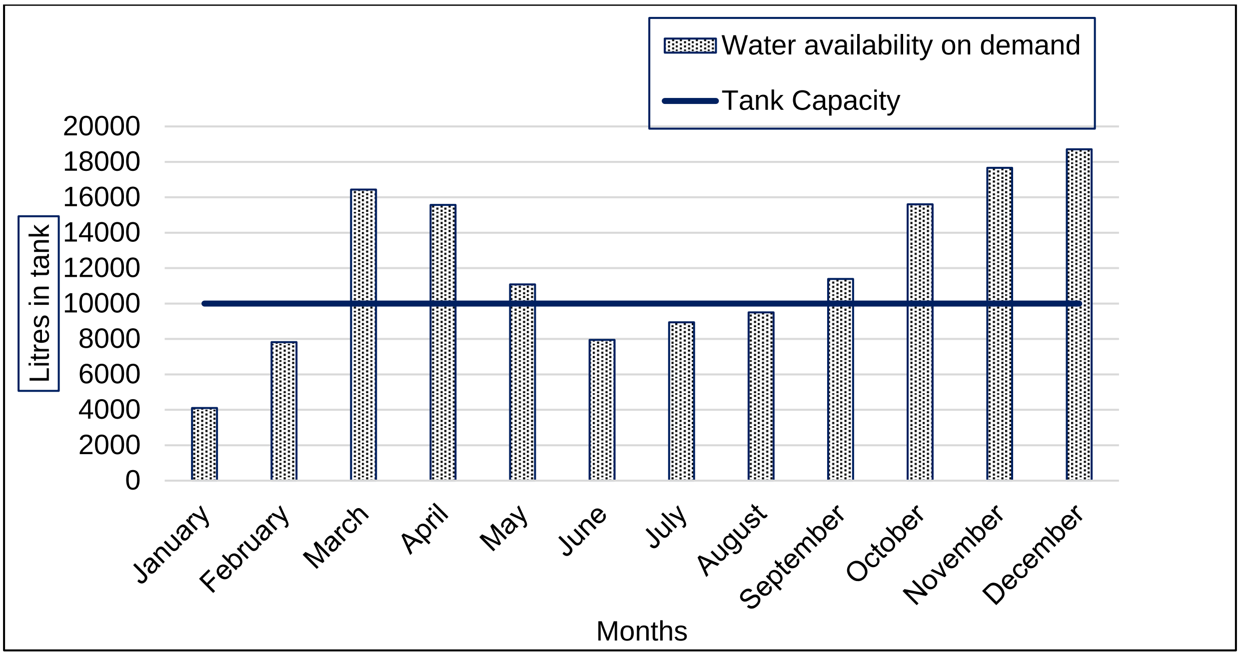

Figure 5-9: Surplus vs Demand based on questionnaire

5.3.3 Water availability potential based on DHS design guidelines

Figure 5-7 shows the demand for the typical consumption of 60l/c/d for a population size of 5 persons in a household. According to the results obtained from Equation 2, rainwater harvesting may not be a viable option as a single source but can be a good substitute and alleviate the pressure from municipal water supply by at least 81% per household. This indicates that the annual rainwater supply for the population per household is less than the required annual demand.

Figure 5-10 is based on the typical consumption of approximately 9300L per month, derived from Table 2-2. According to this demand, Equation 3 proves that there will not be enough rainwater to meet the demand of January and therefore there won't be rainwater available in the storage tank by the end of January. Although there will be rainwater for the month of January, this simply means that it will not be sufficient for the whole month until the last day. Similar with the recurring months, Equation 4 proves that the only months that will have sufficient rainwater are March, April, November and December, while the other months run at a deficit. There is a total amount of approximately 25509L deficit per year. It is also empirical to note that the 61L deficit in the month of October may easily break even if water is used sparingly. More so, it is evident that harvest made from other months cannot supply the months in distress.

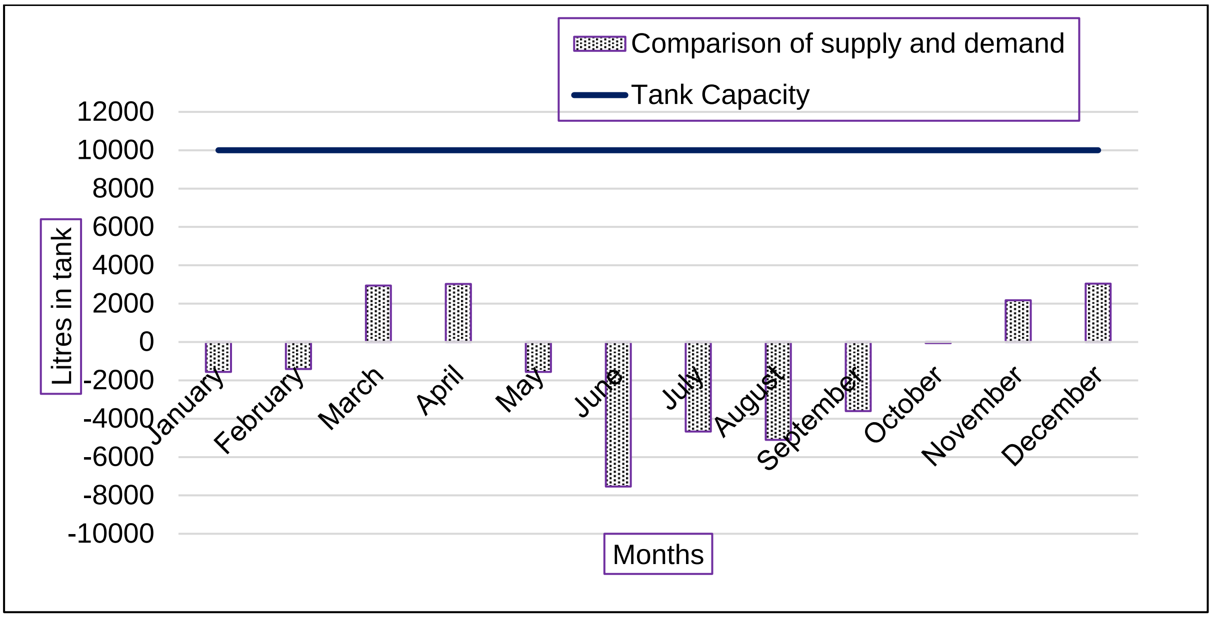

Figure 5-10: Comparison of supply and demand

Overall, Nomlacu area receives relatively high amounts of rainfall, greater than both the country and the worlds average annual rainfall. The study showed that RRWH is practically feasible and can meet the annual demand of rainwater per household when utilized to its optimal potential based on the questionnaire demand and the SA requirement for “indigent homes” demand. Such cannot be said when looking at the typical consumption for water supply. However, it can alleviate the pressure form the current water supply system. Optimal rainwater harvesting can be achieved by using more than two storage tanks. This then makes it possible for the system to alleviate pressure from the municipal water supply.

5.4 Water Quality Results

The objective of this study was to analyse the impact of RRWH quality obtained from different roof types being metal and tiled roofs. Parameters were tested and analysed to determine the difference in water quality between harvested rainwater obtained from metal and tiled roof. The results were furthermore analysed for potability using the

SANS241:2015 Edition 2 as reference and guiding national document. See Appendix H.

5.4.1 Aluminium

Aluminium in drinking water comes mostly from naturally occurring aluminium (Venkatesan and Deo, 2010). Aluminium concentrations for metal roofs ranged from 25µg/L – 58.4 µg/L, while tiled roofing ranged from 25µg/L – 39.7µg/L which were both under the allowable SANS241: 2015 Edition 2 limit of 300µg/L. The highest recorded concentration of Aluminium recorded on metals roofs was 58.4µg/L, while the highest recorded for tiled roofs was 39.7µg/L. It is therefore worthy of noting that although the highest concentration observed was found in metal roofs, tiled roof material presented higher concentrations of aluminium on average of 30.5µg/L compared to the tiled average of 29.5µg/L, as shown in Figure 5-11. These results are similar to a study by (Lee *et al.*, 2012) conducted in South Korea, where galvanized steel roof materials presented high levels of aluminium compared to other roof materials such as clay tiles, concrete tiles and wooden shingles. It is worth noting that galvanized steel roof is composed of zinc and iron, which could be that the present aluminium detected originated in atmospheric dust and dry deposition of the host, thus resulting to higher aluminium levels. However, according to a study done by (Mao *et al.*, 2021) in China, the presence of aluminium was not detected in corrugated metals. This translates to ceramic tiles, concrete and asphalt roofing materials presenting more concentration of aluminium than corrugated metal roofing.

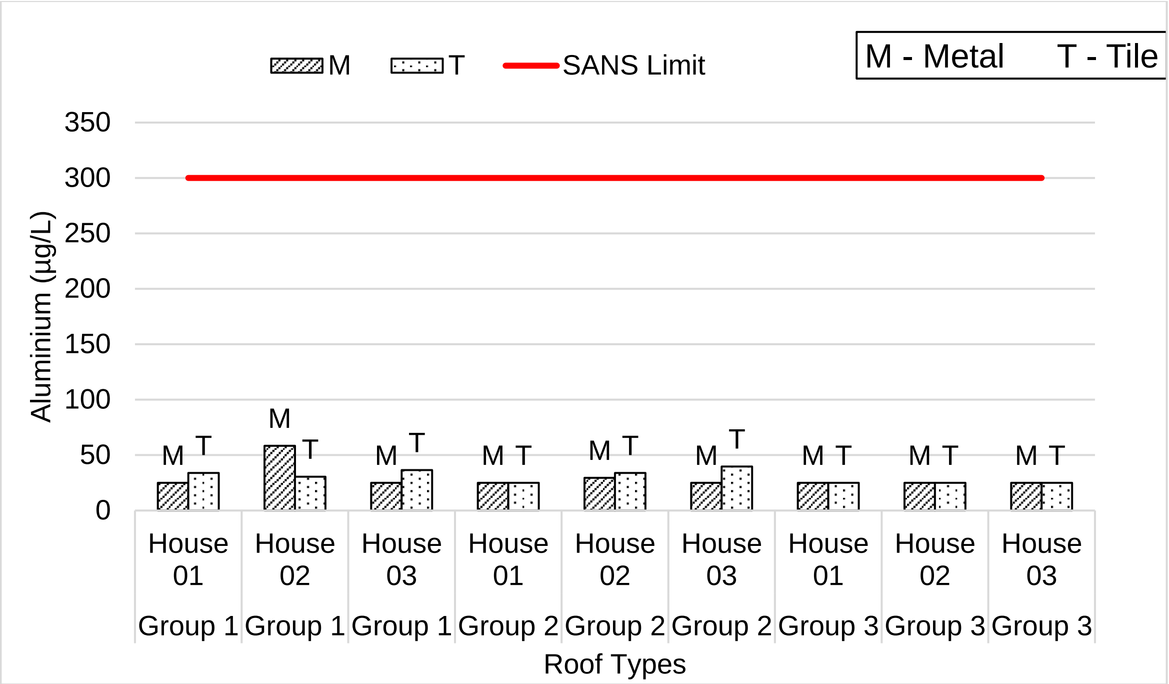

Figure 5-11: Distribution of Aluminium concentrations in RRWH from different roof types

5.4.2 Colour

Colour in water can be caused by decay from organic matter such as vegetation and inorganic matter such as soil. The presence of iron and other metals, whether as natural impurities or as corrosion products, has a significant impact on colour (Venkatesan and Deo, 2010). The colour of the water sample is determined by comparing it to standard colour solutions or coloured glass disks (Omer, 2019). In South Africa, the national acceptable standard for aesthetically appealing water is less than 15 colour units. According to the results presented in Figure 5-12, colour concentration in metal roofs ranged from (1mg/L – 3.5mg/L) while tiled roofs ranged from (1.6mg/L – 4.9mg/L) with an average of 1.78mg/L and 3.01mg/L for tile and metal roof material respectively. The allowable limit for colour according to SANS241:2015 Edition 2 is ≤15mg/L. This means that all the samples tested were within allowable range. These results indicate higher concentrations of colour in tiled roofs compared to the metal roofs. Metal roof materials are expected to have lower concentrations of colour due the smoothness of this material which allows organic matter to be discharged easily. While organic matter and soil particles can be trapped in-between the grooves of tiled roofing, thus resulting into higher concentrations of colour units.

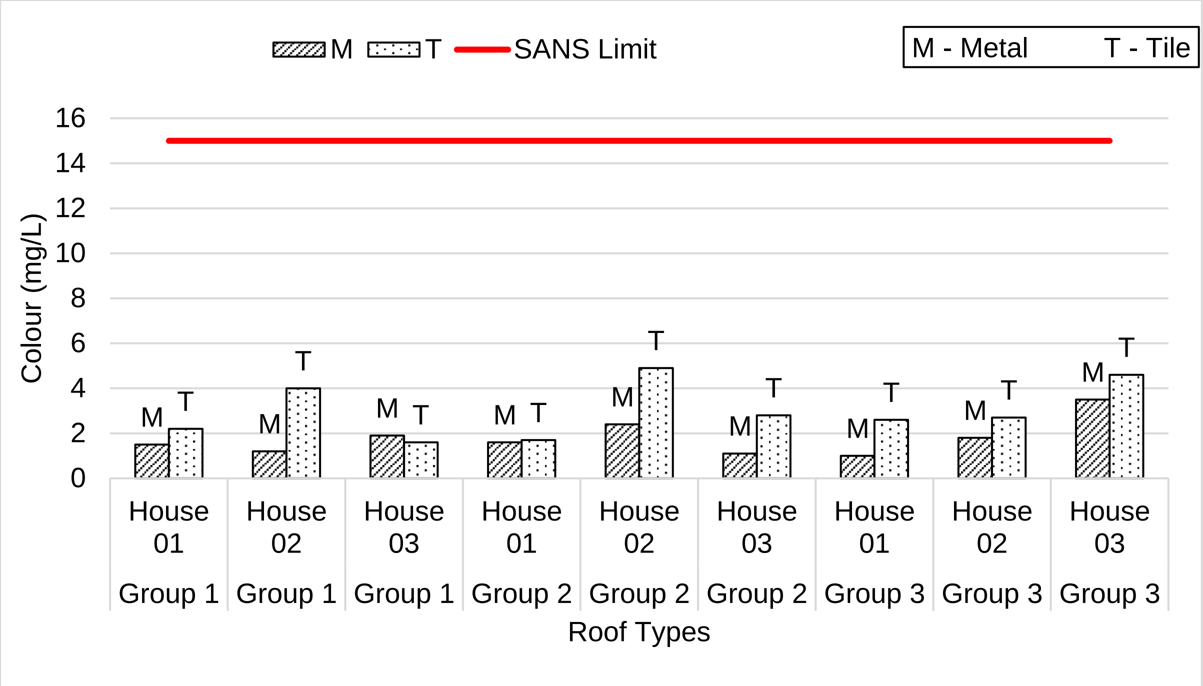

Figure 5-12: Distribution of Colour concentrations in RRWH from different roof types

5.4.3 Conductivity @25°C

The ability of electrical current to flow through water is known as electrical conductivity. It is directly associated with ionized material concentration in water and can also be associated with issues with excessive hardness. According to SANS241:2015 Edition 2, the standard limit of Conductivity is not to exceed 170mS/m. Results from both roof materials were below the maximum standard limit with (2.0mS/m - 6.44mS/m) and (6.19mS/m - 8.19mS/m) ranges for metal and tiled roof respectively. This therefore means that the all samples were within allowable range. The average amount of conductivity for metal and tiled roofs were 4.10mS/m and 7.35mS/m respectively. It is also observed in Figure 5-13 that tiled roofs presented higher level of electrical conductivity compared to zinc metal roofs. These results are quite different than those obtained by (Chang *et al.*, 2004), where metal roofs displayed significant levels of conductivity present in the water.

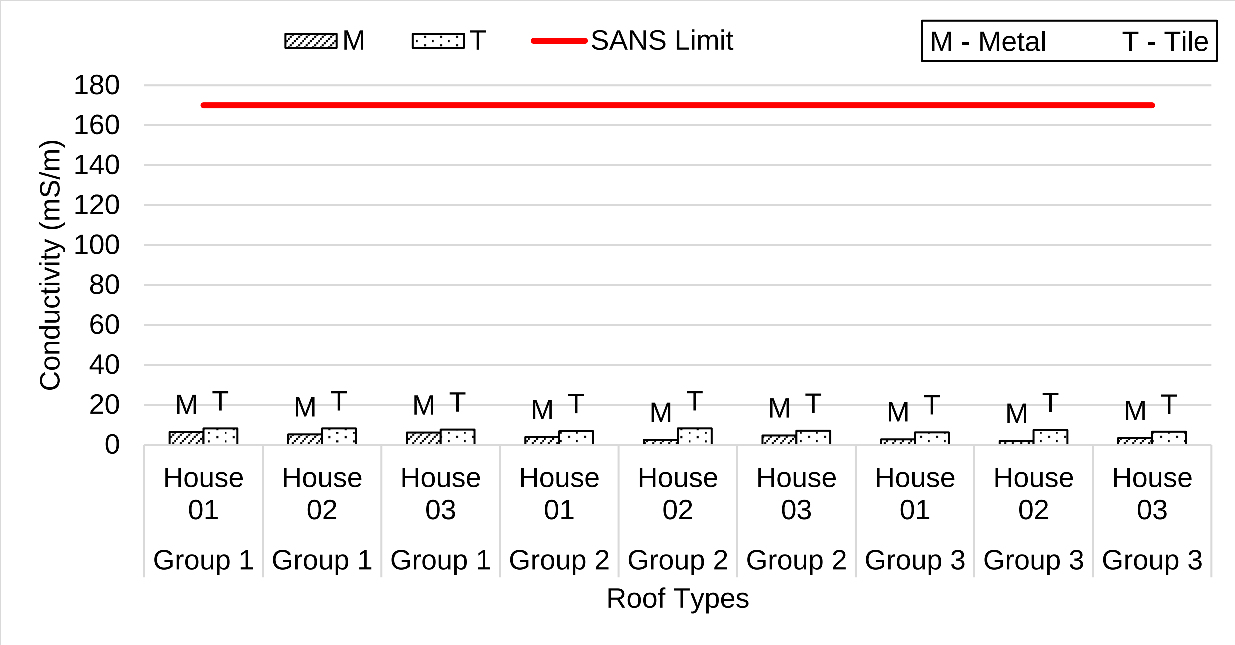

Figure 5-13: Distribution of Conductivity concentrations in RRWH from different roof types

5.4.4 E. coli

Bacteriological quality is one of the important water parameters to be assessed in water potability. Bacteriological quantity is measured by the quantity of pollutant indicators of organisms present in the water such as faecal matter (*Escherichia coli*). *E. coli* is amongst the most reliable indicators of faecal contamination (Adamou *et al.*, 2020). Roof harvested water from both roof types presented inferior results of *E. coli*. The maximum allowable E. coli levels as approved by SANS241:2015 Edition 2 standard is 0 cfu/100mL, which means that *E. coli* levels should not exceed 0 cfu/100mL. Results for both roof types did not comply with the SANS241:2015 Edition 2, where zinc metal roofs ranged from (4 cfu/100mL – 525 cfu/100mL) and tiled roofs ranged from (0 cfu/100mL - <2420 cfu/100mL). The average concentrations for *E. coli* for metal and tiled roofs were 132.44cfu/100mL and 613.67cfu/100mL respectively. Abnormally high levels of *E. coli* as indicated in Figure 5-14 were observed in tile roofs. Similarly, in a study conducted by Satvat *et al.*, (2004),higher bacterial content was found mostly on tile and asbestos roof materials. Likewise to another study conducted by Lee *et al.*, (2012) where both clay and concrete tiles presented results with *E. coli* and galvanised steel roofs presented no *E. coli* counts.

Again, this is expected due to the rough nature of tiled roofs that can be an inhabitant for pollutants. These results indeed prove that the smoothness of metal sheet roofs have fewer chances of retaining contaminations compared to tiled roofs. The presence of *E. coli* in these households may be the result of domestic animals found in all homes. Bird droppings may also have an effect on the results presenting with high *E. coli* level that surpass the national standards. Water in SA is only deemed safe for consumption when the water is compliant in accordance to the full spectrum of SANS241:2015 edition 2. Therefore, due to the high levels of *E. coli* present in the water, harvested rainwater in the study area is deemed unsafe for consumption without treatment. The presence of *E. coli* in water should not be ignored because it is an indicative of recent faecal contamination and can cause harm to human health. In a study on human health risk assessment, it was indicated that 0–10 counts per 100 mL can cause a slight risk of microbial infection with continuous exposure and negligible effects with occasional or short-term exposure; 10–20 counts per 100 mL can cause risk of infectious disease transmission with continuous exposure and slight risk with occasional exposure; and 20 counts per 100 mL will pose significant and increasing risk of infectious disease transmission (DWAF, 1996; Ngubane *et al.*, 2022).

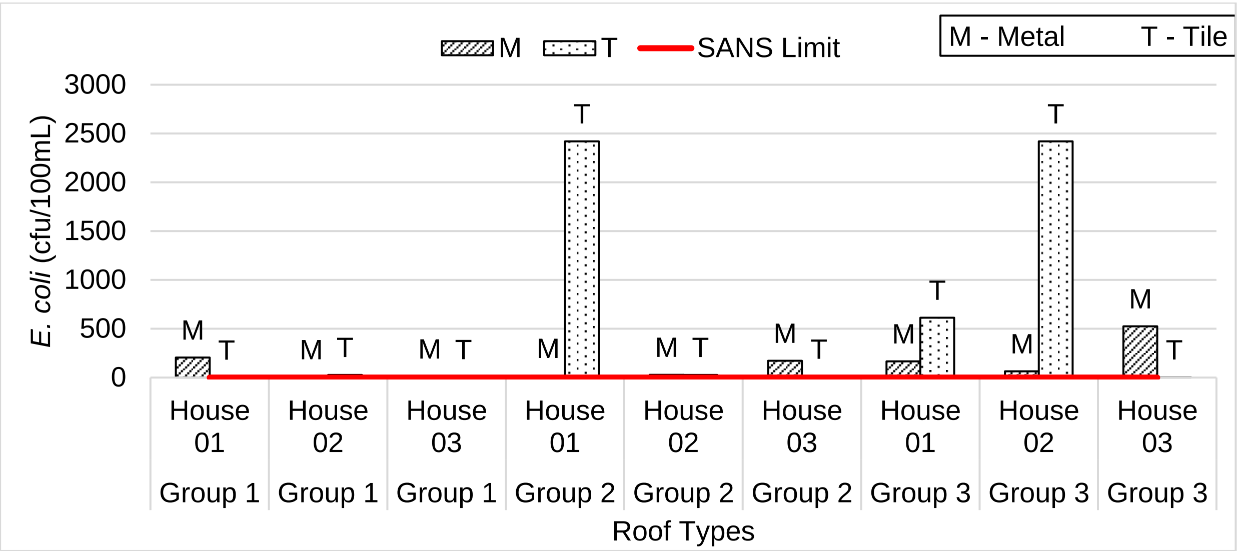

Figure 5-14: Distribution of E. coli concentrations in RRWH from different roof types

5.4.5 Iron

Iron is one of the essential elements in human nutrition. The presence of Iron in drinking water may be due to corrosive steel, iron coagulants and cast-iron fitting used in RRWH systems. The current study presented a range of results from (0.02mg/L – 0.09mg/L) and (0.02mg/L – 0.07mg/L) for metal and tiled roofs with an average of

0.04mg/L and 0.03mg/L respectively. Both metal and tiled roofs met the allowable SANS241:2015 Edition 2 requirements of less than 0.3mg/L as shown in Figure 5-15 . Based on the results observed, it can be concluded that metal and tiled roof materials do not have an impact on the quality produced by RRWH but rather the metal fittings used in the system. Also, Iron levels of 2.1 mg/L for glazed tile roofs were obtained in Australia were found to be highly exceeding the ADWG national guidelines of 0.1mg/L, while zinc metal roofs had metal concentrations that remained under allowable limits (Magyar *et al.*, 2008).

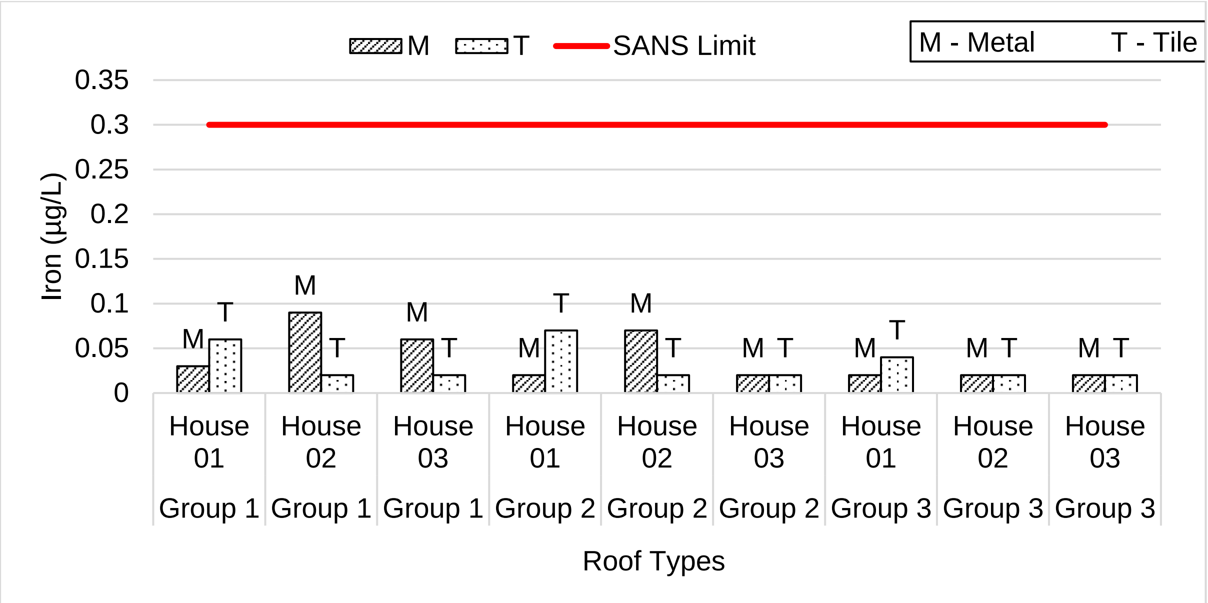

Figure 5-15: Distribution of Iron concentrations in RRWH from different roof types

5.4.6 Odour

Taste and odour in water can be present due to organic and inorganic materials or dissolved gasses which may come from either domestic, agricultural and natural sources. The first group of sampled rainwater tested within the stipulated six hours' transportation time for both metal and tiled roof produced odourless results. These results were within the SANS241:2015 Edition 2 standard, as water need not have any bad odour but rather aesthetically pleasing to the consumer. However, the second and third group of results presented harvested water to have a mild earthy and mild vegetation odour. Similar to tiled roofs, harvested water had a mild earthy odour as shown in Table 5-2.

Table 5-2: Presence of odour in RRWH from different roof types

		Group 1			Group 2			Group 3		
Determinant	Roof type	House 01	House 02	House 03	House 01	House 02	House 03	House 01	House 02	House 03
Odour	Metal	Nil	Nil	Nil	Nil	Mild Earthy	Nil	Nil	Nil	Mild Vegetation
Odour	Tile	Nil	Nil	Nil	Nil	Nil	Nil	Mild Earthy	Mild Earthy	Nil

5.4.7 Lead

The presence of high levels of Lead in water quality may be seen as a cumulative poison which may cause severe damages in infants, foetuses and to the central nervous system. Therefore, long term consumption of rainwater containing high levels of heavy metals such as lead may cause serious health hazards (Satvat *et al.*, 2004). Figure 5-16 represents the results obtained from the study revealed that metal roofs ranged from (4mg/L – 5.6mg/L) while tiled roofs remained constant at 4mg/L. This study found no adverse correlation between the quality of harvested water from tile and metal roof materials due to the close ranges observed for both roof types. Similar results were obtained in a study by Lee *et al.*, (2012), where both concrete tiles and galvanized steel provided similar results of 11 and 12 mg/l respectively. Lead parameters for both roof materials met the SANS241:2015 Edition 2 standards and were below the maximum allowable limit of ≤15mg/L. Compared to other studies, a study performed by Magyar *et al.*, (2008) in Australia found concentrations of lead obtained from glazed tile roofs exceeded the ADWG national guidelines of 0.04 mg/L.

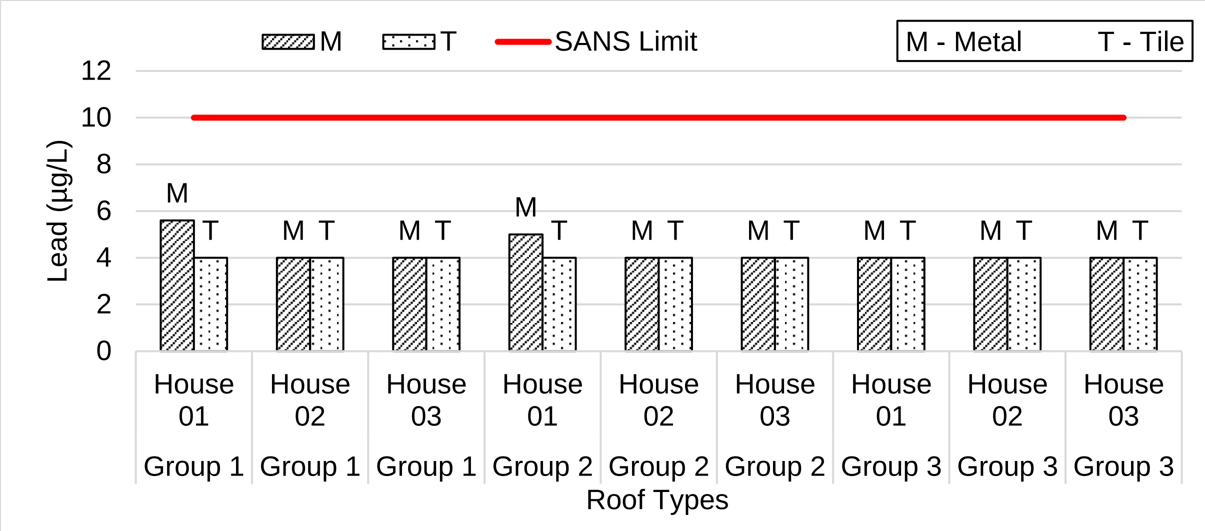

Figure 5-16: Distribution of Lead concentrations in RRWH from different roof types

5.4.8 pH

The pH of water is a crucial factor in determining its viability for different uses, including drinking, bathing, cooking, washing, and agriculture. A pH of 7 is considered to be neutral for pure water. Water with a pH below 7.0 is referred to as acidic, whereas water with a pH above 7.0 is referred to as basic or alkaline (Gorde and Jadhav, 2013). The pH level samples obtained from the rooftop rainwater harvesting systems from the different roof types varied from (6.27µg/L – 7.19µg/L) and (7.05µg/L - 7.39µg/L) for zinc metal roofs and tiled roofs respectively, as shown in Figure 5-17. According to SANS241:2015 Edition 2 the required lower limit is 5µg/L and the upper limit is 9.7µg/L. Although the pH levels for both roof types in between the allowable parameters, it is noted that zinc metal roofs provide acidic water and tiled roof produce alkaline water with averages of 6.67µg/L and 7.22µg/L respectively. Similarly to a study conducted in South Korea, where concrete and clay tile roof materials provided higher levels of pH compared to galvanized steel roofs (Lee et al., 2012). These results have become common because study by Mao et al., (2021) also proved higher pH of rainwater harvested from concrete compared to galvanised metals. It is then understood that the presence and influence of alkaline substances in concrete may be the cause of the results (Mao et al., 2021). However, a study conducted by (Chang *et al.*, 2004) proved different results where metal roofs had a significant influence on pH values.

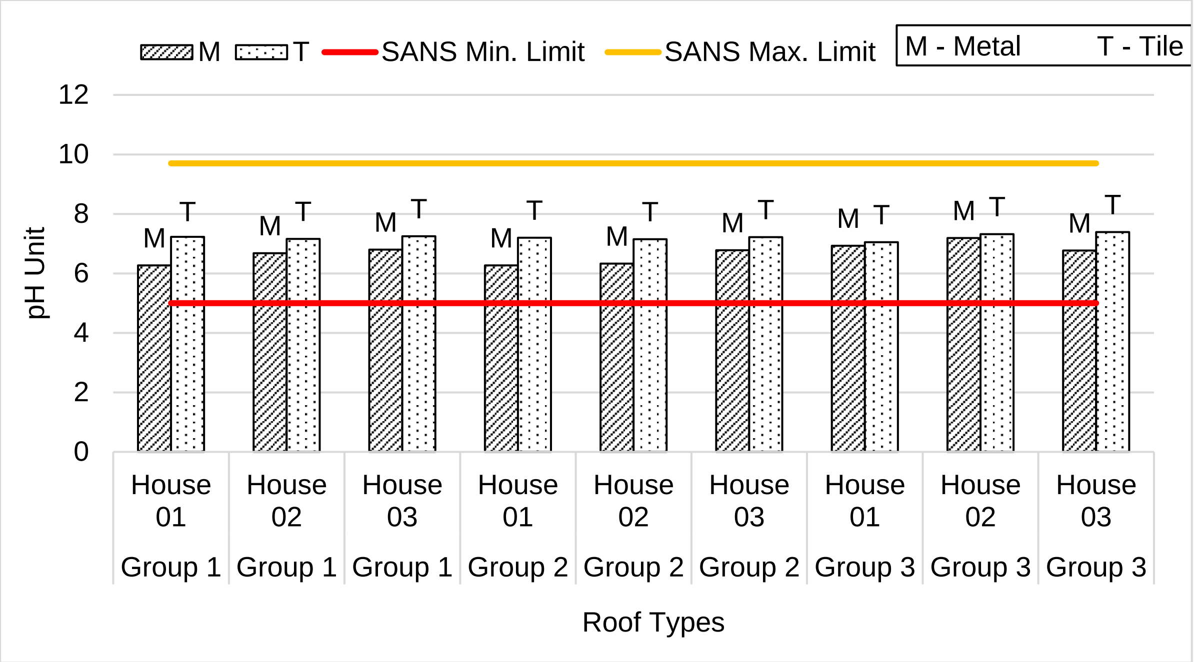

Figure 5-17: Distribution of pH concentrations in RRWH from different roof types

5.4.9 Suspended solids

Suspended solids are organic and inorganic matters that are solution in water. As seen on Figure 5-18, suspended solids for both metal and tiled roof remained constant throughout at 10mg/L for both roof types. This also proves that the roof material does not have an effect on the outcome of RRWH with regards to suspended solids. Samples used in this study were within the allowable national standard, similar to a study conducted by Rahmanian *et al.*, (2015), where suspended solids were also found to be under allowable standards.

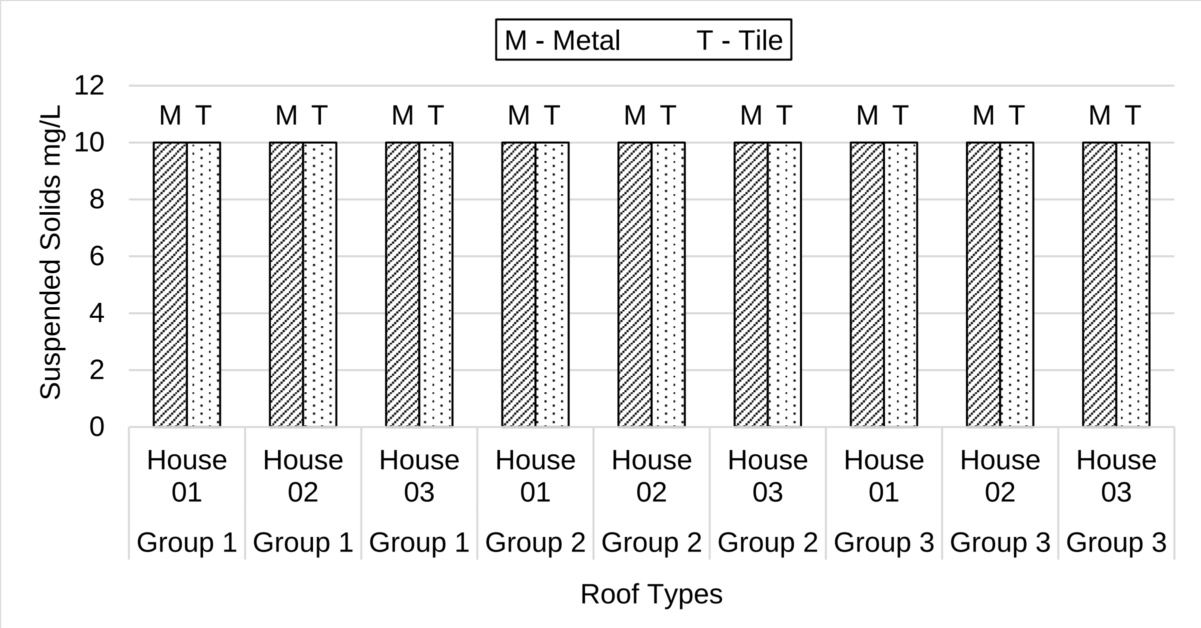

Figure 5-18: Distribution of Total dissolved solids concentrations in RRWH from different roof types

5.4.10 Total dissolved solids @105°C

Total dissolved solids (TDS) represent the different kinds of inorganic matter and small amounts of organic matter present in the water. The allowable value recommended for TDS is ≤1200 mg/l as recommended by the SANS241:2015 Edition 2. The TDS from the roof surfaces ranged from less than 50mg/l to 58mg/l for tiled roofs and below 50mg/l for all zinc metal roofs. These results indicate that the water has a negligible amount of pollutants and minerals. Although Figure 5-19 shows higher amounts of TDS in tiled roofs at an average concentration of 52mg/l compared to the metal roof average of 50mg/l, no significant difference between the two roof types were observed as both roof types produced relatively low amounts of TDS around the same range, ranging from less than 50mg/l to 58mg/l.

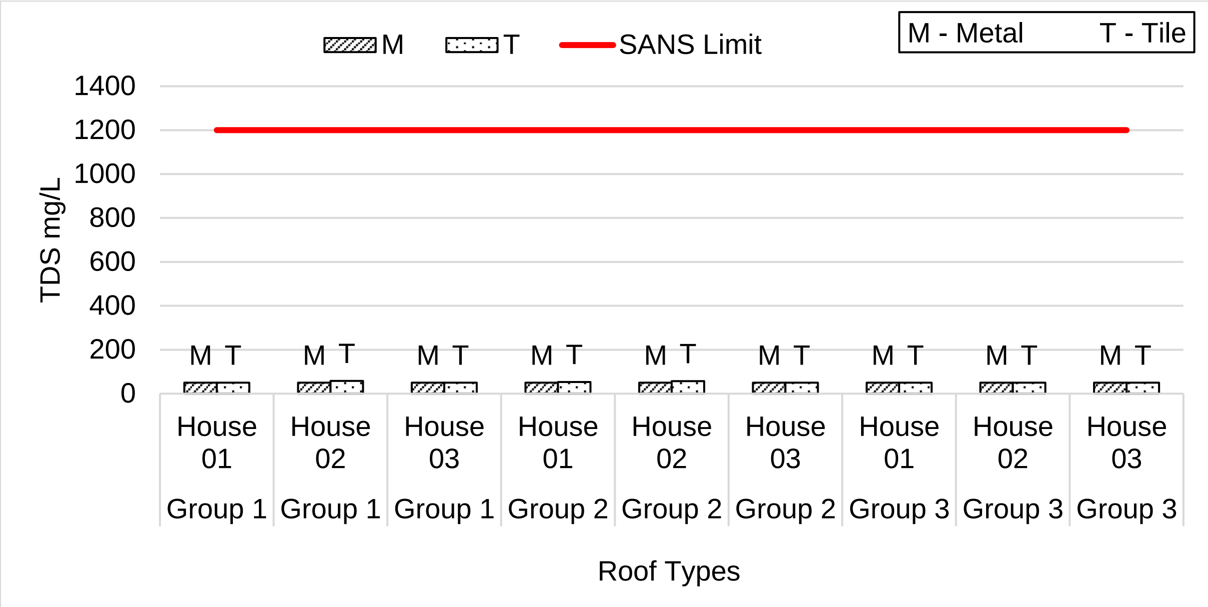

Figure 5-19: Distribution of Total dissolved solids concentrations in RRWH from different roof types

5.4.11 Turbidity

Turbidity can be described as the cloudiness of water. It is a measurement of light's ability to travel through water. Clay, silt, organic material, plankton, and other particle matter suspended in water are some of the substances that generate turbidity. (Omer, 2019). Turbidity is measured using the Nephelometer instrument which measures the intensity of scattered light by turbid particles (Gorde and Jadhav, 2013). According to the SANS 241:2015 (Drucker and Oster, 2015) The maximum permissible level is <1 NTU at operational level and <5 at an aesthetic level . The results show that the roof material does not necessarily have an impact on the quality of water where turbidity is concerned. Turbidity results varied from (0.8 NTU -2.8 NTU) and (0.08 NTU -2.6 NTU) for zinc metal roofs and tiled roofs respectively as shown in Figure 5-20. The fluctuating ranges of results observed did not show any patterns that may suggest the difference on the roof material used. It is also noted that the samples did not meet the SANS241:2015 edition 2 quality standards for the operational limit but were within allowable limit for aesthetically. There was a small difference in the average turbidity samples of obtained from zinc metal (1.51 NTU) and tiled roofs (1.35 NTU) which is also noted to be above the national requirement standard. According to the SANS241:2015 edition 2 quality standards, harvested rainwater in this study area cannot be deemed safe for consumption without prior treatment. Mao *et al.*, (2021) also found no apparent difference between the four roof materials assessed. However, it can be noted the average turbidity from galvanized metal, concrete, asphalt roofs were much higher than the average turbidity for ceramic tile.

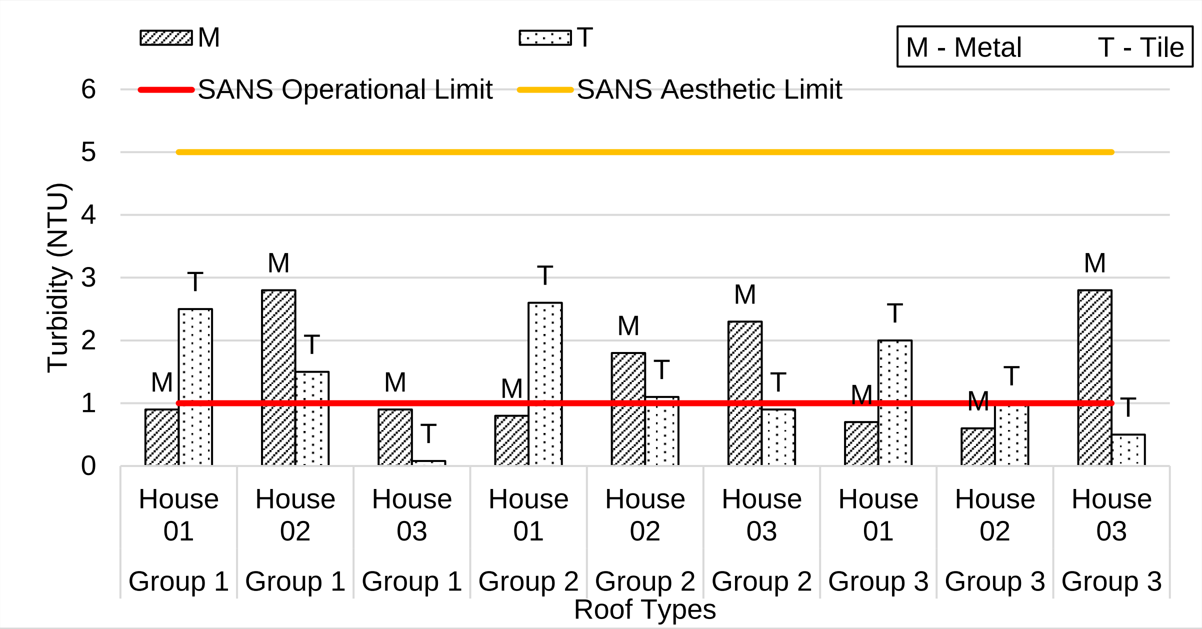

Figure 5-20: Distribution of Turbidity concentrations in RRWH from different roof types

5.4.12 Zinc

When heavy metals are present in drinking water at levels above a specific threshold, negative effects on human health might result. As a result, the study of heavy metals in drinking water is a crucial factor, and heavy metals are typically investigated in drinking water quality studies. Results observed in Figure 5-21 indicated a huge difference in zinc levels where tiled roofs ranged from (<0.3mg/L-0.04mg/L) and zinc metal roof ranging from (2.72mg/L-4.44mg/L). Again, both roof materials met the allowable requirements of less than 5mg/L as per the SANS:241 standards. It is also noted that the highest zinc level observed was 88.8% closer to the allowable limit and approximately 111 times more than results observed for tiled roofs. The average concentrations observed for both metal and tiled roof materials were 3.36mg/L and 0.03mg/L respectively. These results are quite common as authors such as (Lee *et al.*, 2012; Wahyuningsih *et al.*, 2020; Mao *et al.*, 2021) also found higher concentrations of Zinc compared to other roofing materials. These results also proved that metal roofs have a significant influence on zinc levels as studied by (Chang *et al.*, 2004).

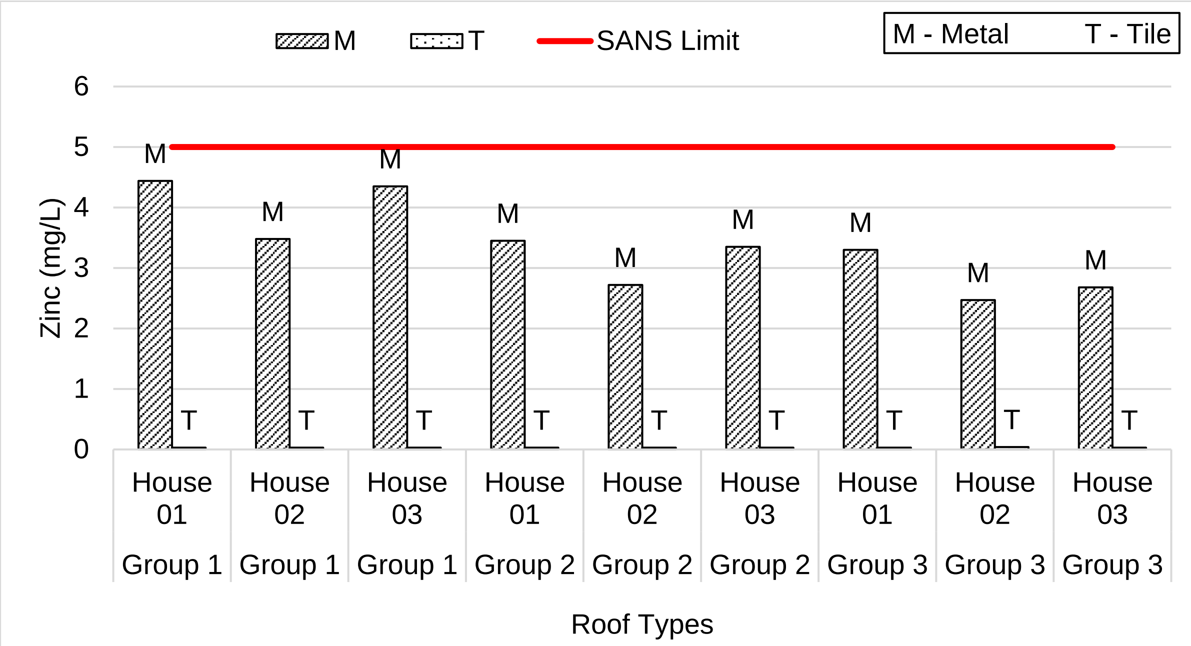

Figure 5-21: Distribution of Zinc concentrations in RRWH from different roof types

5.5 Economic variability

According to the research done from various suppliers about the total of constructing a RRWH system, Table 5-3 below demonstrates the total cost of materials for constructing the RRWH system. The quotations for the RRWH systems were obtained using an average surface area of 105m^2. Based on the water availability results obtained, two storage tanks were used with a capacity of 5250L each.

Table 5-3: Cost of RRWH per service provider

Service Providers	Amount (R)
Build It	**R 31 968. 20**
Builders Warehouse	R 29 073. 80
AL's Hardware	R 18 278. 57

Based on the above table, one can conclude on R31 968.20 for the approximate value of the cost of RRWH per household. The highest quote was adopted as the estimated cost to accommodate worst case scenarios.

Based on Equation 5 stated in Chapter 4, the estimated value for installing rainwater harvesting systems for 1044 households is R33 374 800. 80

Using Equation 6, the interpolated value for providing 2194 people with water supply is R 34 236. 60 per household.

Table 5-4 demonstrates the inflated capital costs that have been calculated using Equation 7 stated in Chapter 4.

Table 5-4: Capital cost for RRWH installation

Year	Average (%)	Capital Cost (R)	
2011	5	R	35 948,43
2012	5,6	R	37 961,54
2013	5,7	R	40 125,35
2014	6,1	R	42 573,00
2015	4,6	R	44 531,36
2016	6,4	R	47 381,37
2017	5,3	R	49 892,58
2018	4,7	R	52 237,53
2019	4,1	R	54 379,27
2020	3,3	R	56 173,79
2021	4,5	R	58 701,61
2022	6,4	R	62 458,59

Based on Table 5-4, the estimated cost for providing water supply for 2194 people is R 62 458.59 per household. Therefore, the estimated amount of providing water supply to 1044 households can be estimated by using Equation 8 stated in Chapter 4. The estimated amount was calculated to be R 65 206 767.96.

In comparison, one can confirm that the installation of RRWH system is less expensive compared to the capital cost of the municipal water supply. It is also worth noting that RRWH is 48.8% less expensive than the capital cost of municipal water supply.

5.6 Discussion

Rainwater harvesting systems as an alternative source of water for both urban and rural settlements can contribute to the decrease in the environmental footprint significantly. Some advantages of harvesting rainwater include the reduction of water and energy use, enhancement of air quality, restore the water cycle, and reduce flood risk (Carollo *et al.*, 2022). Similar to another study where it was also discovered that the use of RRWH systems can retain water and reduce runoff. Thus, lowering the failure rate of drainage systems as well as the occurrence of floods (Freni and Liuzzo, 2019). Therefore, the relevance of this study is that full implementation of RRWH in the study area will not only serve the purpose of water supply, but rather beneficial for the environment in terms flood reduction. Furthermore, this study can help improve and standardize the implementation laws of RRWH in South Africa.

5.7 Summary

This chapter revealed that approximately more than six people occupy each household in Nomlacu. Only about 3% of the population depend on solely RRWH systems, whereas 57% of the population depend on communal tap water and 45% depend on yard tap water. This shows a good representation of the municipal water supply. However, that does not disregard the RRWH as a supportive water supply system as 27% of the community reported unreliability of the current water supply system. Rainwater harvesting can supply the demand by approximately 209% when utilizing the demand of the community from questionnaire. Roughly 124% of the annual demand of RRWH can be met when utilizing the national demand for indigent communities. With the use of the design guide for yard connections obtained from the CSIR, the pressure from the municipal water supply system can be alleviated by at least 77%.

Generally, the quality of the water RRWH samples was satisfactory. Although turbidity and *E. coli* did not meet the SANS241:2015 edition 2 quality standards. It was also noted that turbidity on both zinc metal and tiled roof showed little to no difference with turbidity concentrations, thus one cannot determine whether generally turbidity is higher on which roof type. *E. coli* presented higher concentrations on tiled roofs with an average of 613.67 compared to 132.44 of zinc metal roofs. The presence of higher *E. coli* levels found in tiled roofs may be due to the roughness nature of the tiled roof itself which aids in trapping pollutants on the roof. Also, harvested rainwater in the study area is expected to have excessively high levels of *E. coli* because of the high number of domestic animals in and around the households. However, because the presence of *E, coli* indicates faecal contamination in water and can be a hazard to human health, it is important that it be treated before consumption. Total dissolved solids, pH, colour and conductivity were all under the SANS241:2015 edition 2 allowable limits and it was also observed that they presented higher concentrations on tiled roof materials. Similar to metal roofs where, aluminium, iron, lead and zinc presented higher concentrations and were within the allowable SANS241:2015 edition 2 standard limits.

Economically, installing a RRWH system is financially feasible, especially if the project can be subsidized by the government. It would spare the municipalities approximately 48.8% of the municipal water supply spend to supply water to the municipality should this project be a government initiative.

CHAPTER 6 : CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The aim of this study was to assess the feasibility and effectiveness of RRWH systems in terms of the quality and quantity of water and economic feasibility. The main objective was to investigate whether RRWH can act as an alternative water source to the Nomlacu community to alleviate water demand from municipal water. Additionally, compare the quality of RRWH runoff obtained from different roof materials, thus leading to the determination of water potability per roof material. Moreover, the study further evaluated different domestic water treatment methods to convert roof harvested water to potable water and lastly seek to understand the financial gains or losses of this system.

Findings

- ❖ Domestic RRWH is technically feasible because the WMMM area receives sufficient rainfall to supply the entire population even during the winter season. when appropriate water balance based on local rainfall data is established.
- ❖ The capital cost of RRWH system is the primary challenge in promoting RRWH.
- ❖ There is no significant difference between harvested rainwater from either metal or tiled roofing materials, therefore, both roof materials may be used for harvesting rainwater.
- ❖ The community of Nomlacu found that it is essential to own a RRWH system to alleviate the pressure from municipal water supply as well as saving water for when there is no available running water on municipal water supply.
- ❖ The harvested rainwater quality does not comply fully with the SANS241:2015 Edition 2 standards for both metal and tiled roof materials. This is due to the high levels of *E. coli* and turbidity present in the water. Therefore, harvested rainwater from these roof materials may not be used for consumption purposes without prior treatment.

Overall, the quality of the RRWH samples showed satisfactory results excluding turbidity and *E. coli* excluding turbidity and *E. coli* which did not meet the SANS241:2015 edition 2 quality standards with results ranging from of (0.8 – 2.8 NTU) and (0 - >2420 MPN /100mL) respectively. The study also presented *E. coli* concentrations that were higher on tiled roofs with an average of 613.67 compared to 132.44 of zinc metal roofs. It is also worth noting that total dissolved solids, pH, colour and conductivity were all under the SANS241:2015 edition 2 allowable limits and it was also observed that they presented higher concentrations on tiled roof materials. Similar to metal roofs where, aluminium, iron, lead and zinc presented higher concentrations and were within the allowable SANS241:2015 edition 2 standard limits. Additionally, Results also showed higher pH levels on tiled roofs (7.05 – 7.39) compared to zinc roofs (6.27 – 7.19). In terms of water quality, according to the SANS241:2015 edition 2, RRWH system in the study area is not feasible because of turbidity and E. coli that did not meet the water quality standards for consumption. However, available treatment methods can be used to convert RRWH water to potable water.

The study shows that RRWH is a feasible and a potential solution to alleviate the pressure from the current water supply. Nomlacu area receives relatively high amounts of rainfall, greater than both the country's average annual rainfall. The study presented that RRWH can meet the annual demand of rainwater with an approximate saving of 209% when utilizing the demand of the community by questionnaire. Approximately 124% annual demand of RRWH can be met when utilizing the national demand for indigent communities. Lastly the system can help alleviate the pressure from the municipal water supply system by at least 81% when using the design guide for yard connections obtained from the DHS. The study also proved that installing a RRWH system can be financially feasible, it would spare the municipalities approximately 48.8% of the municipal water supply spend to supply water to the municipality should this project be a government initiative. Based on the cost estimation for RRWH implementation, it can be debatable whether or not the government will subsidize the system. The estimated cost of the system itself is not inexpensive and therefore can be challenging to receive funding or subsidy.

In conclusion, RRWH is not financially feasible for an average community member in the studied area because of the high initial cost and maintenance of the system. The system is observed to be feasible in terms of the potential quantity of harvestable water and can be achieved by using more than two storage tanks in the study area. The most significant and immediate threat to health is that roof collected water poses bacterial contamination. Therefore, it is important to regularly clean the system by using disinfection solutions like chlorine tablets and boiling water before consumption.

6.2 Recommendations

It is astonishing how frequently untreated rainwater is consumed in South Africa's rural areas by locals. For RRWH to fulfil drinking water requirements, it can be combined with a slow sand filtration system, boiling, pasteurization, semi-automatic chlorination process as well as the direct sunlight method. However, further research is required to make the system both technologically and financially feasible. This can be achieved by implanting the following recommendations.

- Sufficient storage needs to be made available for optimal roof rainwater harvesting to be successful.
- RRWH systems should be designed in a manner that an extra tank is used for purified water such that newly harvested water does not mix with the purified water. Harvested rainwater should be treated before human consumption.
- RRWH systems must be properly maintained to improve water quality and reduce the subsequent treatment cost.
- Specific guidelines should be set to enhance acceptance of a RRWH systems.
- Government subsidies and incentives encourage local people to adopt RRWH systems.
- Increase in public education about RRWH system technology to promote an environmentally sustainable environment.

Further research

As rainwater is collected and held over time in tanks, there are concerns that the quality will deteriorate. Further research may be required for the effect of the tank material on water quality as well as the cause, effects and avoidance of stored water quality degradation.

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APPENDICES

Appendix A: Ethics Certificates

Appendix B: Letter of Information

Appendix C: Gate Keeping Authorization

Appendix D:SANS 241:2015 Edition 2 water quality requirements

Appendix E: Questionnaire

Appendix F: RRWH system quotation

Appendix G: CPI Rates

Appendix H: Water Sample Results