

AN ANALYSIS OF WATER DEMAND AND QUALITY WITHIN THE IISHANA-
SYSTEM, NAMIBIA

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ABSTRACT

The Namibian people, particularly those living within the Iishana system, which is a subset of the Cuvelai Basin, often encounter recurrent floods and droughts. After each rainy season, the Iishana system dries up gradually, hence, water for both agricultural and potable purposes becomes crucial. To enhance water availability, this study evaluated water demand and quality within the Namibian Iishana system, considering planned infrastructure developments and the rehabilitation of existing systems. This study employed a physical interaction, as well as the administration of questionnaires, to determine the population per-capita demand within the Iishana system. A thirty-year population projection was used to estimate future water demand. Moreover, the hydrological data (daily rainfall and temperature) from 2012-2021 were incorporated. As the water quantity and quality are inseparable, ten water samples were collected for Water Quality Index (WQI) and Multivariate Statistical Analysis using Minitab (21.2). The Piper diagram generated using Grapher (20.2.321) further classified water types. The current rural population and livestock water demand were estimated to be 2,479 and 4,282 m³/respectively. Projected demand forecasts for 2033 (0.9 Mm³/year), 2043 (0.5 Mm³/year), and 2053 (0.1 Mm³/year) indicate a declining trend, due to outmigration. More so, water availability is found to be affected by climate change, making it insufficient to meet demand. Climate data analysis showed a rising temperature trend, with annual precipitation (310 mm) far exceeded by evaporation (2,500 mm), resulting in water level drops and poor quality. The WQI scores (81.30-320.65) classified the water as unsuitable for human consumption. The Principal Component Analysis (APA) identified key influences: soil formation, mineral dissolution, microorganisms, and agricultural runoff. The Piper diagram classified 100 % of the sampled water as Na⁺-K⁺ water types, indicating salinisation. The water crisis in the area demands urgent, coordinated action to balance supply enhancement with quality control. Therefore, it is crucial to harvest flood and rainwater by expanding the size of natural pans in the study area for use during dry periods. Water treatment for pans can augment the water supply for the rural population.

Keywords: per capita demand, rural population, Iishana system, water demand, water supply, infrastructure, water quality

LIST OF PUBLICATIONS AND CONFERENCES

Eino J, Katte VY, Busari AO, Pires EES, Johannes P, Fahrenberg M, Reinhardt CI, Jüpner R and Schulte A (September 25, 2024). An Analysis of Water Demand of the Rural Population within the Iishana System, Namibia. Published in: Journal of Civil Engineering and Urbanism. <https://dx.doi.org/10.54203/jceu.2024.27>

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ACRONYMS AND ABBREVIATIONS

H_0	Null Hypothesis
H_1	Alternative Hypothesis
AIM	Arithmetical Increase Method
APHA	American Public Health Association
AWWA	American Water Works Association
CA	Cluster Analysis
CB	Cuvelai Basin
CM	Correlation Matrix
DGM	Decreasing Rate of Growth Method
FA	Factor Analysis
GIM	Geometrical Increase Method
GIS	Geographic Information System
GPS	Global Positioning System
GRN	Republic of Namibia
HoD	Head of Department
IB	Ion-Balance error
ICP	Inductively Coupled Plasma
IIM	Incremental Increase Method
l/c/d	liters per capita (person) per day
m	meter
m^3/d	cubic meter per day

MAWLR	Ministry of Agriculture, Water and Land Reform
MHSS	Ministry of Health and Social Services
MS Excel	Microsoft Excel
MURD	Ministry of Urban and Rural development
NamWater	Namibia Water Corporation Ltd
NDP	National Development Plan
NSA	Namibia Statistics Agency
SASSCAL	Southern African Science Service Centre for Climate Change and Adaptive Land Management
UNAM	University of Namibia
UNICEF	United Nations Children's Fund
USA	United States of America
WEF	Water Environment Federation
WHO	World Health Organisation

DECLARATION

I, Junias Eino, hereby declare that this study is my own work and is a true reflection of my thesis, and that this work, or any part thereof has not been submitted for a degree at any other institution. No part of this thesis may be reproduced, stored in any retrieval system, or transmitted in any form, or by means (e.g. electronic, mechanical, photocopying, recording or otherwise) without the prior permission of the author, or the University of Namibia in that behalf. I, Junias Eino, grant the University of Namibia the right to reproduce this thesis in whole or in part, in any manner or format, which the University of Namibia may deem fit.

Junias Eino



OCTOBER 2025

Name of Student

Signature

Date

CHAPTER 1. INTRODUCTION

1.1. General Introduction

Water is a finite and vulnerable resource, vital to sustaining life, development, and the environment (United Nations, 2013). Although water covers 71 % of the Earth's surface, only 2.5 % is freshwater, and just a fraction of this is readily accessible for human use (Cech, 2009; Mays, 2011). The world relies primarily on surface water (rivers, lakes, reservoirs) and groundwater for drinking, agriculture and industry (World Bank, 2022). However, there is a significant groundwater depletion, particularly in regions with intensive irrigation, such as India and the United States (Döll *et al.*, 2014; Scanlon *et al.*, 2023; Wada *et al.*, 2010). Meanwhile, Sub-Saharan Africa faces acute water stress due to limited infrastructure and unequal distribution (World Bank, 2022).

There is clear evidence worldwide of a growing decrease in both the quantity and quality of water due to human population growth and industrialisation (World Bank, 2021). In addition, there is overexploitation and degradation of ecosystems caused by water users and polluters, who face direct consequences for their actions (Genjebo *et al.*, 2023). The main contributing factors are population growth, industrial and agricultural development, deforestation, climate change, and natural changes in the ecosystem (Chaudhry and Malik, 2017).

The Sustainable Development Goal (SDG 6) aims to achieve the availability and sustainable management of water and sanitation for all people by 2030 (United Nation, 2018). Despite efforts to lessen demand and improve access to water, 784 million people worldwide are without access to clean water (World Water Day, 2021). In Namibia,

approximately 16 % of households in rural areas depend on water from streams, while about 13 % on unprotected wells, which are unsafe for consumption (Census, 2011).

1.2. Background of the study

The Iishana system falls within the Cuvelai Basin (CB), which is a transboundary watershed shared by Angola and Namibia, covering about 18, 370 km². According to the Namibia Statistics Agency (NSA), the population growth in the region has exploded in the last decade to approximately 850, 000 people in the area (Census, 2011). Due to the continuous population growth, the demand for freshwater has risen, complicating water supply and its management in the region (MAWF, 2014; Mendelsohn and Weber, 2011).

In terms of climate, the Iishana system is characterized by a single annual precipitation of 350 mm-550 mm and an annual evaporation rate of approximately 3,000 mm (Koeniger *et al.*, 2021). The rainy season runs between November and April, and the dry period runs from May to October. The seasonal variation in rainfall leads to extreme events, such as floods and droughts (Karamouz *et al.*, 2011; Shaamhula *et al.*, 2021). These factors are the main challenges controlling and limiting the development and safety of the inhabitant's livelihood, water availability, and food security (Drees *et al.*, 2017; Shifidi, 2016); focusing the urgent need for effective measures to cope with water scarcity and droughts.

1.3. Statement of the Problem

The Namibian people, particularly those living within the Iishana system which is a subset of the Cuvelai Basin, often encounter recurrent floods and droughts (Shaamhula *et al.*, 2021; Shifidi, 2016). After each rainy season, the Iishana system dries up gradually;

hence, water for both agriculture and potable purposes becomes a pressing concern (Drees *et al.*, 2017).

In response to these challenges, the German Federal Ministry of Research, Technology and Space funded the Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL) Call 2.0, a joint research initiative focused on enhancing water storage within Namibia's Iishana system.

The ephemeral Iishana water system faces mounting pressures from three key stressors: climate change-induced hydrological variability, agricultural runoff contaminating water quality, and unsustainable water extraction driven by rapid socio-economic development (Mendelsohn and Weber, 2011). These factors threaten both the ecological integrity of the system and water security. In this context, understanding water demand and quality is crucial for developing effective coping strategies for regional water security. Therefore, the SASSCAL initiative played a pivotal role in strengthening the capacity of this study to evaluate rural water demand and quality, ultimately supporting an optimised water resources management in the region.

1.4. Aim and Objectives of the Study

The aim of this study was to evaluate water demand and quality within the Namibian Iishana system.

To achieve the main objective, the following specific objectives are to be achieved:

1. To estimate the current and future population within the catchment area from 2023 to 2053 in order to accurately compute water demand.

2. To evaluate the variability in water demand within the Iishana system under changing scenarios.
3. To explore the coping mechanisms employed by dwellers with regard to droughts within the Iishana system.
4. To assess the water quality of selected pans within the basin.

1.5. Research Questions

The study intends to address the following research questions:

1. What are the current and future water demands of the rural population in the Iishana system?
2. How does water demand vary with demographic, socio-economic, and climatic changes?
3. How do people in the Iishana system adapt to droughts?
4. Does the water quality of selected pans meet the required standards for augmenting the water supply?

1.6. Significance of the Study

The Iishana system is within the driest portion of southern Africa and water is a scarce resource. Understanding water demand in the Iishana system helps in managing this resource sustainably, ensuring that it meets the needs of both human populations and ecosystems. Historical evidence underscores the severity of this issue, with notable droughts occurring in the late 1980s, mid-1990s, and more recently, between 2014 and 2019 (Arendt *et al.*, 2021). These drought events have precipitated severe food insecurity, infrastructure resilience and diminished water availability for both agriculture and

domestic purposes (Drees *et al.*, 2017; Zhang & Chansheng, 2016). Such an analysis is critical for the strategic planning and development of secure and protected water infrastructures, particularly to mitigate the impacts of drought periods.

Furthermore, this study is in alignment with the global agenda of achieving the Sustainable Development Goal 6 (SDG), which emphasises ensuring universal access to clean water and sanitation. By understanding water demand, it can fulfill basic human needs and enhance health and quality of life. Through a localised analysis of water demand, this study provides a foundational framework for evidence-based decision-making. It also aims to support the Namibian government in formulating targeted strategies to bridge the gap between water supply and demand, thereby fostering resilience and sustainability in water resource management.

1.7. Delimitations of the Study

This study is restricted to the Namibian portion of the Iishana system only.

1.8. Limitations of the Study

The data analysed were basically for the dry season. Hence, seasonal variability was not considered in the study.

1.9. Layout of Thesis

The thesis comprises of 7 chapters; the contents of these chapters are given below:

Chapter 1 provides an introduction to the study, covering the general introduction, background of the study, statement of the problem, research objectives, research questions, significance of the study, delimitation of the study, and limitations of the study.

Chapter 2 presents the literature on water demand, covering various types of water

demand, the factors that affect it, population forecasts, water demand projections, and aspects of water supply and sanitation.

Chapter 3 details the research design, research instruments, population, sample, procedures, and ethics used for the study. The results and discussions are presented in Chapter 4, and the conclusions and recommendations are made in Chapter 5. The final sections of this thesis include a list of all references cited throughout the study. The ethical clearance certificate, research permission letter, questionnaires, and test results are included in the appendices.

CHAPTER 2. LITERATURE REVIEW

This chapter presents a critical review of the literature on water demand. It includes an overview of the various types of water demand, such as domestic, agricultural, industrial, commercial, fire, and compensation for water loss, as well as it explores the factors that influence them. Additionally, it presents variations of water demand and methods for projecting water demand. Lastly, the review of water supply and sanitation is presented.

2.1. Introduction

Water demand refers to the amount of water that users require to meet their needs (Al-Qaisi & Al-Shammari, 2018; Mays, 2011). It is crucial to accurately assess the total quantity of water needed in a specific area when planning a water supply system (Sipes, 2010). Effective planning for a town or region should take into account the various types of water demand from the public (Basak, 2007). The different types of water demand will be discussed in the following section.

2.2. Types of Water Demand

2.2.1. Domestic Demand

Mays, (2011) defines domestic demand as the water required in houses for drinking, cooking, bathing, washing clothes and utensils, sanitary blocks, private vehicles, gardening, and so on in residential houses. The demand for water for domestic animals is included in overall water consumption. The amount of water used per person in households can vary depending on their living conditions (Anang *et al.*, 2019; Motho *et al.*, 2022; Panagopoulos, 2013). Although the water requirement for domestic use stays relatively constant, it is slightly higher in summer than in winter (Arendt *et al.*, 2021; Eino

et al., 2024). As living standards improve, there is a gradual increase in the demand for water for domestic use. This trend is especially noticeable in developed countries (Basak, 2007).

The total demand for domestic water equals the total design population multiplied by the domestic consumption per capita (MAWF, 2014). Domestic water demand can be estimated from Equation 2.1 (Rangaiah *et al.*, 2021).

$$X = \frac{P \times Y \times 365}{1000} \quad (2.1)$$

Where X = water demand (m³),

P = Present population, and

Y = per capita demand (lcpd), which typically refers to the average daily water usage per person in a specific area.

2.2.2. Commercial Demand

Commercial demand includes the water demand in office buildings, hotels, restaurants, shopping centers, cinema houses, motor garages, laundries, dairies, institutions, and other commercial facilities (Mays, 2011). Precise specifications for water demand in municipal areas are unavailable, so an approximate value for water demand for municipal/commercial purposes is used (Al-Qaisi and Al-Shammari, 2018). The quantity would undoubtedly vary depending on the nature of the area and the number and types of businesses and institutions (Rangaiah *et al.*, 2021).

2.2.3. Industrial Demand

The industrial water demand depends on the type of industry in the area. The number and type of industries such as cloth mill, paper mill cotton mill, sugar mill, chemical industry, hume pipe, rolling mill, and so on should be recorded. The water requirement for industrial use remains constant throughout the year (Cech, 2009; Mays, 2011). However, as industries and power plants continue to grow, their water needs are steadily increasing. Industries such as paper, petrochemicals, and steel are particularly water-intensive. Additionally, thermal and nuclear power plants also have very high water usage. While the water required for these purposes is lower in rural areas, nevertheless a continuous supply is necessary (Rangaiah *et al.*, 2021).

2.2.4. Agricultural Demand

Agricultural water is water used for growing fresh produce like crops, vegetables, fruits, and raising livestock (Abunnour *et al.*, 2016). The major purpose of livestock water use is for drinking, feed lots, dairy operations, fish farming, and other on-farm needs (Mays, 2011). The water requirement for irrigation is not constant; the highest demand for irrigation occurs during the winter season. In years with low rainfall, more irrigation water is needed compared to years with high rainfall. Having a storage reservoir helps protect the area against drought. Some of the storage should be set aside to meet the irrigation demands during periods of water scarcity and drought (Rangaiah *et al.*, 2021).

It is crucial to understand the water needs of crops. When water is scarce, it is essential to choose suitable crops for successful agriculture. Even with available water, it is significant to utilize it properly to meet the crops' water demand (Abunnour *et al.*, 2016). To minimize water usage, the maximum water demand of the crops is typically considered, which

includes the total water consumption by the crops and water losses due to evaporation and deep leakage within fields and irrigation systems (Al-Qaisi & Al-Shammari, 2018).

In addition to crop water demand, livestock water requirements must also be accounted for in comprehensive water resources planning. Livestock demand is calculated by multiplying the number of livestock by the standard water consumption rate adopted in the region. In cases where livestock population data is unavailable, estimates is derived based on the carrying capacity of the area, typically quantified as 10 hectares per Livestock Standard Unit (LSU) (MAWF, 2014). This approach ensures a holistic assessment of agricultural water needs, facilitating informed decision-making for water allocation and management.

2.2.5. Fire and Public Demand

Fire normally breaks out in busy urban areas, and there may not be enough water available from surface sources like ponds, ditches, or open wells to fight fires. Additionally, these sources might not even exist in these areas. Therefore, it is important to store the necessary amount of water for firefighting in storage reservoirs at specific locations and to establish fire hydrants at intervals of about 100-150 meters along the main pipelines. During a fire, firefighting personnel need enough water at high pressure to extinguish the flames. A 10 % of the total demand should be considered for fire and public purposes (Basak, 2007; Mays, 2011).

2.2.6. Compensate for Water Losses

Water loss occurs due to defective pipe joints, cracks in the pipeline, faulty valves and fittings, taps left open by consumers, damaged public taps, and unauthorized connections.

It is important to consider these losses when estimating total water requirements. To account for these losses, it is recommended to allocate an allowance of about 15 % of the total water requirement (Basak, 2007).

To plan the water supply scheme for a specific region, it is vital to know the amount of water needed by the public by analyzing the water sectors discussed. A potential water source is then found based on the total water demand.

2.3. Factors which affect Water Demand

This section provides an overview of the factors which influence water demand. These factors include climatic conditions, population growth, demographics, socio-economic characteristics, and water quality. The following descriptions explore these factors in detail.

2.3.1. Climatic conditions

Climate change is one of the most significant risks affecting the hydrological cycle (Han, 2010; Kannan *et al.*, 2023; Rodell *et al.*, 2018). Climatic conditions, such as temperature and precipitation variability, intensify competition among water users and can lead to conflicts, often exacerbated by seasonal effects on outdoor activities (EPA, 2025; Sukanya & Joseph, 2023). Exposure to severe weather events significantly impacts water demand, putting immense pressure on water availability (Khoi *et al.*, 2021). Climatic variables, along with historical water consumption data, are frequently considered in studies on water resources management. For instance, Wang *et al.* (2018) evaluated changes in water demand due to changes in the environment considering the average temperature. Alshaiqli *et al.* (2021) investigated per capita water consumption in relationship with

temperature, humidity, rainfall, daylight, and sunshine. Meanwhile, research shows that rising temperatures directly impact surface water availability, leading to reductions due to increased evaporation rates (Eino *et al.*, 2024)

2.3.2. Population growth

The amount of water provided is primarily based on the size of the population (MAWF, 2014; Mays, 2011). If the population is lower, less water is supplied, whereas if the population is higher, more water is supplied (Alshaikhli *et al.*, 2021; Anang *et al.*, 2019). This allocation guarantees that every person receives water according to their needs and minimizes water wastage (Genjebo *et al.*, 2023; Lee *et al.*, 2022; Y. Wang *et al.*, 2018). Thus, population is determined to properly estimate water demand (Basak, 2007; Eino *et al.*, 2024; Ismael & Aziz, 2024; Rangaiah *et al.*, 2021).

2.3.3. Demographic Characteristics

Demographic characteristics including population, household size, and the sex and age of occupants, are important factors to consider (Blokker *et al.*, 2010). In this context, Abu-Bakar *et al.* (2023), Ibrahim *et al.* (2021), and Motho *et al.* (2022) investigated the influence of demographic factors, such as the number of children, adult male members, adult female members, elderly members, the sex/gender and ages of occupants on household water demand. These studies revealed a significant association between gender and household size on per capita water demand. The findings of Abu-Bakar *et al.* (2023) indicate a difference in water consumption between genders, with teenage girls using more water than boys during morning showers.

2.3.4. Socio-Economic Characteristics

Socio-economic characteristics encompass income level, occupation, and education level. Numerous studies have incorporated socio-economic variables in their analyses. The findings of Abu-Bakar *et al.* (2023), Ibrahim *et al.* (2021), Motho *et al.* (2022), Ou *et al.* (2023) and Panagopoulos, (2013) indicate that income positively affects water demand, with increases in income leading to higher water usage. However, Motho *et al.* (2022) found no significant association between household water demand and education level.

Price is also an important economic factor for water demand forecasting, as higher prices can lead to reduced consumption. For instance, Panagopoulos (2013) demonstrated that increased water prices resulted in reduced consumption among large consumers. Motho *et al.* (2022) suggest that policymakers should consider socio-economic factors, which significantly influence water use and demand needed to implement effective demand management strategies.

2.3.5. Quality of Water

The quality of water affects public consumption, resulting in higher demand when its quality is good and lower demand when it is poor (Cech, 2009). The quality of water is adversely affected by poor water supply and sanitation (Edokpayi *et al.*, 2018; Ritchie *et al.*, 2024; Strehmel *et al.*, 2016; Tortajada & Biswas, 2018). Water quality standards serve as the basis for protecting water quality. While water quality standards may vary from state to state, they all must meet minimum requirements (Mays, 2011). Typically, water samples are collected from the surface water body and analysed in a laboratory to identify the presence and levels of different contaminants such as nutrients, metals, pathogens, and organic pollutants (Ejoh *et al.*, 2018; Iqbal & Shah, 2013; S. Li & Zhang, 2010; Onipe *et*

al., 2020; RamyaPriya & Elango, 2018; Wu *et al.*, 2019; Zakir *et al.*, 2020). By assessing these parameters, any changes in water quality can be identified and potential environmental issues can be detected (Ejoh *et al.*, 2018; Ithindi *et al.*, 2018; Wanke *et al.*, 2018).

2.3.6. Water Demand Norms

The consumption of water for domestic and non-domestic purposes in both rural and urban areas of Namibia is outlined in Table 2.1. These consumption guidelines were derived from various sources, including databases in Windhoek (MAWF, 2014).

Table 2.1: Domestic and non-domestic water consumption (MAWF, 2014).

Category	unit	Rate of consumption
Communal standpipes (urban) ¹	l/c/d	25
Communal standpipes (rural) ²	l/c/d	25
Low income (urban)	l/c/d	55
Middle income (urban)	l/c/d	80
High income (urban)	l/c/d	130
Low income (rural)	l/c/d	40
Middle income (rural)	l/c/d	60
High income (rural)	l/c/d	80
Day scholars	l/c/d	15
School hostels	l/c/d	100
Clinics: staff and patients	l/patient/d	30
Hospital: patients and staff	l/bed/d	500
Institutional and commercial	l/m ² /d	5

1: Service community within walking distance of 250 m.

2: Service community within walking distance of 250 m to 2.5 km

Table 2.2 depicts the livestock demand norms. MAWF (2014) stated that these demand rates apply to extensive farming conditions and not for intensive farming purposes.

Table 2.2: Livestock demand norms (MAWF, 2014)

Category	Unit	Rate of consumption
Large stock units (including cattle, donkeys and horses)	1/LSU/d	45
Small stock units (including goats and sheep)	1/SSU/d	12

The average rate of daily demand per person varies (from one region to another) and can be analysed based on the factors discussed. Sustainable social and economic growth in ecologically vulnerable, arid areas like Namibia largely depends on water accessibility and sustainable use of water resources. However, due to climate change and human activity, there is a decrease in water supply. In this context, it is crucial to analyse water demand locally. This analysis can assist the government and stakeholders in making informed decisions regarding water supply and demand.

2.4. Variations of water demand

The average rate of daily demand per capita is not constant; it varies due to factors such as climatic conditions, people's habits, income levels, and culture (Abu-Bakar *et al.*, 2023; Alshaikhli *et al.*, 2021; Huang *et al.*, 2017; Lomet *et al.*, 2015). The demand fluctuates from season to season, month to month, day to day, and even from hour to hour (Archer *et al.*, 2018; Basak, 2007; Ibrahim *et al.*, 2021). As a result, per capita water use differs from one region to another. In an area with a high population of seasonal residents, the

per capita rate can vary significantly depending on whether seasonal residents are present (Eino *et al.*, 2024; Gokarna & Aryal, 2020; Ismael & Aziz, 2024). The time of day is also a crucial factor (Blokker *et al.*, 2008, 2010). For example, commuters can impact the per capita rates by consuming more water in the city they commute to during work hours while using less water in their residential area. This fluctuation in demand is also known as variation of demand (Ibrahim *et al.*, 2021).

The concept of per capita water use is often used to compare water consumption over time or among different groups of people (such as cities, counties, etc.) that utilize public water supplies (Blokker *et al.*, 2010; MAWF, 2014). It typically refers to the average amount of water each person in a specific area uses daily, expressed as liters per capita per day (Mays, 2011; Sipes, 2010; Tamason *et al.*, 2016). Water managers utilize per capita measurements for various purposes, such as assessing water demand and identifying usage patterns, setting goals and establishing usage thresholds for permitting, evaluating the effectiveness of conservation programs, and communicating with the public (Alshaikhli *et al.*, 2021; Anang *et al.*, 2019; He *et al.*, 2023; Huang *et al.*, 2017).

To calculate per capita demand, the total annual water consumption is divided by the total population and the number of days in a year (Basak, 2007). The mathematical expression for per capita demand is given by Equation (2.2).

$$\text{Per capita demand} = \frac{\text{Yearly water consumption (in liters)}}{\text{Population} \times 365} \quad (2.2)$$

2.4.1. Climate change

The change in weather patterns affects precipitation, temperature, and evaporation rates. Their variations are estimated using mathematical models. According to Han (2010), the evaporation rate (E_r) is calculated using the energy balance method given by Equation 2.3.

$$E_r = \frac{1}{l_v \rho_w} (R_n - H_s - G) \quad (2.3)$$

Where: E_r is evaporation rate (m/s), H_s is sensible heat flux (in W/m^2 , to change liquid water temperature), G is the ground heat flux (in W/m^2 , to change underlying soil temperature), R_n is the net radiation flux (W/m^2), ρ_w is water specific density (kg/m^3), l_v is the latent heat of vapourization (J/kg), calculated using Equation 2.4

$$l_v = 2.5 \times 10^6 - 2370T \quad (2.4)$$

Where T is temperature in $^{\circ}C$.

Precipitation is properly estimated using the Thiessen Polygon method especially when rain gauges are present in the catchment area (Han, 2010). This widely used method can be plotted by hand or using computer software. The Thiessen Polygon method assumes that the rainfall at any point in a catchment is the same as that at the nearest rain gauge. The depth recorded at a given gauge is then applied to a distance halfway to the next gauge in any direction (Equation 2.5).

$$\bar{R} = \frac{1}{A} \sum_{i=1}^n A_i R_i \quad (2.5)$$

Where; A is the total catchment area, A_i is the catchment area to each gauge and R_i rainfall recorded at the individual gauge.

2.4.2. Demographic and socio-economic variables

The household demographic and socio-economic variables vary from place to place and time to time. Findings from various case studies pertaining to these factors were presented previously in section 2.3. Researchers gather statistical data (such as residents' age, gender, water use and users) from field surveys (Blokker *et al.*, 2010; Tamason *et al.*, 2016). The collected data are strategically analysed using models to provide intuitive visualizations that identify relationships between variables and make predictions (Kumar, 2006). Descriptive statistics and statistical analysis were performed and these are discussed in the following sections.

2.4.2.1. Descriptive statistics

Descriptive statistical analysis involves the use of numerical descriptions to synopsis data in a systematic way. In this study, descriptive statistics such as frequency, percentage, mean, median, and standard deviation are discussed and presented mathematically in this subsection.

i. Frequency

According to Mishra *et al* (2019), frequency statistics involves counting the number of times each variable occurs, like the number of males and females in a sample or population. It is an important area of statistics that deals with the number of occurrences (frequency) and percentage.

ii. Mean

The mean also known as the average is the value of a set of data computed by summing up all the observations and then dividing by the number of observations (Kumar, 2006).

The mean is a popular measure and is easy to calculate. It provides a single value for a group, making it useful for comparing different groups. However, the value of the mean can be easily affected by outliers (Mishra *et al.*, 2019). This is expressed mathematically by Equation 2.6.

$$\bar{x} = \frac{\sum x}{n} \quad (2.6)$$

Where: \bar{x} is the mean, $\sum x$ is the summation of all the observation data and n is the total number of data points.

iii. Median

The median is the middlemost value in an ordered data set and is also known as the positional average. It represents the value that occupies the central position in the data distribution, making it useful for group comparisons. Unlike the mean, the median is not affected by outliers (Mishra *et al.*, 2019).

iv. Standard deviation

The standard deviation (SD) is a measure of how spread-out values are from its mean value and its symbol is σ (sigma). It is called SD because a standard value (mean) is taken to measure the dispersion. The SD is computed using Equation 2.7.

$$\sigma = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n}} \quad (2.7)$$

Where: x_i is individual observation, \bar{x} is the mean value. If the sample size is (less than) <30 'n-1' is used as the denominator, while for sample size (greater than) ≥ 30 'n' is used as the denominator.

2.5. Design period and Population forecast

The future time frame for which a provision is made in the water supply scheme is known as the design period. Fundamentally, the scheme is designed to operate efficiently for at least 30 years (Basak, 2007). The design period is estimated based on the following factors: the useful life of the component like obsolescence, wear and tear; expandability of the system; anticipated growth rate of the population, including industrial and commercial developments as well as migration patterns; availability of resources; and performance of the system during the initial period (MAWF, 2014). These factors help ensure that the water supply scheme can meet future demands effectively.

The amount of water provided is primarily based on the size of the population. If the population is lower, less water is supplied, whereas if the population is higher, more water is supplied. This allocation guarantees that every person receives water according to their needs and minimizes water wastage. Since the population is constantly changing, it can be challenging to determine the exact number, so population forecasts are utilized (Basak, 2007).

Different methods are available for predicting probable future populations (Gokarna & Aryal, 2020; Ismael & Aziz, 2024). The selection of a particular methodology for a given area relies heavily on the factors that are considered within such approaches. The decision ultimately rests on the designer's discretion and acumen (Eino *et al.*, 2024). While none

of these methods are entirely precise and are all founded on probability laws, they can provide only approximate projections for future populations (Basak, 2007; Rangaiah *et al.*, 2021). The Arithmetical Increase Method, Geometrical Increase Method, Incremental Increase Method, and Decreasing Rate of Growth Method are considered in this study and are explained in detail as follows.

2.5.1. Arithmetical Increase Method

In this method, it is assumed that the population increases at a constant rate. The average population increase is calculated based on the records from past decades. This average is then added to the present population and the population of successive decades to obtain the projected population. The population predicted by this method is the lowest among all forecasting methods. The forecasted population (P_n) after 'n' decades from the last known census can be calculated using the following Equation. 2.8:

$$P_n = P_0 + n\bar{x} \quad (2.8)$$

Where: P_0 is the population at the last known census, \bar{x} is the arithmetic mean of population increase in the known decades, and n is the number of decades between the last census and the future.

2.5.2. Geometrical Increase Method

In this method, it is assumed that the percentage increase in population remains constant. The percentage increase is calculated from available census records. Subsequently, the population of future decades is estimated using this percentage increase. This method yields the highest predicted population of all. The forecasted population (P_n) after 'n' decades is given by Equation 2.9:

$$P_n = P_0 \left(1 + \frac{r}{100}\right)^n \quad (2.9)$$

Where: P_0 is the population at the last known census, r is the probable rate of population increase per year (%).

2.5.3. Incremental Increase Method

In this method, the average population increase is calculated using the arithmetic increase method. Then, the average incremental increase is calculated. Finally, both averages are combined to project the population in future decades. The population predicted by this method falls between the predictions of the arithmetic increase method and the geometrical increase method. The population after "n" decades from the last known census is given by Equation 2.10.

$$P_n = P_0 + l_a + nl_c \quad (2.10)$$

Where: P_0 is the population at the last known census, l_a is the average Arithmetical increase, l_c is the average Incremental increase.

2.5.4. Decreasing Rate of Growth Method

The growth of life is limited and at times, growth starts fast and then slows down at a decreasing rate. To calculate this, the average decrease in percentage increase is determined and subtracted from the percentage increase of each following decade. The population of the successive decades is then computed accordingly. This method yielded suitable results in various studies compared to other methods and was considered to predict future populations (Eino *et al.*, 2024; Rangaiah *et al.*, 2021).

2.6. Water Demand Projections

Water demand projections are used for various purposes such as optimising water infrastructural systems, planning for future scheme expansion, and setting water tariffs or revenue estimations (Eino *et al.*, 2024; Huang *et al.*, 2017; Myllis *et al.*, 2024; Rangaiah *et al.*, 2021; Stańczyk *et al.*, 2022). The estimation of future water demand is very complex and intense. Various mathematical models are, however, utilised for predicting future water demand. These include extrapolating historical trends, using simulation modeling, or correlating demand with socio-economic factors (Alshaikhli *et al.*, 2021; García-Soto *et al.*, 2024; Lomet *et al.*, 2015; Wang *et al.*, 2018).

The methods differ in complexity based on the number of criteria considered and how extensively water users are broken down by sectors, geographical location, season, or other variables (MAWF, 2014). This section provides an overview of the different approaches and methodologies used in projecting water demand.

Table 2.3 presents a comparative analysis of water estimation methods, along with their frequency of application, as derived from the selected reviewed literature.

2.6.1. Regression Analysis

Regression analysis is the most widely employed method for predicting water usage. The selection of independent variables in the regression model is informed by available data on various factors that influence water consumption and their relative significance in either increasing or decreasing usage (Uyanık & Güler, 2013). Various models such as linear, logistic, and polynomial regression are utilised based on the relationship. If there is more than one independent variable, the model is termed a multivariate model. Linear and nonlinear regression were used in Huang *et al.* (2017) to quantify the impact of factors

and develop a water consumption estimation model. Numerous studies (Alshaikhli *et al.*, 2021; Shine *et al.*, 2018; Stańczyk *et al.*, 2022) have applied multiple linear regression models to predict water consumption. While this method is favored for its simplicity and performance (Uyanık & Güler, 2013), it often falls short in providing long-term projections and can result in an overestimation of future water demand (Ghannam & Hussain, 2024; MAWF, 2014).

2.6.2. Statistical models

The statistical model is an effective method for improving the accuracy of water use projections by categorizing water use into distinct sectors, regions, or seasons and applying the most suitable model for each category (MAWF, 2014). Lomet *et al.* (2015) utilised the statistical model to forecast domestic water consumption, while Rangaiah *et al.* (2021) conducted a water demand analysis across various sectors, including agriculture, domestic, commercial, industrial, and public water use, based on models relevant to each category. MAWF (2014) also used a statistical model to estimate water demand in both urban and rural areas. As in Wang *et al.* (2018), the statistical model effectively assessed changes in domestic water demand due to environmental factors. Recently, Eino *et al.* (2024) used a similar method to analyse water demand for the rural population. This approach is advantageous as it allows for the incorporation of specific explanatory variables tailored to each type of water use, leading to more precise overall projections (Helsel *et al.*, 2002)

2.6.3. Time Series Analysis

Time series analysis involves examining the internal structure of the data in order to develop a model. This structure may account for auto-correlation, trend, or seasonal

variation. Time series models are constructed from auto-regressive and moving average values. The model consists of two main components: the auto-regressive (AR) component, which reflects past values of the time series, and the moving average (MA) component, which represents past errors (Lee *et al.*, 2022). The error value is beneficial because the model updates itself using knowledge gained from recent samples (Vijai & Bagavathi, 2018).

ARMA model is beneficial as it does not necessitate strong priors and requires minimal computational time. Its variations are employed in diverse forecasting applications, including water consumption (Lomet *et al.*, 2015; Salimaco, 2023), underwater reserves (Myllis *et al.*, 2024), drought analysis, and the assessment of seasonal trends (Ristow *et al.*, 2021). Myllis *et al.* (2024) integrated deep learning techniques with traditional statistical models to extract and analyse water level trends, resulting in more precise predictions of future water demand. More so, Ristow *et al.* (2021) found the model to be particularly effective for forecasting water consumption, with mean absolute percentage errors ranging from 1.19 to 15.74 %.

2.6.4. Artificial Neural Network (ANN)

In developed countries, there has been a growing use of Artificial Neural Network (ANN) models in various studies related to smart city implementations. The main reason for the widespread use of ANN is their ability to handle data aspects like nonlinearities, discontinuities, and polynomial components (Ghannam & Hussain, 2024). ANN are self-adaptive models that can understand the nonlinear behavior of real-time data without making any statistical assumptions as done in time series analysis (De Souza *et al.*, 2019).

ANN was adopted in Huang *et al.* (2017) to develop an estimation model for water consumption. Vijai & Bagavathi (2018) compared the performance between the time series, statistical model, and ANN model to forecast water demand, with the ANN model demonstrating strong results in all short-term predictions. Likewise, deep neural networks were employed to forecast water consumption in urban areas, yielding accurate results (García-Soto *et al.*, 2024). However, despite their widespread use, ANN faces limitations when learning from highly noisy data (De Souza *et al.*, 2019).

Table 2.3: Comparison of water estimation methods.

Estimation methods	Frequency of use (%)	Comparison
Regression Analysis	27	<ul style="list-style-type: none"> • Easy to use. • Best for linear relationship,
Statistical Model	33	<ul style="list-style-type: none"> • User-friendly. • Best for testing hypotheses. • Ideal for data distribution.
Time Series	27	<ul style="list-style-type: none"> • Complex to use. • Temporal forecasting
Artificial Neural Networks	13	<ul style="list-style-type: none"> • Difficult to use. • Ideal for non-linear relationships.

The projections for water use may involve using one or more of the discussed methods, depending on the available data and the most suitable model for the specific application. It is important to remember that the accuracy of the projections depends on the quality of the data and the precision of future population and economic growth scenarios. In a developing country like Namibia, where economic and demographic factors change

significantly in the short term, accurately predicting long-term water demand can be very challenging.

The review reveals that the statistical model fits the conditions in rural southern Africa as it is easy to use and allows the use of explanatory variables in a given type of water use making predictions accurate. The research findings from the reviewed studies are summarised in

Table 2.4.

Table 2.4: Methods for forecasting water demand based on the reviewed literature.

Serial No	Title	Author & Year	Methodology	Findings
1	A multi-linear regression model to predict the factors affecting water consumption in Qatar	Alshaikhli <i>et al.</i> (2021)	A multi-linear regression model	The model predicts that water consumption per capita increases with the increase in temperature and decreases with the increase in population.
2	Linear prediction modelling of electricity & on-farm direct water consumption on pasture based dairy farms.	Shine <i>et al.</i> (2018)	Multiple linear regression modeling	Water consumption was accurately predicted with relative prediction error values of 49%.
3	Improving short-term water demand forecasting using evolutionary algorithms	Stańczyk <i>et al.</i> (2022)	Linear regression model	The method can be applied during data preprocessing to enhance short term water demand forecasting.
4	Factor Analysis and Estimation Model of Water Consumption of	Huang <i>et al.</i> (2017)	Linear and nonlinear regression	The established models can be used to evaluate methods for saving water.

Government Institutions in Taiwan.				
5	Domestic water demand forecasting in the Yellow River basin under the changing environment	Wang <i>et al.</i> (2018)	Statistical-based model	The model significantly evaluates the changes in domestic water demand due to environmental changes.
6	Water demand analysis for selected rural regions in Visakhapatnam district	Rangaiah <i>et al.</i> (2021)	Statistical model	The agricultural sector consumes the most water at 94% and the industrial sector is the least with 0.5%.
7	Influence of household demographic and socio-economic factors on water demand in Ngamiland District, Botswana	Motho <i>et al.</i> (2022)	Statistical model	Gender is highly associated with water demand. Household size mostly influences water demand.
8	Seasonal Variation of Rainy and Dry Season Per Capita Water Consumption in Freetown City Sierra Leone	Ibrahim <i>et al.</i> (2021)	Statistical model	High per capita water consumption in the rainy season than in the dry season. Water consumption increases with income.
9	An Analysis of Water Demand of the Rural Population within the Iishana System, Namibia	Eino <i>et al.</i> (2024)	Statistical model	The method estimated the domestic and livestock demand effectively.
10	Statistical modeling for real domestic water consumption.	Lomet <i>et al.</i> (2015)	Time series model	The model forecasted the real domestic water volume and the real data obtained show that the approach is very promising.

11	Forecasting the Water Consumption in the city of Mati with Time Series Analysis	Salimaco (2023)	Time Series Analysis	Autoregressive Integrated Moving Average (ARIMA) was found to be the best model and forecasted a 15.48 % rise in water consumption.
12	Short-Term Water Demand Forecasting from Univariate Time Series of Water Reservoir Stations.	Myllis <i>et al.</i> (2024)	Univariate Time Series	The method extracted and analysed water level trends, enabling more accurate predictions of future water demand.
13	Models for forecasting water demand using time series analysis: A case study in southern brazil.	Ristow <i>et al.</i> (2021)	Time Series Analysis	The results showed that the method is more adequate to predict water consumption, with errors between 1.19 to 15.74 %.
14	Factor analysis and estimation model of water consumption of government Institutions in Taiwan	Huang <i>et al.</i> (2021)	Artificial Neural Networks (ANNs)	The ANNs model presented a good fit to the actual data and both models could evaluate for water saving if complete data are available.
15	Water consumption time series forecasting in urban centers using deep neural networks.	García-Soto <i>et al.</i> (2024)	Deep Neural Networks	The method yielded accurate results.

2.7. Water Supply and Sanitation

Water supply and sanitation play a critical role in public health, economic development, and environmental sustainability. This section discusses water supply and sanitation in detail.

2.7.1. Water supply

Water supply involves sourcing, treating, and distributing water for various uses such as domestic, industrial, and agricultural. The following are the types of water sources to meet water supply and demand.

2.7.1.1. Surface Water

Surface water refers to any water that accumulates on the earth's surface, including rivers, streams, lakes, ponds, and reservoirs (Han, 2010; Sipes, 2010). It is replenished naturally by precipitation and lost through evaporation, groundwater recharge, evapotranspiration, and discharge to the oceans (Cech, 2009; Mays, 2011). The total quantity of water available in a specific catchment area is influenced by various factors, such as the runoff characteristics of the land in the watershed, storage capacity in lakes, streams, and artificial reservoirs, the timing of precipitation, and the permeability of the soil beneath these storage bodies (Genjebo *et al.*, 2023; Liuzzo *et al.*, 2016).

Various methods of water storage systems are used encompassing roof water harvesting, run-off harvesting, flood water harvesting, and subsurface water harvesting (Alem, 1999). The positive aspects that encourage the use of rainwater-harvesting systems include easy setup, low maintenance, and energy costs (Ghisi & Mengotti de Oliveira, 2007; Kingspan, 2024). These characteristics promote the adoption of rainwater-harvesting systems in rural and urban areas, especially in arid climates where water scarcity is a concern (Ghisi &

Ferreira, 2007; Gurung & Sharma, 2014; Z. Li *et al.*, 2010; López Zavala *et al.*, 2018). An advantage of effective rainwater harvesting is the reduction of pressure on public water supply systems, which are often not functional due to logistical and infrastructure issues (Adham *et al.*, 2016; Imteaz *et al.*, 2011, 2012; Judeh *et al.*, 2022; Khastagir & Jayasuriya, 2010; Liuzzo *et al.*, 2016).

Rainwater and runoff harvesting systems are widely used as alternatives in regions facing high water stress to help meet demand (Cook *et al.*, 2014; Imteaz *et al.*, 2012; Judeh *et al.*, 2022; López Zavala *et al.*, 2018). In 2009, CuveWaters have piloted rainwater harvesting facilities in the Cuvelai Basin, where rainwater is collected from rooftops and concrete surfaces. The harvested water is typically of good quality and is primarily intended for gardening, cooking, washing and livestock drinking.

More so, in recent years, the Namibian government constructed about 34 earth dams between 2008 and 2011, in the Cuvelai-Etosha Basin, whereby 5 are in Niipele, 7 in Olushandja and 22 are in the Iishana Basin. The dams were designed with dimensions of 50 m x 50 m and 3.7 m deep, with a total storage capacity of 314, 500 cubic meters intended to collect rainwater and runoff down the ephemeral stream (Zandler, 2011). On the other hand, surface water and flood harvesting infrastructures are susceptible to sedimentation during flood events, which fills the reservoirs and hinders water storage (Cech, 2009; Niipare, 2020; Sipes, 2010).

2.7.1.2. Groundwater

Groundwater is comprised of water from wells, springs, and aquifers, and serves as an important resource in semi-arid to arid areas for drinking and agricultural purposes (Döll *et al.*, 2014; Olivier & Xu, 2019; Vörösmarty *et al.*, 2010; Wada *et al.*, 2010). The annual

rainfall and floodwater help to replenish and recharge the underground water (Sipes, 2010). Groundwater quality studies have demonstrated that in many countries, it has noticeably deteriorated in recent years (Mehdi *et al.*, 2023; Oboh & Egun, 2017).

The degradation of groundwater quality is mainly categorized by the hydrogeochemical characteristics resulting from the multifaceted interactions of geology, hydrogeology, topography, drainage systems, hydrometeorology, and anthropogenic activities, which lead to groundwater deterioration (Rajesh *et al.*, 2019). In regions with ample groundwater, water quality suffers from high salinity (Mendelson *et al.*, 2000; Scanlon *et al.*, 2023), necessitating desalination. Meanwhile, a groundwater desalination plant has been established in rural northern Namibia, producing between 0.5 and 3.3 m³ of safe drinking water every day (Cuve Waters). Consequently, groundwater has been effectively utilized to prevent water supply crises (Arendt *et al.*, 2021; Olivier & Xu, 2019; Scanlon *et al.*, 2023).

2.7.2. Sanitation

Sanitation refers to the systems for safely disposing of human waste, maintaining hygiene, and preventing disease transmission (Pedro *et al.*, 2020; Zhou *et al.*, 2018). According to UNICEF (2023), 3.5 billion people lack access to safely managed sanitation services, worldwide. Approximately 8 % of the world's population practice open defecation. However, there have been some significant changes in the last three (3) decades as about 2.4 billion people gained access to improved toilets and pit latrines (World Bank Group, 2023).

Multiple studies indicate that stopping open defecation can save children's lives by decreasing disease transmission, stunting, and undernutrition (Abubakar, 2018; Ali & Stevens, 2009; Dery *et al.*, 2020). These factors are crucial for childhood cognitive development and future economic productivity. In the absence of proper sanitation facilities, girls are at a higher risk of dropping out of school or becoming vulnerable to attacks while seeking privacy (Lebu *et al.*, 2024; Ritchie *et al.*, 2024). To ensure safe water supply and sanitation, the water quality is assessed to determine the water parameters present and the source of pollutants (Kumar *et al.*, 2023; Zakir *et al.*, 2020).

In Namibia, especially in the rural area, it is important to provide access to clean toilets and safe waste disposal. Facilities such as flush toilets and pit latrines need to be located at ideal positions to protect both surface and groundwater. This can help to manage the available water sources and reduce the spread of waterborne diseases like cholera. The procedures to analyse water quality are discussed in the section below.

2.7.2.1. Water Quality

To ensure safe water supply and sanitation, the water quality is assessed to determine the water parameters present and the source of pollutants (WHO, 2011). According to Haingotseheno *et al.* (2020), the quality of water is assessed based on three broad types of monitoring data: physical, chemical, and biological, as well as its intended uses as given in Table 2.5. Variations in pollutant loads are influenced by shifts in climatic and weather conditions, as well as various anthropogenic activities. Thus, regular assessments of surface and groundwater are conducted as in (Bilgin & Konanç, 2016; Faulstich *et al.*, 2023; Isah, 2013; Khatoon *et al.*, 2013; Singh *et al.*, 2023), to identify any contamination arising from rapid socio-economic growth.

Table 2.5: Types of water quality parameters and their definitions used in this study.
Source: (Omer, 2019; World Health Organization, 2011).

Parameters	Definitions
Physical	
Temperature	Temperature affects palatability, viscosity, solubility, odors, and chemical reactions, aiding in understanding the thermal characteristics of water bodies and their influence on aquatic life.
Electrical Conductivity	This is a measure of the ability of a solution to conduct electrical current, vital for determining water suitability for irrigation and firefighting.
Turbidity	It is the cloudiness of water that measures the ability of light to pass through water. It is caused by suspended materials such as clay, silt, organic matter, plankton, and other particulate materials in water.
Total Dissolved Solids	It contains inorganic salts such as calcium, potassium, sodium, magnesium, bicarbonates, sulfates, chlorides and small amounts of dissolved organic matter.
Color	This is the perspective of the entire color of the water sample, encompassing both dissolved and suspended components.
Taste and Odour	Taste and odour in water may result from natural, household, and agricultural contaminants.
Chemical	
pH	It is not a health concern for consumers and is an important parameter for water quality operations.
Dissolved Oxygen	It is a critical test for water pollution. The higher the level of dissolved oxygen, the better the water quality.
Alkalinity Total	The alkalinity of water refers to its capacity to neutralize acids, which is important for determining the amount of lime and soda required for water softening.

Chloride	Chloride in drinking water comes from natural sources, industrial effluents, sewage, urban runoff with de-icing salt, and saline intrusion.
Ammonium	Ammonium originates from metabolic, agricultural and industrial processes and disinfection with chloramine.
Nitrate	This is a naturally occurring ion that can reach the surface water and groundwater from agricultural activity, wastewater disposal and oxidation of nitrogenous waste products in human and other animal excreta, including septic tanks.
Nitrite	It can be formed through microbial reduction of nitrate and in vivo by reduction from ingested nitrate.
Sulphate	Sulphates occur naturally in numerous minerals and are used commercially, primarily in the chemical industry.
Calcium	Calcium ions are the primary cause of water hardness, entering water mainly through contact with soil and rock, particularly limestone deposits.
Iron	Iron is one of the most abundant metals in Earth's crust.
Magnesium	Magnesium ions are a major cause of water hardness, entering water mainly from soil and rock, particularly limestone deposits.
Potassium	Potassium is widely present in the environment, including all natural bodies of water.
Sodium	These are dissolved ions in water which increases both the salinity and conductivity.
Biological	
Total Coliforms	These bacteria are typically found in water that has been contaminated by human or animal waste.
Faecal Coliforms	These are a subgroup of total coliforms for instance Escherichia coli found specifically in the gut and faeces of warm-blooded animals.

Water quality standards serve as the basis for protecting the quality of water. In the United States of America (USA), each state assesses water quality according to the standards set in compliance with the Clean Water Act. While water quality standards may vary from state to state, they all must meet minimum requirements (Mays, 2011). This monitoring process helps in identifying problems and enables quick responses to emergencies such as spills and floods. Additionally, it assists in targeting specific pollution prevention or remediation programs to address these problems.

Table 2.6 shows the ideal and acceptable standards for surface water in Namibian. This monitoring process helps in identifying problems and enables quick responses to emergencies such as spills and floods. More so, it assists in targeting specific pollution prevention or remediation programs to address these problems (Sipes, 2010).

Table 2.6: Surface water quality standard. (MAWLR, 2023).

Parameter	Abbreviations	Units	Ideal	Acceptable
Electrical Conductivity	EC	$\mu\text{S}/\text{cm}$	80	300
Turbidity	NTU	mg/l	0.3	5
pH	pH	pH units	6-8.5	6-9
Dissolved Oxygen	DO	mg/l	5	10
Hardness total	CaCO_3	mg/l	200	400
Alkalinity Total	CaCO_3	mg/l	-	-
Chloride	Cl^-	mg/l	100	300
Ammonium	NH_4	mg/l	0.2	0.5
Nitrate	NO_3^-	mg/l	6	11
Nitrite	NO_2^-	mg/l	0.1	0.15
Sulphate	SO_4^{2-}	mg/l	100	300
Calcium	Ca^{2+}	mg/l	80	150

Iron	Fe ⁺	mg/l	200	300
Magnesium	Mg ²⁺	mg/l	30	70
Potassium	K ⁺	mg/l	25	100
Sodium	Na ⁺	mg/l	100	300
Total Coliforms	TC	cfu/100ml	0	5
Faecal Coliforms	FC	cfu/100ml	0	1

2.7.2.2. Water Quality Index (WQI)

For the purpose of clarity, it is important to note that the term water quality index (WQI) is sometimes used as a general term to describe all indices developed to address water quality (Bharti N & KatyalD, 2011; Ejoh *et al.*, 2018; Guenouche *et al.*, 2024; Oboh & Egun, 2017; Singh *et al.*, 2023). However, for this study, it exclusively refers to the WQI presented in (Ithindi *et al.*, 2018). The said WQI was formulated following the WHO and Indian Standard (BIS 10500, 1991) and proposed 12 parameters including TDS, HCO₃, Cl, SO₄, PO₄, NO₃, F, Ca, Mg, Na, K, and Si (Ahmed *et al.*, 2022). The weight (w_i) is assigned with values between 1-5 according to its relative importance in the overall quality of water for drinking purposes. The mathematical expression for it is presented in Equation 2.11. Five water quality classes was proposed as presented in Table 2.7.

$$WQI = \sum SI_i = \sum (w_i \times q_i) = \sum \left[\left(\frac{w_i}{\sum_{i=1}^n w_i} \right) \times \left(\frac{C_i}{S_i} \times 100 \right) \right] \quad (2.11)$$

Where: C_i is the concentrations of each parameter, S_i is the guideline limit value for each parameter, w_i is the assigned weight according to its relative importance in the overall quality of water for drinking purposes, SI_i is the sub-index of i th parameter, q_i is the rating based on the concentration of i th parameter and n is the number of parameters.

Table 2.7: WQI classification value adopted from (Ahmed *et al.*, 2022).

WQI values	Grading
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very poor
>100	Unsuitable for drinking

2.7.2.3. Multivariate Statistical Analysis

Multivariate statistical methods are utilised for the analysis and interpretation of large datasets as well as the assessment of water quality and management of surface and underground water (Kothari *et al.*, 2021). Multivariate techniques such as correlation matrix (CM), cluster analysis (CA), and factor analysis (FA) are used in numerous studies (Bilgin & Konanç, 2016; Guenouche *et al.*, 2024; Isah, 2013; Mehdi *et al.*, 2023; Rajesh *et al.*, 2019; Semar *et al.*, 2013; Sharma *et al.*, 2021; Shukla, 2023; Singh *et al.*, 2023). These methods are discussed in this subsection.

i. Correlation Matrix

Correlation analysis is a preliminary descriptive technique used to estimate the degree of association among multiple variables involved in the study (Kothari *et al.*, 2021). A correlation matrix can be computed to show the degree of linear association between any two parameters, measured by the correlation coefficient (R). The R-value helps identify highly correlated and interrelated water quality parameters that may affect the water quality of an area. The value of R ranges from -1 to +1; an R-value of +1 or close to it indicates a strong positive linear correlation between two parameters, while an R-value of

-1 or close to it indicates a strong negative linear correlation. Thus, the matrix helps evaluate which parameters significantly affect an area's water quality level (Rajesh *et al.*, 2019).

ii. Cluster Analysis

Cluster analysis is a commonly used multivariate statistical method for classifying grouped data based on their similarities (Sharma *et al.*, 2021). There are two primary methods for performing clustering: hierarchical clustering and nonhierarchical clustering. The most widely used approach is hierarchical clustering, which measures the distance between samples as a similarity measure. Hierarchical agglomerative clustering analysis employs various similarity measures, including full connection, average connection (between and within groups), and data normalized with Ward's methods, using Euclidean distances. The dendrogram provides a visual summary of the groups and their proximity (Mehdi *et al.*, 2023).

iii. Factor Analysis

Factor analysis is a key statistical method for interpreting hydrological data. It helps to identify the fundamental independent dimensions of variables (Sharma *et al.*, 2021). Generally, the factor is associated with the largest eigenvalue and explains the most variance in the dataset. An eigenvalue greater than 1 is considered significant. Factor loadings are rated as strong, moderate, or weak based on their total values of > 0.75 , 0.50 – 0.750 , and 0.30 – 0.50 , respectively (Rajesh *et al.*, 2019).

2.7.2.4. Piper diagram

The Piper diagram illustrates the chemical composition of water from various water sources. It displays the relationship between major cations and anions in a triangular diagram representing the water bodies. The position of the different combinations of elements indicates the relative composition of the water body (Mehdi *et al.*, 2023).

The analysis of a Piper diagram involves converting the concentrations of measured parameters from milligrams per liter (mg/L) to milliequivalents per liter (meq/L) using Equation 2.12. Following this conversion, the relative concentrations are calculated by dividing the milliequivalents per liter by the total concentrations of cations and anions (in meq/L), respectively. This process is essential for accurately creating the Piper diagram in software such as R Studio, Grapher, and others (Semar *et al.*, 2013).

$$\frac{meq}{L} = \frac{Concentration \left(\frac{mg}{L}\right) \times Valence}{molecular\ weight} \quad (2.12)$$

2.8. Summary

Analysing water demand is a complex task due to the ever-changing conditions that affect it. There is currently no consensus among researchers regarding the best methods for predicting water demand, as each approach is influenced by unique anomalies. The review highlighted that statistical models are particularly well-suited for the conditions prevalent in rural southern Africa. These models are not only user-friendly but also allow for the integration of explanatory variables that account for various types of water usage, thereby enhancing the accuracy of predictions. Following the establishment of such a model, an

estimation of supply potential can be derived, providing valuable insights for water resource planning and management.

Numerous researchers emphasise the importance of continuous water quality testing to monitor changes in pollution levels. In Namibia, water resources are particularly under pressure due to climate change, population growth, and agricultural activities. Seasonal variations exacerbate the issue, impacting water quality and underscoring the need to monitor pollution parameters over time. Understanding these parameters within a specific water body is crucial for accurately estimating water treatment costs.

In studying water demand, it is fundamentally crucial to first assess how households allocate water among various uses. Next, an assessment of local water supply conditions for households should be conducted to inform decisions made by policymakers and relevant stakeholders. Lastly, performing water quality tests will help identify the costs associated with water treatment. Together, these steps will effectively address water demand and supply challenges for sustainable infrastructure planning and maintenance.

Table 2.8 provides a summary of the selected articles that were critically analysed and helped gather knowledge on the research topic. The reviewed literature identified key indicators influencing the water demand and quality nexus, including infrastructure gaps, competing water uses, climate variability, and pollution. To address these challenges, the studies highlighted several management strategies, such as integrated water resources management, quality protection and treatment, monitoring and data-driven solutions, policy, and governance framework. The findings underscore that balancing water demand and quality necessitates multi-sectoral coordination to develop sustainable solutions that simultaneously mitigate scarcity and pollution risks.

Table 2.8: Summary of critically reviewed articles.

Serial No	Title	Author & Year	Methodology	Findings	Gaps
1	Measuring domestic water use: a systematic review of methodologies that measure unmetered water use in low-income settings	Tamason <i>et al.</i> (2016)	Questionnaires Observations	Water use in the selected studies was found to range from two to 113 l per capita per day.	To define all components that make up water use and determine how they will be measured. Day-to-day and seasonal variations need to be included.
2	A multi-linear regression model to predict the factors affecting water consumption in Qatar	Alshaikhli <i>et al.</i> (2021)	A multi-linear regression model	The model predicts that water consumption per capita increases with the increase in temperature and decreases with the increase in population.	The analysis was significantly impacted by the lack of data on the transient population and the duration of residence. Therefore, measuring the transient population is essential, as this factor has a greater environmental impact on water consumption.
3	Factor analysis and estimation model of water consumption of government Institutions in Taiwan	Huang <i>et al.</i> (2021)	Regression model and Artificial Neural Networks (ANNs)	The ANNs model presented a good fit to the actual data and both models could evaluate for water saving if complete data are available.	The established models would allow for the estimation of water consumption, which can then be used to determine whether the water usage of government institutions is considered reasonable.
4	Domestic water demand forecasting in the Yellow River basin under changing environment	Wang <i>et al.</i> (2018)	Statistical-based model	The model significantly evaluates the changes in domestic water demand due to environmental changes.	This study focused solely on average temperature to assess the impacts of climate change on domestic water demand. However, incorporating additional climatic variables, such as maximum and minimum temperatures and humidity, could enhance the accuracy of the model.

5	Water demand analysis for selected rural regions in Visakhapatnam district	Rangaiah <i>et al.</i> (2021)	Statistical model	The agricultural sector consumes the most water at 94% and the industrial sector is the least with 0.5%.	A multipurpose project utilizes water for various needs. The water stored in the reservoir should be used collaboratively for these purposes, ensuring proper coordination and compatibility.
6	Simulating residential water demand with a stochastic end-use model	Blokker <i>et al.</i> (2010)	Stochastic end-use model	The model shows a high peak demand in the morning, low water consumption in the afternoon, and a rise in water consumption in the evening.	Validation of the model is suggested for non-residential buildings.
7	Influence of household demographic and socio-economic factors on water demand in Ngamiland District, Botswana	Motho <i>et al.</i> (2022)	Questionnaire survey. Statistical model	Gender is highly associated with water demand. Household size mostly influences water demand.	The socio-economic factors are analysed to significantly influence water use and demand; therefore, it is recommended that policymakers implement effective demand management strategies.
8	Seasonal Variation of Rainy and Dry Season Per Capita Water Consumption in Freetown City Sierra Leone	Ibrahim <i>et al.</i> (2021)	questionnaire survey. Statistical model	High per capita water consumption in the rainy season than in the dry season. Water consumption increases with income.	Water pricing is found as an ineffective strategy for regulating per capita water consumption. This has highlighted the need for a policy to install more water supply points at shorter distances to help reduce the long distance people travel and minimise queuing times.

9	Methods for Assessing the Groundwater Quality	Rajesh <i>et al.</i> (2019)	Multivariate Statistical Analysis	TDS, Ca, TH, SO ₄ and Cl dominates groundwater. Groundwater is mainly influenced by natural geological sources rather than anthropogenic sources.	The water samples were collected in January, making it essential to test them consistently throughout the year.
10	Multivariate Statistical Analysis of Groundwater Quality of Hassi R'mel, Algeria	Mehdi <i>et al.</i> (2023)	Multivariate Statistical Analysis	Hard and soft water was observed. Multivariate statistical analysis has yielded very satisfactory results, as it explains 66.35% of the data used.	The frequency monitoring of these boreholes is essential to track mineral levels, especially in those with hard water, as high concentrations of Ca ²⁺ and Mg ²⁺ could lead to kidney stones.
11	Utilization of Water Quality Index (WQI) in Water Quality Assessment of Groundwater in Agbor Metropolis, Delta State Nigeria	Oboh & Egun, (2017)	Weighted arithmetic index method	Indicates the overall quality of water at a specific location and time, based on multiple parameters.	It is recommended to continuously monitor groundwater and the types of pollutants discharged into the aquifer, particularly in areas designated for aquifer recharge, in order to maintain water quality.

CHAPTER 3. RESEARCH METHODS

This chapter discusses the study area, research design, research instrument and procedures undertaken. It also presents the data analysis presentation tools, reliability and validity and research ethics.

3.1. Study area

The study area shown in Figure 3.1 is located within southern Angola and north-central parts of Namibia. It has a coverage surface area of 18,370 km^2 (47.4 % in Angola and 52.6 % in Namibia). The rural area covers 9,516 km^2 and has a total current rural population of 61,969 within Namibia. The region is complex, where water availability depends on annual rainfall, temperature, and recurrent flooding, which replenishes the shallow ephemeral river streams, locally known as Iishana (plural) or Oshana (singular), and recharge groundwater (Kluge *et al.*, 2008; Wanke *et al.*, 2018).

The Iishana system landscape is mainly arid, with a high evaporation rate of approximately 2500-3000 mm/year (Eino *et al.*, 2024; Koeniger *et al.*, 2021). The wet season runs for about six (6) months between November to April, meanwhile, the dry season lasts from May to October. High interannual precipitation variability leads to a more intense occurrence of floods and drought events in the system (Ketai Mabande, 2011; Shaamhula *et al.*, 2021). The arid climate and little precipitation, have put the region at risk in terms of water and food security (Drees *et al.*, 2017).

The geology of the area consists mainly of loosely packed to partially compacted sand and gravel with calcrete (Mendelson *et al.*, 2000). The main soil type in the region is Arenosols, with other soil types including Cambisols, Calcisols, Leptosols, Gypsisols,

Ferrasols, Vertisols, and Acrisols are also present (Mendelsohn & Weber, 2011). As for freshwater, the inhabitants depend mainly on treated water, groundwater, and traditional water sources such as wells, surface water, and rainfall for domestic consumption (Dragnich *et al.*, 2007; Niipare, 2020). Thousands of people live in the Iishana system, where their survival depends highly on rain-fed agriculture and livestock farming (Arendt *et al.*, 2021; Mendelsohn & Weber, 2011).

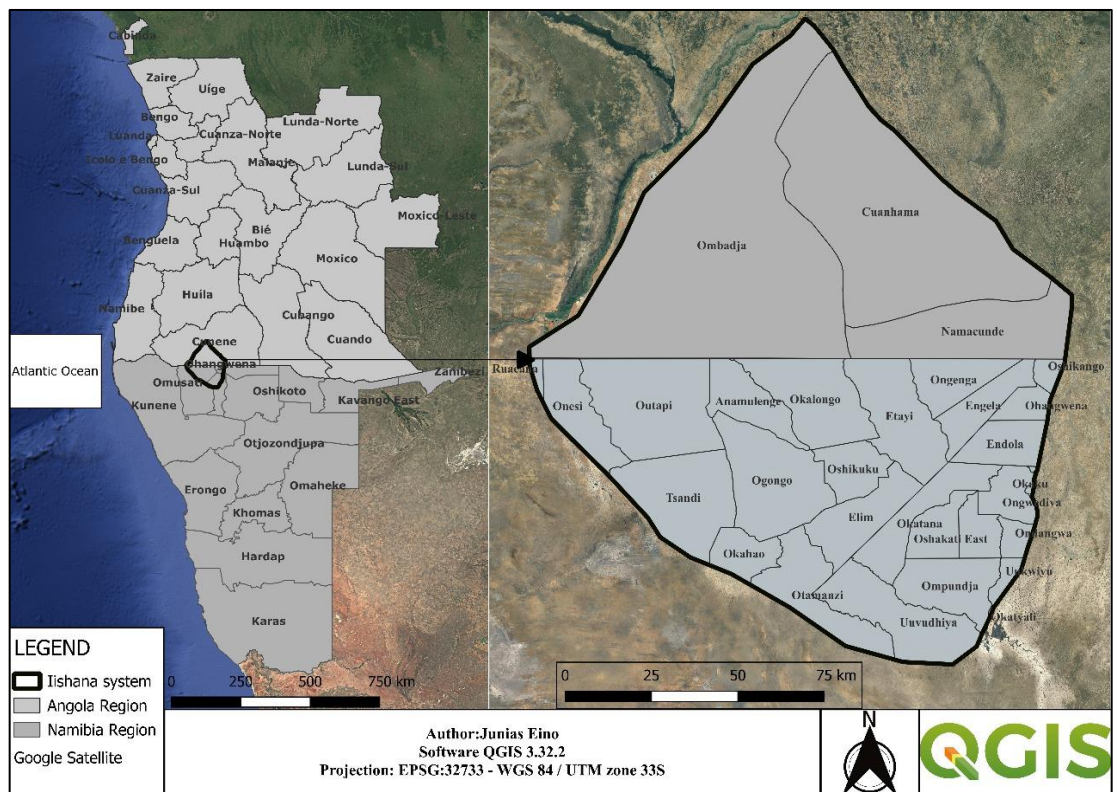


Figure 3.1: The study area of the Iishana system.

3.2. Research Design

This study adopted the mixed-method research design. According to Garbarino *et al.* (2009), the hybrid-method approach combines qualitative and quantitative methods to gain a better understanding of the research problem. The quantitative approach involves gathering close-ended data that was analysed statistically, while the qualitative approach entails the collection of open-ended data that focuses on realities that are interpreted by the researcher (Garbarino *et al.*, 2009; Kumar, 2006; Meissner *et al.*, 2011).

In this study, quantitative data were collected using a structured survey questionnaire to draw links between the household's daily water demand and demographic (age, gender, etc.) and socio-economic (education, career/job type, income level and household size) variables. Qualitative data were collected through physical interaction to explore people's perceptions about household water use practices.

A structured approach was adopted to achieve the primary objective of the study. First, the water demand was estimated to establish a baseline understanding of current and projected needs. This was followed by an analysis of variations in water demand to identify temporal fluctuations and their implications for water resource management. Subsequently, the study explored the mechanisms employed to address water scarcity and mitigate the impacts of drought. Finally, surface water quality tests were conducted on selected pans to evaluate their potential for augmenting water supply. The methodology flow chart is depicted in Figure 3.2.

Objective 1: To estimate the population available within the catchment area from 2023 to 2053 in order to accurately compute water demand.

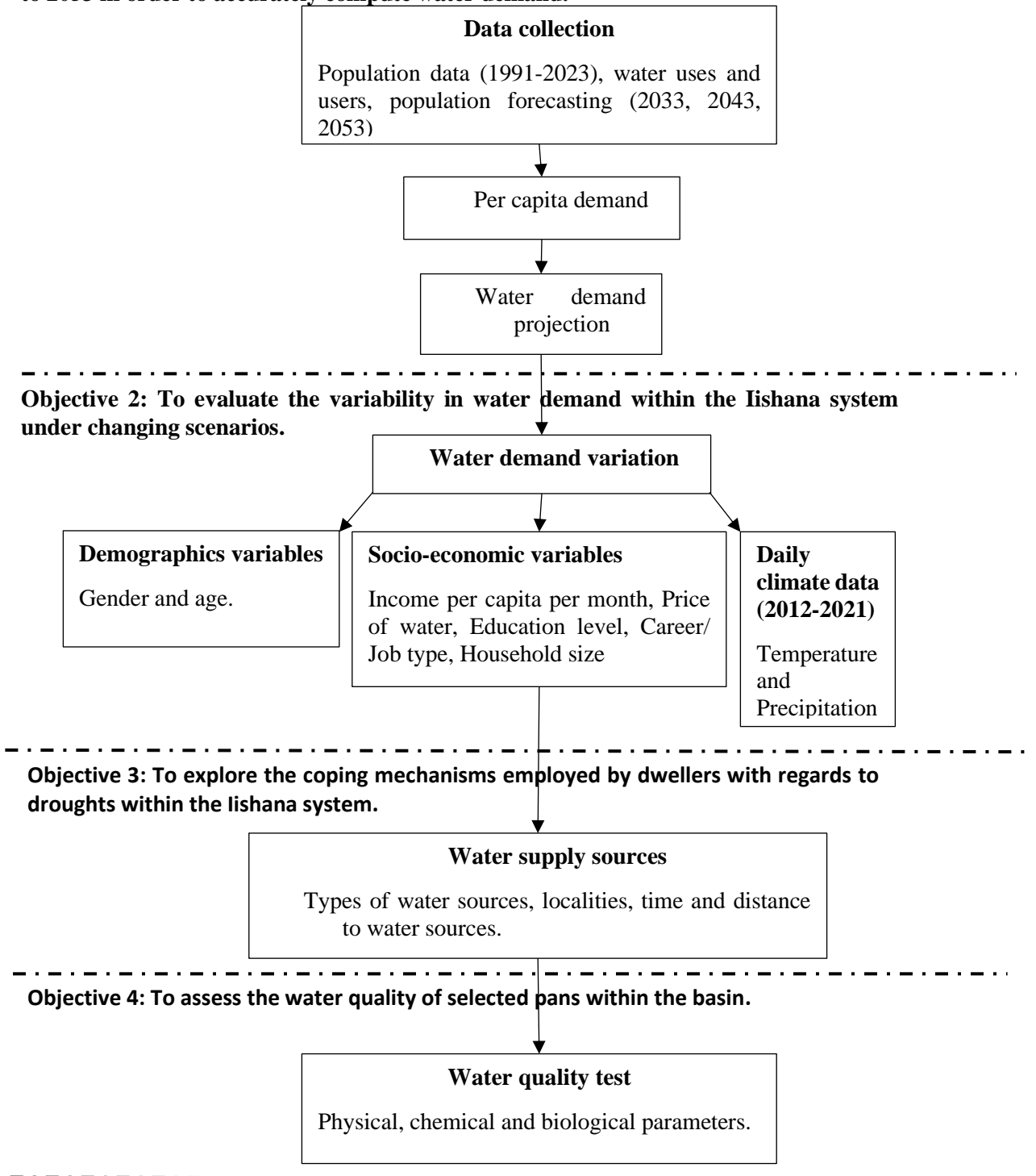


Figure 3.2: Methodology flow chart.

3.3. Sample size

The sample size is obtained using an Operating Characteristic (OC) curve in a Minitab tool (version 21.2). The OC curve quantifies the probability of acceptance versus the percentage of defective items (Muscad, 2022). With a population of 61, 969 and a margin of error of plus/minus five (± 5) a sample size of 248 was determined at a 95 % confidence level. However, only 152 responses were obtained from the survey questionnaires between June and August 2024 (drought period).

3.4. Research Instruments/ Data Collection

The following instruments were used.

- i. Handout survey questionnaires
- ii. Geographic Information System (GIS): mapping sites
- iii. Geographic Positioning System (GPS): site coordinates
- iv. Turbidity meter (2100Q)
- v. Dissolved Oxygen (DO)/Electrical Conductivity (EC) meter (HQ430D)

3.5. Procedures

The following are the brief procedures followed in this study to provide the balance between water demand and supply in terms of surplus/deficit with respect to per capita demand.

- i. Obtain census population records from 1991 to 2023.
- ii. Forecast future the rural population for the next three (3) decades.
- iii. Obtain the average amount of water used per person per day within the rural area through household survey.

- iv. Compute current and future water demand based on per capita water demand and the population projection.
- v. Collect information regarding household demographic and socioeconomic characteristics, technological advancement and climate change within the Iishana system.
- vi. Establish the variation in water demand based on the local demographic and socioeconomic attributes.
- vii. Collect information on the types of water sources utilised by the residents, during the drought period.
- viii. Conduct a water quality test from the surface water sources in the basin.
- ix. Make possible recommendations to meet water demand during the drought period.

3.5.1. Procedures for Projecting Population

The probable population was estimated to assist in computing current and future water demand for the rural Iishana basin. The population record (Table 3.1) was obtained from the official census records (Census, 1991, 2011, 2023). The government usually conducts the population census every ten (10) years.

Table 3.1: Urban population within the Iishna system (Census, 1991, 2011, 2023).

Urban	Area (ha)	2023	2011	2001	1991
Oshikuku	792	5,499	2,761	*	*
Outapi	2,768	13,671	6,437	2640	*
Tsandi	703	2,595	*	*	*
Ongwediva	4,182	27,784	20,260	10,742	6,197

Oshakati	5,630	58,696	36,541	28,255	21,603
TOTAL	14,675	112,764	67,664	41,637	27,800

* These areas were not yet proclaimed as urban.

In order to evaluate the total population size of the study area, the first step was to calculate the population for each region. Figure 3.3 shows the regional zones of the Iishana system. The second step was to use the population density for each region to calculate the population in each area, and then the totals were summed to get the overall population numbers.

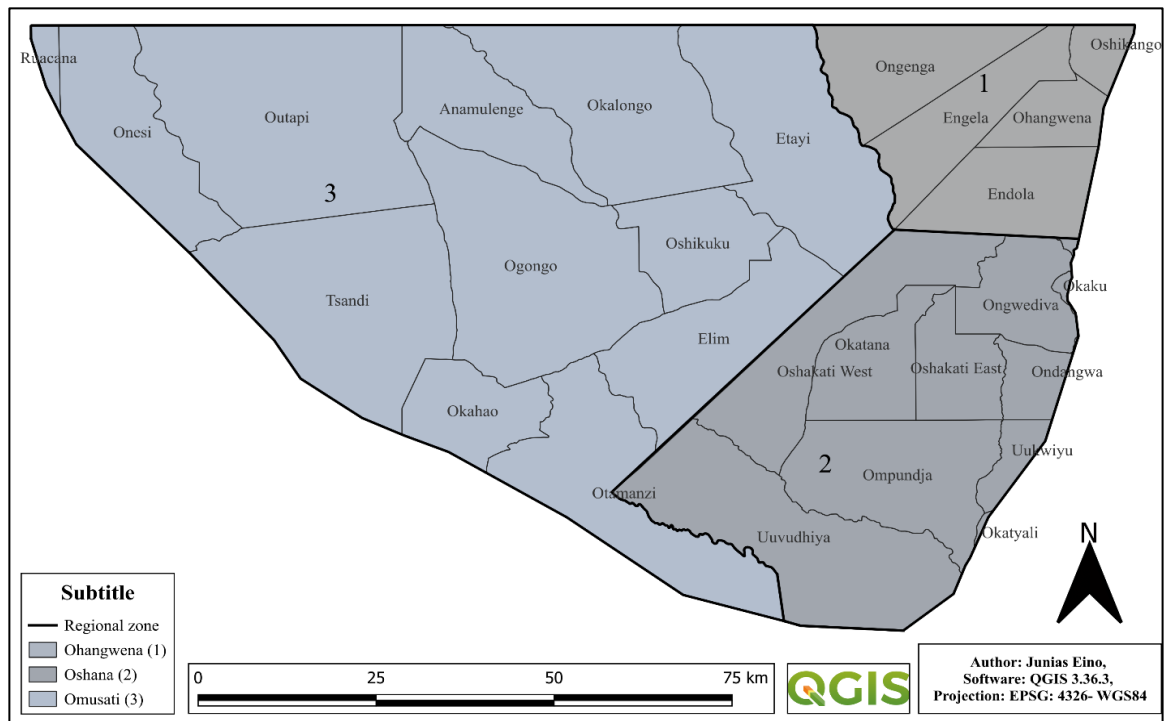


Figure 3.3: Regional zones of the Iishana system.

The rural population in 2023 and the preceding three decades was calculated by subtracting the urban population (depicted in Table 3.1) from the total population numbers (refer to Table 3.2). The future population for the next 3 decades was consequently calculated based on the rural population of 2023 and the past 3 decades. The probable

future populations was predicted using different methods reviewed in Chapter 2, section 2.5. While none of these methods are entirely precise and are all founded on probability laws, they provided only approximate projections for future population. The selection of a particular methodology relied heavily on the factors that are considered within such approaches. Therefore, the Arithmetical Increase Method, Geometrical Increase Method, Incremental Increase Method, and Decreasing Rate of Growth Method were considered in this study.

Table 3.2: The population within the Iishana system from 1991 to 2023 (Census, 1991, 2011, 2023).

Year	Region	Area	Population density	Population per	Population	Urban	Rural
			Per km²	region		Population	Population
		km²	Person/ km²	[No]	[Total No]	[Total]	[Total]
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	Ohangwena	1,136	32	36,352			
2023	Oshana	2,411	27	65,097	174,733	112,764	61,969
	Omusati	6,107	12	73,284			
	Ohangwena	1,136	23	26,128			
2011	Oshana	2,411	20	48,220	129,311	67,664	61,647
	Omusati	6,107	9	54,963			
	Ohangwena	1,136	21	23,856			
2001	Oshana	2,411	19	45,809	124,628	41,637	82,991
	Omusati	6,107	9	54,963			
	Ohangwena	1,136	18	20,448			
1991	Oshana	2,411	26	62,686	174,739	27,800	146,939
	Omusati	6,107	15	91,605			

*[6] Total population numbers of the 3 regions in the respective year.

3.5.2. Procedures for Calculating Water Demand

The calculation of water demand was aligned with the overarching objective of the research study, which aims to inform the development of new infrastructure and the enhancement of existing ones to address water needs during drought events. This process involved estimating both the current and future water demand, with projections based on a recommended 30-year design period to ensure long-term sustainability and resilience (Basak, 2007; MAWF, 2014). Data on water demand across various sectors during dry periods were collected through field surveys, supplemented by relevant secondary data, as outlined in Chapter 2, Section 2.2.

The water demand calculations were conducted using statistical models, which were primarily informed by available census data and field interviews. These models were tailored to reflect the specific conditions and challenges prevalent in rural southern Africa, as discussed in Chapter 2, Section 2.6. Their application proved valuable due to data scarcity (inconsistent monitoring datasets), nonlinear demand drivers (climate change, migration, etc.), and infrastructure constraints (the Iishana system requires adaptive models that account for intermittent supply) in the study area.

The surface water in the rural Iishana system is widely used for domestic and livestock drinking, according to the field survey. Thus, this study mainly focused on the domestic and livestock demand as estimated in the next subsections.

3.5.2.1 Water demand for domestic use

The inhabitants use water in their households for drinking, cooking, bathing, sanitation, and gardening, with their access and consumption largely dependent on living conditions.

Using the average water per capita of 40 l/c/d obtained from the field survey within the Iishana system, the domestic water demand was determined successfully. The theoretical demand for water was calculated by multiplying the projected rural population by the individual domestic consumption.

3.5.2.2 Water demand for livestock

The residents rely on livestock farming, raising draught animals such as cattle, sheep, goats, and donkeys. These animals drink from natural water sources like iishana (shallow oshanas), burrow pits, and ponds. On average, large stock unit (LSU), including cattle, donkeys, or horses, consume about 45 liters/stock unit/day (MAWF, 2014). The livestock demand was computed by multiplying the livestock figure with the water consumption adopted in the region. Table 3.3 shows the livestock number for the study area calculated based on the carrying capacity of the rural areas at 10 ha/LSU (MAWF, 2014).

Table 3.3. Livestock numbers within the Iishana system

Area	Carrying capacity	Livestock Numbers*
[ha]	[ha/LSU]	[Total]
951,587	10	95,156

*Equivalent large stock units

3.5.3. Procedures to evaluate variation of water demand

After estimating the current and future water demand, it was essential to analyse variations in water consumption to assist policymakers in managing water sources effectively. The variation in water demand was assessed based on different scenarios, taking into account local factors such as demographics and socioeconomic conditions. Data were gathered

after the rainy season to effectively evaluate changes in water demand during dry conditions. More so, the impacts of climate change, including variations in precipitation and temperature, were analysed to understand their effects on both water demand and the potential for water provision in the area.

3.5.3.1. The implications of demographic and socio-economic characteristics on water demand

The demographic data (gender, civil status and age) and socio-economic data (income per capita per month, price of water, education level, career/ job type, and household size) were collected during the field interviews. Thus, this study presents the results of the household demographic and socioeconomic factors to help address the imbalance between water demand and the existing water supply in the Iishana system.

3.5.3.2. Water provision procedures

Water provision was determined based on the historical hydrological dataset daily data for the period 2012-2021, obtained from (SASSCAL WeatherNet). The study considered the Okalongo, Mahenene, Omafo, Ogongo and UNAM weather stations within the Iishana system, as depicted in Figure 3.4. The determination of water provision follows the analysis of temperature and precipitation. The evaporation rate was also analysed based on the mathematical model reviewed in section 2.4, utilising temperature and solar radiation data.

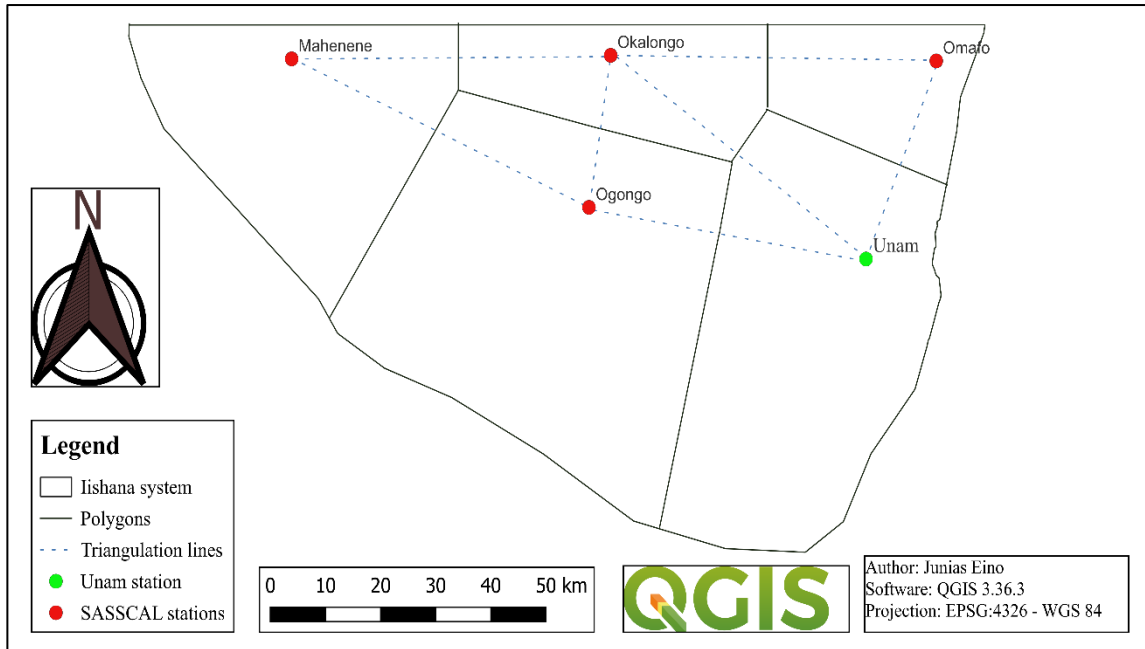


Figure 3.4: Weather stations within the Iishana system.

A three (3) year moving average was used to get an overall idea of the trends of the rainfall data. Precipitation for the entire region was calculated using the Thiessen Polygon method, as reviewed in section 2.4. This method follows the assumption that the rainfall at any point in a catchment was the same as that recorded at the nearest rain gauge (Han, 2010). Therefore, the catchment area of each gauge was divided accordingly as shown in Figure 3.4. The annual rainfall amount collected at each gauge was analysed based on the recorded data. To assess water availability, the amount of rainfall received was compared to the evaporation rate. This comparison enabled the determination of the balance between water supply and demand, indicating whether there was a surplus or deficit relative to per capita demand.

3.5.4. Procedures to explore coping mechanisms

While knowing the variations in water demand, it was necessary to understand the current coping mechanisms to help anticipate new water infrastructural development and the augmentation of existing ones to enhance water availability. The study examined the coping mechanisms that residents used to meet their current water needs during periods of scarcity and drought. This involved collecting information from the inhabitants about their views on the water sources and the quality of the water.

During the field survey, respondents were interviewed about the types of water sources they use to meet their water needs during droughts. The survey also assessed the proximity of these water sources to their homes to determine the time spent fetching water. Additionally, the seasonality of the water sources was examined, and opinions regarding the water supply in the area were gathered.

The study also focused on the types of sanitation facilities used in the area. Facilities such as pit latrines can directly impact both groundwater and surface water, making it essential to analyse their depths and distances from water sources. To validate the status of water quality from these sources, on-site measurements and laboratory tests were conducted.

3.6. Water Quality Test Procedure

According to Ithindi *et al.* (2018), water quality testing is a critical process to ensure the safety and suitability of water for various uses and to determine the cost of water treatment. Hence, ten (10) water samples were taken from the surface water bodies enclosed within the Iishana system for analysis (Figure 3.5). Sterilized plastic bottles were used to collect the water samples, which were then transported in a cooler box to prevent any changes in water quality within 24 hours to the laboratory. Before collecting the

sample water, all bottles were thoroughly washed and rinsed with water from the site. The rinse water was poured away from the sampling area to prevent any form of contamination. The water samples were collected 30 cm below the water level, taking care not to disturb the sediment at the bottom (MAWLR, 2023). The measured parameters and methods of testing these parameters are briefly discussed in the next subsections.

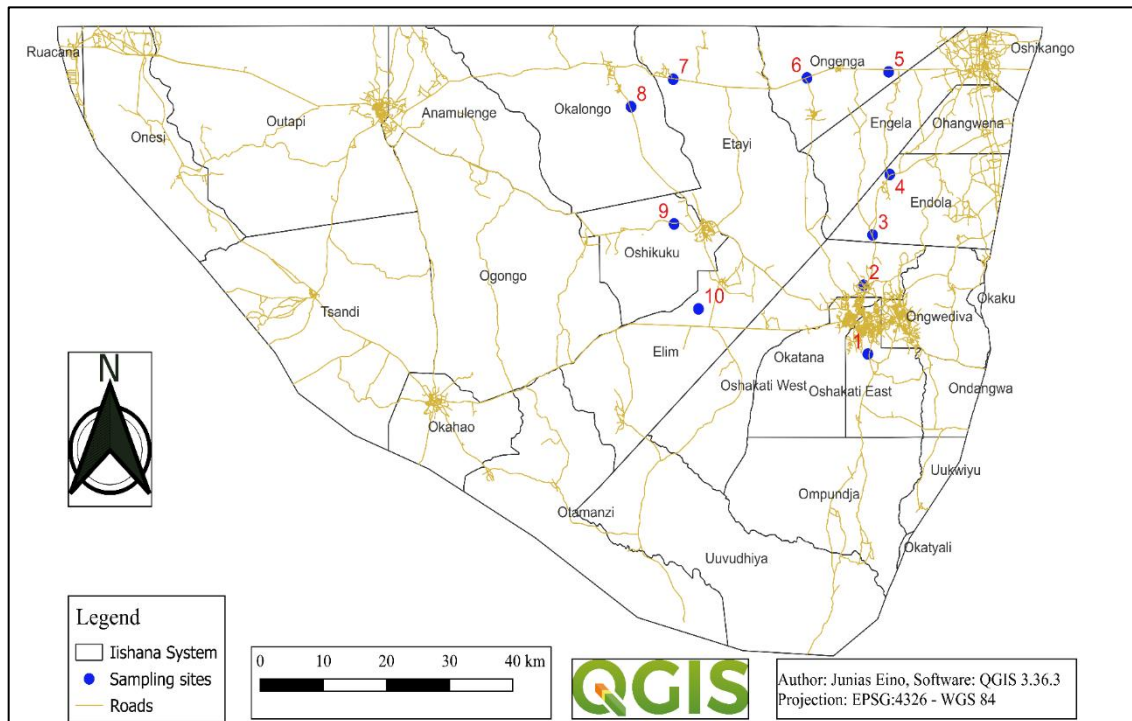


Figure 3.5: Water sampling sites.

3.6.1. Water Quality Parameters

The selected parameters were chosen based on their significant impact on the deterioration of surface water quality. Physical parameters were measured on-site, while the elemental and biological compositions were analysed in the laboratory at Namibia Water Corporation Ltd (NamWater).

Table 3.4 highlights the methods that were used for testing these parameters. The testing methods are based on the Standard Methods for the Examination of Water and Wastewater, published by the American Water Works Association (AWWA), American Public Health Association (APHA), and Water Environment Federation (WEF).

Table 3.4: Methods for testing physicochemical and bacteriological parameters.

Parameter	Testing method
Psychochemical	
pH	pH meter
Turbidity	Turbidimeter (2100Q)
Electrical conductivity (EC)	Measured with a conductivity meter (HQ430D)
Dissolved Oxygen (DO)	Measured with a DO meter (HQ430D)
Potassium	AWWA/APHA: 3120-K B. Inductively Coupled Plasma (ICP) Method
Sulphate	AWWA/APHA: 4500-SO ₄ ²⁻ F. Automated Methyl Blue Method
Nitrate/ Nitrite	AWWA/APHA: 4500-NO ₃ F. Automated Cadmium Reduction Method
Sodium	AWWA/APHA: 3120-Na B. Inductively Coupled Plasma (ICP) Method
Chloride	AWWA/APHA: 4500-Cl ⁻ E. Automated Ferricyanide Method
Total Alkalinity	AWWA/APHA: 2320 B. Titration Method
Calcium	AWWA/APHA: 3120-Ca B. Inductively Coupled Plasma (ICP) Method
Magnesium	AWWA/APHA: 3120-Mg B. Inductively Coupled Plasma (ICP) Method
Iron	AWWA/APHA: 3120-Fe B. Inductively Coupled Plasma (ICP) Method
Ammonia	Photometric determination using the indophenol blue method analogous to AWWA/APHA 4500-NH ₃ F
Microbiology	
Total Coliforms	IDEXX method at 35 °C.

3.6.2. Water Quality Analysis

The quality of water was evaluated using the Namibian standard guideline given in Table 2.6 (Chapter 2). The assessment of the water quality identifies pollutant levels and detects potential environmental issues (Wanke *et al.*, 2018). To achieve this, the characterization of the ten (10) sampled water of the Iishana system was done via the physico-chemical and bacteriological parameters of the sampled water to determine the water quality index (WQI) and establish the level of correlation among parameters using multivariate statistical analysis. The WQI was computed using Equation 2.11 as shown in Section 2.7.2, and reported in Bharti & Kathyal (2011), Haingotseheno *et al.* (2020), Oboh & Egun (2017) and Sharma *et al.* (2021).

The multivariate statistical analysis includes the hierarchical cluster, principal component, correlation matrix, and factor analysis using Minitab (21.2) and the Piper diagram was executed using Grapher (20.2.321) software. This method has been applied by several authors in the literature (Mehdi *et al.*, 2023; Panagopoulos, 2013; Rajesh *et al.*, 2019; Semar *et al.*, 2013 and Sharma *et al.*, 2021). Thus, this study presents the results of a multivariate statistical analysis of selected surface water pans within the Iishana system to assess their potential for the purpose of augmenting the existing water sources in the basin.

3.7. Research Ethics

The researcher has consistently followed the UNAM higher degrees policy. The researcher applied for an ethical clearance certificate and obtained the research permission letter from the Head of Department (HoD) of Civil and Mining Engineering to conduct field interviews. During the field interviews, the researcher ensured the protection of human rights by not disclosing the details of interviewees and by avoiding discrimination based on color, gender, or race. The researcher also made sure to acknowledge the works of others.

3.8. Summary

This chapter provides a detailed overview of the fieldwork design approach used in this study, along with the analysis techniques and pertinent information related to the fieldwork.

The primary aim of survey was to gather statistical data on water usage and users at the household level. The study also considered various attributes influencing water demand, such as age, civil status, gender, household size, income, and pricing. Daily climate change data was collected to analyse the potential for water supply to meet water demand. Equally important, the survey explored existing water supply and sanitation issues, and water quality tests were conducted. The collected data was statistically analysed and presented in tables, graphs, and charts for clearer interpretation. Overall, research protocols were strictly followed throughout the study.

CHAPTER 4. RESULTS AND DISCUSSIONS

This chapter presents the results of a thorough analysis of the fieldwork conducted and the discussions of the results.

4.1. Population Forecasting and justification of the adopted method

The probable future population was estimated using different methods highlighted in Chapter 2. The theoretical results obtained from each of these methods were then compared with the actual population in 2023. Figure 4.1 shows the comparison of the actual and estimated population by various approaches for the Iishana system. The Arithmetic Increase Method (A.I.M) gives higher results than the actual one. The Geometric Increase Method (G.I.M) and the Incremental Increase Method (I.I.M) gave almost the same results, and the results were higher than the actual one. The Decreasing Rate of growth Method (D.R.M) exceeded the actual population slightly. This method gave satisfactory results compared to the other three methods. Hence, the D.R.M was used to estimate the probable future population. This method also yielded suitable results in Rangaiah *et al* (2021) compared to other methods and was considered to predict future populations.

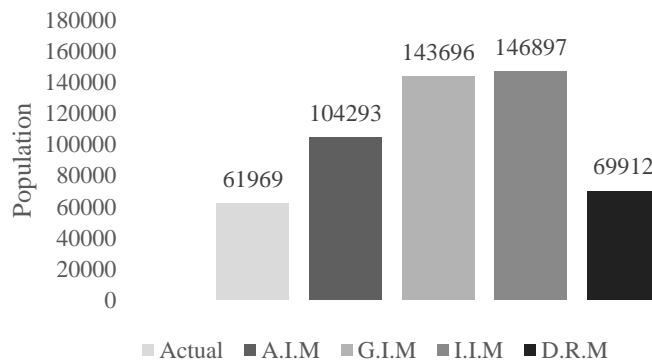


Figure 4.1: Comparison of actual and estimated population for the Iishana system.

Figure 4.2 shows the estimation of the probable future population for the Iishana system using the Decreasing Rate of Growth Method. A declining population has been predicted furtherance to previous trends based on census data. A significant population decline of 84,970 has been observed between 1991 and 2023 (Table 3.2). The decrease is attributed to people moving from rural areas to urban centers in search of better economic and social opportunities (Census, 2011).

Similarly, the same findings were observed in the study area by Shooya (2017), with the well-being and livelihood of rural communities reportedly affected by several challenges, such as poor maintenance of water infrastructure, long distances to communal taps, inability to pay for municipal water supply, limited capacity to carry water, and specific times allocated for collecting water.

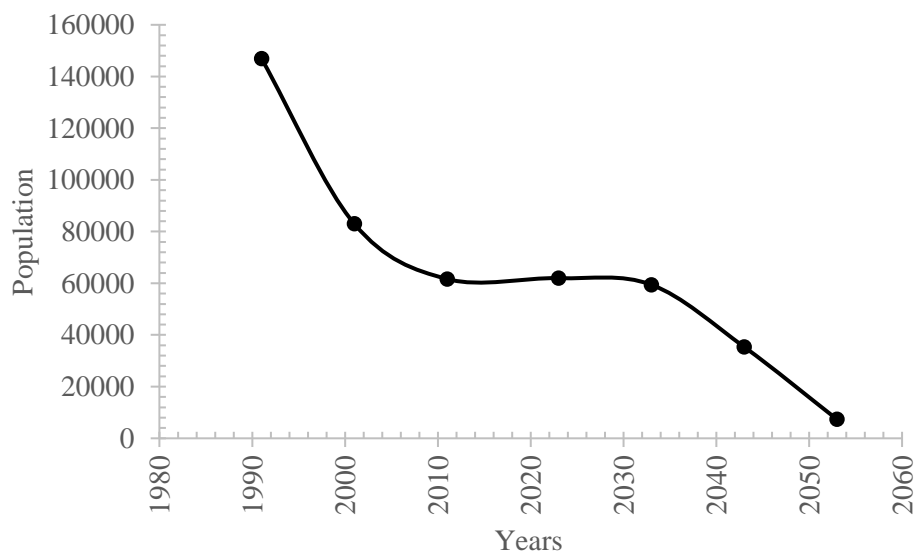


Figure 4.2: Estimation of the probable future population for the Iishana system.

4.2. Current Rural Water Demand Estimation

The estimated water demand for the present year 2023/24 was calculated based on the current domestic population and livestock numbers, using adopted water consumption norms. The resulting estimate of the current rural water demand is shown in (Table 4.1).

Table 4.1: Estimated current (2023/24) water demand of the Iishana system.

Domestic			Livestock			Total
Rural	Water	Demand	Livestock	Water	Demand	Rural
Population	Consumption		Numbers	Consumption		Water
	Per capita			per stock		Demand
[Total]	[m ³ /capita/d]	[m ³ /d]	[Total]	[m ³ /stock/d]	[m ³ /d]	[m ³ /d]
61,969	0.04	2,479	95,156	0.045	4,282	6,761

The total current rural water demand was calculated at 6,761 m³/d, with the domestic demand at 2,479 m³/d and the livestock demand at 4,282 m³/d, being 37 % and 63 % of the total, respectively (Figure 4.3).

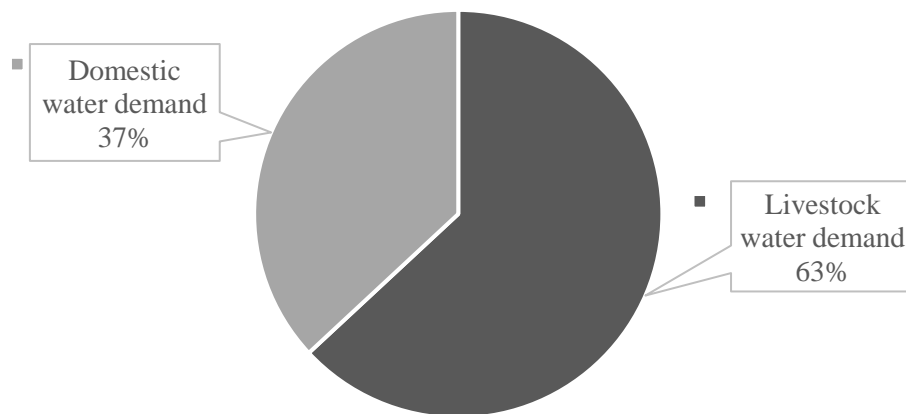


Figure 4.3: The water demand for various purposes within the Iishana system.

4.3. Projected Future Rural Water Demand of the Iishana System

The anticipated future demand for water in the rural areas were estimated based on the projected future rural population. However, livestock numbers were not considered because they depend on the grazing capacity of the rangeland, which was not expected to improve over time. Figure 4.4 displays the estimated water demand for the rural population for the Iishana system. The water demand projections for 2033, 2043, and 2053 are 0.9, 0.5, and 0.1 Mm³/year, respectively.

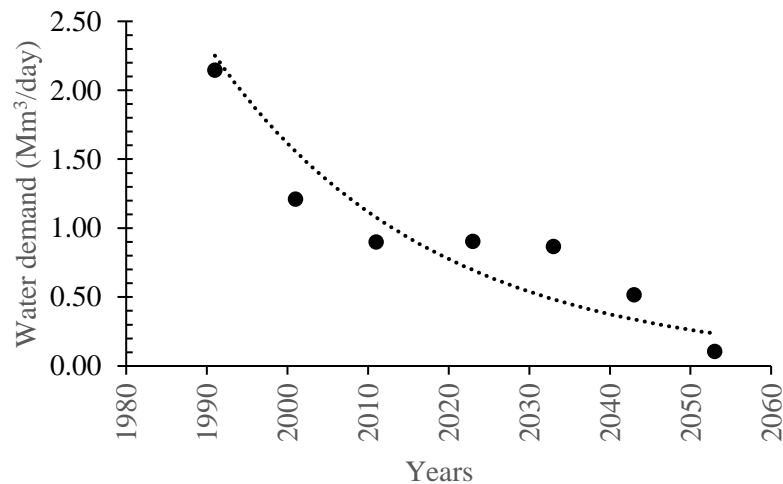


Figure 4.4: Estimated water demand for the rural population for the Iishana system.

The decrease in water demand was a result of a population decline (Figure 4.2), raising concerns about economic decline in the region. Lower demand might lead to satisfaction, delaying necessary upgrades until the system fails. If demand rebounds unexpectedly, for instance, due to population growth or climate extremes, the limited infrastructure may be inadequate (Alshaikhli *et al.*, 2021; Anang *et al.*, 2019).

4.4. Demographic characteristics and Implications on water demand

This section provides information about demographic characteristics of households and how they impact water demand.

4.4.1. Gender

The study finds that the households in the Iishana system have more females (57 %) than males as depicted in (Table 4.2). These results are supported by the Namibia Census (2023), which estimates 51.2 % of females and 48.8 % of males.

Table 4.2: Gender, Age group and Civil Status of the respondents.

Variables	Percentage (%)
Gender	
Female	57
Male	43
Age Group	
<25	36
26-35	55
36-45	5
46-55	3
>55	1
Civil Status	
Single	89
Married	10
Divorced	1

Figure 4.5 illustrates the percentage distribution of gender in charge of fetching water, with women (31.6 %) and female teenagers (26.3 %) taking on the responsibility more than men (21.1 %) and male teenagers (21.1 %). Females are probably using more water than males because they are primarily responsible for household water-related activities as caretakers or homemakers. Similarly, the findings of Abu-Bakar *et al.* (2023) indicate a

difference in water consumption between genders, with teenage girls using more water than boys during morning showers.

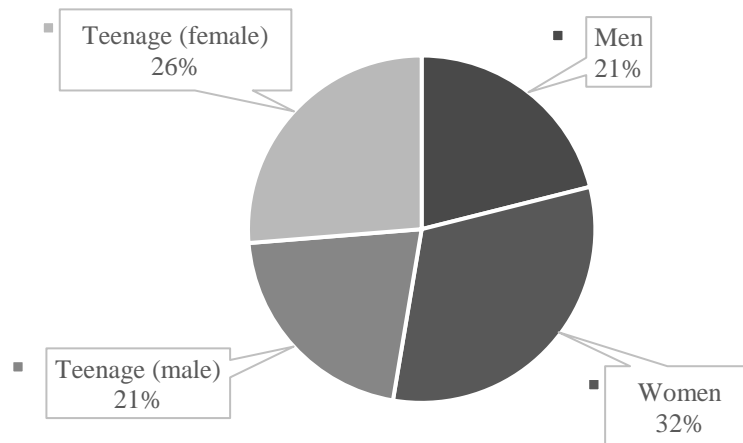


Figure 4.5: The percentage of the gender in charge of fetching water.

4.4.2. Household Age Group

The age of household members also affects water demand (Blokker *et al.*, 2010). The most prevalent age group in the area are those between 26-35, making up 5 % of the respondents (Table 4.2). This age group generally consists of young people who prefer convenient and comfortable lifestyles. They prioritize personal hygiene and laundry activities, hence high water demand.

4.4.3 Civil Status

The majority of people in the Iishana system are single (89 %) according to the survey results (Table 4.2). Based to statistics from Namibia Census (2023), almost 70 % of the population aged 15 and older are never married, with the percentage being 5 points higher among males than females. Although couples typically use more water due to larger

household needs, single individuals also prioritise hygiene and laundry to maintain a presentable appearance, leading to significant water demand in both groups.

4.5. Socio-economic characteristics and Implications on water demand

This section provides information about the socioeconomic characteristics of households and how they impact water demand.

4.5.1. Education level

The survey results indicate that 91 % of the respondents have tertiary qualifications, while 6 % have secondary qualifications and 3 % have not attended school (Figure 4.6). The percentage of individuals attending primary or secondary school has risen from 23.6 % in 2011 to 31.2 % in 2023, with the proportion of females completing tertiary education slightly higher than that of their male counterparts (Census, 2023). Given the presence of residents with limited education, there is likely little awareness of proper water management practices. This highlights the need for community education programs on water supply and sanitation to promote sustainable usage and improve public health.

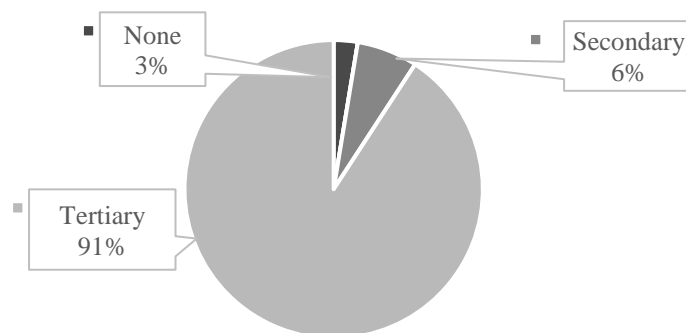


Figure 4.6: Education level within the Iishana System

4.5.2. Career/ Job type

The results shown in Figure 4.7 revealed that 19 % of the respondents have government employment. About 10 % of them are entrepreneurs. Most (38 %) of the population are students, and 20 % of the respondents work in private companies, and 13 % are unemployed. The working population may impact water demand due to differences in house size, infrastructures, cleaning and laundry activities.

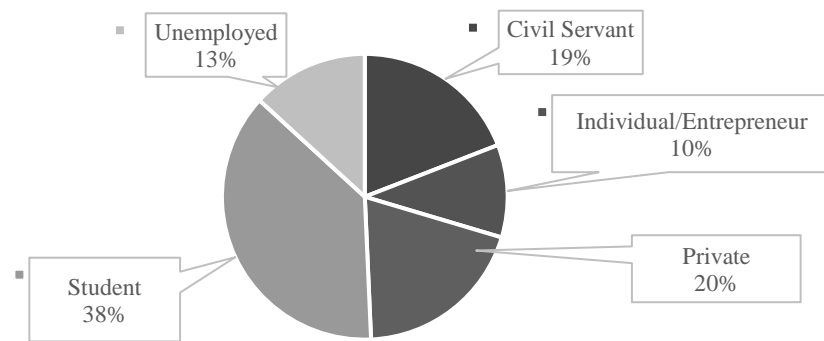


Figure 4.7: Career/Job type within the Iishana System.

4.5.3. Income per capita per month

In Figure 4.8, the results show the income per capita per month of the respondents. Households were asked to identify their primary sources of income, which included farming, non-farming business activities, wages and salaries, retirement funds, old age pensions and grants for orphans as well as for individuals living with disabilities. Approximately 49 % of the respondents receive an income of less than N\$ 5,000 per month, while 18 % receive an income between N\$ 5,000 and N\$ 10,000. About 10 % of the respondents have an income between N\$ 10,000 and N\$ 15,000, and another 10 % have an income between N\$ 15,000 and N\$ 20,000. Additionally, 13 % receive an income

of more than N\$ 20,000 with the possibility of water demand peaking in this income group.

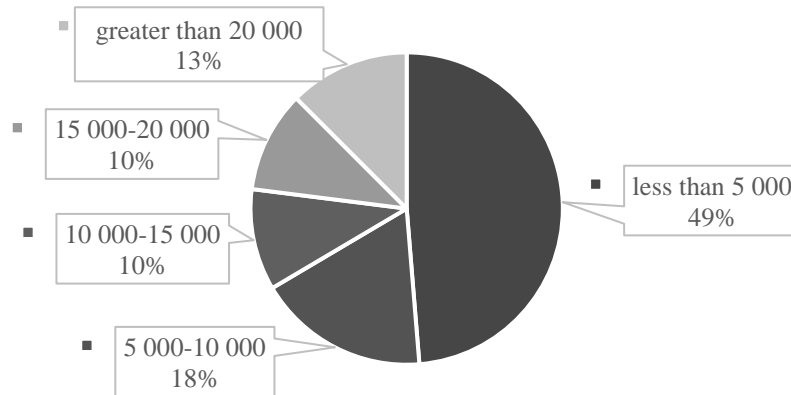


Figure 4.8: Income per capita per month within the Iishana System.

4.5.4. Cost of water

The survey found that 91 % of rural inhabitants are charged for tap water, while only 9 % do not pay for water (Figure 4.9). Among those who pay for water, 32 % pay between N\$ 150 and N\$ 300, 17 % pay from N\$ 500 to N\$ 100, and another 17 % pay between N\$ 100 and N\$ 150. Approximately, 19 % of respondents reported paying N\$ 300 or more for water, while 15 % indicated they pay less than N\$ 50 (Figure 4.10). During the field interview, households with tap water reported an increase in the cost of water during the dry season, as livestock drink water at home when the Iishana dried up.

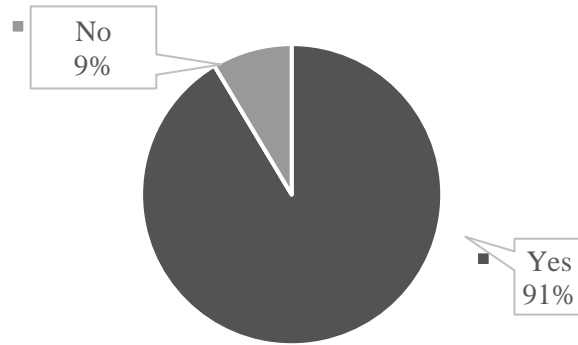


Figure 4.9: The proportion of the residents charged for water within the Iishana System.

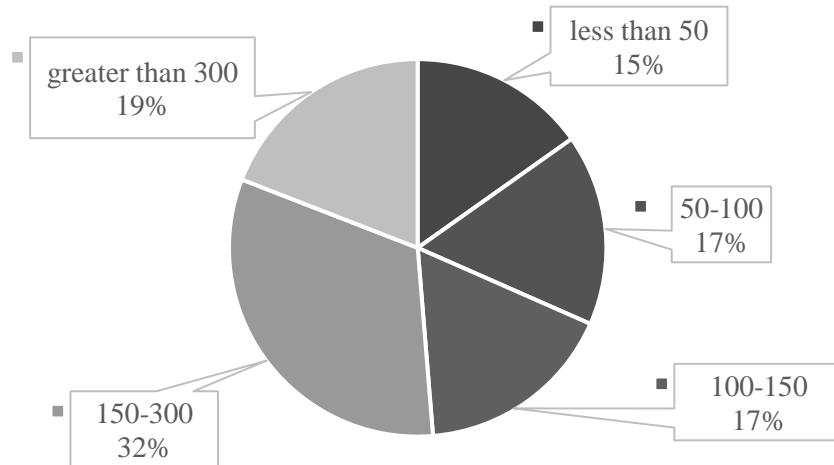


Figure 4.10: The cost of water per month (in Namibian dollars) within the Iishana System.

4.5.5. Household size

The result in Figure 4.11 shows that 57 % of households have 6-10 members. About 21 % of households have less than 5 people, while 16 % have 11-15 members. Only 6 % of households have above 15 members. The commonly household size (6-10 people) in the Iishana basin is slightly large, which may possibly increase water demand. Meanwhile, a study in the Ngamiland District found that larger households demonstrated higher consumption (Motho *et al.*, 2022).

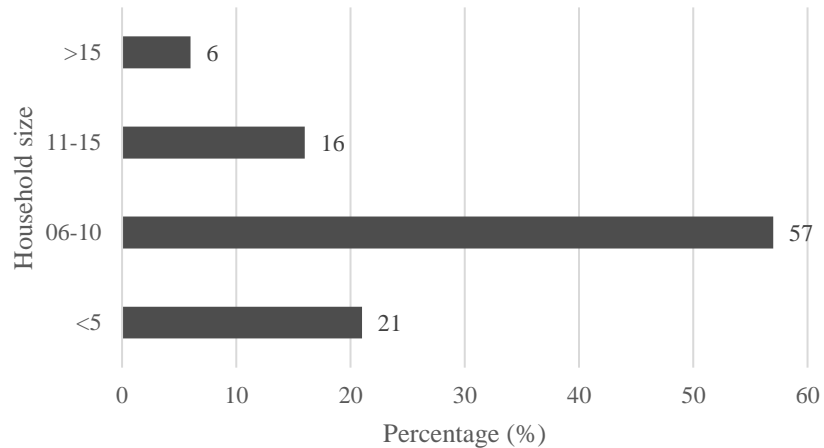


Figure 4.11: Household size within the Iishana System.

4.6. Water provision

4.6.1. Precipitation

The results shown in Figure 4.12 highlight the variability of rainfall in the Iishana system and demonstrate trends in precipitation over the last years, from 2012 to 2021 based on a 3 year moving average. The Mahenene and UNAM stations show a negative trend in rainfall from 2016 to 2018, indicating the onset of drought conditions in 2019. Similarly, Ogongo station experienced a decline in rainfall from 2017 to 2018, which also led to droughts in 2019. However, there was an increase in rainfall at Ogongo during 2020 and 2021.

All three stations exhibited fluctuations in rainfall trends over the years, highlighting the vulnerability of the region to climate change. High rainfall can result in flooding, while low rainfall can cause drought, both of which significantly impact economic development, food security, and water availability. Floods can damage property, including businesses, homes, and crops, and can also lead to loss of life for both humans and livestock (Arnell *et al.*, 2014; Karamouz *et al.*, 2011; Shifidi, 2016). On the other hand, drought conditions

can create challenges in water management, including stream pollution, infrastructure design and management, agricultural practices, and domestic water supply (Drees *et al.*, 2017; He & Zhang, 2016).

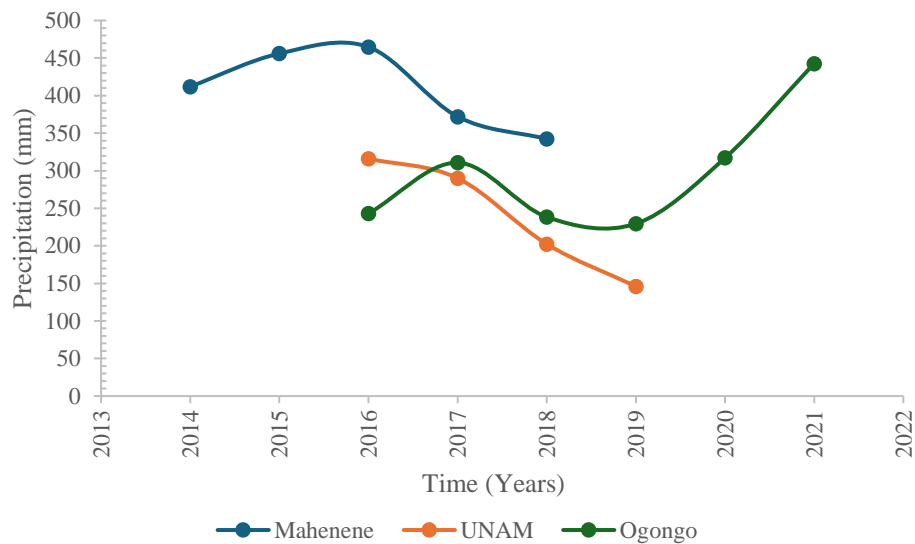


Figure 4.12: Total yearly precipitation for the Iishana system (2012-2021), recorded at UNAM, Mahenene and Ogongo station.

The average calculated areal rainfall across the stations in the region was 310 mm per annum (Table 4.3). This amount is considered low, particularly for semi arid areas (MAWF, 2014; Mendelsohn & Weber, 2011), hence insufficient to meet current water demand (Table 4.1 above). Strategic harvesting of flood and rainwater could significantly alleviate water scarcity in the region by: enhancing water storage capacity during the wet season and creating a buffer supply to meet demand during prolonged dry periods. The study by Arendt *et al.* (2021) revealed more than 63,000 existing pans capable of storing 0.63 km³ of water. Furthermore, the study identified over 700 pans for potential expansion, which could simultaneously enhance water security and flood protection.

Table 4.3: Areal rainfall recorded at UNAM, Mahanene and Ogongo stations.

Station	A_i (mm ²)x10 ¹⁵	R_i (mm)	$A_i R_i$ x10 ¹⁸
Mahenene	2.23	379	0.844
Ogongo	3.16	324	1.03
UNAM	2.51	231	0.58
TOTAL	7.89		2.45
			310

$$\bar{R} = \frac{1}{A} \sum_{i=1}^n A_i R_i$$

4.6.2. Temperature

Figure 4.13 and Figure 4.14 show the daily temperature pattern for the Iishana system, recorded at Ogongo station. It is visible that the temperature series followed a positive trend in both figures. Increased temperatures are problematic as they raise evaporation rates, leading to lower water levels and poorer water quality (Lecoq *et al.*, 2014). Cordes at Omafo and Okalongo stations (Figure 4.15 and Figure 4.16) indicate a high daily temperature with a slight decrease from 2019 to 2021. The temperature drop at these stations (upper stream) is attributed to increased rainfall in Angola.

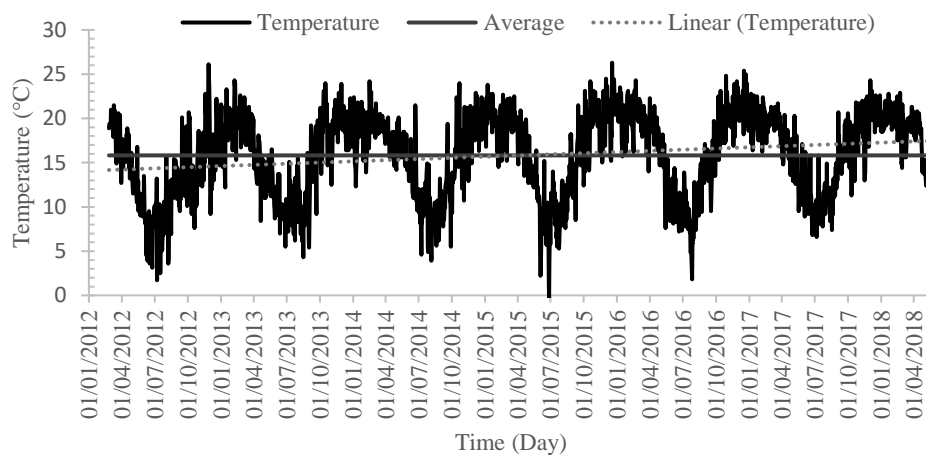


Figure 4.13: Daily temperature for the Iishana system (2012-2018), recorded at Ogongo station.

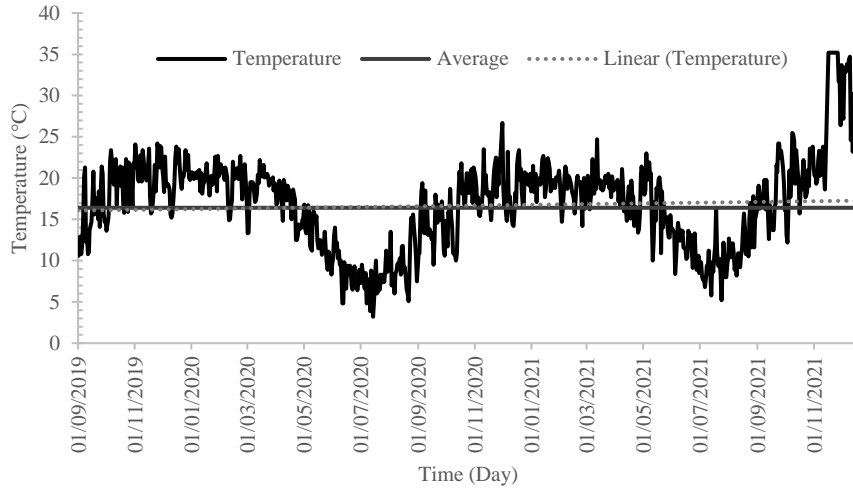


Figure 4.14: Daily temperature for the Iishana system (2019-2021), recorded at Ogongo station.

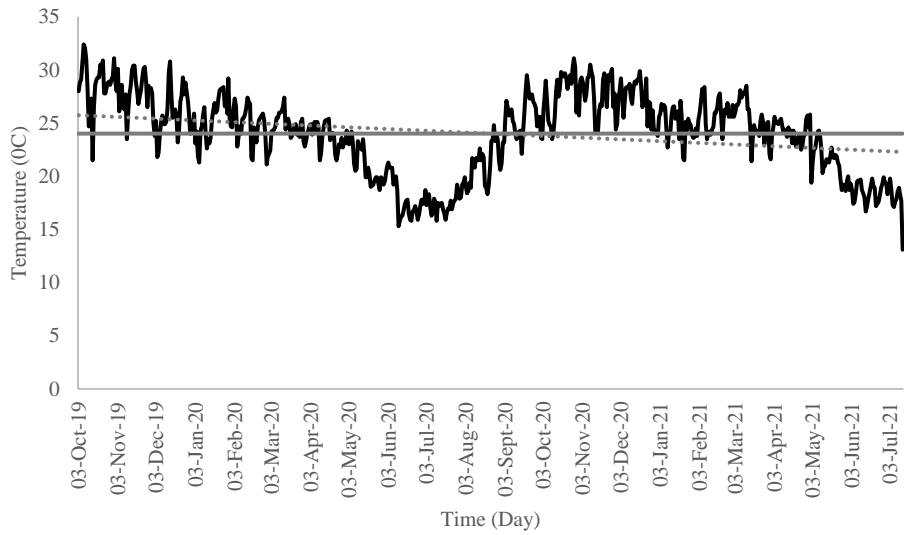


Figure 4.15: Daily temperature for the Iishana system (2019-2021), recorded at Omafo station.

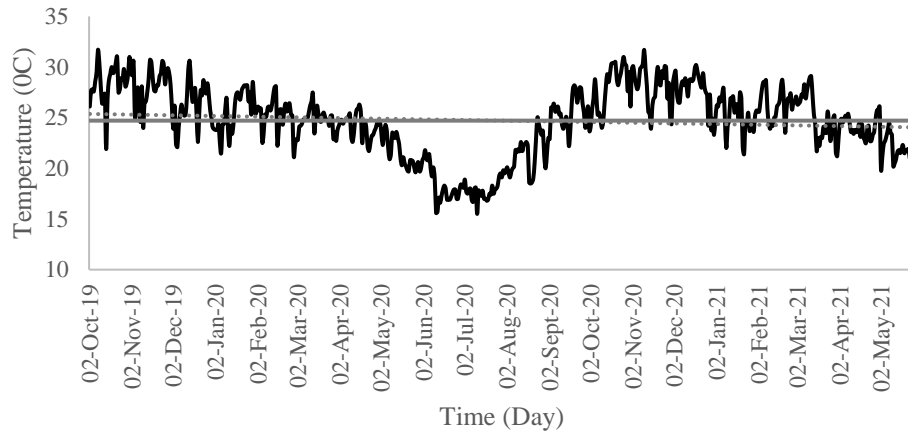


Figure 4.16: Daily temperature for the Iishana system (2019-2021), recorded at Okalongo station.

4.6.3. Evaporation

Figure 4.17 illustrates the evaporation levels within the Iishana system, as recorded at the Ogongo station from 2012 to 2021. The data shows that the yearly average evaporation rate fluctuated between 1,000 and 3,400 mm from 2012 to 2020. Notably, a spike in the evaporation rate was recorded in 2021, reaching 4,000 mm.

With an average annual evaporation rate of 2,500 mm at the Ogongo station and an average annual rainfall of only 310 mm, the evaporation exceeds the rainfall by eight times. Such a high evaporation rate can quickly deplete surface water, leaving local residents without sufficient water and leading to drought conditions (Drees *et al.*, 2017). Thus, increasing the depth of natural pans to boost water availability can consequently decrease the evaporation rate.

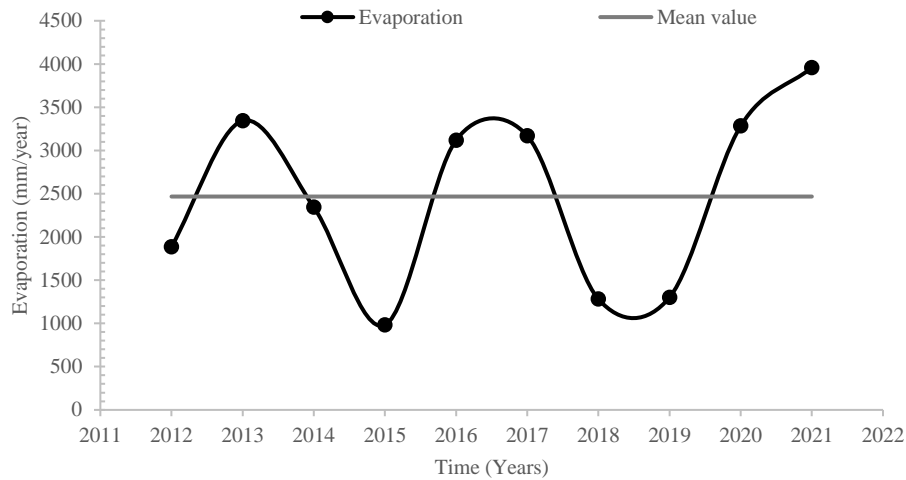


Figure 4.17: Evaporation within the Iishana system, recorded at Ogongo stations (2012-2021).

4.7. Results on the coping mechanisms adopted during water scarcity and drought

4.7.1. Water Sources

The field survey revealed that tap water was the most important water source for the 70 % of the households during the drought period. The use of tapwater become expensive during the dry period as both human and livestock depend on it. The NamWater experience high pressure to supply water during the dry season due to increased demand (Drees *et al.*, 2017). Some inhabitants use natural pans, wells, burrow pits, and boreholes, but these sources are seasonal, leaving the population with no water for domestic and livestock drinking. As a result, residents have to walk over 500 m distances (Table 4.4) to access water, which particularly affects the health of females, who are primarily responsible for fetching water (Figure 4.5 above). This also means that females have

limited time for other activities, as they spend more time (2 or more hours) fetching water and other household chores.

The majority of residents (57 %) store water in tanks or containers if they have taps in their homes. 40 % of residents use containers holding less than 300 liters, while (12 %) use containers holding 1000-2500 liters, and some (11 %) use containers with a capacity of over 2500 liters. Even with a low income in rural areas (Figure 4.8), residents strive to obtain water tanks or containers, which is helpful in case of low water pressure or temporary water main closures.

Table 4.4: Types of water sources, variability, distance to water sources, time spent to water sources and water storage tank.

Water Access	
Types	Percentage (%)
Boreholes	5
Burrow pits	6
Well	8
Natural pans	11
Tapwater	70
Water sources variability	
	Percentage (%)
Seasonal	45
Perennial	55
Distance to water sources	
Distance (m)	Percentage (%)
0-100	60
100-500	15
500-1000	20
>1000	5
Time spent to and from water sources	
Time (min)	Percentage (%)
0-30	55
30-60	26
60-90	11
90-120	5
>120	3
Households with water storage tank	
	Percentage (%)
Yes	57
No	43
Water storage capacity	

Capacity (l)	Percentage (%)
<300	40
300-500	23
500-1000	14
1000-2500	12
>2500	11

4.7.2. Water and Sanitation

In Table 4.5 is the results of the water quality perception, water treatment and sanitation facilities utilised by the rural communities. The majority of the respondents (84 %) indicated that the water quality is good. Clean water includes water from taps, covered boreholes and protected wells. However, 16 % of the respondent who depends on surface water reported poor water quality. Based on the field interview, 16 % of households treat surface water for drinking by boiling, filtering, and settling.

Sanitation in rural areas is considered poor, as 31 % of households practice open defecation which contaminates water sources. During the rainy season, human waste can end up in the water, degrading its quality and leading to water borne diseases (Dery *et al.*, 2020; Pedro *et al.*, 2020). Among the 41 % of pit latrines used in the Iishana system, of which 30 % were located within 0-15 m of water sources and 21 % have a depth greater than 5 m, which can easily contaminate water sources (Nash & Still, 2002).

Table 4.5: Water quality status, water treatment and sanitation facilities.

Water quality	
Status	Percentage (%)
Good	84
Poor	16
Households that treat water	
	Percentage (%)
Yes	16
No	84
Sanitation facility	
Types	Percentage (%)
Flushing	28
Pit-latrine	41
Open defecation	31
Depth of pit-latrine	
Depth (m)	Percentage (%)
<3	22
3-5	57
>5	21
Distance of the latrines from the water sources	
Distance (m)	Percentage (%)
0-15	30
15-30	22
30-50	17
>50	31

4.7.3. Water Quality Tests

4.7.3.1. Descriptive Statistics

The physicochemical and biological characteristics of the surface water samples are shown in Table 4.6. The general order of abundance of cations is $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+ > \text{Fe}^{2+}$, whereas for anions is $\text{Cl}^- > \text{SO}_4^{2-} > \text{NO}_3^- > \text{NO}_2^-$.

Table 4.6: Physico-chemical and bacteriological parameters of the sampled water.

Site	EC	Turbidity	pH	DO	Hardness	Alkalinity	Cl ⁻	NH ₃	NO ₃ ⁻	NO ₂ ⁻	SO ₄ ²⁻	Ca ²⁺	Fe ²⁺	Mg ²⁺	K ⁺	Na ⁺	Total coliform/ 100 ml	faecal coliform/ 100 ml
1	358	51.5	8	7.72	52	86	16	0.04	0.5	0.1	17	35	0.72	17	3	50	166	488
2	170	100	8	8.09	58	44	2	0.08	0.5	0.1	14	38	6.4	21	4	18	687	461
3	458	25.7	8.5	7.11	66	76	31	0.07	0.5	0.1	33	45	0.21	21	3	60	2420	87
4	326	100	8.1	7.88	101	78	2	0.31	0.5	0.1	8	68	1.4	33	9	26	2420	1046
5	440	26.8	8.2	7.38	162	58	1	0.05	0.5	0.1	124	133	0.03	29	5	27	161	55
6	3.91	100	9.3	8.03	53	510	640	0.37	0.5	0.1	113	40	0.88	13	10	690	2420	2420
7	1846	100	8.1	7.45	124	174	350	0.06	0.5	0.1	112	83	0.24	42	21	265	2420	2420
8	357	100	8.2	7.3	67	64	39	0.19	0.5	0.1	8	50	0.17	17	6	41	921	770
9	56.4	28.3	7.4	7.65	48	36	1	0.22	0.5	0.1	5	40	0.69	8	3	4	2420	120
10	727	100	8.2	7.81	33	106	109	0.06	0.5	0.1	34	20	2.7	13	5	134	2420	2420
Acceptable limit	300	5	9	10	400	No guide value	300	0.5	11	0.15	300	150	300	70	100	300	5	1

The results including minimum and maximum are provided in Table 4.7. Na^+ concentrations vary from 4 to 690 mg/l: 80 % of the samples fall within the acceptable drinking limit and 20 % of the samples (sites 6 and 7) are not acceptable according to the Namibian standard (MAWLR, 2023). High concentrations of Na^+ are harmful and cause high blood pressure, heart and liver diseases (Amu *et al.*, 2022).

The Cl^- concentrations vary from 1 to 640 mg/l: 80 % of the samples are within the acceptable limit whereas, the samples from sites 6 and 7 surpassed the standard limit. High levels of Cl^- may pose health risks by impacting the heart and kidneys (WHO, 2011). Ca^{2+} concentrations range between 20 and 133 mg/l. Sites 4, 5, and 7 show high mineralization, but all the sampled locations fall within the acceptable limit.

Mg^{2+} concentrations span from 8 to 42 mg/l. Sites 4, 5 and 7 are more mineralised but all samples are under the acceptable limit. K^+ concentrations vary from 3 to 21 mg/l. Sites 4, 6 and 7 are more mineralised but fall within the acceptable limit. Fe^{2+} concentrations span from 0.03 to 6.4 mg/l. Site 2 is more mineralised but is under the acceptable limit.

SO_4^{2-} concentrations range from 5 to 124 mg/l. Sites 5, 6 and 7 are more dominated by SO_4^{2-} but lie below the acceptable limit. NO_3^- and NO_2^- concentrations are 0.5 and 0.1 mg/l, respectively, in all samples and both NO_3^- and NO_2^- fall within the acceptable drinking limit.

The EC concentrations range from 3.9 to 1846 $\mu\text{S}/\text{cm}$. About 70 % of the samples have an EC higher than the acceptable limit while sites 2 and 6 are within the acceptable limit. The high EC levels in sites 1, 3, 4, 5, 7, 8, and 10 indicate that there are significant amounts of agricultural runoffs and dissolved cations and anions such as calcium, magnesium,

sodium, potassium, chloride, and sulphate. Elevated EC in water is problematic and can lead to increased salinity levels (Rajesh *et al.*, 2019), which negatively impacts aquatic life, irrigation practices, and the overall suitability of water for various purposes (Kumar *et al.*, 2023). Hence, high water treatment cost.

The pH values of the sampled water range between 8 and 9.3, with 10% of the sampled water (site 6) exceeding the permissible pH limit of 9. pH indicates the concentration of hydrogen ions in water. The spike in pH can be influenced by the presence of bicarbonate ions, which are formed by the combination of CO₂ with water to create carbonic acid (Rajesh *et al.*, 2019). The pH values are also attributed to the presence of calcium and magnesium ions (Haingotseheno *et al.*, 2020). Water with a high pH has a bitter taste, making it unpleasant to drink (Indian Standard (BIS 10500), 1991).

Turbidity ranges from 25.7 to 100 NTU, which exceeds the acceptable limits. Sites 1, 2, 4, 6, 7, 8 and 10 are more turbid and higher levels of turbidity promote the growth of harmful microorganisms in water (WHO, 2011).

Total coliforms range from 161 to 2420 cfu/100 ml with a mean value of 1646 cfu/100 ml. High levels of Total coliforms are found at sites 3, 4, 6, 7, 9 and 10, which pose risks such as Gastrointestinal illness (Indian Standard (BIS 10500), 1991). Faecal coliform concentrations range from 55 to 2420 cfu/100 ml. Sites 4, 6, 7 and 10 are found with high levels of faecal coliforms, which can cause Gastrointestinal illness as well (Indian Standard (BIS 10500), 1991).

The traces of Total coliforms and faecal coliforms rendered the sampled water unsuitable for drinking unless they are treated. Dissolved Oxygen (DO) concentrations vary from 7

to 8 mg/l. Alkalinity concentrations range from 36 to 510 mg/l. The most alkaline sites are 6, 7 and 10. Water with a higher alkalinity often has a bitter taste, making it unpleasant to drink (Rajesh *et al.*, 2019).

Total hardness ranges from 33 to 162 mg/l. Sites 4, 5, and 7 are associated with high levels of total hardness, although they remain within acceptable limits. Elevated hardness in water can lead to issues such as scale buildup in utensils and soap scum formation (Indian Standard (BIS 10500), 1991). NH₃ concentrations range from 0.04 to 0.4 mg/l. Sites 4 and 6 have a high content of NH₃ but are within the acceptable limit.

Table 4.7: Descriptive statistics of the surface water parameters.

Variable	Units	Minimum	Maximum
Turbidity	NTU	25.7	100
DO	mg/l	7	8
EC	μS/cm	3.9	1846
pH	pH units	7.4	9.3
Na ⁺	mg/l	4	690
K ⁺	mg/l	3	21
SO ₄ ²⁻	mg/l	5	124
Cl ⁻	mg/l	1	640
Alkalinity	mg/l	36	510
Hardness	mg/l	33	162
Ca ²⁺	mg/l	20	133
Mg ²⁺	mg/l	8	42
Fe ²⁺	mg/l	0.03	6.4
NH ₃	mg/l	0.04	0.4
NO ₃ ⁻	mg/l	0.5	0.5
NO ₂ ⁻	mg/l	0.1	0.1
Total coliforms	cfu/100 ml	161	2420
faecal coliform	cfu/100 ml	55	2420

4.7.3.2. Water Quality Index

The Water Quality Index (WQI) for site 1 is computed using equations 2.11 as shown in section 2.7.2. After calculating the sub-index value and the unit weight for each parameter based on the measured data and the Namibian standard, the WQI was properly computed to be 143.89 (Table 4.8).

Table 4.8: Computation of Water Quality Index (Typical of Site 1)

Parameter s	Acceptable limit	Measured value	wi	Wi	qi	WQI*100
EC	300	358	1	0.03	1.19	3.62
Turbidity	5	51.5	4	0.12	10.30	124.85
pH	9.0	8	1	0.03	0.89	2.69
DO	10	7.72	1	0.03	0.77	2.34
Hardness	400	52	1	0.03	0.13	0.39
Cl ⁻	300	16	4	0.12	0.05	0.65
NH ₃	0.5	0.04	1	0.03	0.08	0.24
NO ₃ ⁻	11	0.5	1	0.03	0.05	0.14
NO ₂ ⁻	0.15	0.1	1	0.03	0.67	2.02
SO ₄ ²⁻	300	17	2	0.06	0.06	0.34
Ca ²⁺	150	35	2	0.06	0.23	1.41
Fe ²⁺	300	0.72	1	0.03	0.002	0.01
Mg ²⁺	70	17	3	0.09	0.24	2.21
K ⁺	100	3	5	0.15	0.03	0.45
Na ⁺	300	50	5	0.15	0.17	2.53
Sum			33	1		143.89

The WQI in the study area ranges from 81.30 to 320.65, as shown in Table 4.9. Based on the WQI classification, the sampled points fall into categories ranging from very poor to unsuitable for human consumption as potable water. These results indicate a decline in surface water quality. Notably, the survey data obtained reveals that 16 % of respondents (Table 4.5) experience poor water quality during the the drought period.

Table 4.9: The status of the water samples at different sites.

Site	WQI	Class
1	143.89	Unsuitable
2	258.57	Unsuitable
3	84.98	Very poor
4	265.60	Unsuitable
5	91.91	Very poor
6	320.65	Unsuitable
7	311.30	Unsuitable
8	263.77	Unsuitable
9	81.30	Very poor
10	272.81	Unsuitable

4.7.3.3. Multivariate Statistical Analysis

i. Correlation Matrix

The correlation matrices were prepared using the parameters in Table 4.10. Turbidity shows a low to moderate correlation with dissolved oxygen (DO), potassium (K^+), and faecal coliforms. DO shows a moderate correlation with iron (Fe^{2+}). Electrical conductivity (EC) shows a moderate correlation ($r > 0.7$) with K^+ and Mg^{2+} . The pH indicated a high positive correlation with sodium (Na^+) and alkalinity, and a low to moderate correlation with sulfate (SO_4^{2+}) and chloride (Cl^-). The Na^+ indicates a high positive correlation with Cl^- and alkalinity, and a low to moderate correlation with SO_4^{2+} , ammonia (NH_3), and faecal coliform. Some groups show a moderate to strong correlation: Cl^- -alkalinity-faecal coliforms and hardness- Ca^{2+} - Mg^{2+} . Some combinations show a low to moderate correlation: K^+ - SO_4^{2+} - Cl^- - Mg^{2+} -faecal coliforms, SO_4^{2+} - Cl^- -alkalinity-hardness- Ca^{2+} , alkalinity- NH_4 -faecal coliforms, Ca^{2+} - Mg^{2+} , and total coliforms-faecal coliforms. This suggests that the changes in ionic concentration are primarily caused by soil weathering, mineral dissolution, and anthropogenic activities such as agriculture.

Table 4.10: Correlation Matrix of physicochemical and bacteriological parameters

Variables	Turbidity	DO	EC	pH	Na ⁺	K ⁺	SO ₄ ²⁻	Cl ⁻	Alkalinity	Hardness	Ca ²⁺	Mg ²⁺	Fe ²⁺	NH ₄	Total coliforms/100 ml	faecal coliform/100 ml
Turbidity	1															
DO	0.527	1														
EC	0.236	-	1													
pH	0.296	0.345	0.109	1												
Na ⁺	0.389	0.332	0.049	0.808	1											
K ⁺	0.511	-	0.776	0.215	0.485	1										
SO ₄ ²⁻	-0.012	-	0.404	0.533	0.619	0.567	1									
Cl ⁻	0.425	0.278	0.198	0.741	0.985	0.615	0.654	1								
Alkalinity	0.364	0.363	-	0.832	0.992	0.417	0.579	0.959	1							
Hardness	-0.178	-	0.422	-	-	0.439	0.607	-	-0.131	1						
Ca ²⁺	-0.278	0.372	0.302	0.028	0.119	0.323	0.620	0.053	-0.128	0.983	1					
Mg ²⁺	0.196	0.386	0.708	0.030	0.123	0.707	0.416	0.074	-0.108	0.800	0.676	1				
Fe ²⁺	0.417	0.675	-	0.020	0.073	-	-	-	-0.151	-0.352	-	-	1			
NH ₃	0.321	0.403	-	0.133	0.142	0.219	0.329	0.167	0.565	-0.177	0.386	0.134	-			
Total coliforms/100 ml	0.207	0.051	0.215	0.182	0.387	0.382	0.017	0.421	0.351	-0.249	-	0.000	-	0.449	1	
faecal coliform/100 ml	0.726	0.357	0.482	0.476	0.721	0.685	0.415	0.768	0.664	-0.131	-	0.152	0.024	0.235	0.516	1

ii. Hierarchical Cluster Analysis

Hierarchical Cluster Analysis (HCA) was carried out on the 10 samples obtained from the different pans. The HCA grouped the pan samples of the Iishana into 4 types of cluster groups based on their similarities (Figure 4.18). Group 1 includes turbidity and faecal coliforms, pH, Na⁺, alkalinity, and Cl⁻. Group 2 includes NH₃ and total coliforms. Group 3 includes DO and Fe²⁺. Group 4 combines K⁺, EC, Mg²⁺, hardness, Ca²⁺, and SO₄²⁻. The CA groups principally originate from agricultural activities. The high concentrations of Ca²⁺ and Mg²⁺ are due to the Arenosol soil types from which are leached into the water pans during rainfall (Mendelsohn & Weber, 2011), as well as evaporation after the rainy season.

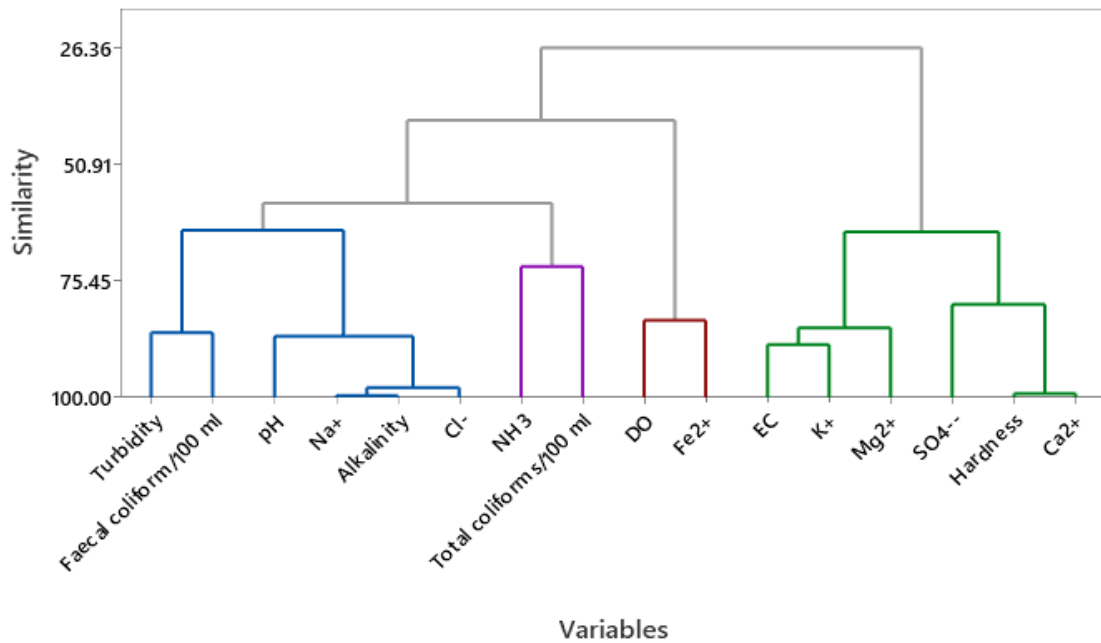


Figure 4.18: Dendrogram of hierarchical cluster analysis of surface water samples of the study area.

iii. Factor Analysis

The factor analysis (FA) was conducted using the variables in Table 4.11. The factor analysis is connected with the largest eigenvalue and an eigenvalue greater than 1 is considered significant, which shows that the cumulative variance of 92.3 % was sufficient to explain the chemistry of the sampled pans. Factor values between 0.3-0.5, 0.5-0.7 and >0.75 were used in this study to categorise the parameters as weak, moderate and strong, respectively (Rajesh *et al.*, 2019; Semar *et al.*, 2013).

Factor 1 is categorised by the weak loads between pH, Na⁺, Cl⁻, Alkalinity, and faecal Coliforms, hence this factor explains the salt concentration present in the pans. Factor 2 is also characterised by weak loads between EC, Hardness, Ca²⁺, and Mg²⁺. This factor explains the occurrence of soil formation and dissolution of minerals during the rainy season. Factor 3 is categorised by weak loads between turbidity, EC, and Fe²⁺, which describes the dissolution of natural minerals during the rainy season. Factor 4 is characterised by moderate loads of Total coliforms and weak loads between DO and Fe²⁺. This factor describes the presence of microorganisms in the area. Lastly, factor 5 is characterised by the strong loads of NH₃ and weak loads of Total Coliforms. This factor explains the agricultural runoff in the area, which affects the surface water formation. These factors work together to influence the characteristics and quality of the surface water.

Table 4.11: Results of the Factor Analysis

Variable	F1	F2	F3	F4	F5
Turbidity	0.235	-0.113	0.437	0.153	0.121
DO	0.127	-0.291	0.229	0.433	0.158
EC	0.121	0.332	0.358	-0.272	-0.24
pH	0.304	-0.056	-0.27	0.138	-0.192
Na ⁺	0.388	-0.083	-0.167	0.038	-0.121
K ⁺	0.295	0.251	0.259	-0.102	0.136
SO ₄ ²⁻	0.263	0.277	-0.202	0.199	-0.231
Cl ⁻	0.398	-0.033	-0.101	-0.01	-0.117
Alkalinity	0.377	-0.106	-0.212	0.075	-0.068
Hardness	0.014	0.441	-0.07	0.253	0.229
Ca ²⁺	-0.007	0.421	-0.161	0.28	0.213
Mg ²⁺	0.079	0.395	0.254	0.112	0.212
Fe ²⁺	-0.056	-0.23	0.399	0.428	-0.119
NH ₃	0.197	-0.204	-0.191	0.009	0.696
Total coliforms/ 100 ml	0.201	-0.084	0.088	-0.535	0.319
Faecal coliform/100 ml	0.354	-0.032	0.257	-0.12	-0.135
Eigenvalue	5.87	4.2756	2.1253	1.4646	1.0369
Variance (%)	36.7	26.7	13.3	9.2	6.5
Cumulative variance (%)	36.7	63.4	76.7	85.8	92.3

4.7.3.4. Piper diagram

Figure 4.19 depicts a Piper diagram which was utilised to illustrate the chemical composition of water from various pans. The position of the combination of different elements indicates the relative composition of the surface water. In this representation, hydrogen carbonate (HCO_3^-) values are determined by converting the alkalinity to the equivalent concentration. Na^+ and K^+ are observed to dominate at sites 4, 7, and 10. Ca^{2+} and Mg^{2+} , along with SO_4^{2-} and Cl^- are dominant at site 5, which is upstream of the area. HCO_3^- is the prevailing anion in the lower regions of the Iishana system, specifically at sites 1, 2, 4, and 9. Overall, the distribution of anions is more diverse across the sampled sites.

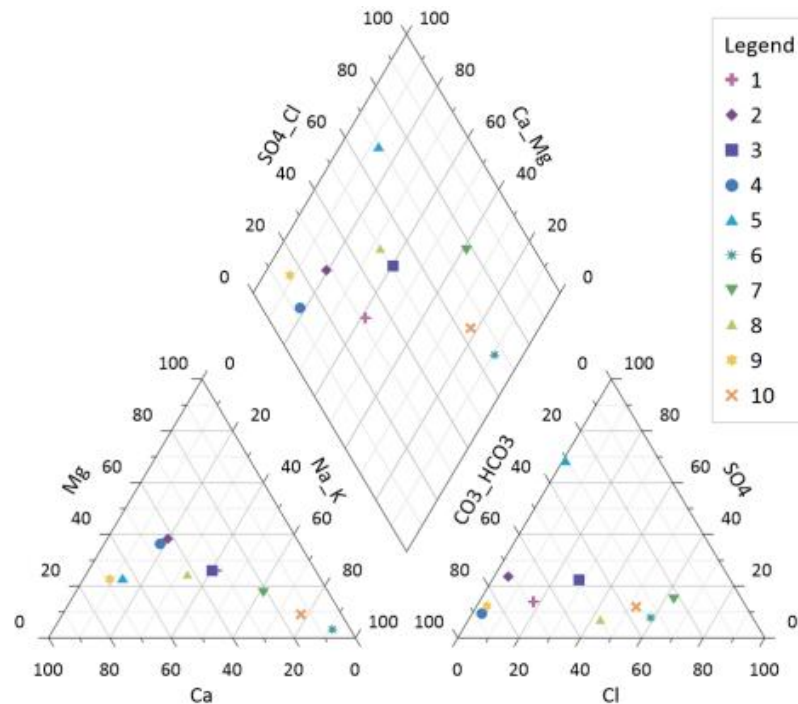


Figure 4.19: Classification of the 10 samples from different pans on the Piper diagram.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

The conclusions from this study and recommendations for future research are presented in this chapter.

5.1 Conclusions

The primary objective of this study was to analyse the per capita water demand within the Namibian Iishana system, of which four (4) specific objectives were stated to attain the main objective and a conclusion was drawn as follows:

The findings from objective 1 indicated that the Decreasing Rate of Growth method offers a more accurate estimation of the population compared to other methods. The current rural population was estimated at 61,969, with a declining trend. The total water demand for livestock and the population in the rural area was 6,761 m³/d, with livestock accounting for 63% of this demand. The population water demand projection was estimated at 0.9, 0.5, and 0.1 Mm³/year for the years 2033, 2043, and 2053 respectively.

The findings from objective 2 indicated that females dominate the region and they are primarily responsible for fetching water. On average, a household unit consists of 6-10 members and 91% of the respondents have received tertiary education. Rural households typically belong to a low income group and approximately, 91 % of the households pay for tap water. More so, the area experiences low precipitation and high evaporation rates, with an average estimated precipitation of 310 mm and evaporation of 2,500 mm per annum.

The outcomes from objective 3 indicated that the local households rely on a variety of water sources based on their availability, with 45 % of these sources being seasonal and

of poor quality. Consequently, residents walk over 500 m to access water. About 28 % of the households use flushing toilets and 41 % use pit latrines for sanitation, while 31 % of households practice open defecation.

The outcomes of objective 4 showed the characterisation of physicochemical and bacteriological parameters of 10 samples, which revealed that the pH level in 10 % of the sampled water exceeds the permissible limit and the EC also surpasses the acceptable limit in all samples. Na^+ is the prominent cation in the study area, with its concentration exceeding the permissible limit in 20 % of the samples. Total coliforms span from 161 to 2420 cfu/100 ml. Based on the WQI analysis, the overall water quality ranges from 81.30 to 320.65, which is classified as very poor to unsuitable for drinking.

Multivariate statistical analysis revealed a high correlation between Na^+ and other parameters, including pH, EC, alkalinity, SO_4^{2+} and Cl^- . The CA classified the water as $\text{Na}^+\text{-Cl}^-$ mixed with faecal coliform, along with a mixed Ca^{2+} - EC - Mg^{2+} . Thus, five factors related to the formation of surface water in the Iishana are established: salinisation, soil formation, the dissolution of natural minerals during the rainy season, the presence of microorganisms and agricultural runoffs in water sources. The factor analysis identified NH_3 as the dominant water type in the area, while the Piper diagram displayed the $\text{Na}^+\text{-K}^+$ water type for all sampled water, alongside anions distributed throughout the region. All of these factors negatively impact water quality.

This study underscores the urgent need for integrated water management strategies combining infrastructure development, demand forecasting, and quality control to ensure sustainable water access in the Iishana system.

5.2. Recommendations

With these aforementioned findings, the following recommendations for further research are hereby given.

- i. The rural population in the study area is experiencing a decline, partly due to insufficient water availability to meet increasing demand. To mitigate this trend, it is essential to enhance water availability by improving the storage capacity of natural pans. Removing accumulated sediment from these pans can significantly increase their water retention capacity. Furthermore, deepening the pans can help reduce evaporation rates, thereby conserving more water for community use.
- ii. The study area is characterized by semi-arid climates, which severely impact water availability. Implementing ecological restoration measures, such as planting trees within the basin, can help mitigate this issue. Trees not only reduce evaporation but also contribute to flood control and enhance the resilience of rural livelihoods to climate change impacts.
- iii. A significant proportion of the rural population belongs to low-income groups, making it difficult for them to afford piped water. Many residents are forced to travel long distances to access water, exacerbating their vulnerability. To address this, MAWLR must establish robust policies and regulations that balance water supply and demand, taking into account the socio-economic characteristics of the region.
- iv. The rural population includes many educated young people. Therefore, if the Ministry of Urban and Rural development (MURD) and MAWLR offers

graduates allowances to stay in rural areas and contribute to socio-economic development, it could be highly beneficial.

- v. The tested water samples from the pans were found to be unsuitable for drinking without proper treatment. There is an urgent need by Ministry of Health and Social Services (MHSS) and MAWLR for advocacy campaigns to educate the rural community about the risks of consuming untreated water and to promote the use of appropriate water treatment methods. Treated water can be repurposed for non-potable uses such as construction, irrigation, and other agricultural activities, thereby reducing pressure on freshwater resources.
- vi. Since the study concentrated exclusively on dry periods, further research on wet periods is necessary to understand seasonal variations in water demand and quality. Regular monitoring of surface water samples within the Iishana System is essential to detect contamination caused by rapid socio-economic development, agricultural activities, and climate change. This proactive approach will enable timely interventions to maintain water quality and ensure sustainable water management.

6. REFERENCES

- Abu-Bakar, H. (Halid), Williams, L., & Hallett, S. H. (2023). Contextualising household water consumption patterns in England: A socio-economic and socio-demographic narrative. *Cleaner and Responsible Consumption*, 8. <https://doi.org/10.1016/j.clrc.2023.100104>
- Abubakar, I. R. (2018). Exploring the determinants of open defecation in Nigeria using demographic and health survey data. *Science of the Total Environment*, 637–638, 1455–1465. <https://doi.org/10.1016/J.SCITOTENV.2018.05.104>
- Abunnour, M. A., Hashim, N. B. M., & Bin Jaafar, M. (2016). Agricultural water demand, water quality and crop suitability in Souk-Alkhamis Al-Khums, Libya. *IOP Conference Series: Earth and Environmental Science*, 37(1). <https://doi.org/10.1088/1755-1315/37/1/012045>
- Adham, A., Riksen, M., Ouessar, M., & Ritsema, C. J. (2016). A methodology to assess and evaluate rainwater harvesting techniques in (semi-) arid regions. *Water (Switzerland)*, 8(5). <https://doi.org/10.3390/w8050198>
- Ahmed, M., Mumtaz, R., & Anwar, Z. (2022). An Enhanced Water Quality Index for Water Quality Monitoring Using Remote Sensing and Machine Learning. *Applied Sciences*, 12(24), 12787. <https://doi.org/10.3390/app122412787>
- Alem, G. (1999). *Rainwater harvesting in Ethiopia: an overview*. <https://wedc-knowledge.lboro.ac.uk/resources/conference/25/387.pdf>

- Ali, M., & Stevens, L. (2009). Integrated approaches to promoting sanitation: A case study of Faridpur, Bangladesh. *Desalination*, 248(1–3), 1–7. <https://doi.org/10.1016/J.DESAL.2008.05.030>
- Al-Qaisi, A. Z., & Al-Shammari, M. J. (2018). Calculation of Water Demand for Multiple Uses in a Specified Region Using a SWAT Model. *IOP Conference Series: Materials Science and Engineering*, 433(1). <https://doi.org/10.1088/1757-899X/433/1/012005>
- Alshaikhli, M., Aqeel, S., Valdeolmillos, N., Fathima, F., & Choe, P. (2021). A Multi-Linear Regression Model to Predict the Factors Affecting Water Consumption in Qatar. *IOP Conference Series: Earth and Environmental Science*, 691(1). <https://doi.org/10.1088/1755-1315/691/1/012004>
- Amu, O. O., Amu, E. O., Igibah, E. C., & Agashua, L. O. (2022). Human health risk evaluation of sodium and ironic elements variability in ground water: A case study of Abuja North, Nigeria. *Fuel Communications*, 10, 100041. <https://doi.org/10.1016/j.jfueco.2021.100041>
- Anang, Z., Padli, J., Abdul Rashid, N. K., Alipiah, R. M., & Musa, H. (2019). Factors affecting water demand: Macro evidence in Malaysia. *Jurnal Ekonomi Malaysia*, 53(1), 17–25. <https://doi.org/10.17576/JEM-2019-5301-2>
- Archer, E., Engelbrecht, F., Hänslér, A., Landman, W., Tadross, M., & Helmschrot, J. (2018). Seasonal prediction and regional climate projections for southern Africa. *Biodiversity & Ecology*, 6(June), 14–21. <https://doi.org/10.7809/b-e.00296>

- Arendt, R., Beck, L., Faulstich, L., Johannes, P., Lengricht, J., Martinis, S., & Ullmann, T. (2021). Natural pans as an important surface water resource in the cuvelai basin—metrics for storage volume calculations and identification of potential augmentation sites. *Water (Switzerland)*, 13(2). <https://doi.org/10.3390/w13020177>
- Arnell, N., Benito, G., Bouwer, L. M., Brakenridge, G. R., Handmer, J., Honda, Y., & Takahashi, K. (2014). Flood risk and climate change global and regional perspectives.pdf. *Hydrological Sciences Journal*, 59(1), 1–28. <https://doi.org/10.1080/02626667.2013.857411>
- Basak, N. N. (2007). *Environmental Engineering* (1st ed.). New Delhi. <https://dokumen.pub/environmental-engineering-1ed-0070494630-9780070494633.html>
- Bharti, N., & Kathyal, D. (2011). Water Quality Indices Used for Surface Water Vulnerability Assessment. *International Journal of Environmental Sciences*, 2(1), 154–173. <http://ssrn.com/abstract=2160726>
- Bilgin, A., & Konanç, M. U. (2016). Evaluation of surface water quality and heavy metal pollution of Coruh River Basin (Turkey) by multivariate statistical methods. *Environmental Earth Sciences*, 75(12). <https://doi.org/10.1007/s12665-016-5821-0>
- Blokker, E. J. M., Vreeburg, J. H. G., Buchberger, S. G., & Van Dijk, J. C. (2008). Importance of demand modelling in network water quality models: A review.

Drinking Water Engineering and Science, 1(1), 27–38.
<https://doi.org/10.5194/dwes-1-27-2008>

Blokker, E. J. M., Vreeburg, J. H. G., & van Dijk, J. C. (2010). Simulating Residential Water Demand with a Stochastic End-Use Model. *Journal of Water Resources Planning and Management*, 136(1), 19–26.
[https://doi.org/10.1061/\(asce\)wr.1943-5452.0000002](https://doi.org/10.1061/(asce)wr.1943-5452.0000002)

Cech, Thomas. V. (2009). Principles of Water Resources. In *Historical Perspective of Water Use and Development* (3rd ed., pp. 1–23). John Wiley & Sons, Inc.

Census. (1991). *Population and Housing Census*.
https://cms.my.na/assets/documents/1991_Population_and_Housing_Census_Basic_Analysis_with_Highlights.pdf

Census. (2011). *Namibia 2011 Population and Housing Census Main Report*.
https://nsa.nsa.org.na/new_publications/namibia-population-and-housing-census-main-report-2011/

Census. (2023). *2023 Population & Housing Census Preliminary Report 2023 Population & Housing Census*. <https://nsa.org.na/>

Chaudhry, F., & Malik, M. (2017). Factors Affecting Water Pollution: A Review. *Journal of Ecosystem & Ecography*, 07(01). <https://doi.org/10.4172/2157-7625.1000225>

Cook, S., Sharma, A. K., & Gurung, T. R. (2014). Evaluation of alternative water sources for commercial buildings: A case study in Brisbane, Australia.

Resources, Conservation and Recycling, 89, 86–93.
<https://doi.org/10.1016/J.RESCONREC.2014.05.003>

Cuve Waters. (n.d.). *The Cuvelai-Etосha Basin*. Retrieved February 23, 2025, from
<http://www.cuvewaters.net/The-Cuvelai-Etосha-Basin.121.0.html>

Dang, X., Li, A., Fan, L., & Cui, J. (2024). Resident water conservation behaviors among different age groups in rural areas of the Weibei arid belt, China. *Journal of Cleaner Production*, 456. <https://doi.org/10.1016/j.jclepro.2024.142389>

De Souza, G. G., Costa, M. A., & Libânio, M. (2019). Predicting water demand: A review of the methods employed and future possibilities. *Water Science and Technology: Water Supply*, 19(8), 2179–2198.
<https://doi.org/10.2166/ws.2019.122>

Dery, F., Bisung, E., Dickin, S., & Dyer, M. (2020). Understanding empowerment in water, sanitation, and hygiene (WASH): a scoping review. *Journal of Water, Sanitation and Hygiene for Development*, 10(1), 5–15.
<https://doi.org/10.2166/WASHDEV.2019.077>

Döll, P., Müller Schmied, H., Schuh, C., Portmann, F. T., & Eicker, A. (2014). Global-scale assessment of groundwater depletion and related groundwater abstractions: combining hydrological modeling with information from well observations and GRACE satellites. *Water Resour. Res.*, 50(7), 5698–5720.
<https://doi.org/10.1002/2014wr015595>

- Dragnich, P. A., Dungca, A. C., Pendelton, N. L., & Tracy, A. R. (2007). *The Cuvelai-Etosha Basin Management Approach: Assessing Water Resource Management in the iishana Sub-Basin*. <http://theeis.com/elibrary/search/6505>
- Drees, L., Luetkemeier, R., Liehr, S., & Stein, L. (2017). Blended drought index: Integrated drought hazard assessment in the Cuvelai-Basin. *Climate*, 5(51). <https://doi.org/10.3390/cli5030051>
- Edokpayi, J. N., Enitan, A. M., Mutileni, N., & Odiyo, J. O. (2018). Evaluation of water quality and human risk assessment due to heavy metals in groundwater around Muledane area of Vhembe District, Limpopo Province, South Africa. *Chemistry Central Journal*, 12(1). <https://doi.org/10.1186/S13065-017-0369-Y>
- Eino, J., Katte, V. Y., Busari, A. O., Pires, E. E. S., Johannes, P., Fahrenberg, M., Reinhardt-Imjela, C., Jüpner, R., & Schulte, A. (2024). An Analysis of Water Demand of the Rural Population within the Iishana System, Namibia. *Journal of Civil Engineering and Urbanism*, 14(3s), 263–270. <https://doi.org/10.54203/jceu.2024.27>
- Ejoh, A. S., Unuakpa, B. A., Ibadin, F. H., & Edeki, S. O. (2018). Dataset on the assessment of water quality and water quality index of Ubogo and Egini rivers, Udu LGA, Delta State Nigeria. *Data in Brief*, 19, 1716–1726. <https://doi.org/10.1016/J.DIB.2018.06.053>
- EPA. (2025). *Climate Change Impacts on Freshwater Resources | US EPA*. <https://www.epa.gov/climateimpacts/climate-change-impacts-freshwater-resources>

- Faulstich, L., Arendt, R., Reinhardt-Imjela, C., Schulte, A., Lengricht, J., & Johannes, P. (2023). Water and sediment pollution of intensively used surface waters during a drought period — a case study in Central Northern Namibia. *Environmental Monitoring and Assessment*, 195(8).
<https://doi.org/10.1007/s10661-023-11505-1>
- Garbarino, Sabine., & Holland, Jeremy. (2009). *Quantitative and qualitative methods in impact evaluation and measuring results*. Governance and Social Development Resource Centre. <https://www.gsdr.org/docs/open/eirs4.pdf>
- García-Soto, C. G., Torres, J. F., Zamora-Izquierdo, M. A., Palma, J., & Troncoso, A. (2024). Water consumption time series forecasting in urban centers using deep neural networks. *Applied Water Science*, 14(2).
<https://doi.org/10.1007/s13201-023-02072-4>
- Genjebo, M. G., Kemal, A., & Nannawo, A. S. (2023). Assessment of surface water resource and allocation optimization for diverse demands in Ethiopia's upper Bilate Watershed. *Heliyon*, 9(10).
<https://doi.org/10.1016/j.heliyon.2023.e20298>
- Ghannam, S., & Hussain, F. (2024). Short-term water demand forecasting: a review. In *Australian Journal of Water Resources*. Taylor and Francis Ltd.
<https://doi.org/10.1080/13241583.2024.2350102>
- Ghisi, E., & Ferreira, D. F. (2007). Potential for potable water savings by using rainwater and greywater in a multi-storey residential building in southern Brazil.

Building and Environment, 42(7), 2512–2522.
<https://doi.org/10.1016/J.BUILDENV.2006.07.019>

Gokarna, R., & Aryal, M. P. (2020). Methods of Population Estimation and Projection. *Population and Development*.
<https://www.nepjol.info/index.php/jpd/article/download/33104/26063/96845#:~:text=Basically%2C%20there%20are%20three%20techniques,Method%20and%20Cohort%20Component%20Method.&text=Mathematical%20method%20is%20frequently%20used,i.e.%20less%20than%2010%20years>.

Guenouche, F. Z., Mesbahi-Salhi, A., Zegait, R., Chouia, S., Kimour, M. T., & Bouslama, Z. (2024). Assessing water quality in North-East Algeria: a comprehensive study using water quality index (WQI) and PCA. *Water Practice and Technology*, 19(4), 1232–1248. <https://doi.org/10.2166/wpt.2024.073>

Gurung, T. R., & Sharma, A. (2014). Communal rainwater tank systems design and economies of scale. *Journal of Cleaner Production*, 67, 26–36.
<https://doi.org/10.1016/J.JCLEPRO.2013.12.020>

Haingotsehen, R., Chrysostome, R. J., Robert, R., & Tojonirina, A. R. (2020). Water Quality Index (Wqi) Calculation for the Evaluation of Physico-Chemical Quality of Rainwater Collected in Reservoirs Full of Sand(Rfs). *Ijariie*, 6(6), 1050–1061. <http://www.ijariie.com/>

Han, Dawei. (2010). *Concise Hydrology* (1st ed.). Venus. <http://bookboon.com>

He, F., Ou, Z., Zhu, Y., Lu, P., & Wang, L. (2023). Analysis of driving factors of water demand based on explainable artificial intelligence. *Journal of*

Hydrology: Regional Studies, 47(April), 101396.
<https://doi.org/10.1016/j.ejrh.2023.101396>

Helsel, D. R., Hirsch, R. M., Ryberg, K. R., Archfield, S. A., & Gilroy, E. J. (2002). Statistical methods in water resources. *U.S. Geological Survey Techniques and Methods*, 2020(4-A3), 1–484. <https://doi.org/10.3133/tm4a3>

Huang, A.-C., Lee, T.-Y., Lin, Y.-C., Huang, C.-F., & Shu, C.-M. (2017). Factor Analysis and Estimation Model of Water Consumption of Government Institutions in Taiwan. *Multidisciplinary Digital Publishing Institute*, 9(7). <https://doi.org/10.3390/w9070492>

Ibrahim, A. S., Memon, F. A., & Butler, D. (2021). Seasonal variation of rainy and dry season per capita water consumption in Freetown city sierra Leone. *Water (Switzerland)*, 13(4). <https://doi.org/10.3390/w13040499>

Imteaz, M. A., Ahsan, A., Naser, J., & Rahman, A. (2011). Reliability analysis of rainwater tanks in Melbourne using daily water balance model. *Resources, Conservation and Recycling*, 56(1), 80–86. <https://doi.org/10.1016/J.RESCONREC.2011.09.008>

Imteaz, M. A., Rahman, A., & Ahsan, A. (2012). Reliability analysis of rainwater tanks: A comparison between South-East and Central Melbourne. *Resources, Conservation and Recycling*, 66, 1–7. <https://doi.org/10.1016/J.RESCONREC.2012.05.009>

Indian Standard (BIS 10500). (1991). *Water Quality Standards*. <https://rwua.org.in/download/INDIAN%20STANDARD%20FOR%20DRINK>

ING%20WATER%20-
%20SPECIFICATION%20IS%2010500%20%201991.pdf

Iqbal, J., & Shah, M. H. (2013). Health Risk Assessment of Metals in Surface Water from Freshwater Source Lakes, Pakistan. *Human and Ecological Risk Assessment*, *19*(6), 1530–1543. <https://doi.org/10.1080/10807039.2012.716681>

Isah, A. (2013). Application of Multivariate Methods for Assessment of Variations in Rivers/Streams Water Quality in Niger State, Nigeria. *American Journal of Theoretical and Applied Statistics*, *2*(6), 176. <https://doi.org/10.11648/j.ajtas.20130206.14>

Ismael, S. O., & Aziz, S. Q. (2024). Population Forecasting Till 2050 Using Various Methods and Water Supply Strategy for Erbil City. *Polytechnic Journal*, *14*(1). <https://doi.org/10.59341/2707-7799.1803>

Ithindi, J., Kgabi, N., Atekwana, E., Mathuthu, M., Kalumbu, G., & Tshivhase, V. (2018). Radon, Salinity and Elemental Concentrations of Water Sources within the Kuiseb and Cuvelai-Etoshia Basin, Namibia. *Namibian Journal for Research, Science and Technology*, *1*(1), 55–62. <https://doi.org/10.54421/njrst.v1i1.11>

Judeh, T., Shahrour, I., & Comair, F. (2022). Smart Rainwater Harvesting for Sustainable Potable Water Supply in Arid and Semi-Arid Areas. *Sustainability* *2022*, Vol. 14, Page 9271, *14*(15), 9271. <https://doi.org/10.3390/SU14159271>

Kannan, V., Priya, R. P., Tharkeshwari, K., Mazumder, B., Gayatri, P., & Neha, J. (2023). Assessment of water demand and potential water sources to face future

water scarcity of hilly regions. *AQUA - Water Infrastructure, Ecosystems and Society*, 72(3), 299–312. <https://doi.org/10.2166/AQUA.2023.212>

Karamouz, M., Noori, N., Moridi, A., & Ahmadi, A. (2011). Evaluation of floodplain variability considering impacts of climate change. *Hydrological Processes*, 25(1), 90–103. <https://doi.org/10.1002/hyp.7822>

Ketai Mabande, P. (2011). *Application of A Satellite Based Rainfall-Runoff Model for Large Scale Flood Simulation: A Case Study of Cuvelai Basin in Namibia* [University of Twente]. <https://essay.utwente.nl/93327/1/Pricila%20Ketai%20Mabande-24069.pdf>

Khastagir, A., & Jayasuriya, N. (2010). Optimal sizing of rain water tanks for domestic water conservation. *Journal of Hydrology*, 381(3–4), 181–188. <https://doi.org/10.1016/J.JHYDROL.2009.11.040>

Khatoon, N., Khan, A. H., Rehman, M., & Pathak, V. (2013). Correlation Study For the Assessment of Water Quality and Its Parameters of Ganga River, Kanpur, Uttar Pradesh, India. *IOSR Journal of Applied Chemistry (IOSR-JAC)*, 5(3), 80–90. www.iosrjournals.org

Khoi, D. N., Nguyen, V. T., Sam, T. T., Mai, N. T. H., Vuong, N. D., & Cuong, H. V. (2021). Assessment of climate change impact on water availability in the upper Dong Nai River Basin, Vietnam. *Journal of Water and Climate Change*, 12(8), 3851–3864. <https://doi.org/10.2166/wcc.2021.255>

- Kingspan. (2024, January). *The Role of Rainwater Harvesting in Sustainable Water Management* | *Kingspan IE*. <https://www.kingspan.com/ie/en/knowledge-articles/rainwater-harvesting-for-water-conservation/>
- Kluge, T., Liehr, S., Lux, A., & Urban, W. (2008). IWRM concept for the Cuvelai Basin in northern Namibia. *Physics and Chemistry of the Earth, Parts A/B/C*, 33(1–2), 48–55. <https://doi.org/10.1016/J.PCE.2007.04.005>
- Koeniger, P., Hamutoko, J., Post, V. E. A., Beyer, M., Gaj, M., Himmelsbach, T., & Wanke, H. (2021). Evaporation loss along the Calueque-Oshakati Canal in the Cuvelai-Etосha Basin (Northern Namibia): evidence from stable isotopes and hydrochemistry. *Isotopes in Environmental and Health Studies*, 57(1), 53–66. <https://doi.org/10.1080/10256016.2020.1830082>
- Kothari, V., Vij, S., Sharma, S. K., & Gupta, N. (2021). Correlation of various water quality parameters and water quality index of districts of Uttarakhand. *Environmental and Sustainability Indicators*, 9(June 2020), 100093. <https://doi.org/10.1016/j.indic.2020.100093>
- Kumar, D., Singh, V. K., Abed, S. A., Tripathi, V. K., Gupta, S., Al-Ansari, N., Vishwakarma, D. K., Dewidar, A. Z., Al-Othman, A. A., & Mattar, M. A. (2023). Multi-ahead electrical conductivity forecasting of surface water based on machine learning algorithms. *Applied Water Science*, 13(10). <https://doi.org/10.1007/s13201-023-02005-1>
- Kumar, L., Kumari, R., Kumar, A., Tunio, I. A., & Sassanelli, C. (2023). Water Quality Assessment and Monitoring in Pakistan: A Comprehensive Review. In

Sustainability (Switzerland) (Vol. 15, Issue 7). MDPI.
<https://doi.org/10.3390/su15076246>

Kumar, S. Y. (2006). *Fundamental of Research Methodology and Statistics*. New Age International (P) Limited,.
<https://mfs.mkcl.org/images/ebook/Fundamental%20of%20Research%20Methodology%20and%20Statistics%20by%20Yogesh%20Kumar%20Singh.pdf>

Lebu, S., Sprouse, L., Akudago, J. A., Baldwin-SoRelle, C., Muoghalu, C. C., Anthonj, C., Evans, B., Brown, J., Bartram, J., & Manga, M. (2024). Indicators for evaluating shared sanitation quality: a systematic review and recommendations for sanitation monitoring. *Npj Clean Water* 2024 7:1, 7(1), 1–15. <https://doi.org/10.1038/s41545-024-00386-7>

Lecoq, L., Flick, D., Plana-Fattori, A., Laguerre, O., Lecoq Abcd, L., Plana-Fattori, A., & Laguerre, O. (2014). *Characterization of evaporation rate, temperature, velocity and humidity fields in a cold chamber*. <https://hal.science/hal-01463277v1>

Lee, J., Sanneh, J., Mauro, A. D., & Wang, Y. (2022). Water demand forecasting_time series data. *The International Water Association*.
https://doi.org/doi:10.2166/9781789062380_0075

Li, S., & Zhang, Q. (2010). Spatial characterization of dissolved trace elements and heavy metals in the upper Han River (China) using multivariate statistical techniques. *Journal of Hazardous Materials*, 176(1–3), 579–588.
<https://doi.org/10.1016/J.JHAZMAT.2009.11.069>

- Li, Z., Boyle, F., & Reynolds, A. (2010). Rainwater harvesting and greywater treatment systems for domestic application in Ireland. *Desalination*, 260(1–3), 1–8. <https://doi.org/10.1016/J.DESAL.2010.05.035>
- Liuzzo, L., Notaro, V., & Freni, G. (2016). A reliability analysis of a rainfall harvesting system in Southern Italy. *Multidisciplinary Digital Publishing Institute*, 8(1). <https://doi.org/10.3390/W8010018>
- Lomet, A., Suard, F., & Cheze, D. (2015). Lomet (2015)_Statistical modeling for real domestic water consumption. *Elsevier*, 70, 379–387. <https://doi.org/10.1016/j.egypro.2015.02.138>
- López Zavala, M. Á., Prieto, M. J. C., & Rojas, C. A. R. (2018). Rainwater harvesting as an alternative for water supply in regions with high water stress. *Water Supply*, 18(6), 1946–1955. <https://doi.org/10.2166/WS.2018.018>
- MAWF. (2014). *A pre-feasibility study into: The augmentation of water supply to the central area of Namibia and the Cuvelai*. [http://the-eis.com/elibrary/sites/default/files/downloads/literature/2014_07_25_PART II_Cuvelai_Interim Report No_1.pdf](http://the-eis.com/elibrary/sites/default/files/downloads/literature/2014_07_25_PART%20II_Cuvelai_Interim%20Report%20No_1.pdf)
- MAWLR. (2023). Water resources management regulations. *Government Gazette*, 6105(100), 1–29. <https://namiblii.org/akn/na/act/gn/2023/269/eng@2023-08-29>
- Mays, L. W. (2011). *Water Resources Engineering* (2nd ed.). John Wiley & Sons, Inc.

- Mehdi, M., Hakim, D. K., Amina, A., & Nourredine, G. (2023). Multivariate Statistical Analysis of Groundwater Quality of Hassi R'mel, Algeria. *Journal of Ecological Engineering*, 24(5), 22–31. <https://doi.org/10.12911/22998993/161140>
- Meissner, H. I., Creswell, J. W., Klassen, A. C., Clark, V. L. P., & Smith, K. C. (2011). *Best Practices for Mixed Methods Research in the Health Sciences*. https://obssr.od.nih.gov/sites/obssr/files/Best_Practices_for_Mixed_Methods_Research.pdf
- Mendelsohn, J., & Weber, B. (2011). *The Cuvelai Basin its water and people in Angola*. <https://www.raison.com.na/>
- Mendelson, J., Obeid, el S., & Robert, C. (2000). Profile of north-central Namibia. *Gamsberg Macmillan*. <https://www.raison.com.na/sites/default/files/Profile%20of%20north-central%20Namibia.pdf>
- Milan, M. (2006). Literature Review of Water Demand. *International Water Association*. <http://home.etf.rs/~vm/papers/Paper%2012.pdf>
- Mishra, P., Pandey, C. M., Singh, U., Gupta, A., Sahu, C., & Keshri, A. (2019). Descriptive statistics and normality tests for statistical data. *Annals of Cardiac Anaesthesia*, 22(1), 67–72. https://doi.org/10.4103/aca.ACA_157_18
- Motho, M., Kolawole, O. D., Motsholapheko, M. R., & Mogomotsi, P. K. (2022). Influence of household demographic and socio-economic factors on water

- demand in Ngamiland District, Botswana. *Water Science*, 36(1), 48–59.
<https://doi.org/10.1080/23570008.2022.2048581>
- Muscad, O. (2022). *What is Operating Characteristic Curves*. <https://datamyte.com/>
- Myllis, G., Tsimpiris, A., & Vrana, V. (2024). Short-Term Water Demand Forecasting from Univariate Time Series of Water Reservoir Stations. *Information (Switzerland)*, 15(10). <https://doi.org/10.3390/info15100605>
- Nash, S. R., & Still, D. A. (2002). *Groundwater Contamination due to Pit Latrines Located in a Sandy Aquifer A Case Study from Maputaland*. https://sswm.info/sites/default/files/reference_attachments/STILL%20and%20NASH%202002%20Groundwater%20contamination%20due%20to%20pit%20latrines%20located%20in%20a%20sandy%20aquifer.pdf
- Niipare, E. (2020). *Assessment of floodwater harvesting infrastructures in the Namibian Cuvelai-Etосha basin* (Issue April). <https://repository.unam.edu.na/handle/11070/2986>
- Oboh, I. P., & Egun, N. K. (2017). Utilization of Water Quality Index (WQI) in Water Quality Assessment of Groundwater in Agbor Metropolis, Delta State Nigeria. *International Science Technology Journal*, 10, 48–55.
<https://pdfs.semanticscholar.org/5f3a/c516b304b507216f27bba393d877cf576ab9.pdf>
- Olivier, D. W., & Xu, Y. (2019). Making effective use of groundwater to avoid another water supply crisis in Cape Town, South Africa. *Hydrogeol. J.*, 27(3), 823–826. <https://doi.org/10.1007/s10040-018-1893-0>

- Omer, N. H. (2019). *Water Quality Parameters*. IntechOpen.
<https://www.intechopen.com/>
- Onipe, T., Edokpayi, J. N., & Odiyo, J. O. (2020). A review on the potential sources and health implications of fluoride in groundwater of Sub-Saharan Africa. *Journal of Environmental Science and Health - Part A Toxic/Hazardous Substances and Environmental Engineering*, 55(9), 1078–1093.
<https://doi.org/10.1080/10934529.2020.1770516>
- Ou, Z., He, F., Zhu, Y., Lu, P., & Wang, L. (2023). Analysis of driving factors of water demand based on explainable artificial intelligence. *Journal of Hydrology: Regional Studies*, 47. <https://doi.org/10.1016/j.ejrh.2023.101396>
- Panagopoulos, G. P. (2013). Assessing the impacts of socio-economic and hydrological factors on urban water demand: A multivariate statistical approach. *Journal of Hydrology*, 518(PA), 42–48.
<https://doi.org/10.1016/j.jhydrol.2013.10.036>
- Pedro, J. P. B., Oliveira, C. A. da S., de Lima, S. C. R. B., & von Sperling, M. (2020). A review of sanitation technologies for flood-prone areas. *Journal of Water, Sanitation and Hygiene for Development*, 10(3), 397–412.
<https://doi.org/10.2166/WASHDEV.2020.019>
- Rajesh, R., Elango, L., & Brindha, K. (2019). Methods for assessing the groundwater quality. In *GIS and Geostatistical Techniques for Groundwater Science*. Elsevier Inc. <https://doi.org/10.1016/B978-0-12-815413-7.00006-7>

- RamyaPriya, R., & Elango, L. (2018). Evaluation of geogenic and anthropogenic impacts on spatio-temporal variation in quality of surface water and groundwater along Cauvery River, India. *Environmental Earth Sciences*, 77(1). <https://doi.org/10.1007/S12665-017-7176-6>
- Rangaiah, J., Mallikarjuna, V., & Udaya Bhaskar, P. (2021). Water Demand Analysis for Selected Rural Regions in Visakhapatnam District. *IOP Conference Series: Earth and Environmental Science*, 796(1). <https://doi.org/10.1088/1755-1315/796/1/012045>
- Ristow, D. C. M., Henning, E., Kalbusch, A., & Petersen, C. E. (2021). Models for forecasting water demand using time series analysis: A case study in southern brazil. *Journal of Water Sanitation and Hygiene for Development*, 11(2), 231–240. <https://doi.org/10.2166/washdev.2021.208>
- Ritchie, H., Spooner, F., & Roser, M. (2024). *Clean Water and Sanitation*. Our World in Data. <https://ourworldindata.org/clean-water-sanitation>
- Rodell, M., Famiglietti, J. S., Wiese, D. N., Reager, J. T., Beaudoin, H. K., Landerer, F. W., & Lo, M. H. (2018). Emerging trends in global freshwater availability. *Nature*, 557(7707), 651–659. <https://doi.org/10.1038/s41586-018-0123-1>
- Salimaco, R. A. (2023). Forecasting the Water Consumption in the City of Mati with Time Series Analysis. In *Sci.Int.(Lahore)* (Vol. 35, Issue 2). <https://www.researchgate.net/publication/369145946>
- SASSCAL WeatherNet. (n.d.). *SASSCAL WeatherNet*. <https://sasscalweathernet.org/>

Scanlon, B. R., Fakhreddine, S., Rateb, A., de Graaf, I., Famiglietti, J., Gleeson, T., Grafton, R. Q., Jobbagy, E., Kebede, S., Kolusu, S. R., Konikow, L. F., Long, D., Mekonnen, M., Schmied, H. M., Mukherjee, A., MacDonald, A., Reedy, R. C., Shamsudduha, M., Simmons, C. T., ... Zheng, C. (2023). Global water resources and the role of groundwater in a resilient water future. *Nature Reviews Earth & Environment* 2023 4:2, 4(2), 87–101. <https://doi.org/10.1038/s43017-022-00378-6>

Semar, A., Saibi, H., & Medjerab, A. (2013). Contribution of multivariate statistical techniques in the hydrochemical evaluation of groundwater from the Ouargla phreatic aquifer in Algeria. *Arabian Journal of Geosciences*, 6(9), 3427–3436. <https://doi.org/10.1007/s12517-012-0616-4>

Shaamhula, L. V., Smit, H. A. P., & van der Merwe, J. (2021). Community responses to the annual flooding (efundja) in the Cuvelai-Etoshia basin, Northern Namibia. *International Journal of Disaster Risk Reduction*, 61, 102372. <https://doi.org/10.1016/J.IJDRR.2021.102372>

Sharma, G., Lata, R., Thakur, N., Bajala, V., Kuniyal, J. C., & Kumar, K. (2021). Application of multivariate statistical analysis and water quality index for quality characterization of Parbati River, Northwestern Himalaya, India. *Discover Water*, 1(1). <https://doi.org/10.1007/s43832-021-00005-3>

Shifidi, V. T. (2016). Impact of flooding on rural livelihoods of the Cuvelai Basin in Northern Namibia. *Journal of Geography and Regional Planning*, 9(6), 104–121. <https://doi.org/10.5897/jgrp2015.0536>

- Shine, P., Scully, T., Upton, J., & Murphy, M. D. (2018). *Linear prediction modelling of electricity & on-farm direct water 1 consumption on pasture based dairy farms*. <https://www.sciencedirect.com/science/article/pii/S0168169917315247>
- Shooya, O. N. (2017). *Barriers and enablers to water access and community wellbeing in the Onesi constituency of Namibia: The case of Okalonga B and Onandjandja villages* [University of Cape Town]. <https://open.uct.ac.za/>
- Shukla, S. K. (2023). *The Correlation and Regression Analysis of Physicochemical Water Quality Parameters of Wainganga River, India*. 43(1), 11–17. [www.http://op.niscair.res.in/index/php/JIAEM/index](http://op.niscair.res.in/index/php/JIAEM/index)
- Singh, G., Jindal, T., Patel, N., Bhowmik, A., & Ahirwal, J. (2023). Appraisal of river water quality using multivariate statistics and water quality indices: a case of Hindon River (India). *Sustainable Water Resources Management*, 9(3). <https://doi.org/10.1007/s40899-023-00881-8>
- Sipes, J. L. (2010). *Sustainable Solutions for Water Resources*. John Wiley & Sons, Inc.
- Stańczyk, J., Kajewska-Szkudlarek, J., Lipiński, P., & Rychlikowski, P. (2022). Improving short-term water demand forecasting using evolutionary algorithms. *Scientific Reports*, 12(1). <https://doi.org/10.1038/s41598-022-17177-0>
- Strehmel, A., Schmalz, B., & Fohrer, N. (2016). Evaluation of Land Use, Land Management and Soil Conservation Strategies to Reduce Non-Point Source Pollution Loads in the Three Gorges Region, China. *Environmental Management*, 58(5), 906–921. <https://doi.org/10.1007/S00267-016-0758-3>

- Sukanya, S., & Joseph, S. (2023). Climate change impacts on water resources: An overview. *Visualization Techniques for Climate Change with Machine Learning and Artificial Intelligence*, 55–76. <https://doi.org/10.1016/B978-0-323-99714-0.00008-X>
- Tamason, C. C., Bessias, S., Villada, A., Tulsiani, S. M., Ensink, J. H. J., Gurley, E. S., & Mackie Jensen, P. K. (2016). Measuring domestic water use: a systematic review of methodologies that measure unmetered water use in low-income settings. *Tropical Medicine and International Health*, 21(11), 1389–1402. <https://doi.org/10.1111/tmi.12769>
- Tortajada, C., & Biswas, A. K. (2018). Achieving universal access to clean water and sanitation in an era of water scarcity: strengthening contributions from academia. *Current Opinion in Environmental Sustainability*, 34, 21–25. <https://doi.org/10.1016/J.COSUST.2018.08.001>
- UNICEF. (2023). *Sanitation*. <https://data.unicef.org/topic/water-and-sanitation/sanitation/>
- United Nation. (2018). *World Water Development Report 2018*. <https://www.unwater.org/publications/world-water-development-report-2018>
- United Nations. (2013). *Technical, Socioeconomic and Legal Terminology*. UN-ILibrary. <https://doi.org/https://doi.org/10.18356/70b462ce-en>
- Uyanık, G. K., & Güler, N. (2013). A Study on Multiple Linear Regression Analysis. *Procedia - Social and Behavioral Sciences*, 106, 234–240. <https://doi.org/10.1016/j.sbspro.2013.12.027>

- Vijai, P., & Bagavathi, S. P. (2018). Performance comparison of techniques for water demand forecasting. *Procedia Computer Science*, *143*, 258–266. <https://doi.org/10.1016/j.procs.2018.10.394>
- Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S. E., Sullivan, C. A., Liermann, C. R., & Davies, P. M. (2010). Global threats to human water security and river biodiversity. *Nature*, *467*(7315), 555–561. <https://doi.org/10.1038/nature09440>
- Wada, Y., Van Beek, L. P. H., Van Kempen, C. M., Reckman, J. W. T. M., Vasak, S., & Bierkens, M. F. P. (2010). Global depletion of groundwater resources. *Geophys. Res. Lett.*, *37*(20), L20402. <https://doi.org/10.1029/2010gl044571>
- Wang, X. jun, Zhang, J. yun, Shahid, S., Yu, L., Xie, C., Wang, B. xuan, & Zhang, X. (2018). Domestic water demand forecasting in the Yellow River basin under changing environment. *International Journal of Climate Change Strategies and Management*, *10*(3), 379–388. <https://doi.org/10.1108/IJCCSM-03-2017-0067>
- Wang, Y., Wan, T., & Tortajada, C. (2018). Water demand framework and water development: The case of China. *Water (Switzerland)*, *10*(12), 1–16. <https://doi.org/10.3390/w10121860>
- Wanke, H., Beyer, M., Hipondoka, M., Hamutoko, J., Gaj, M., Koeniger, P., & Himmelsbach, T. (2018). The long road to sustainability: integrated water quality and quantity assessments in the Cuvelai-Etoshia Basin, Namibia. *Biodiversity & Ecology*, *6*, 32. <https://doi.org/10.7809/b-e.00307>

- World Bank. (2021). *Climate Risk country profile: Namibia*.
https://climateknowledgeportal.worldbank.org/sites/default/files/2021-08/15931-WB_Namibia%20Country%20Profile-WEB.pdf
- World Bank. (2022, October 5). *Water Resources Management Overview*.
<https://www.worldbank.org/en/topic/waterresourcesmanagement#2>
- World Bank Group. (2023). *Sanitation*.
<https://www.worldbank.org/en/topic/sanitation>
- World Health Organization. (2011). Guidelines for Drinking Water Quality. In *Proceedings of the Royal Society of Medicine* (Vol. 55).
https://doi.org/10.5005/jp/books/11431_8
- World Water Day. (2021). *10 Facts About the Water Crisis*. Higher Life Foundation.
<https://www.higherlifefoundation.com/>
- Wu, J., Lu, J., Wen, X., Zhang, Z., & Lin, Y. (2019). Severe Nitrate Pollution and Health Risks of Coastal Aquifer Simultaneously Influenced by Saltwater Intrusion and Intensive Anthropogenic Activities. *Archives of Environmental Contamination and Toxicology*, 77(1), 79–87. <https://doi.org/10.1007/S00244-019-00636-7>
- Zakir, H. M., Sharmin, S., Akter, A., & Rahman, M. S. (2020). Assessment of health risk of heavy metals and water quality indices for irrigation and drinking suitability of waters: a case study of Jamalpur Sadar area, Bangladesh. *Environmental Advances*, 2. <https://doi.org/10.1016/J.ENVADV.2020.100005>

Zandler, H. (2011). *Near surface groundwater recharge modelling in the Cuvelai-Iishana Subbasin, Namibia Declaration of originality* [Universitat Wein].
<https://www.academia.edu/>

Zhang, B., & Chansheng, H. (2016). A modified water demand estimation method for drought identification over arid and semiarid regions. *Agricultural and Forest Meteorology*, 230–231, 58–66.
<https://doi.org/10.1016/j.agrformet.2015.11.015>

Zhou, X., Li, Z., Zheng, T., Yan, Y., Li, P., Odey, E. A., Mang, H. P., & Uddin, S. M. N. (2018). Review of global sanitation development. *Environment International*, 120, 246–261. <https://doi.org/10.1016/J.ENVINT.2018.07.047>

7. APPENDICES

7.1. Permission letter

CENTRE FOR RESEARCH SERVICES

Office of the Pro-Vice Chancellor: Research, Innovation & Development

University of Namibia, Private Bag 13301, Windhoek, Namibia

340 Mandume Ndemutayo Avenue, Pioneers Park, Office F223 - Fblock, Second Floor

☎ +264 61 206 4673; E-mail: malikmbulu@unam.na; URL: <http://www.unam.edu.na>



RESEARCH PERMISSION LETTER

Date: 27/01/2025

Student Name: Junias Eino

Student Number: 201714553

Programme: Master of Science in Civil Engineering

Approved Research Title: An Analysis of Water Demand in the Rural Area, Iishana System, Namibia

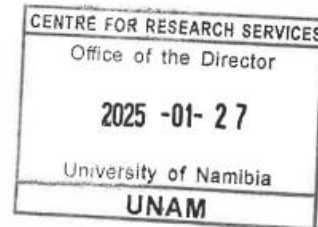
TO WHOM IT MAY CONCERN:

I hereby confirm that the above-mentioned student is registered at the University of Namibia for the programme indicated. The proposed study met all the requirements as stipulated in the University guidelines and has been approved by the relevant committees.

The proposal adheres to ethical principles as per attached Ethical Clearance Certificate. Permission is hereby granted to carry out the research as described in the approved proposal.

Best Regards

Dr. AEE Shikongo
Head: Postgraduate Research Support Services
Tel: +264 61 206 3129
E-mail: aeshikongo@unam.na



7.2. Ethical Clearance Certificate

RESEARCH ETHICS CLEARANCE CERTIFICATE



Reference Number: JED0424

Date: 5 December 2024

Dear Mr Junias Eino

This is to inform you that your application for research ethics approval has been approved for the duration of your studies. **You are required to apply for permission to conduct research from the relevant ministry/institution, if applicable, in addition to this ethical clearance.** You may contact the Ethics office (ethics@unam.na) for additional information.

Project title: An Analysis of Water Demand in the Rural Area, Iishana System, Namibia

Student number: 201714553

Level of degree: Masters

Name of degree: Master of Science in Civil Engineering

Email address: juniaselno@gmail.com

Supervisor(s): Dr A. Busari

Please note the following standard requirements for approval:

This ethical approval is issued by the University of Namibia's Research Ethics Committee following the University of Namibia's Research Ethics Policy and Guidelines. Ethical approval is given in respect of undertakings contained in the research ethics guidelines outlined below:

1. Any significant changes in the conditions or undertakings outlined in the approved Proposal must be communicated to the ethics committee. An application to make amendments may be necessary.
2. Any breaches of ethical undertakings or practices that have an impact on the ethical conduct of the research must be reported to the ethics committee.
3. The Principal Researcher must report issues of ethical compliance to the ethics committee (through the Chairperson) at the end of the Project or as may be requested by the ethics committee.
4. The ethics committee retains the right to:
 - i) Withdraw or amend this Ethical Clearance if any unethical practices (as outlined in the Research Ethics Policy) have been detected or suspected,
 - ii) Request for an ethical compliance report at any point during the research.

The ethics committee wishes you the best in your research.

Yours sincerely

Dr, Erasmus Shaanika (Chairperson of School of Engineering and the Built Environment Decentralized Ethics Committee)

Prof. Davis Mumbengegwi (Head of MRS, Centre for Research Services)

University of Namibia, Centre for Research Services
Office of the Pro-Vice Chancellor: Research Innovation and Development
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+264-61-2064624; ethics@unam.na, Fax+264-61-206 4624

7.3. Survey questionnaire.

SASSCAL WIRE 2.0_ WATER DEMAND WITHIN THE IISHANA SYSTEM, NAMIBIA

This is an anonymous survey created by a researcher at UNAM (201714553@unam.na). This survey is designed to collect data to be used in the preparation of a master's thesis by UNAM. Responses will be used exclusively for the purposes of the study and respondents are asked to answer truthfully about water demand. Your participation is extremely vital to this work and will surely contribute to identifying the water demand needs in the Iishana system in the Namibian side.

** Indicates required question*



Personal information

1. Settlement *

Mark only one oval.

Rural

2. Village *

3. Constituency *

4. Region *

Mark only one oval.

- Omusati
- Oshana
- Oshana

5. Gender *

Mark only one oval.

- Male
- Female

6. Age *

Mark only one oval.

- 18-25
- 26-35
- 36-45
- 46-55
- >55

7. Civil Status *

Mark only one oval.

- Single
- Married
- Divorced
- Widow
- Other: _____

8. Education level *

Mark only one oval.

- None
- Primary
- Secondary
- Tertiary

9. Career/Job type *

Mark only one oval.

- Civil Servant
- Individual/Entrepreneur
- Private
- Student
- Other: _____

Household Characteristics

10. How many people currently reside in your household? *

11. How many males live in your house? *

12. How many females live in your house? *

13. Please indicate the age group of the people in your household. *

Check all that apply.

- <29
 30-40
 40-50
 50-60
 >60

14. Could you please specify the income per capita per month? (N\$) *

Mark only one oval.

- <5 000
 5 000-10000
 10 000-15 000
 15 000-20 000
 >20 0000

Water sources

15. What type of water source do you use? *

Check all that apply.

- Borehole
 Burrow pits
 Well
 Spring
 Tap water
 Water pans
 Other: _____

16. Are the water sources seasonal or perennial? *

Mark only one oval.

Seasonal

Perennial

17. How far are the water sources from your house? (meters) *

Mark only one oval.

0-100

100-500

500-1000

>1000

18. What is the time spent to water sources and return home? (mins) *

Mark only one oval.

0-30

30-60

60-90

90-120

>120

19. Who fetch water? *

Mark only one oval.

Men

Women

Teenage (male)

Teenage (female)

20. Who is the provider of your drinking water service? *

Mark only one oval.

- Community-based
- Municipality
- Personal
- Other: _____

21. Are you charged for water? *

Mark only one oval.

- Yes
- No

22. How much does it cost per month? (N\$) *

Mark only one oval.

- <50
- 50-100
- 100-150
- 150-300
- >300
- Not Applicable

23. Who receives the payment? (Livestock) *

Mark only one oval.

- Community committee
- Municipality
- Private company
- Not Applicable

24. Who receives the payment? (Drinking) *

Mark only one oval.

- Community committee
- Municipality
- Private company
- Not Applicable

25. Does the cost for water varies along the year? *

Mark only one oval.

- Yes
- No
- Not Applicable

26. Has the access to water improved in the past 5-10 years? *

Mark only one oval.

- Yes
- No

27. Is the water sufficient? *

Mark only one oval.

- Yes
- No

Water demand

28. What are the various uses of water in your household? *

Check all that apply.

- Domestic (drinking, cooking, bathing, washing clothes and so on in residential houses)
- Irrigation
- Livestock
- Other: _____

29. Does your household use a water storage tank/container? *

Mark only one oval.

- Yes
- No

30. What is the capacity of the storage unit/tank? (liters) *

Mark only one oval.

- <300
- 300-500
- 500-1000
- 1000-2500
- >2500
- Not Applicable

31. What is the average amount of water used per person per day in your household? *

Mark only one oval.

- <40
- 40-80
- >80

Drought/climatic events

32. Do you use the same water sources all year? (rainy/dry season) *

Mark only one oval.

Yes

No

33. Does nomadic herder share water sources with you? *

Mark only one oval.

Yes

No

Not Applicable

Sanitation

34. What is the current status of the water quality? *

Mark only one oval.

Good

Poor

35. Do you treat the water from the water sources? *

Mark only one oval.

Yes

No

36. What is the sanitation facility that members of your household use? *

Mark only one oval.

- Flushing or flushing manually
- Open defecation
- Latrine

37. How deep is the latrine? (meters) *

Mark only one oval.

- <3
- 3-5
- >5
- Not Applicable

38. How far is the latrine from the water sources? (meters) *

Mark only one oval.

- 0-15
- 15-30
- 30-50
- >50
- Not Applicable

39. Where is the sanitation facility located? *

Mark only one oval.

- Near own home
- Neighbor's house
- Not Applicable
- Other: _____

Could you please give your opinions for improvement?

40. How can the water supply in the lishana system be improved? *

7.4. Water Sampled locations

Table 7.1: Location of the sampled water.

Location Description	Coordinate
Oshakati Burrow Pit (1)	17°43'52"S, 15°42'49"E
Okatana Pond (2)	17°39'59"S, 15°43'19"E
Endola Burrow Pit - Onanandi village (3)	17°35'11"S, 15°44'50"E
Endola Burrow Pit - Okamukwa village (4)	17°27'02"S, 15°44'42"E
Engela Burrow Pit (5)	17°27'01"S, 15°42'11"E
Ongenga Stengal dam (6)	17°27'39"S, 15°42'57"E
Okalongo Pond (7)	17°26'02"S, 15°19'14"E
Okalongo Burrow pit (8)	17°26'46"S, 15°15'48"E
Oshikuku Canal (9)	17°29'52"S, 15°21'40"E
Elim Burrow Pit (10)	17°45'54.2", 15°27'44.23"

7.5. Water quality data from NamWater



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Tel: (061) 71 2102

MICROBIOLOGY ANALYSIS REPORT

DETAILS OF SAMPLE

SENDER : Junias Eino, University of Namibia
 SAMPLE POINT NAME : Junias Eino, University of Namibia
 DATE SAMPLE TAKEN : 03 September 2024
 DATE SAMPLE RECEIVED : 03 September 2024

Sample Number	Location Description	Chlorine Reading		Heterotrophic plate count/1 ml after 48h at 35°C	Total coliforms count/100 ml after 22h at 35°C	Faecal coliform count/100 ml after 22h at 44.5°C	E.coli confirmation test after 24h at 35°C	Remarks
		Free Cl ₂	Total Cl ₂					
MB 77685	1. Oshakati Burrow Pit				166	488		Untreated water
MB 77686	2. Okatana Pond				687	461		Untreated water
MB 77687	3. Endola Burrow Pit - Onanandi village				>2420	87		Untreated water
MB 77688	4. Endola Burrow Pit - Okamukwa village				2420	1046		Untreated water
MB 77689	5. Engela Burrow Pit				161	55		Untreated water
MB 77690	6. Ongenga Stengal dam				>2420	>2420		Untreated water
MB 77691	7. Okalongo Pond				>2420	2420		Untreated water
MB 77692	8. Okalongo Burrow pit				921	770		Untreated water
MB 77693	9. Oshikuku Canal				>2420	120		Untreated water
MB 77694	10. Elim Burrow Pit				>2420	>2420		Untreated water



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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER : DS69507
 SENDER : University of Namibia: Ongwediva Campus
 SAMPLE POINT NAME : Iishana
 AREA DESCRIPTION : Cuvelai Basin
 LOCATION DESCRIPTION : Sample 1 -
 COMMENTS : EW17703

DATE SAMPLE TAKEN : 03 09 2024
 TIME TAKEN : 3:30 pm
 DATE SAMPLE RECEIVED : 05 09 2024
 DATE SAMPLE ANALYSED : 09 09 2024

DETERMINANT :	Value	Units	Classification
pH	8.0		Ideal
Sodium as Na	50	mg/l	Ideal
Potassium as K	3	mg/l	Ideal
Sulphate as SO ₄	17	mg/l	Ideal
Nitrate as N	<0.5	mg/l	Ideal
Nitrite as N	<0.1	mg/l	Ideal
Chloride as Cl	16.0	mg/l	Ideal
Total Alkalinity as CaCO ₃	86.0	mg/l	
Total Hardness as CaCO ₃	52	mg/l	Ideal
Calcium as CaCO ₃	35	mg/l	Ideal
Magnesium as CaCO ₃	17	mg/l	Ideal
Iron as Fe	0.72	mg/l	Below Standard
Ammonia as N	0.04	mg/l	



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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER : DS69508
 SENDER : University of Namibia: Ongwediva Campus
 SAMPLE POINT NAME : lishana
 AREA DESCRIPTION : Cuvelai Basin
 LOCATION DESCRIPTION : Sample 2 -
 COMMENTS : EW17704

 DATE SAMPLE TAKEN : 03 09 2024
 TIME TAKEN : 9:00 am
 DATE SAMPLE RECEIVED : 05 09 2024
 DATE SAMPLE ANALYSED : 09 09 2024

DETERMINANT :	Value	Units	Classification
pH	8.0		Ideal
Sodium as Na	18	mg/l	Ideal
Potassium as K	4	mg/l	Ideal
Sulphate as SO ₄	14	mg/l	Ideal
Nitrate as N	<0.5	mg/l	Ideal
Nitrite as N	<0.1	mg/l	Ideal
Chloride as Cl	2.0	mg/l	Ideal
Total Alkalinity as CaCO ₃	44.0	mg/l	
Total Hardness as CaCO ₃	58	mg/l	Ideal
Calcium as CaCO ₃	38	mg/l	Ideal
Magnesium as CaCO ₃	21	mg/l	Ideal
Iron as Fe	6.4	mg/l	Below Standard
Ammonia as N	0.08	mg/l	



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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER : DS69509
 SENDER : University of Namibia: Ongwediva Campus
 SAMPLE POINT NAME : Iishana
 AREA DESCRIPTION : Cuvelai Basin
 LOCATION DESCRIPTION : Sample 3 -
 COMMENTS : EW17705

DATE SAMPLE TAKEN : 03 09 2024
 TIME TAKEN : 9:40 am
 DATE SAMPLE RECEIVED : 05 09 2024
 DATE SAMPLE ANALYSED : 09 09 2024

DETERMINANT :	Value	Units	Classification
pH	8.5		Ideal
Sodium as Na	60	mg/l	Ideal
Potassium as K	3	mg/l	Ideal
Sulphate as SO ₄	33	mg/l	Ideal
Nitrate as N	<0.5	mg/l	Ideal
Nitrite as N	<0.1	mg/l	Ideal
Chloride as Cl	31.0	mg/l	Ideal
Total Alkalinity as CaCO ₃	76.0	mg/l	
Total Hardness as CaCO ₃	66	mg/l	Ideal
Calcium as CaCO ₃	45	mg/l	Ideal
Magnesium as CaCO ₃	21	mg/l	Ideal
Iron as Fe	0.21	mg/l	Acceptable
Ammonia as N	0.07	mg/l	



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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER : DS69510
 SENDER : University of Namibia: Ongwediva Campus
 SAMPLE POINT NAME : Iishana
 AREA DESCRIPTION : Cuvelai Basin
 LOCATION DESCRIPTION : Sample 4 -
 COMMENTS : EW17706

DATE SAMPLE TAKEN : 03 09 2024
 TIME TAKEN : 9:35 am
 DATE SAMPLE RECEIVED : 05 09 2024
 DATE SAMPLE ANALYSED : 09 09 2024

DETERMINANT :

	Value	Units	Classification
pH	8.1		Ideal
Sodium as Na	26	mg/l	Ideal
Potassium as K	9	mg/l	Ideal
Sulphate as SO ₄	8	mg/l	Ideal
Nitrate as N	<0.5	mg/l	Ideal
Nitrite as N	<0.1	mg/l	Ideal
Chloride as Cl	2.0	mg/l	Ideal
Total Alkalinity as CaCO ₃	78.0	mg/l	
Total Hardness as CaCO ₃	101	mg/l	Ideal
Calcium as CaCO ₃	68	mg/l	Ideal
Magnesium as CaCO ₃	33	mg/l	Ideal
Iron as Fe	1.4	mg/l	Below Standard
Ammonia as N	0.31	mg/l	



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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER : DS69511
 SENDER : University of Namibia: Ongwediva Campus
 SAMPLE POINT NAME : lishana
 AREA DESCRIPTION : Cuvelai Basin
 LOCATION DESCRIPTION : Sample 5 -
 COMMENTS : EW17707

DATE SAMPLE TAKEN : 03 09 2024
 TIME TAKEN : 11:55 am
 DATE SAMPLE RECEIVED : 05 09 2024
 DATE SAMPLE ANALYSED : 09 09 2024

DETERMINANT :	Value	Units	Classification
pH	8.2		Ideal
Sodium as Na	27	mg/l	Ideal
Potassium as K	5	mg/l	Ideal
Sulphate as SO ₄	124	mg/l	Acceptable
Nitrate as N	<0.5	mg/l	Ideal
Nitrite as N	<0.1	mg/l	Ideal
Chloride as Cl	1.0	mg/l	Ideal
Total Alkalinity as CaCO ₃	58.0	mg/l	
Total Hardness as CaCO ₃	162	mg/l	Ideal
Calcium as CaCO ₃	133	mg/l	Ideal
Magnesium as CaCO ₃	29	mg/l	Ideal
Iron as Fe	0.03	mg/l	Ideal
Ammonia as N	0.05	mg/l	



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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER : DS69512
 SENDER : University of Namibia: Ongwediva Campus
 SAMPLE POINT NAME : Iishana
 AREA DESCRIPTION : Cuvelai Basin
 LOCATION DESCRIPTION : Sample 6 -
 COMMENTS : EW17708

 DATE SAMPLE TAKEN : 03 09 2024
 TIME TAKEN : 12:30 pm
 DATE SAMPLE RECEIVED : 05 09 2024
 DATE SAMPLE ANALYSED : 09 09 2024

DETERMINANT :

DETERMINANT :	Value	Units	Classification
pH	9.3		Below Standard
Sodium as Na	690	mg/l	Below Standard
Potassium as K	10	mg/l	Ideal
Sulphate as SO ₄	113	mg/l	Acceptable
Nitrate as N	<0.5	mg/l	Ideal
Nitrite as N	<0.1	mg/l	Ideal
Chloride as Cl	640	mg/l	Below Standard
Total Alkalinity as CaCO ₃	510	mg/l	
Total Hardness as CaCO ₃	53	mg/l	Ideal
Calcium as CaCO ₃	40	mg/l	Ideal
Magnesium as CaCO ₃	13	mg/l	Ideal
Iron as Fe	0.88	mg/l	Below Standard
Ammonia as N	0.37	mg/l	



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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER : DS69513
 SENDER : University of Namibia: Ongwediva Campus
 SAMPLE POINT NAME : Iishana
 AREA DESCRIPTION : Cuvelai Basin
 LOCATION DESCRIPTION : Sample 7 -
 COMMENTS : EW17709

DATE SAMPLE TAKEN : 03 09 2024
 TIME TAKEN : 1:00 pm
 DATE SAMPLE RECEIVED : 05 09 2024
 DATE SAMPLE ANALYSED : 09 09 2024

DETERMINANT :	Value	Units	Classification
pH	8.1		Ideal
Sodium as Na	265	mg/l	Acceptable
Potassium as K	21	mg/l	Ideal
Sulphate as SO ₄	112	mg/l	Acceptable
Nitrate as N	<0.5	mg/l	Ideal
Nitrite as N	<0.1	mg/l	Ideal
Chloride as Cl	350	mg/l	Below Standard
Total Alkalinity as CaCO ₃	174	mg/l	
Total Hardness as CaCO ₃	124	mg/l	Ideal
Calcium as CaCO ₃	83	mg/l	Ideal
Magnesium as CaCO ₃	42	mg/l	Ideal
Iron as Fe	0.24	mg/l	Acceptable
Ammonia as N	0.06	mg/l	



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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER : DS69514
 SENDER : University of Namibia: Ongwediva Campus
 SAMPLE POINT NAME : lishana
 AREA DESCRIPTION : Cuvelai Basin
 LOCATION DESCRIPTION : Sample 8 -
 COMMENTS : EW17710

DATE SAMPLE TAKEN : 03 09 2024
 TIME TAKEN : 1:30 pm
 DATE SAMPLE RECEIVED : 05 09 2024
 DATE SAMPLE ANALYSED : 09 09 2024

DETERMINANT :	Value	Units	Classification
pH	8.2		Ideal
Sodium as Na	41	mg/l	Ideal
Potassium as K	6	mg/l	Ideal
Sulphate as SO ₄	8	mg/l	Ideal
Nitrate as N	<0.5	mg/l	Ideal
Nitrite as N	<0.1	mg/l	Ideal
Chloride as Cl	39.0	mg/l	Ideal
Total Alkalinity as CaCO ₃	64.0	mg/l	
Total Hardness as CaCO ₃	67	mg/l	Ideal
Calcium as CaCO ₃	50	mg/l	Ideal
Magnesium as CaCO ₃	17	mg/l	Ideal
Iron as Fe	0.17	mg/l	Ideal
Ammonia as N	0.19	mg/l	



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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER : DS69515
 SENDER : University of Namibia: Ongwediva Campus
 SAMPLE POINT NAME : lishana
 AREA DESCRIPTION : Cuvelai Basin
 LOCATION DESCRIPTION : Sample 9 -
 COMMENTS : EW17711

DATE SAMPLE TAKEN : 03 09 2024
 TIME TAKEN : 2:05 pm
 DATE SAMPLE RECEIVED : 05 09 2024
 DATE SAMPLE ANALYSED : 09 09 2024

DETERMINANT :

	Value	Units	Classification
pH	7.4		Ideal
Sodium as Na	4	mg/l	Ideal
Potassium as K	3	mg/l	Ideal
Sulphate as SO ₄	5	mg/l	Ideal
Nitrate as N	<0.5	mg/l	Ideal
Nitrite as N	<0.1	mg/l	Ideal
Chloride as Cl	<1.0	mg/l	Ideal
Total Alkalinity as CaCO ₃	36.0	mg/l	
Total Hardness as CaCO ₃	48	mg/l	Ideal
Calcium as CaCO ₃	40	mg/l	Ideal
Magnesium as CaCO ₃	8	mg/l	Ideal
Iron as Fe	0.69	mg/l	Below Standard
Ammonia as N	0.22	mg/l	



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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:

SAMPLE NUMBER : DS69516
 SENDER : University of Namibia: Ongwediva Campus
 SAMPLE POINT NAME : lishana
 AREA DESCRIPTION : Cuvelai Basin
 LOCATION DESCRIPTION : Sample 10 -
 COMMENTS : EW17712

DATE SAMPLE TAKEN : 03 09 2024
 TIME TAKEN : 2:42 pm
 DATE SAMPLE RECEIVED : 05 09 2024
 DATE SAMPLE ANALYSED : 09 09 2024

DETERMINANT :	Value	Units	Classification
pH	8.2		Ideal
Sodium as Na	134	mg/l	Acceptable
Potassium as K	5	mg/l	Ideal
Sulphate as SO ₄	34	mg/l	Ideal
Nitrate as N	<0.5	mg/l	Ideal
Nitrite as N	<0.1	mg/l	Ideal
Chloride as Cl	109	mg/l	Acceptable
Total Alkalinity as CaCO ₃	106	mg/l	
Total Hardness as CaCO ₃	33	mg/l	Ideal
Calcium as CaCO ₃	20	mg/l	Ideal
Magnesium as CaCO ₃	13	mg/l	Ideal
Iron as Fe	2.7	mg/l	Below Standard
Ammonia as N	0.06	mg/l	

7.6. Computation of Water Quality Index (WQI)

Table 7.2: Computation of Water Quality Index (Site 2).

Parameter s	Acceptable limit	Measured value	wi	Wi	qi	WQI*100
EC	300	170	1	0.03	0.57	1.72
Turbidity	5	100	4	0.12	20	242.42
pH	9.0	8	1	0.03	0.89	2.69
DO	10	8.09	1	0.03	0.81	2.45
Hardness	400	58	1	0.03	0.15	0.44
Cl ⁻	300	16	4	0.12	0.05	0.65
NH ₃	0.5	0.08	1	0.03	0.16	0.48
NO ₃ ⁻	11	0.5	1	0.03	0.05	0.14
NO ₂ ⁻	0.15	0.1	1	0.03	0.67	2.02
SO ₄ ²⁻	300	14	2	0.06	0.05	0.28
Ca ²⁺	150	38	2	0.06	0.25	1.54
Fe ²⁺	300	6.4	1	0.03	0.02	0.06
Mg ²⁺	70	21	3	0.09	0.3	2.73
K ⁺	100	4	5	0.15	0.04	0.61
Na ⁺	300	18	5	0.15	0.06	0.91
Sum			33	1		259.14

Table 7.3: Computation of Water Quality Index (Site 3).

Parameter s	Acceptable limit	Measured value	w i	Wi	qi	WQI*100
EC	300	458	1	0.03	1.53	4.63
Turbidity	5	25.7	4	0.12	5.14	62.30
pH	9.0	8.5	1	0.03	0.94	2.86
DO	10	7.11	1	0.03	0.71	2.15
Hardness	400	66	1	0.03	0.17	0.50
Cl ⁻	300	31	4	0.12	0.10	1.25
NH ₃	0.5	0.07	1	0.03	0.14	0.42
NO ₃ ⁻	11	0.5	1	0.03	0.05	0.14
NO ₂ ⁻	0.15	0.1	1	0.03	0.67	2.02
SO ₄ ²⁻	300	33	2	0.06	0.11	0.67
Ca ²⁺	150	45	2	0.06	0.3	1.82
Fe ²⁺	300	0.21	1	0.03	0.001	0.002
Mg ²⁺	70	21	3	0.09	0.3	2.73
K ⁺	100	3	5	0.15	0.03	0.45
Na ⁺	300	60	5	0.15	0.2	3.03
Sum			3	1		84.98
			3			

Table 7.4: Computation of Water Quality Index (Site 4).

Parameter s	Acceptable limit	Measured value	wi	Wi	qi	WQI*100
EC	300	326	1	0.03	1.09	3.29
Turbidity	5	100	4	0.12	20	242.42
pH	9.0	8.1	1	0.03	0.9	2.73
DO	10	7.88	1	0.03	0.79	2.39
Hardness	400	101	1	0.03	0.25	0.77
Cl ⁻	300	2	4	0.12	0.01	0.08
NH ₃	0.5	0.31	1	0.03	0.62	1.88
NO ₃ ⁻	11	0.5	1	0.03	0.05	0.14
NO ₂ ⁻	0.15	0.1	1	0.03	0.67	2.02
SO ₄ ²⁻	300	8	2	0.06	0.03	0.16
Ca ²⁺	150	68	2	0.06	0.45	2.75
Fe ²⁺	300	1.4	1	0.03	0.01	0.03
Mg ²⁺	70	33	3	0.09	0.47	4.29
K ⁺	100	9	5	0.15	0.09	1.36
Na ⁺	300	26	5	0.15	0.09	1.31
Sum			33	1		265.62

Table 7.5: Computation of Water Quality Index (Site 5).

Parameter s	Acceptable limit	Measured value	wi	Wi	qi	WQI*10 0
EC	300	44	1	0.03	0.15	0.44
Turbidity	5	26.8	4	0.12	5.36	64.97
pH	9.0	8.2	1	0.03	0.91	2.76
DO	10	7.38	1	0.03	0.74	2.24
Hardness	400	162	1	0.03	0.41	1.23
Cl ⁻	300	1	4	0.12	0.00	0.04
NH ₃	0.5	0.05	1	0.03	0.10	0.30
NO ₃ ⁻	11	0.5	1	0.03	0.05	0.14
NO ₂ ⁻	0.15	0.1	1	0.03	0.67	2.02
SO ₄ ²⁻	300	124	2	0.06	0.41	2.51
Ca ²⁺	150	133	2	0.06	0.89	5.37
Fe ²⁺	300	0.03	1	0.03	0.00	0.00
Mg ²⁺	70	29	3	0.09	0.41	3.77
K ⁺	100	5	5	0.15	0.05	0.76
Na ⁺	300	27	5	0.15	0.09	1.36
Sum			33	1		87.91

Table 7.6: Computation of Water Quality Index (Site 6).

Parameter s	Acceptable limit	Measured value	wi	Wi	qi	WQI*10 0
EC	300	3.91	1	0.03	0.01	0.04
Turbidity	5	100	4	0.12	20	242.42
pH	9.0	9.3	1	0.03	1.03	3.13
DO	10	8.03	1	0.03	0.80	2.43
Hardness	400	53	1	0.03	0.13	0.40
Cl ⁻	300	640	4	0.12	2.13	25.86
NH ₃	0.5	0.37	1	0.03	0.74	2.24
NO ₃ ⁻	11	0.5	1	0.03	0.05	0.14
NO ₂ ⁻	0.15	0.1	1	0.03	0.67	2.02
SO ₄ ²⁻	300	113	2	0.06	0.38	2.28
Ca ²⁺	150	40	2	0.06	0.27	1.62
Fe ²⁺	300	0.88	1	0.03	0.003	0.01
Mg ²⁺	70	13	3	0.09	0.19	1.69
K ⁺	100	10	5	0.15	0.1	1.52
Na ⁺	300	690	5	0.15	2.3	34.85
Sum			33	1		320.65

Table 7.7: Computation of Water Quality Index (Site 7).

Parameter s	Acceptable limit	Measured value	wi	Wi	qi	WQI*10 0
EC	300	1846	1	0.03	6.15	18.65
Turbidity	5	100	4	0.12	20	242.42
pH	9.0	8.1	1	0.03	0.9	2.73
DO	10	7.45	1	0.03	0.75	2.26
Hardness	400	124	1	0.03	0.31	0.94
Cl ⁻	300	350	4	0.12	1.17	14.14
NH ₃	0.5	0.06	1	0.03	0.12	0.36
NO ₃ ⁻	11	0.5	1	0.03	0.05	0.14
NO ₂ ⁻	0.15	0.1	1	0.03	0.67	2.02
SO ₄ ²⁻	300	112	2	0.06	0.37	2.26
Ca ²⁺	150	83	2	0.06	0.55	3.35
Fe ²⁺	300	0.24	1	0.03	0.001	0.002
Mg ²⁺	70	42	3	0.09	0.60	5.45
K ⁺	100	21	5	0.15	0.21	3.18
Na ⁺	300	265	5	0.15	0.88	13.38
Sum			33	1		311.30

Table 7.8: Computation of Water Quality Index (Site 8).

Parameter s	Acceptable limit	Measured value	wi	Wi	qi	WQI*10 0
EC	300	357	1	0.03	1.19	3.61
Turbidity	5	100	4	0.12	20	242.42
pH	9.0	8.2	1	0.03	0.91	2.76
DO	10	7.3	1	0.03	0.73	2.21
Hardness	400	67	1	0.03	0.17	0.51
Cl ⁻	300	39	4	0.12	0.13	1.58
NH ₃	0.5	0.19	1	0.03	0.38	1.15
NO ₃ ⁻	11	0.5	1	0.03	0.05	0.14
NO ₂ ⁻	0.15	0.1	1	0.03	0.67	2.02
SO ₄ ²⁻	300	8	2	0.06	0.03	0.16
Ca ²⁺	150	50	2	0.06	0.33	2.02
Fe ²⁺	300	0.17	1	0.03	0.001	0.002
Mg ²⁺	70	17	3	0.09	0.24	2.21
K ⁺	100	6	5	0.15	0.06	0.91
Na ⁺	300	41	5	0.15	0.14	2.07
Sum			33	1		263.77

Table 7.9: Computation of Water Quality Index (Site 9).

Parameter s	Acceptable limit	Measured value	wi	Wi	qi	WQI*10 0
EC	300	56.4	1	0.03	0.19	0.57
Turbidity	5	28.3	4	0.12	5.66	68.61
pH	9.0	7.4	1	0.03	0.82	2.49
DO	10	7.65	1	0.03	0.77	2.32
Hardness	400	48	1	0.03	0.12	0.36
Cl ⁻	300	1	4	0.12	0.00	0.04
NH ₃	0.5	0.22	1	0.03	0.44	1.33
NO ₃ ⁻	11	0.5	1	0.03	0.05	0.14
NO ₂ ⁻	0.15	0.1	1	0.03	0.67	2.02
SO ₄ ²⁻	300	5	2	0.06	0.02	0.10
Ca ²⁺	150	40	2	0.06	0.27	1.62
Fe ²⁺	300	0.69	1	0.03	0.002	0.01
Mg ²⁺	70	8	3	0.09	0.11	1.04
K ⁺	100	3	5	0.15	0.03	0.45
Na ⁺	300	4	5	0.15	0.01	0.20
Sum			33	1		81.30

Table 7.10: Computation of Water Quality Index (Site 10).

Parameter s	Acceptable limit	Measured value	wi	Wi	qi	WQI*10 0
EC	300	727	1	0.03	2.42	7.34
Turbidity	5	100	4	0.12	20	242.42
pH	9.0	8.2	1	0.03	0.91	2.76
DO	10	7.81	1	0.03	0.78	2.37
Hardness	400	33	1	0.03	0.08	0.25
Cl ⁻	300	109	4	0.12	0.36	4.40
NH ₃	0.5	0.06	1	0.03	0.12	0.36
NO ₃ ⁻	11	0.5	1	0.03	0.05	0.14
NO ₂ ⁻	0.15	0.1	1	0.03	0.67	2.02
SO ₄ ²⁻	300	34	2	0.06	0.11	0.69
Ca ²⁺	150	20	2	0.06	0.13	0.81
Fe ²⁺	300	2.7	1	0.03	0.01	0.03
Mg ²⁺	70	13	3	0.09	0.19	1.69
K ⁺	100	5	5	0.15	0.05	0.76
Na ⁺	300	134	5	0.15	0.45	6.77
Sum			33	1		272.81

7.7. Piper diagram Analysis

7.7.1. Equivalent concentrations

Table 7.11: Equivalent concentrations of the major cations and anions.

Site	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	SO ₄ ²⁻	Cl ⁻	HCO ₃ ⁻	Cations sum	Anions sum
1	2.17	0.08	1.75	1.40	0.35	0.45	1.72	5.40	2.52
2	0.78	0.10	1.90	1.73	0.29	0.06	0.88	4.51	1.23
3	2.61	0.08	2.25	1.73	0.69	0.87	1.52	6.66	3.08
4	1.13	0.23	3.39	2.72	0.17	0.06	1.56	7.47	1.78
5	1.17	0.13	6.64	2.39	2.58	0.03	1.16	10.33	3.77
6	30.01	0.26	2.00	1.07	2.35	18.05	10.20	33.34	30.60
7	11.53	0.54	4.14	3.46	2.33	9.87	3.48	19.66	15.68
8	1.78	0.15	2.50	1.40	0.17	1.10	1.28	5.83	2.55
9	0.17	0.08	2.00	0.66	0.10	0.03	0.72	2.91	0.85
10	5.83	0.13	1.00	1.07	0.71	3.07	2.12	8.02	5.90

7.7.2. Relative concentrations

Table 7.12: Relative concentrations of the major cations and anions.

Site	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	SO ₄ ²⁻	Cl ⁻	HCO ₃ ⁻
1	40.30	1.42	32.36	25.92	14.02	17.87	68.11
2	17.36	2.27	42.05	38.32	23.74	4.60	71.66
3	39.19	1.15	33.72	25.95	22.30	28.38	49.32
4	15.14	3.08	45.43	36.35	9.34	3.16	87.49
5	11.37	1.24	64.28	23.11	68.49	0.75	30.76
6	90.04	0.77	5.99	3.21	7.69	58.99	33.32
7	58.63	2.73	21.07	17.58	14.87	62.95	22.18
8	30.59	2.63	42.79	23.99	6.54	43.20	50.26
9	5.99	2.64	68.71	22.66	12.22	3.31	84.47
10	72.64	1.59	12.44	8.82	11.99	52.09	35.91