SCHOOL OF POSTGRADUATE STUDIES

THE EFFECTS OF CLIMATE CHANGE ON URBAN WASH SYSTEMS IN ZAMBIA'S CHIRUNDU DISTRICT: ASSESSING VULNERABILITIES AND EXPLORING NON-REVENUE WATER MANAGEMENT AS AN ADAPTATION STRATEGY.

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Declaration

I Melody Chama Kunda declare that the work presented for assessment conforms to copyright and academic writing rules and the University research ethics.

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Dedication

I dedicate this dissertation to the all-mighty God. I would also like to dedicate this work to my parents for creating the foundation I had in order for me to attain this achievement. To my siblings for being there for me and supporting me. I wish to dedicate this to my mentor for the encouragement and direction given.

Acknowledgements

I would like to extend my profound gratitude to all entities and individuals whose contributions were pivotal in the execution of the Research Study. I would like to acknowledge the Ministry of Community Development and Social Services (MCDSS), Water Resources Management Authority (WARMA), Meteorological Department Zambia, Southern Water Supply and Sanitation Company (SWSC) for providing me with the data that was used to develop this dissertation.

I would like to appreciate the participants during the research study for providing the information and willingly participating in this study. The access to homes and facilities is appreciated as it eased the process of the research. Additionally, I would like to thank the enumerators for their diligence in this research study. My appreciation goes towards my supervisor, Dr Alick Muvundika, for his patience and diligence in responding and providing guidance throughout the research.

It is with hope that this dissertation will provide insight to the community and aid decision makers to better Chirundu district.

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List of Acronyms/ Abbreviations

°C	Degrees Celsius
8NDP	Eighth National Development Plan
DMAs	District Metered Areas
ENSO	El Niño/Southern Oscillation
GHG	Greenhouse Gas
GRZ	The Government of the Republic of Zambia
HOMIS	Holistic Management Information System
LWSC	Lusaka Water and Sanitation Company
MVI	Multidimensional Vulnerability Index
MWDS	Ministry of Water Development and Sanitation
NAP	National Adaptation Plan for Zambia
NRW	Non-Revenue Water
NWASCO	National Water Supply and Sanitation council
PRV	Pressure Reducing Valve
SCADA	Supervisory Control and Access to Data
SDGs	Sustainable Development Goals
SWSC	Southern Water and Sanitation Company Limited
UNICEF	United Nations International Children's Emergency Fund
VIP	Ventilated Improved Pit latrines
WARMA	Water Resources Management Authority
WASH	Water, Sanitation and Hygiene
WBG	World Bank Group
WRI	World Resources Institute
ZMW	Zambian Kwacha

Abstract

Access to water is a basic human right and essential to health. Water, Sanitation and Hygiene (WASH) are vital and but also vulnerable to climate change. Increasing temperatures and dropping precipitation poses a threat to the water supply in the urban area of Chirundu district. Climatic events such as drought and floods affect the water quality and quantity, which in turn also affects sanitation and hygiene. The objectives of this research was to assess the vulnerabilities of WASH systems in Chirundu district to climate change as well as to explore the potential of Non-Revenue Water (NRW) management as an adaptation strategy. Therefore, a case study of Chirundu's urban area was conducted using the mixed methodology.

Chirundu's urban area is currently experiencing a drought caused by the El Niño which has worsened the water supply situation. Chirundu is experiencing water scarcity which is also affecting sanitation and hygiene. With the projected increase in temperature and lowered water supply, this situation is seen to worsen over the decades if resilience against climate change is not strengthened. Vulnerabilities were said to include, diseases such as diarrhea, dysentery and typhoid. Additionally, the old water supply infrastructures make WASH vulnerable to climate change.

With the water crisis and scarcity due to climate change, it is important that water losses are avoided. Water losses also puts a financial strain on water utility companies as there is lost revenue which prevents the expansion and sustainability of the water utilities. This study found that NRW is high with the highest percentage at 67% and an average of 32.57% experienced by the water utility Southern Water and Sanitation Company (SWSC) Chirundu in 2024 mostly attributed to leakages and low metering ratio. The ratio between the total water billed and total production was found to be 1:1.60, with the total water produced being twice as much as the total water billed. This coupled with the high-power consumption expenses with a total of Three Hundred Seventy-Seven Thousand Thirty-Three Zambian Kwacha (ZMW 377,033) for the period of January to August in 2024 indicates the unsustainability of their operations especially in the face of climate change. Innovative methods such as SCADA could be used to reduce NRW.

1 Introduction

1.1 The Background

Climate refers to long-term patterns of weather, including temperature, precipitation, and storm events (Dietz, et al., 2020). Climate change involves both shifts in long-term averages and increased variation around them. This is due to increased concentration of greenhouse gas (GHG) in the atmosphere including carbon dioxide, methane, nitrous oxides, and chlorofluorocarbons while also decreasing the albedo, or reflectivity, of the earth's surface, thus, extreme events becoming more frequent and severe (Ibid).

Samer Fawzy et.al (2020) defines climate change as the shift in climate patterns. This has been attributed to greenhouse gas (GHG) emissions which trap heat in the earth's atmosphere. Natural systems such as forest fires, earthquakes, oceans, permafrost, wetlands and volcanoes as well as anthropogenic activities predominantly related to energy production, industrial activities, land use and land-use change have been stated to be the main source of GHGs (Fawzy, et al., 2020).

Statistical analysis was conducted by Xi-Liu Yue and Qing-Xian Gao, to illustrate the significance of global GHG emissions from natural systems and anthropogenic activities. A conclusion was drawn which demonstrated that the earth's natural system can be considered as self-balancing and that anthropogenic emissions are an added extra pressure on the earth system (Yue & Gao, 2018). While the earth's climate has always been dynamic, there are substantial and rapid changes currently experienced that could overwhelm the adaptive capacity and might put the climate and biosphere into immensely disruptive patterns (Dietz, et al., 2020).

Water, Sanitation and Hygiene (WASH) has three main components namely access and availability to water, adequate sanitation, and hygiene (Mackinnon, et al., 2019). WASH interventions are diverse which include water access (i.e., water quality, water quantity, and distance to water), sanitation access (i.e., access to improved latrines, latrine maintenance, and faecal sludge management), and hygiene practices (e.g., handwashing before eating and/or after defecation, water treatment, use of soap and water storage practices) (Ross, et al., 2020).

There are negative and positive effects of climate change on human and natural systems such as livelihoods, health and wellbeing, ecosystems and species, services, infrastructure, and economic, social and cultural assets (IPCC, 2018). Climate change influences the frequency, duration, intensity, and geographic distribution of climate hazards. Climate change affects WASH by increasing risks to services and access. It is the possibility that a physical WASH system, for instance a piped water supply or sanitation facility, is exposed to a hazard and the severity of the consequences. Decreased rainfall, combined with increased water abstraction driven by population increase, high water consumption per capita, or greater water demand driven by an increase of extremely hot days, can lead to the overexploitation and eventually depletion of water resources (Megaw, et al., 2020). Water scarcity is projected to increase with the rise of global temperatures resulting from climate change (UN, 2023).

In 2022, 2.2 billion people lacked safely managed drinking water, 3.5 billion people lacked safely managed sanitation and 2 billion lacked a basic handwashing facility globally (ibid). Lack of access to WASH causes 1.6 million deaths every year, with 1.2 million attributed to gastrointestinal illnesses such as diarrhoea and acute respiratory infections (e.g., pneumonia). Poor WASH reduces nutrition as well as educational attainment. Additionally, it causes stress endangering vulnerable populations, most especially women and girls (Chirgwin, et al., 2021).

WASH has been a priority on the development agenda for the past fifty (50) years (Mackinnon, et al., 2019). In the 1980s, The International Drinking-Water, Supply and Sanitation Decade (IDWSSD) began a new approach towards the water sector development with the goal of providing all people with safe quality water in adequate quantity and basic sanitation facilities by 1990 (O'Rourke, 1992). This was followed by the Millennium Development Goals (MDGs) from 2000 to 2015 to increase access to WASH. The United Nations' Sustainable Development Goals (SDGs) 2015 to 2030 renewed and expanded the targets under MDGs. SDG 6, Clean Water and Sanitation, targets to 'ensure availability and sustainable management of water and sanitation for all' (Mackinnon, et al., 2019).

Zambia's Eighth National Development Plan (8NDP) 2022 to 2026 aims for a social economic transformation for improved livelihoods. It indicates that over exploitation and poor management of natural resources have increased the effects of climate change such as droughts, floods and extreme temperatures, thereby affecting the water sector and limiting access to clean and safe drinking water. Strategic development area Environmental Sustainability, focuses on enhanced adaptation and mitigation as well as sustainable environment and natural resources management. Strategic development area Human and Social Development, highlights the development outcome Improved Water Supply and Sanitation. The strategy on improved access to clean and safe water prioritizes infrastructure development and maintenance, and water quality monitoring. Additionally, improved sanitation services focus on Infrastructure development and maintenance, solid waste management, sanitation and hygiene promotion, and investment promotion (GRZ, 2022).

It is predicted that by 2030, nearly 50% of the world's population will face water crisis. Therefore, effective water distribution is required to minimise the water losses and to ensure sustainability of water reserve for a long period. Water losses or Non-Revenue Water (NRW) refers to the treated water that has been produced from water plant which did not reach the customer/ consumer and did not give any revenue (Malek, et al., 2021). Additionally, it can also be defined as the difference between the amount of water supplied into the distribution system and the amount charged to customers. High levels of NRW reflect large volumes of water being lost (AbuEltayef, et al., 2023).

Reducing NRW has great importance in running a sustainable operation and a vital component in reaching the UN Sustainable Development Goal (SDG 6) on Clean Water and Sanitation. NRW and the loss of water are a world-wide problem, making it difficult to protect our water resources, especially in water-scarce regions. NRW undermines progress toward multiple SDGs related to clean water access, infrastructure development, responsible consumption, climate change and economic growth (AbuEltayef, et al., 2023).

Chirundu district is semi-arid, and its temperatures tend to be higher than elsewhere in the country. The district is experiencing direct climate-change effects, such as reductions and uneven distributions of rainfall, increasing frequency and intensity of droughts, occasional flooding, increasing temperatures and environmental degradation (Tarusarira, et al., 2023). The Southern Water and Sanitation Company Limited (SWSC) is mandated to provide water and sanitation services in Chirundu district. The Lusaka Water and Sanitation Company (LWSC) previously had the mandate to supply water and sanitation services in Chirundu district up until 2021 when the district was moved from being under Lusaka Province to Southern Province under The Provincial and District Boundaries Act, Statutory Instrument No. 114 of 2021, Amendment No. 2, thus, giving SWSC the mandate over Chirundu district. Chirundu district has 928 household and 60 commercial piped connections. The current meter coverage is about 45% of the connections, whilst the rest is on fixed charges. The company provides water to communal water points through kiosks (CRIDF, 2016). This research intends to highlight the effects of climate change on WASH systems in urban Chirundu district Southern Province and how reducing NRW can be used as an adaptation strategy.

1.2 Operational Definitions

Adaptation: This is the adjustment to actual or expected climate effects, in order to moderate harm or exploit beneficial opportunities.

Climate Change Effects: Negative or positive impacts of climate change on human and natural systems.

Climate Change: A change of climate directly or indirectly attributed to human activity, as well as natural climate variability, shifting the composition of the global atmosphere observed over long periods of time.

Climate Hazards: Floods, droughts, hurricanes and cyclones occurring at greater frequency, with greater intensity or in different places than historically.

Non-Revenue Water: The difference between the amount of water supplied into the distribution system and the amount charged to customers.

Resilience: The capacity or ability of social, economic and environmental systems to handle hazardous events.

Vulnerability: Conditions determined by physical, social, economic and environmental factors or processes which increase the exposure of an individual, a community, assets or systems to the impacts of hazards.

WASH Systems: Integrated programs, services and practices related to access to Water, Sanitation, and Hygiene (WASH).

1.3 Statement of the Research Problem

Challenges in accessing Water, Sanitation, and Hygiene (WASH) services are increasing in Chirundu district due to the impacts of climate change. The region is characterised by high variability in rainfall, frequent droughts, and occasional flooding, all of which threaten the availability and quality of water resources (CRIDF, 2016). Climate change is predicted to increase the pressures on water resources, leading to more water shortages, contamination, and infrastructure damage. The degradation of water resources not only impacts drinking water supplies but also affects sanitation and hygiene practices, leading to increased risks of waterborne diseases (SMM, 2022).

Despite increasing challenges, limited research has been conducted on adapting WASH systems to the impacts of climate change in Zambia. Furthermore, the problem of non-revenue water (NRW) remains inadequately addressed. High levels of NRW contribute to inefficiencies in water supply systems, worsening water scarcity and reducing resilience to climate-related stresses. According to the National Non-Revenue Water Management Strategy by the Ministry of Water Development and Sanitation (MWDS), in 2021 Zambia had NRW of 55.8% and a revenue loss of 1,126,646,345 Zambian Kwacha (ZMW) (MWDS, 2022). With the stresses of climate change and extreme weather events, having such a high NRW should not be the case.

Given the importance of water security for the health and well-being of communities, there is an urgent need to assess the vulnerabilities of WASH systems in Zambia's Chirundu district, Southern Province to climate change. Additionally, exploring the potential of NRW management as an adaptation strategy may enhance the resilience and sustainability of these systems. Addressing these issues is essential to ensuring that communities have continued access to safe water and sanitation in the face of climate change.

1.4 Research Objectives

1.4.1 General Objective

The aim of this research was to assess the vulnerabilities of WASH systems in Chirundu district to climate change as well as to explore the potential of NRW management as an adaptation strategy.

1.4.2 Specific Objectives

Therefore, the specific research objectives were as follows:

1. **Specific Objective 1:** To examine the current and projected effects of climate change on WASH systems and assess the vulnerabilities in Chirundu district.
2. **Specific Objective 2:** To investigate the extent and causes of NRW in Chirundu district.
3. **Specific Objective 3:** To assess the potential of improved NRW management as a climate change adaptation strategy for WASH systems in Chirundu district.

These were used to develop the research questions as illustrated in the section below.

1.5 Research Questions

1. What are the current and projected effects of climate change on WASH systems in Chirundu district?
2. What are the key vulnerabilities of WASH systems to climate change in Chirundu district?
3. What is the current extent and cause of NRW in water supply systems in Chirundu district?
4. How can NRW management be leveraged as an adaptation strategy to enhance the resilience of WASH systems to climate change in Chirundu district?

1.6 Scope of the Study

The study was conducted in urban Chirundu district Southern Province, Zambia. Chirundu district is characterized by very hot weather, with temperatures reaching about 50 Degrees Celsius (°C) in summer, and low average annual rainfall of less than 800mm. The district is semi-arid, and its temperatures tend to be higher than elsewhere in the country (Tarusarira, et al., 2023).

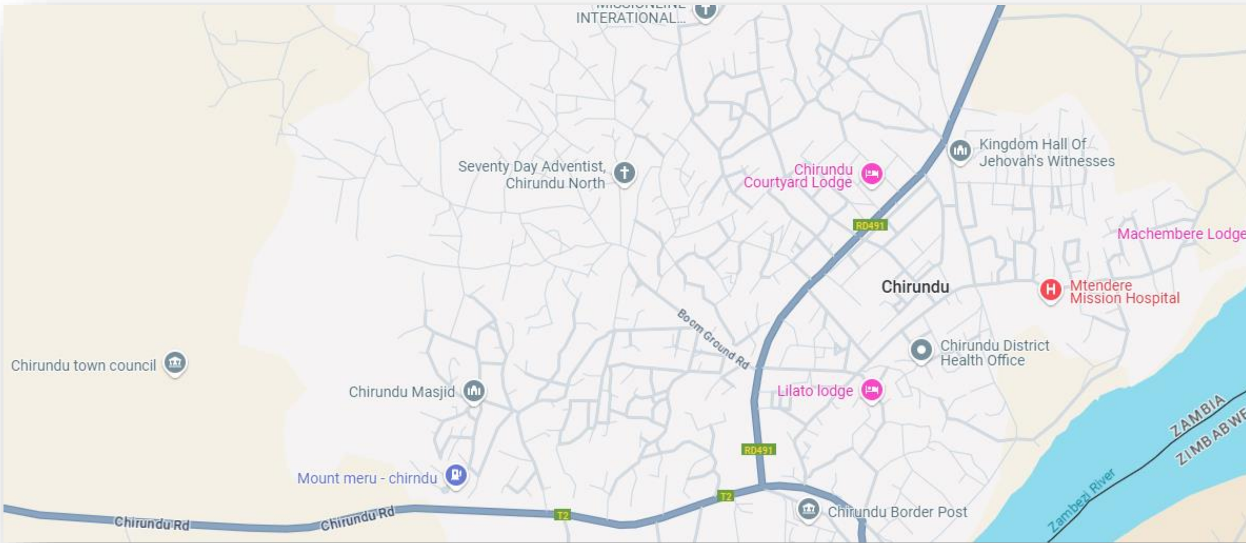

Figure 1-1: Chirundu District Urban Area

Source: Google maps

The research specifically examined areas prone to extreme weather events such as droughts and floods, which are common and have significant implications for WASH systems. The research study focused on assessing how climate change affects water availability, water quality, sanitation, hygiene and WASH infrastructure in urban communities. The research investigated the extent and causes of NRW in urban water supply systems and explored how reducing NRW could be used as a strategy to improve water efficiency and resilience against climate change. The primary population of interest includes urban communities, particularly those that rely on water supply from SWSC. This will involve a representative sample of households as well as key informants from relevant institutions.

1.7 Significance of Study

The findings of this study will provide valuable insights into how climate change is affecting WASH systems in Chirundu district. By identifying specific vulnerabilities, the study will help local governments, NGOs, and communities develop targeted adaptation strategies that can enhance the resilience of these systems. This is crucial for ensuring that communities maintain access to safe water and sanitation.

The exploration of Non-Revenue Water (NRW) management as an adaptation strategy will offer practical solutions for reducing water losses in water supply systems. By addressing issues such as leaks, theft, and metering inaccuracies, the study could lead to more efficient use of water resources, which is important in drought-prone areas. Improved water efficiency not only supports the sustainability of WASH services but also helps to mitigate the wider impacts of climate change on water availability.

While the study is focused on Chirundu district, Southern Province Zambia, its findings will contribute to the global knowledge on climate change adaptation, particularly in the context of urban WASH systems in developing countries.

1.8 The Organization of The Report

This report consists of seven (7) chapters as outlined below;

1. **Introduction:** This highlights the research, the research problem as well as research questions that were used to guide the research study.
2. **Literature Review:** This gives an in-depth understanding of the research study highlighting various literature.
3. **Methodology:** This is an elaboration on the methods used to undertake the research study.
4. **Presentation and Analysis of Results:** This presents the findings of the research study.
5. **Discussion of Findings:** The discussion summarizes the findings by giving an overview of the results and what they intel.
6. **Conclusions and Recommendations:** From the discussions, conclusions and recommendations were drawn to emphasize the best way forward.
7. **References:** This includes all references made in the document.

2 Literature Review

2.1 Empirical Review

This research study focused on climate change and its effect on WASH in Chirundu's urban area. Similar studies have been conducted in order to aid in the ongoing issue of water shortage especially while experiencing climate change. For example, CRIDF conducted a feasibility study on Chirundu's water supply and sanitation in 2016. The report was mainly focused on accessing the viability for private sector investments. This report illustrates the effects of climate change on WASH. It also illustrates the use of NRW as an adaptation strategy.

2.1.1 Critique of the Literature Review

Observations of the literature review indicate the data is in accordance with one another. The WRI and WBG are both indicative of climate change and the effects it poses on WASH. Other studies conducted in the WASH sector have shown the relevance and need to develop a climate resilient system that would aid the communities and reduce their vulnerability to the effects of climate change. Therefore, this study highlights what other researchers have evidenced as well as supports the need to strategize and implement on the management of NRW to reduce the misuse of the resource and aid in sustainable development.

2.2 Theoretical Framework

2.2.1 Climate Change

Climate change is the shift in climate patterns primarily caused by greenhouse gas (GHG) emissions in the earth's atmosphere which traps heat, thereby causing global warming (Fawzy, et al., 2020). According to the emissions gap report 2023, Global GHG emissions increased by 1.2% from 2021 to 2022 and hit a new record of 57.4 gigatons of carbon dioxide equivalent (GtCO2e) (UNEP, 2023).

Over the 20th century, observed climate changes include increases in global air and ocean temperature, global rising sea levels, reduction of snow and ice cover, changes in atmospheric and ocean circulation and regional weather patterns, influencing seasonal rainfall conditions (WBG, 2024). In 2023, the world encountered a total of 399 natural disasters. These events resulted in 86,473 fatalities and affected 93.1 million people globally (CRED, 2023).

Zambia mainly experiences a sub-tropical climate with three distinct seasons including a hot and dry season (mid-August to mid-November), a wet rainy season (mid-November to April) and a cool dry season (May to mid-August). Rainfall is strongly influenced by the movement of the Inter-Tropical Convergence Zone (ITCZ) as well as the El Niño/Southern Oscillation (ENSO) phenomenon (WBG, 2024). Zambia's annual rainfall averages between 700 millimeters (mm) in the south and 1,400mm in the north. The hot months are very dry, receiving almost no rainfall, thus, drought is endemic to Zambia. Zambia in the past has experienced drought years which of these include 1987/88, 1991/92, 1994/95, 1997/98, 2001/03, 2004/05, 2011/12, 2015/16 and 2018/2019. This sequence implies that drought is experienced every 4 to 5 years, and future predictions indicate an increase in the frequency due to climate change (WBG, 2024). The 2023-24 El Niño phenomenon, one of the strongest on record, is exacerbating the already challenging conditions. El Niño has escalated regional climate patterns, causing dry conditions and erratic rainfall, subsequently affecting crop production, and worsening disease outbreaks (UNICEF, 2024). The National Adaptation Plan for Zambia (NAP) indicates climate trends showing many climate-induced hazards having increased in frequency and intensity over the past few decades. Zambia is predicted to experience a distinguished rise in compound heat, drought and flood events by 2030. Average temperature in Zambia is set to increase from +1.5 °C to +3 °C by 2050s while the total annual rainfall is said to be decreasing by up to 35% by 2100. One of the vulnerabilities to climate change identified in the NAP is reduced availability of water supply and sanitation (GRZ, 2023).

2.2.2 WASH and Climate Change

2.2.2.1 Overview of WASH and Climate Change

Water supply and sanitation services are vulnerable to climate change. There is a potential disruption or destruction of WASH services due to climate hazards, which would undermine people's health and livelihoods. The greatest consequences of climate change effects on WASH are borne by the poorest, the marginalised and women. Extreme events have an effect on WASH services as well as other climate hazards including slow onset changes (sea-level rise, salinisation), trends (long-term rainfall and temperature changes) and increased unpredictability and variability such as changing seasons and timing of rainfall (SMM, 2022).

Climate Change has various impacts on WASH including; impacts on consumption (average volumes of water consumed per user per day) which influences water extractions and water supply service lifespan. Further, climate change impacts WASH infrastructure and facilities, which affects the operation and sustainability as well as the economic viability forecasts, which are based on the size of the facilities installed. This additionally impacts service quality, which encompasses the quality of the water distributed and service availability (pS-Eau, 2018).

Climate change weakens facilities if not climate proofed. It makes them less efficient and damages infrastructure. Climatic events such as floods could lead to flooded wells, silting, flooded electrical equipment, erosion of facilities, weakened and burst pipes causing network leakages (i.e., NRW). Water reservoirs are debilitated after being placed under too much pressure and stress. This leads to service interruptions in water supply due to damaged facilities. Floods could also hinder access to water points such as kiosk. Further, a drop in the quality of water distributed is experienced due to greater pollution and higher turbidity of water resources caused by soil leaching and flooded sanitation facilities (ibid).

The United Nations (UN) estimated that at least 29% of the global population relies on fecal or chemically contaminated or unimproved water source for drinking (Haque & Freeman, 2021). In Zambia, the overall water supply coverage slightly reduced from 88.2% to 87.7% in 2022 and 2023 respectively, and for sanitation, there was a marginal increase in coverage from 73.2% to 73.6% in 2022 and 2023 respectively (NWASCO, 2023).

Climate change is affecting water and sanitation operators and the communities. Utilities are particularly under stress due to significant losses and damages to infrastructure, water sources, supply and quality, while urban populations grow rapidly and water demand increases (Draganic, et al., 2022). High climate variability coupled with inadequate storage infrastructure and management result in water scarcity during years of low rainfall (Hamududu & Ngoma, 2019).

A feasibility study carried out by CRIDF in 2016 on Chirundu districts' water supply and sanitation highlighted the vulnerability of Chirundu district to climate change. The study indicated drought severity to be medium to high. The risk of water under climate change was high with a high record in climate change pressure. Seasonal variability was indicated as extremely high with flood occurrence at medium to high and access to water at an extremely high risk to climate change. Climate projections indicated variability in precipitation, decreased winter rainfall, increased aridity and drying out of seasonal wetlands by 2055. Thus, water supply is challenged by increased temperatures and more erratic rainfall patterns (CRIDF, 2016).

This is further elaborated by the findings of the World Resources Institute (WRI) on Chirundu district's climatic conditions as shown in the figures below;

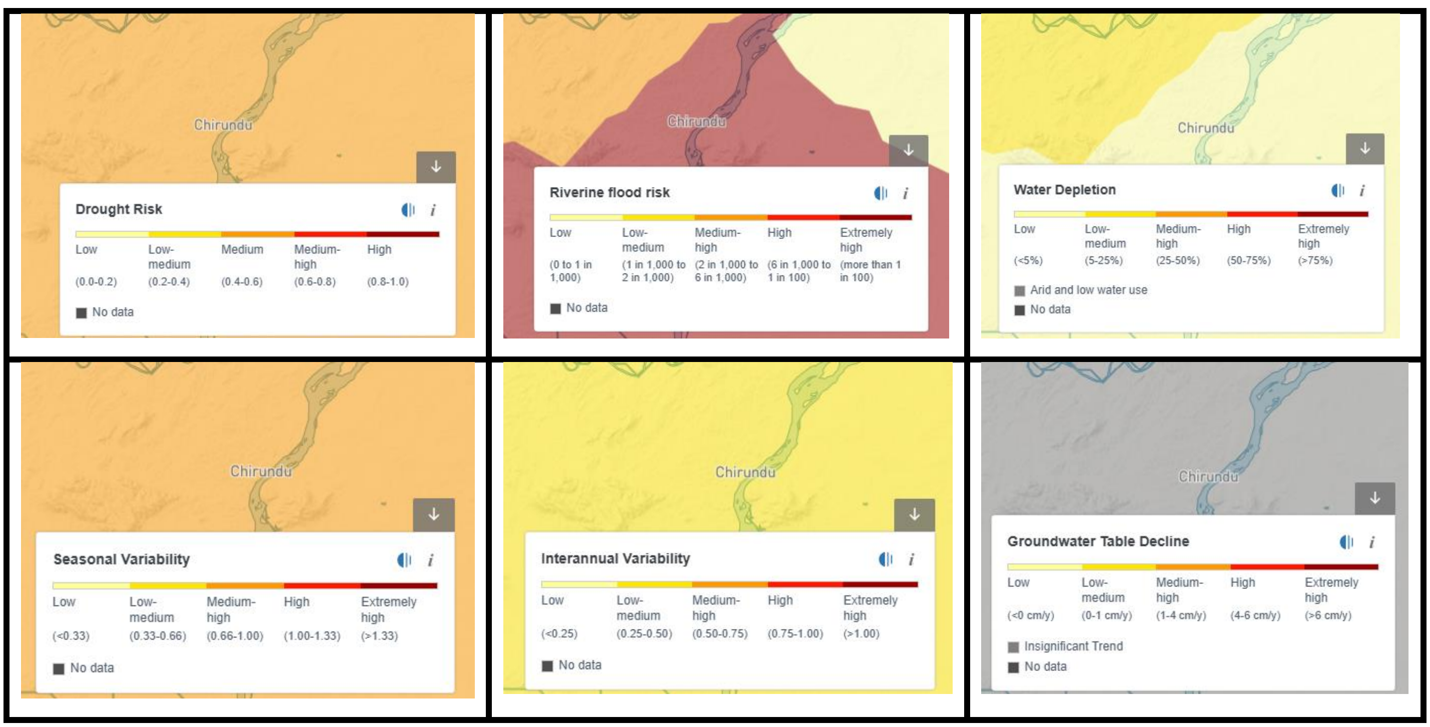

Figure 2-1: Chirundu District's Climatic Conditions

Source: (WRI, 2023)

To summarize the above figures the current climatic conditions, indicate, drought risk at a medium rate, riverine flood risk is rated high and seasonal variability has a medium to high rating.

Flooding poses a climatic risk on Chirundu district as raw water is abstracted from the Zambezi River, downstream of Lake Kariba and could have an impact. The figure above shows Chirundu district having a high risk of flooding which could damage ablution building and also flood the septic tank. The most vulnerable to flooding include urban services, particularly in developing countries. Flooding poses a high risk of water and sanitation service breakdowns and an increase in diarrheal diseases (pS-Eau, 2018). Drought, is a recurrent issue in Chirundu district and is likely to intensify with climate change. Drought could affect the water levels in the river affecting the intake (CRIDF, 2016). In the face of drought, the poorest communities have a high vulnerability as well as a high risk of over-using the water resources still available, water shortages and a rise in conflicts over access to the resource (pS-Eau, 2018). Chirundu district experiences seasonal variability. However, Chirundu has a low risk of water depletion and has an insignificant trend of groundwater table decline.

Future predictions from 2030 to 2080 on Chirundu's urban area on water stress and water supply are as depicted in the figure below.

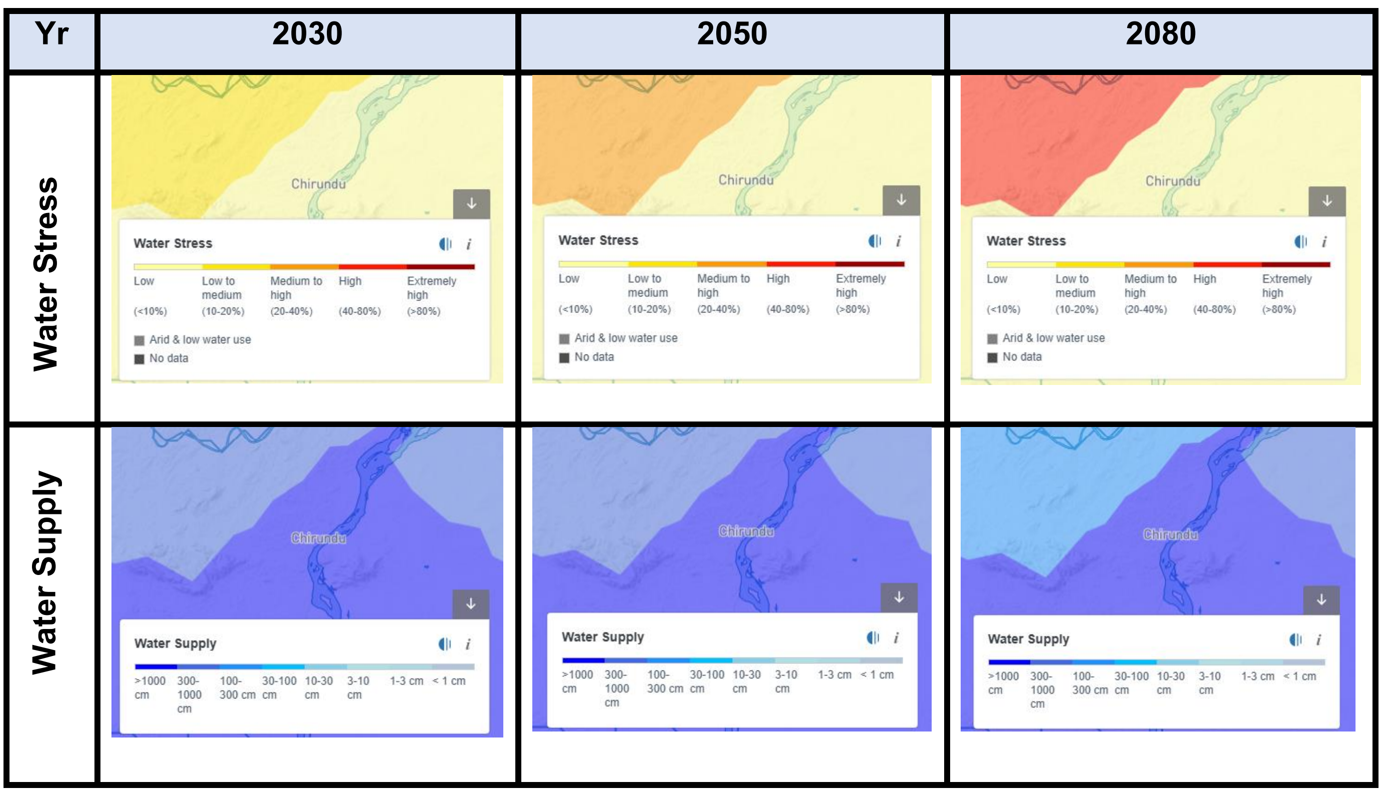

Figure 2-2: Projected Water Stress and Water Supply from 2030 to 2080

Source: (WRI, 2023)

WRI illustrates some parts of Chirundu district's urban area would experience water stress over time. Additionally, water supply in these areas would reduce from a period of 2030 to 2080. World Bank, on the other hand, projected the average mean surface air temperature for Southern Province, Zambia as illustrated in the graph below with Chirundu currently experiencing 2˚C with a predicted increase of 5˚C by 2080 and 7˚C by 2100.

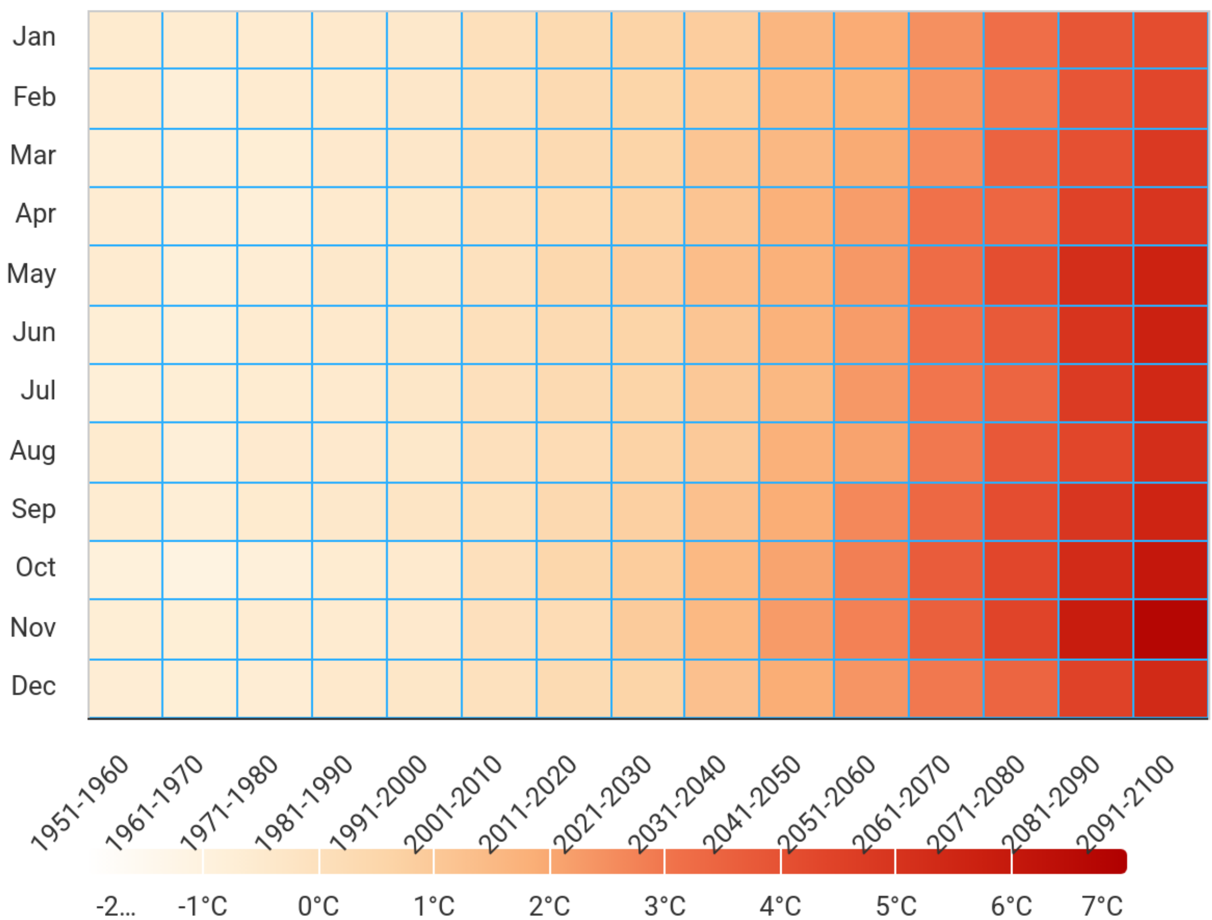

Figure 2-3: Projected Average Mean Surface Air Temperature for Southern Province

Source: (WBG, 2024)

The Multidimensional Vulnerability Index (MVI) score for Zambia is 48.6 being one of the most vulnerable and least resilient countries. Zambia's vulnerability was rated at 41.55 and lack of resilience at 54.78 (UN, 2024). The risks are often greatest for the most vulnerable such as women, children, the elderly and disabled, the poor and people living in crisis situations. Vulnerable areas include regions in the tropics that rely on consecutive dry and rainy seasons, areas with low rainfall, arid areas, hot areas and densely populated urban areas (pS-Eau, 2018). Water zoning and reducing Non-Revenue Water (NRW) would reduce the impact of drought significantly. Reduction of NRW, could influence the volume of water required to supply the town (CRIDF, 2016).

The National Adaptation Plan for Zambia has identified vulnerabilities within the water sector including reduced water quality and quantity as a result of droughts. Exposure to hazards was rated high as droughts can induce water scarcity. Reduced water in water bodies compromise the water quality which affects populations utilizing the resource. The adaptive capacity of the population is rated low meaning the country is highly vulnerable to climatic events. Drought effects on water quality and access has a high climatic risk level. Due to these effects, the NAP identified key adaptation actions that align to this vulnerability. These include; Promotion of rainwater harvesting; Construction of new and rehabilitation of existing dams in accordance with climate-smart codes and standards; Development of well fields; Promotion of recycling and use for domestic, agricultural and industrial use; Water quality monitoring and control; Improve resource management around water points and boreholes, Mapping and assessment of available groundwater resources; and lastly Strengthen Water Catchment Management and Protection. Under this vulnerability, one of the target groups was the water utility companies (GRZ, 2023).

Another vulnerability listed in the NAP is reduced availability of water supply and sanitation. One of the affected areas is Southern province with a high exposure rating especially for communities whose water sources are affected by droughts and those without health posts. The identified adaptive actions under this vulnerability include the following: Enhance water demand management; Improved water harvesting techniques; Promote ecological sanitation which uses less water and finally Enhance water resource management (ibid).

2.2.2.2 Water Supply

Access to safe drinking-water is imperative as a health as well as development issue at national, regional and local levels. Investments in water supply and sanitation could have economic benefits. This is due to reductions in adverse health effects and healthcare costs which outweigh the costs of undertaking the WASH interventions. This has been proved whether for investments as large as major water supply infrastructure or to water treatment in the home. Interventions in improving access to safe water favour the poor in particular, whether in rural or urban areas, thus, can be an effective part of poverty mitigation strategies. Climate change can be seen in the form of increased and more severe periods of drought or more intense rainfall events leading to flooding. These can have an impact on both the quality and the quantity of water and will require planning and management to minimize adverse impacts on drinking water supplies. Climate change also needs to be considered in the light of demographic change, such as the continuing growth of cities, which itself brings significant challenges for drinking water supply (WHO, 2011).

The effects of climate change on water supply include a reduction resulting from declining rainfall, water shortages and droughts. This could affect both piped and non-piped water systems, as both groundwater and surface water supplies may be reduced (SMM, 2022). This could be caused by climate variability of seasonal rainfall patterns. A rise in average temperatures causes heatwaves and drought, thereby causing a reduction in the quantity and quality of surface water and groundwater. Additionally, this could cause higher concentrations of various (chemical and organic) pollutants in the water due to poor dilution. It could also cause decreased groundwater recharge and increased salinity, as river water becomes more saline due to reduced water flows. Regions mostly affected are those found in the tropics that heavily rely on rainfall (pS-Eau, 2018).

Households may switch to unsafe water sources due to droughts or seasonal variability that force people to use unsafe, unimproved water sources. Infrastructural damage and poor water quality are attributed to heavy rainfall and flooding, which could affect major urban water supplies. (SMM, 2022). Intense rainfall events lead to an increased risk of flooding Storms, strong winds and cyclones. This in turn causes pollution of surface water and later groundwater through infiltration as pollutants leach into the soil. Flooding also causes higher volumes of discharged untreated wastewater from pit latrines (pS-Eau, 2018).

Zambia faces challenges in providing access to clean and safe water which is attributed to inadequate investments, high cost of water treatment and high NRW owing to old and dilapidated infrastructure (GRZ, 2024). Climate change has caused water supply disruptions, which are experienced in the Chirundu urban area. Residents experience low pressure and intermittent supply. As regards quality, the feasibility report by CRIDF indicated water having brownish colour and some solids particularly in the rainy season. Boreholes had a metallic taste and residents complained of gastric problems. During times of water deficit, residents are forced to utilise extremely unsafe water from the Zambezi River (CRIDF, 2016). A study conducted by Hamududu and Ngoma shows the total internal renewable water resources per capita has reduced from 17,886 m^3 /person /year in 1962 to 4,947 m^3 /person /year as of 2014, in Zambia. Further, the study on the Zambezi Basin indicates that temperatures are projected to increase while experiencing a significant reduction in rainfall from 2020 to 2100, indicating a 6.7% reduction in water resources availability from the current 48 km^3 to 45 km^3 towards 2100 (Hamududu & Ngoma, 2019). Furthermore, WRI has registered high levels of unimproved/ no drinking water in Chirundu district as shown in the figure below;

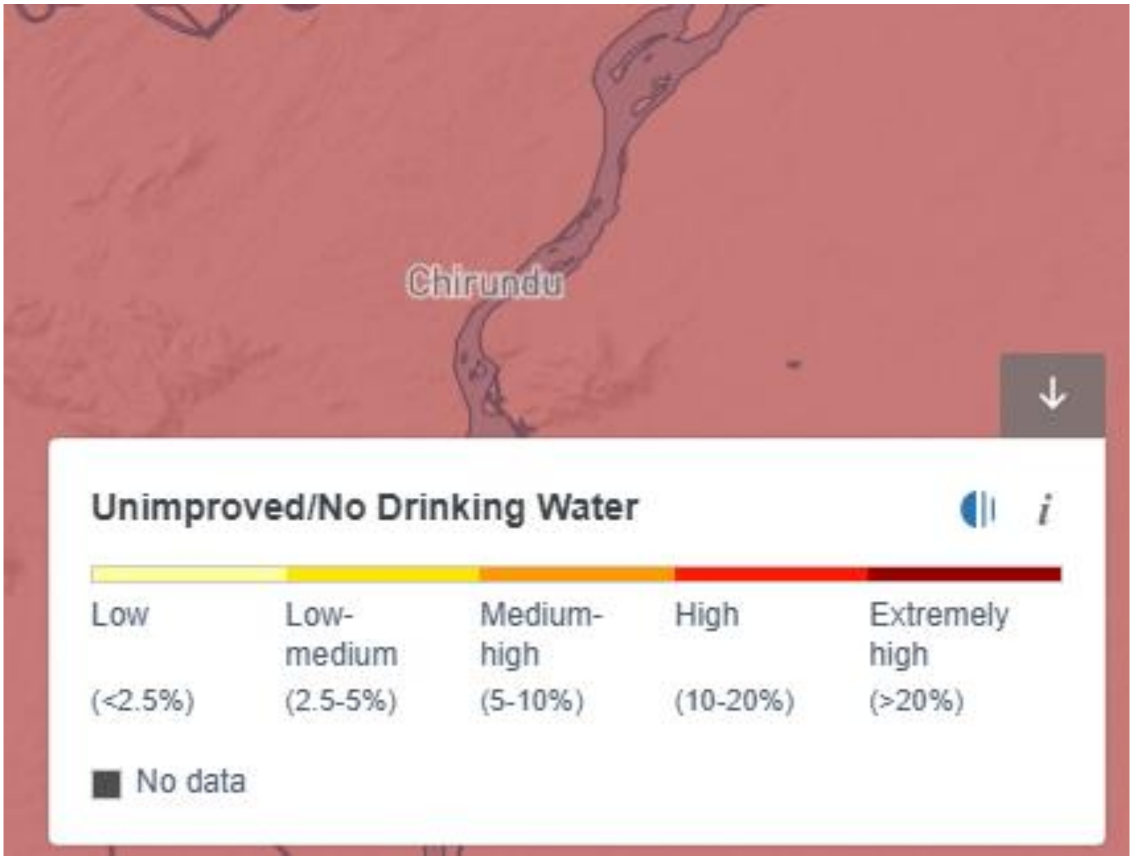

Figure 2-4: Unimproved/ No Drinking Water in Chirundu District

Source: (WRI, 2023)

2.2.2.3 Sanitation

Sanitation mainly focuses on minimising the health and environmental risks of failing to hygienically dispose of pathogen-containing wastewater and excreta (pS-Eau, 2018). Documented effects of climate change on sanitation services include faecal contamination of urban environments when onsite systems are flooded. This may be due to rising groundwater or inundation from surface water. This additionally causes a high risk of pathogen exposure in cities having combined sewers (sewers with stormwater) as overflow occurs during heavy rainfall. People often return or resort to open defecation when their primary toilet is inaccessible due to flooding or inadequate flushing water. Pit latrines overflow or collapse with heavy rainfall and flooding. Further, flooding causes failure of wastewater treatment plants as well as potential overloading, reducing treatment efficacy (SMM, 2022). Pit emptying services are interrupted. Working sanitation facilities become unavailable, as these have been destroyed or can no longer be used. An increase in waterborne diseases is notable as there is a higher risk of people coming into contact with polluted water (pS-Eau, 2018).

Alternatively, increase in average temperatures causes variability of seasonal rainfall patterns thereby producing heatwaves and droughts which causes the failure of biological treatment to function. The condition of infrastructure and facilities weaken, for instance, increased production of hydrogen sulphide (H2S) causes concrete structures to deteriorate and poisoning through inhalation. The wastewater discharged from the treatment plant if not properly treated results in reduced water resource quality, disruptions to ecosystems and biodiversity (aquatic ecosystems) (pS-Eau, 2018).

Referencing CRIDF’s report, it was observed that Chirundu district mainly used pit latrines (Ventilated Improved Pit latrines (VIPs)) but flush toilets were also reported. Sanitation challenges included cleanliness mainly attributed to challenges in water supply. Some people would opt to use unfinished buildings or practice open defecation. Flush toilets have become pour toilets due to the lack of water, hence households constructing pit latrines as a backup (CRIDF, 2016).

WRI recorded a high rate of unimproved/ no sanitation in Chirundu district as depicted in the image below;

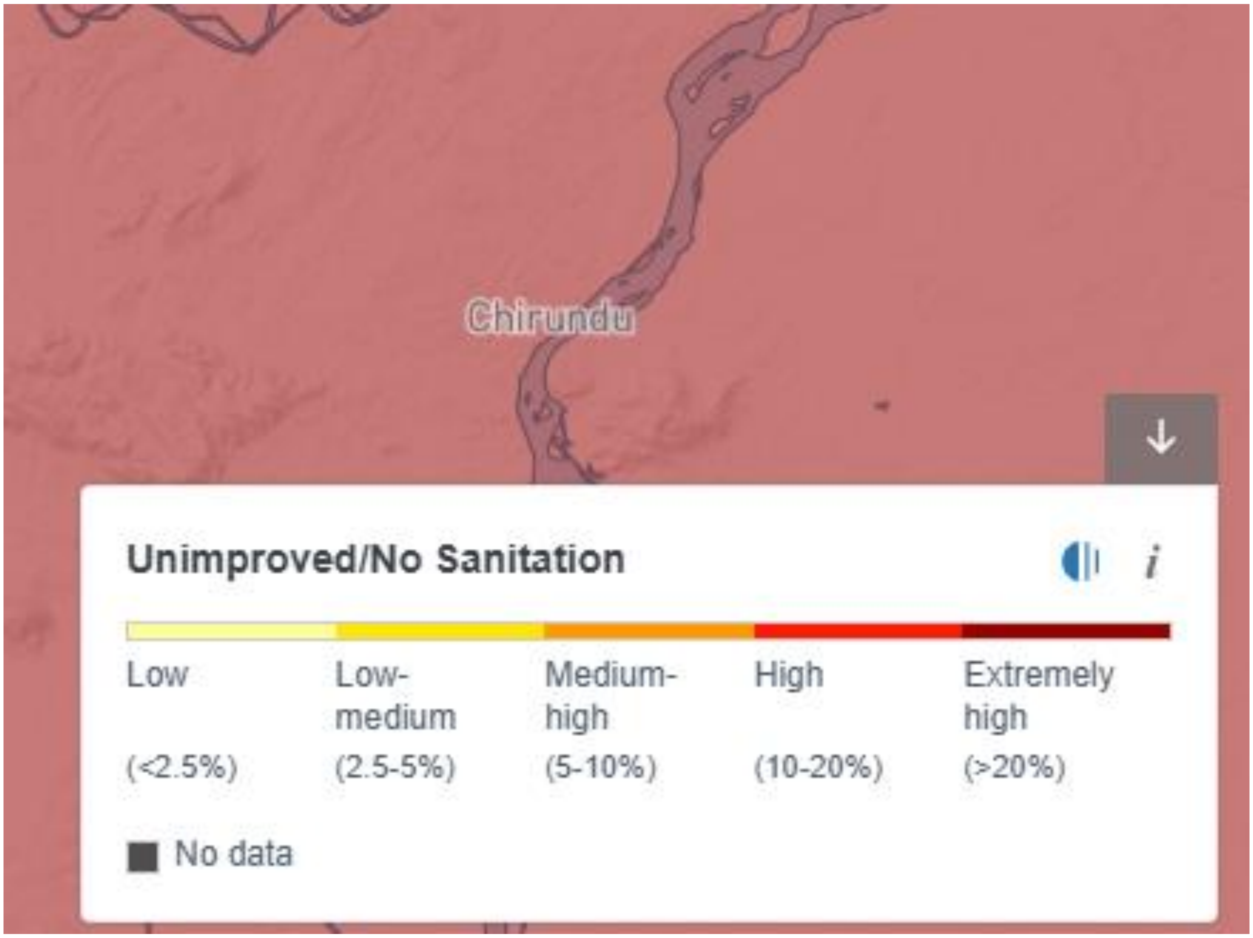

Figure 2-5: Unimproved/ No Sanitation in Chirundu District

Source: (WRI, 2023)

2.2.2.4 Hygiene

Climate change has effects on hygiene practices such as, menstrual hygiene as it is a key challenge for women and girls. Kenya recorded women being highly affected in flood-prone areas. Water-borne and water-washed diseases increase during droughts. Handwashing behaviour and practices decline with water scarcity, which lead to increased cases of diarrhoea and has shown to reduce food handling safety thus risking the spread of cholera (SMM, 2022). In Chirundu district, women expressed dissatisfaction in the unscheduled disruptions of water supply, which in turn causes stress amongst users (CRIDF, 2016).

2.2.3 Non-Revenue Water (NRW)

2.2.3.1 NRW Overview

As stated above, climate change has affected water supply, sanitation and hygiene. Non-Revenue Water (NRW) management is one direction that can be taken towards adaptation to climate change. The rapid growth of the world's urban areas and the negative impact of climate change has resulted in less water availability than in the past. If the world's volume of NRW was reduced by one third, assuming a per capita consumption of 150 liters per day, the savings would be sufficient to supply 800 million people (Liemberger & Wyatt, 2018). Utilities can use NRW management to improve and expand their services, enhance financial performance, increase climate change resilience and reduce energy consumption. Revenues from saved water improve the utilities' bottom line whilst low water abstraction increases city resilience (Kingdom, et al., 2016).

The global volume of Non-Revenue Water (NRW) each year of treated water amounts to more than 32 billion cubic meters (m^3). Additionally, 16 billion m^3 annually are delivered to customers but are not invoiced due to theft, poor metering, or corruption. An estimate of the total annual cost of water lost worldwide is US$14 billion. In some low-income countries, this loss signifies 50-60% of water supplied, with a global average estimated at 35%. If half of this amount were saved, an additional 100 million people would have access to water supply without further investment (Nasara, et al., 2021).

Operators must understand how climate change is linked to changes in the water cycle which would aid in preparations for severe droughts, floods and unpredictable rainfall patterns. Water and sanitation operators should focus on smart solutions that build resilience (Draganic, et al., 2022). Reasons utilities are not making progress could be attributed to weak capacity, lack of incentives, low financial discipline and less effort required to find and fix leaks compared to building new treatment facilities (Kingdom, et al., 2016).

NRW directly impacts Sustainable Development Goal (SDG) Six (6) which has its focus on the importance of ensuring sustainable water management and access to clean water and sanitation for all. Climate change impacts cause the reduction in the availability of clean water for consumers. By addressing NRW, water utility companies can improve clean water availability and accessibility and can help ensure a more sustainable and equitable water supply. This would aid in supporting progress toward SDG 6. The most relevant targets for NRW under SDG 6 include the following; “6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all”. Reducing NRW would increase water supply. Secondly, target 6.2 indicates “By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations”. NRW management entails more revenue which would aid in expansion and provision of sanitation and hygiene. Target 6.4 indicates “By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity, and substantially reduce the number of people suffering from water scarcity”. Target 6.5 states “By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate.” 6.6 states “By 2030, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers, and lakes” which would be achieved by collecting more revenue from NRW management which can be diversified. Lastly “6.B Support and strengthen the participation of local communities in improving water and sanitation management.” Climate change is felt mostly through the water cycle. Strong water and sanitation utilities are important to meeting the Sustainable Development Goal on water (SDG 6) (AbuEltayef, et al., 2023).

NRW management additionally contributes to other SDGs such as SDG 7, SDG 12 and SDG 13. SDG 7’s primary focus does not have a direct interlinkage with NRW. Its focus is on energy access and sustainability. However, the adoption of energy-efficient practices, utilization of renewable energy, integrated planning, and capacity building can indirectly contribute to reducing NRW. This could be achieved by optimizing water infrastructure operations, reducing leakages, and improving water management practices. SDG 7 highlights the importance of adopting a holistic and integrated approach to achieve the sustainable development outcomes across multiple sectors. Therefore, indirect contribution towards NRW reduction can be made through addressing energy-related challenges. On the other hand, SDG 12 focuses on promoting sustainable consumption and production patterns. NRW is a representation of wasteful consumption and inefficient production of water resources. Therefore, reducing NRW contributes to responsible water consumption and sustainable water resource management. Many utilities are already struggling with weak operational and management approaches, inadequate resources, and deteriorating infrastructure. Climate change as well as the rising global temperatures have resulted in an increased demand for water, thereby, placing stress on freshwater supplies. NRW exacerbates this issue by the substantial quantities of water lost. Preventing water losses can increase the availability of water, thereby alleviating the need for developing new water sources. Harnessing digital technologies in the water production and distribution process can aid in decreasing NRW and enhancing operational effectiveness. SDG 13, Climate Action, aims to take urgent action to combat climate change and its impacts. NRW worsens the impacts of climate change by increasing water resources depletion due to water scarcity. Water systems become more resilient to climate variability with the reduction of NRW, which in turn contributes to climate adaptation efforts and SDG 13. SDG 13 emphasizes the urgent need for taking action against climate change and mitigating its environmental impacts (ibid).

The National Water Supply and Sanitation Council (NWASCO) established in Zambia have a mandate which includes Strategic Plan implementation, monitoring of service providers, awareness creation and regulatory enhancement. NWASCO recorded a NRW level of 57.3% and the challenges faced during the year 2023 which included, but not limited to; high levels of Non-Revenue Water (NRW); vandalism and theft of water installations (water meters), and increased equipment failures due to inadequate maintenance (NWASCO, 2023).

Zambia has recently made progress towards the reduction of NRW by developing policies and strategies, and incorporating NRW management. This includes, the Water Resources Management Act 2011, the development and implementation of the National Urban Water Supply and Sanitation Program 2011 – 2030, the National Non-Revenue Water Framework 2016-2018, the development of the National Non-Revenue Water Management Strategy 2022 – 2026 and the National Water Policy 2024. The Integrated Water Resources Management Plan supports for the creation of WASH committees at

Provincial, District and Village. However, it does not consider the management of NRW. The Water Resources Management Act 2011 Section 6 (q) provides “the management, development and utilization of water resources shall take into account climate change adaptation.” The NUWSSP 2011 – 2030 intends to support measures to reduce non-revenue water and increasing the metering ratio with the main implementation period being 2011 – 2015 (GRZ, 2011). However, NRW was seen to have increased during this period.

The graph below is a depiction of Zambia’s urban and peri-urban water supply NRW trends from 2001 to 2021 as extracted from the National Non-Revenue Water Management Strategy 2022 – 2026;

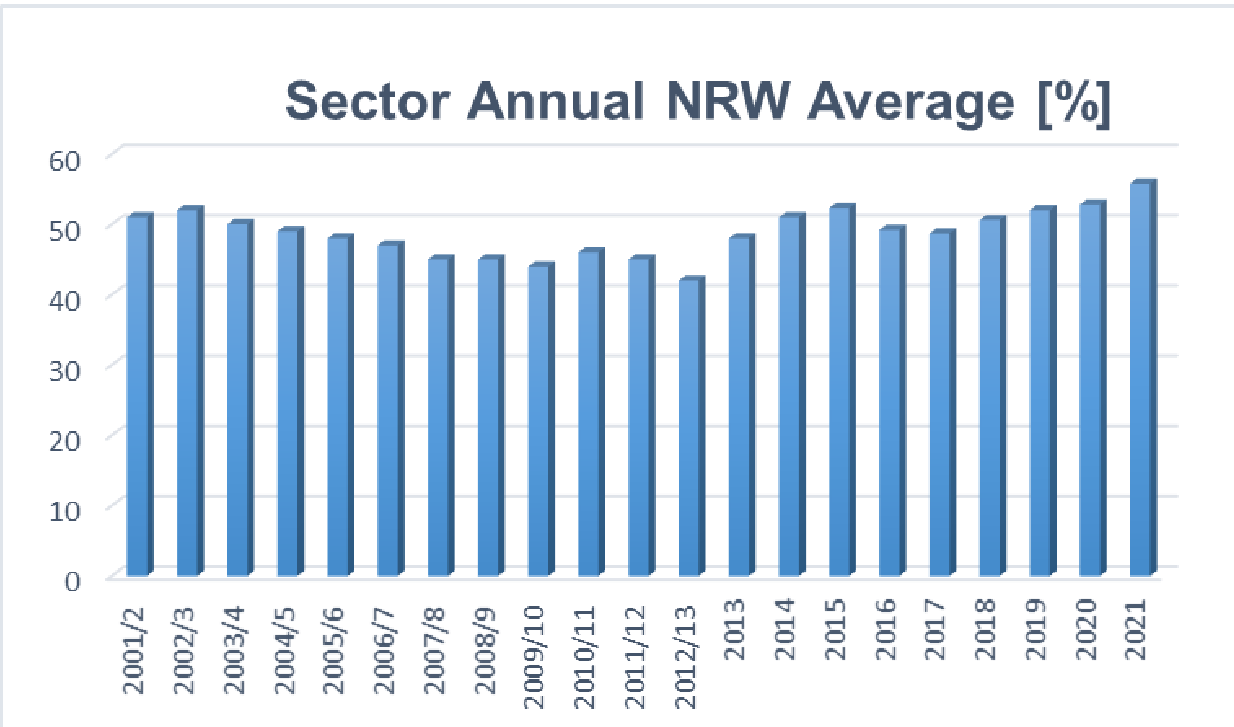

Figure 2-6: Zambia's Urban and Peri-Urban Water Supply NRW Trends

Source: (GRZ, 2021)

This gives an average of 48.43% over the past 20 years. During this time, the annual revenue loss has amounted to ZMW 10,044,002,755 which is 50% of the total billing over the same period (GRZ, 2021).

NRW is a cost to water service providers as it impacts on the operating costs that go into the production of potable water, such as labor, energy for pumping, repair and maintenance materials, water treatment chemicals and other overhead costs. Further, the quality of service that customers receive is affected with reduced hours of supply, rationing, reduced water pressures, limited coverage and compromised water quality. This may result in customer dissatisfaction and unwillingness to pay for services. Negative effects on the environment and ecosystem integrity result from over abstraction of water resources in an attempt to mitigate demand deficiencies, thus, increasing the carbon footprint through increased energy consumption and waste generation (GRZ, 2021).

If NRW is not addressed, it would mean increased energy consumption and greenhouse gas emissions. For instance, treating lost water or recovering water lost cause higher pumping requirements to compensate for leakages as well as maintaining water pressure in the system can lead to increased energy costs. This could have a significant impact on the overall operational expenses of water utilities and indirectly affect consumer water bills. Reducing NRW inadvertently reduces energy consumption, leading to lower GHG emissions and minimizing the ecological footprint associated with water production and distribution (Kingdom, et al., 2016).

2.2.3.2 <u>Challenges of NRW</u>

NRW has been one of the biggest challenges in water utility management. This is due to lack in majorly needed resources for the development of infrastructure to provide sufficient, and safe quality water. Lack of technical expertise and equipment to effectively manage water loss further reduces the availability of adequate good quality water to consumers (Nasara, et al., 2021). Aged and dilapidated infrastructure often leads to leaks and frequent pipe bursts hence contributing to increased NRW. Inaccurate measurements are recorded from aged water meters contributing to NRW. Unregulated high pressures lead to increased leak flow rates and increased pipe burst frequencies, particularly in ageing networks. Inadequate knowledge, skills, tools, equipment and materials as well as non-dedicated personnel to lead the management of NRW results in the poor management of water infrastructure, therefore leading to high NRW (GRZ, 2021).

High demands resulting from rapid growing populations, limits on natural resources (water), increasing costs of operation and maintenance resulting from regulations and customer demands, leads to the conclusion that it would be unrealistic to allow water loss (Nasara, et al., 2021). NRW indicates lost opportunities for resource efficiency in water supply systems. The significant water losses due to leaks, unbilled water, prevent the efficient utilization of water resources leading to water scarcity, financial losses, and inadequate access to clean water. This is particular in urban areas with rapid population growth and aging infrastructure. Lack of financial resources limits the ability of water utilities to invest in improving water infrastructure, thus continuing the cycle of water losses and delaying progress (AbuEltayef, et al., 2023).

Further, NRW signifies an inefficient use of water resources, as water is produced, treated, and distributed but not effectively utilized. NRW can be seen as wasted water which further strains limited water supplies, aggravating water scarcity concerns, thereby, hindering sustainable development efforts. Lack of knowledge sharing, capacity building and allocation of resources leads to weak collaborative efforts among governments, water utilities, communities, and stakeholders towards reducing NRW, thus, hindering progress toward SDG 17 which focuses on Partnerships and Collaboration Furthermore, water utilities experience substantial financial losses due to NRW. This hinders their ability to invest in infrastructure upgrades, repairs, and expansion. Reduced revenue collection from water losses compromises the financial sustainability of water utilities, thereby, limiting their ability to provide reliable and quality water services. This hinders progress towards the achievement of SDG 9, which emphasizes on the need for sustainable infrastructure development. Inefficient water management consequential from NRW hinders urban development, disrupts service delivery, and undermines the overall sustainability of cities (ibid).

The Global Commission on Adaptation’s Water Action Track, launched in September 2019 to hasten climate change adaptation action in water and water-related sectors, prioritizes three Water Action areas namely; Water Resilience Preparedness, Resilient Basin Future and City Water Resilience. City Water Resilience stipulates that by 2030, 100 cities should be supported to develop and implement integrated urban water resilience planning. Additionally, investments should be made to address vulnerabilities in water-related infrastructure and management as well as build water security for growing urban populations (SIWI, 2019).

2.2.3.3 <u>Benefits of NRW Reduction</u>

NRW water management has a number of benefits for the water sector including WASH. These include improved service as it reduces stress on the available water resources, thereby allowing more households to be served by the same water source. It additionally leads to increased supply continuity for a more stable water supply due to improved performance, providing full pressure distribution 24 hours a day, 7 days a week. It also contributes to improved water quality as a result of enhanced water distribution. Management of the chlorine content in the distributed water would be more effective, thus reducing the risk of pollution caused by cloudbursts and periods of low pressure or vacuum (Beitzel, 2021).

Other benefits of NRW management include improved performance, reduced leakage, conservation of water resources, economic and environmental benefits. Improved performance leads to increased revenue due to the sale of saved and previously unbilled water. The outcomes are better customer services and support for decision-making due to new management systems. NRW management reduces leakages and their damages: This is a strong basis for establishing a long-term rehabilitation and investment plan for the water network system as well as acquiring better knowledge of the water network. It also leads to improved water quality of tap water by minimizing contamination in the water network system. NRW management aids in the conservation of water resources as water utilities would gain access to more revenue in self-generated cash flow. NRW management achieves greater fairness between users by reducing illegal connections, thus making water utility companies more efficient and sustainable as well as providing improved service to their customer service. Economic protection is achieved through the management of NRW such that the improved finances from increased water sales and the reduction of production, provides service to more customers for longer hours. This additionally reduces the need for huge investments in treatment facilities, and increase the revenues of the services. NRW management strategies and plans would increase public awareness of NRW, thereby increasing knowledge of the water distribution system and reducing the risk of contamination of the water (AbuEltayef, et al., 2023).

Environmental benefits from NRW management would include reduced energy footprint and GHG emissions that contribute to climate change (ibid). Reducing the carbon footprint would mean the country contributing to the Nationally Determined Contribution (NDC) to the Paris Agreement on climate change in which goals in the reduction of carbon foot print have been set. Zambia has conditionally pledged to reducing GHG emissions by 25% (20,000 Gg CO2 eq.) by 2030 against a base year of 2010 with regards to the Business as Usual (BAU) scenario insinuating there is limited international support. However, provided the substantial international support, Zambia would reduce GHG emissions by 47% (38,000 Gg CO2 eq.) (GRZ, 2021 b). Other environmental benefits also include decreased energy requirements and operational costs. NRW reduction programs could affect the water supply operators such that there would be a reduction in the consumption of water resources in the utility, thus increasing the working capacities of the utility. Less water extraction will be required as the energy consumption will be reduced. Reduced leakages lead to decreased load on sewage systems, thereby decreasing the treatment costs (AbuEltayef, et al., 2023).

While NRW management has benefits, not treating it would have serious consequences. NRW has socioeconomic costs that would affect society as a whole. These costs comprise of the opportunity cost of the lost water. This lost water could have been utilized for productive purposes such as agriculture, or other economic activities. Further, NRW contributes to increased water stress. As there are more water needs, there will be more water abstraction to compensate for the water losses. This would lead to environmental degradation, reduced water availability even for others as well as increased energy consumption for water pumping and treatment (ibid). Environmental impacts of NRW would include wastage of water resources, energy consumption (increasing carbon footprint) associated with water treatment and distribution and potential damage to ecosystems (Beitzel, 2021). There is need to assess and mitigate these environmental impacts which may require additional investments. Losses in drinking water in the distribution network would mean producing more to cover the needs of consumers. The consequences of more and more raw water resources drawn from the water supply would have an impact on the environment. Additionally, more electricity and chemicals are consumed, thereby contributing to higher carbon dioxide (CO^2) emissions (AbuEltayef, et al., 2023).

Between NRW management and supply augmentation, NRW management offers better cost-effectiveness. Additionally, financial performance of service providers is enhanced due to the revenue generated from saved water, whereas reducing water abstraction also improves the resilience of cities. However, the advantages resulting from minimizing NRW have not yet become significant motivators for addressing water losses especially in developing countries. The hindrances that are preventing utilities from making progress include inadequate capacity, lack of incentives, inadequate financial discipline as well as the efforts required to locate and repair leaks. Consequently, this has created a weariness as climate change pressures are on the rise, increased water scarcity and the increasing demand and expectations from consumers (Kingdom, et al., 2016).

2.2.3.4 <u>Strategies for NRW Management</u>

Accurate quantification of NRW is imperative. One of the strategies used in the reduction of NRW is network monitoring. This is done by establishing a robust monitoring system which involves the strategic placement of bulk meters at key delivery points. Further, dividing the network into District Metered Areas (DMAs) allows for the precise monitoring of flow and pressure while integrating smart meters for large consumers and all customers. The data can be used strategically to determine day and night consumption of water. This approach allows for early detection of leaks, thus proactive interventions can be made to address problems. Another method for NRW reduction is pressure management which include; the installation of tank filling controls due to very low pressure by customer side tank usage for the regulation of network pressures. This addresses the issues of intermittent supplies and the detection of bursts and leaks. Pressure Reducing Valves (PRV) lower leakage levels by reducing unrequired high levels of pressure in the network. Thirdly, regular analysis and reporting aids in NRW reduction. This is done by leveraging data analysis and consistent reporting based on monitored data. The data collected informs interventions, such as prioritizing repairs, PRV schemes, and identification of deteriorating water mains and connections for timely maintenance and repair. Overall efficiency of water utilities is enhanced with strategic planning due to comprehensive data analysis. Fourthly, implementation of leak detection technology, from advanced acoustic sensors to data analytics, is a proactive approach in identifying and addressing leaks within the water distribution network. Swift responses to water problems and rapid repairs are enhanced by rapid detection, thereby minimizing NRW and infrastructural damage. Lastly, training teams with the necessary skills and knowledge is crucial for effective NRW management. Training programs incorporating leak awareness, fundamental operational principles, and technology empower personnel to manage water networks efficiently (Crowder, 2024).

Challenges being faced in water management including old infrastructure, water scarcity, increased demand, and the essential efficiency in resource allocation, are effectively addressed through the supervisory control and access to data (SCADA). SCADA provides real-time surveillance, control, and automation of water systems. It resolves high levels of water loss from leakages and inefficient water distribution. This is done by allowing real-time control of water flow, early detection of pressure, and improved system management, thereby causing a reduction in non-income water. This system involves devoting a Non-Revenue Water Team, training of the NRW Team; engaging the service providers; and setting up a NRW Practitioner Team that would give the specialized advice as well as provide aid to the lower service providers in order to apply the Strategy. It is also required that an audit of the NRW components is done to establish a more "reliable" standard and detect authentic issues that would be impacting the operational efficiency of the water utilities. NRW has five major components such as the volume of system inputs, authorized consumption billed, unauthorized consumption, apparent/commercial losses, and real losses (Ahmed, 2024).

As the population is increasing, water distribution can be improved by providing different consumption patterns through the use of SCADA. It can deliver cautious control of water treatment and distribution processes as well as guaranteeing better resource allocation and effective operation of water treatment plants. Additionally, SCADA solves the challenges faced by many on data management and decision making. The real-time data collection and analysis and the delivery of good information to decision makers makes this possible. SCADA provides real-time data, control, and automation to enhance the reliability, efficiency and sustainability of water systems, thus solving the water management challenges currently being faced. Some activities that need to be undertaken in the implementation of SCADA include, conducting the Customer Identification Survey to identify commercial losses among users. There is need to deploy the leak detection staff so as to install pressure and flow meter sensors for the continuous monitoring of the designated region. It is essential to implement a mobile application for the seamless transfer of GIS links that would connect the customer meters to the commercial. Identification of physical features in the region can be done with the use of satellite imagery (ibid).

For example, the water utility VCS Denmark was ranked the best water utility in Europe with an Infrastructure Leakage Index (ILI) of only 0.7. The NRW level was reduced to just 6%. These remarkable figures are the result of dedicated efforts in the past twenty (20) years. District Metered Areas (DMAs) are supervised by SCADA, which provides a reliable online monitoring of leakages (State of Green, 2018). The main devices needed for the execution of SCADA are pressure devices, flow meters, Remote Terminal Unit (RTU), panels and SIM cards. SCADA provides for improved efficiency and resources whilst providing insights into water use patterns, aiding the water utility companies to improve distribution and implement demand management strategies. SCADA also enhances resilience and disaster response by building the resilience of water infrastructure which is achieved during emergencies through the provision of real-time situational awareness (Ahmed, 2024).

In Emirates of Abu Dhabi (United Arab Emirates), the city of Al Ain managed to reduce its NRW levels from 45% to 10% within a year for 19 DMAs. These results were achieved by implementing an integrated approach which included the use of real-time hydraulic modelling, automated water balance calculations, installation of flow and pressure monitoring instruments. It also included deploying noise loggers for automatic leakage detection and the Holistic Management Information System (HOMIS). HOMIS incorporated the use of operational data systems such as GIS, SCADA, noise loggers, water quality sampling, customer care, billing and finances (State of Green, 2018).

2.3 Conceptual Framework

The conceptual framework for this research study is focused on climate change effects on Water, Sanitation and Hygiene (WASH). Additionally, the research focused on the management of Non-Revenue Water (NRW) as an adaptative strategy towards building resilience against the negative impacts of climate change. The study focused on the urban area of Chirundu district by engaging with residents as well as the water utility company, Southern Water and Sanitation Company (SWSC), and other organizations relevant to the water sector.

3 Methodology

This chapter outlines the methodology used for this research study.

3.1 Research Approach

The mixed methods research approach was adopted for this study. Both quantitative and qualitative data were collected to answer the research questions of the study. Quantitative data was collected to understand climate change the effects it poses on WASH. Qualitative data was collected to understand the perspectives of the residents as well as their vulnerabilities. The research used both primary and secondary data to arrive at conclusions and recommendations.

3.2 Research Design

This research used the pragmatic research paradigm which combines both positivism and interpretivism by gathering empirical evidence and understanding the social context. Therefore, both quantitative and qualitative data was collected and analysed to draw up conclusions and recommendations. Thus, the concurrent mixed methods research design was used for this research study. This was used to gather comprehensive data on the effects of climate change on WASH systems and the potential for NRW management as an adaptation strategy.

3.3 Study population

According to the Zambian Census of Population and Housing Report of 2022, Chirundu district has a population of 78,780 people (ZAMSTATS, 2022). The Urban population is approximately 35,400 people and with a standard of 5 people per household, there is approximately 7,080 households in Chirundu's urban area. According to the SWSC records, as of October 2024, SWSC in Chirundu district service a population of 28,043 with 9,000 serviced through kiosks and 19,043 with individual connections. There are 2,643 connections serviced by SWSC. The primary focus was on communities, local water management authorities and government authorities involved in climate change and WASH services.

3.4 Sample Size

Using Cochran's formula, a population size of 2,643, the confidence level of 95% and 0.05 margin of error, the sample size for this research study was 336 households. Key Informants from institutions such as Community Development, Meteorological Department Zambia, Water Resources Management Authority (WARMA) and Southern Water and Sanitation Company (SWSC) were approached.

3.5 Sampling Design/ Techniques

The research employed a stratified random sampling approach to collect data from the communities, local water management authorities and government authorities involved in WASH services. Chirundu is divided into wards, of these two (Chirundu and Chirundu West wards) were examined. Chirundu district is located in the valley and is the hottest district in the country with temperatures as high as 50 °C. Additionally, Chirundu’s urban area has a rapidly growing population. This in turn has an effect on WASH services in the area. Chirundu’s urban area is also found along the Zambezi River. For these reasons, Chirundu’s urban area is an appropriate location for the study to understand the effects of climate change on WASH and how the management of NRW could be used as a strategy. Particularly, the study will focus on those receiving service from SWSC.

3.6 Data Collection/ Instruments

The research study used semi-structured survey tools to engage with community members. Focus group discussions were also used to have an overall understanding of the current situation. Key Informant Interviews were done using semi-structured survey tools for community leaders and local water management authorities and government authorities. Both primary and secondary data were collected for this research study.

3.7 Data Analysis

Quantitative data was analysed using inferential analysis to identify relationships between climate variables and WASH system performance. Trend analysis was also used to analyse quantitative data such as climate trends in the districts. Thematic analysis was additionally used to analyse the qualitative data collected during the study. Additionally, descriptive statistical analysis was used to present the data collected. Microsoft Excel was used to analyse the data. Geographic Information System (GIS) analysis was conducted for visualisation.

3.8 Study Variables

The following were the study variables considered during this research study; Weather conditions and climate events, WASH infrastructure, Water supply, Water usage, Disease vectors, Rainfall, Water sources, Sanitation, hygiene and Water loss.

3.9 Ethical Consideration

Ethical approval was obtained before the research study was conducted. Informed consent was sort from participants while data privacy and confidentiality was ensured and upheld throughout the process.

4 Presentation and Analysis of Results

The Meteorological Department Zambia provided data on the weather conditions. A Meteorological Station has not been established in Chirundu district. This made the research difficult as it was unable to collect accurate weather data for Chirundu district. However, the nearest Meteorological Station was used to give an overview of the weather conditions experienced. Thus, the Lusitu Meteorological Station's data was used for this study. However, the provided data was only for the years between 1989 to 1997 as the station was closed. This however, provided the data required to show historical weather conditions.

The data provided was the Daily Minimum Temperature, Daily Maximum Temperature and Precipitation. The graphs below depict the analysis of the data gathered.

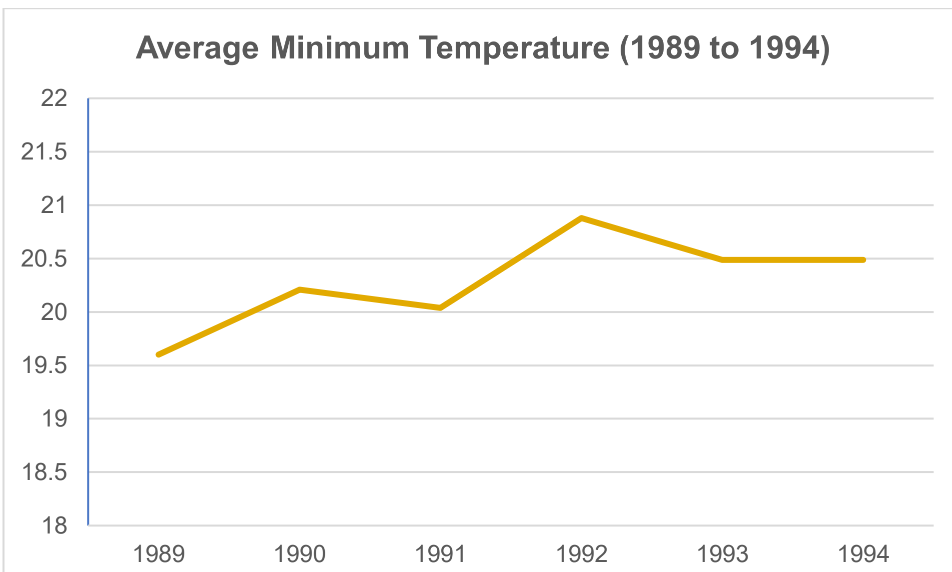

Figure 4-1: Average Minimum Temperature (1989 to 1994)

The average minimum temperature, as shown in the graph above, illustrates an upward trend. The minimum temperatures are seen to be increasing over the years. During this period, the lowest minimum temperature was experienced in 1994 with 5.8 °C and the highest minimum temperature in 1989 with 37.6 °C. The average minimum temperature experienced during 1989 to 1994 was 20.26 °C.

The maximum temperature was analysed between the years 1989 to 1996. The analysis presented an upward trend showing an increase in the average maximum temperature as depicted in Figure 4-2. The lowest maximum temperature experienced during this period was 22.4 °C in 1994 and the highest maximum temperature was 46.4 °C in 1990. The average maximum temperature for this period was 34.09 °C.

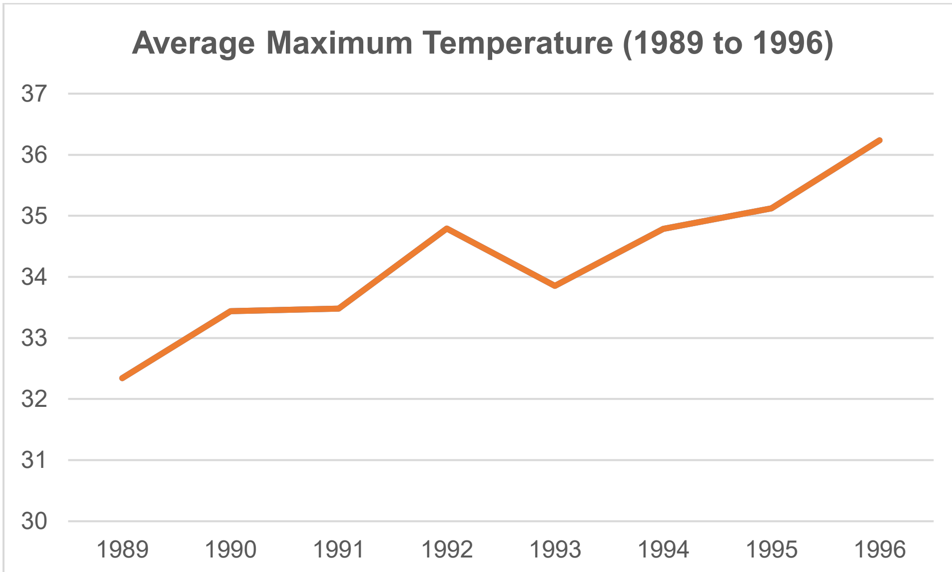

Figure 4-2: Average Maximum Temperature (1989 to 1996)

According to the weather station in Karoi, Zimbabwe, Chirundu district experienced an increase in the average temperature of the maximum and minimum temperatures from 2011 to 2024.

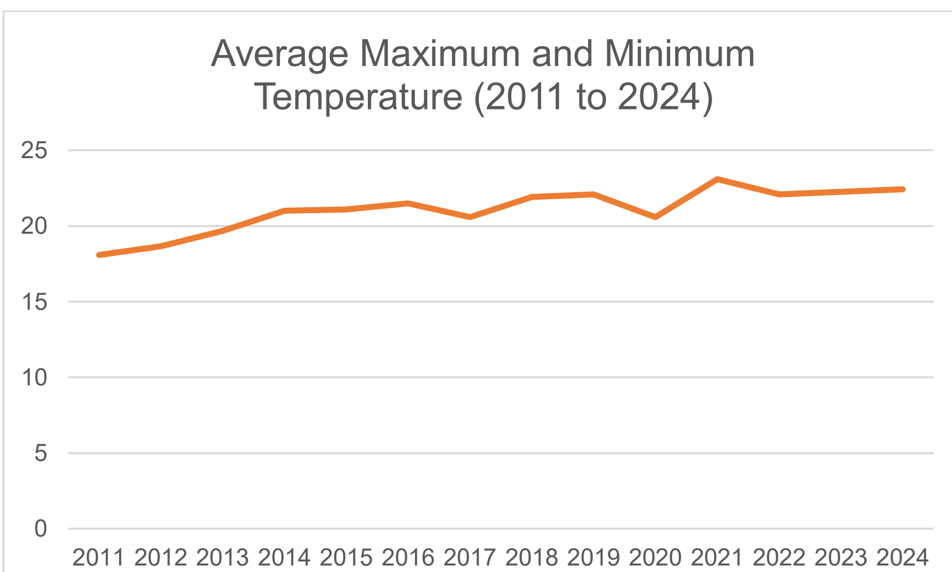

Figure 4-3: Chirundu Average Maximum and Minimum Temperature (2011 to 2024)

Source: (Weather station: Karoi, Zimbabwe, 2024)

Daily precipitation records from the Lusitu weather station indicated an average of 1.51mm from 1989 to 1996. The highest record was 100mm in 1992. Figure 4-4 shows a downward trend of the average precipitation.

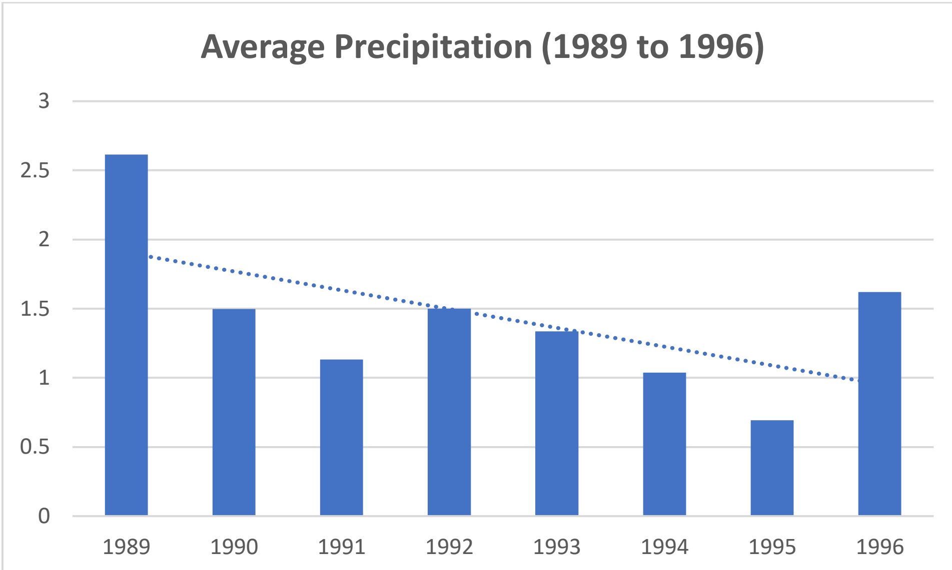

Figure 4-4: Average Precipitation (1989 to 1996)

Data was collected from Climate Data, therefore, analysis of the data led to the graph as illustrated below;

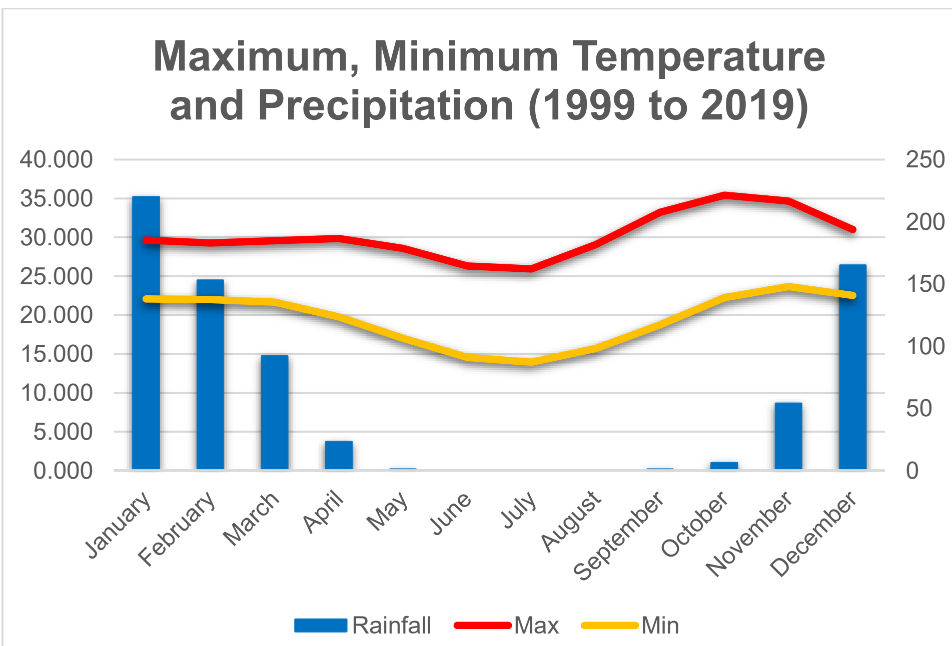

Figure 4-5: Average Maximum, Minimum Temperature and Precipitation (1999 to 2019)

Source: (Climate Data, 2019)

Figure 4-5 shows the average maximum and minimum temperature as well as precipitation of each month from 1999 to 2019. The graph depicts the seasonal weather conditions of Chirundu district. Rainfall is experienced in the months of January, February, March, April, May, September, October, November and December. The highest temperatures are experienced in months with little to no rainfall.

The Table 4-1 presents the water quality data of the Zambezi River collected from WARMA headquarters from 2017 to 2022. As shown below, the pH of the water varies from 5 to 7 with a temperature of 23 °C to 27 °C.

Table 4-1: Water Quality of Zambezi River

Station Name	River	Date	pH	EC	TDS	Tem	Turbidity
				µS/cm	mg/l	°C	NTU
Chirundu Bridge	Zambezi	Feb-17	6.95	883	44.3	25.4	-
Chirundu Bridge	Zambezi	Sep-18	5.76	84.5	42.2	24.1	-
Chirundu Bridge	Zambezi	Nov-20	6.86	104.1	56.95	27.1	2.9
Chirundu Bridge	Zambezi	Sep-22	7.02	9.34	53.18	23.9	1.48
Chirundu Bridge	Zambezi	Nov-22	7.16	98.56	53.24	27	53.3

The figure below is a depiction of water distribution in Zambia and Borehole distribution in Chirundu district.

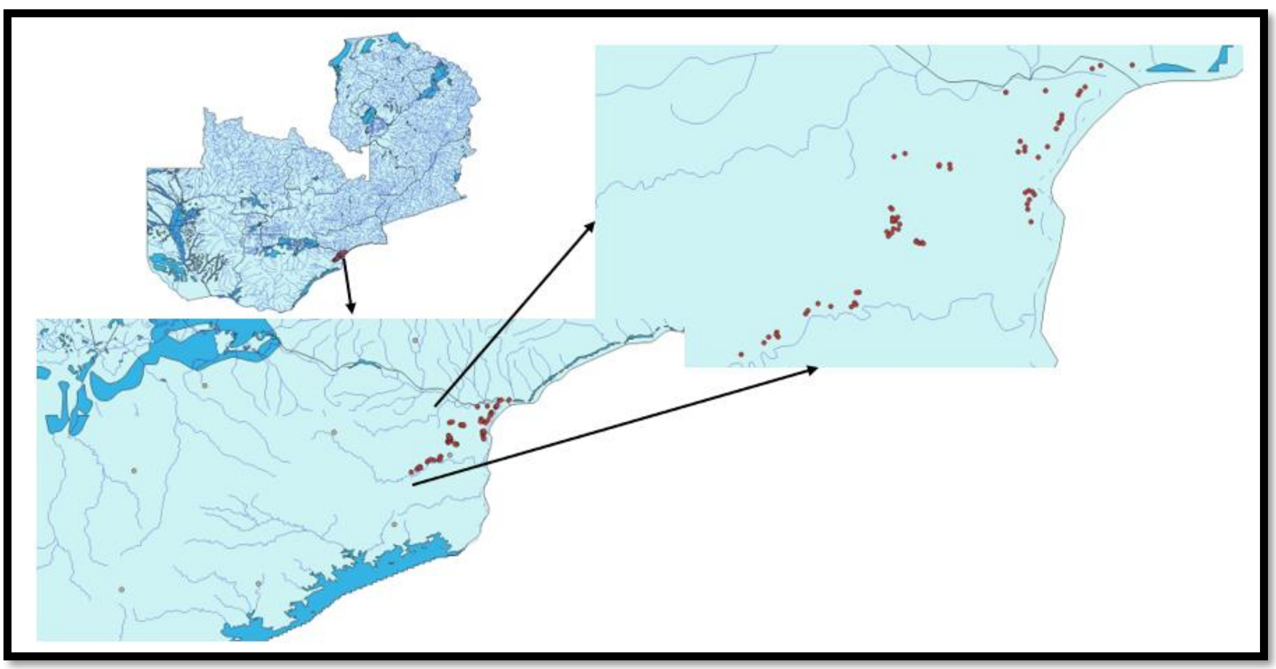

Figure 4-6: Water and Borehole Distribution in Chirundu District
Source: Researcher's Analysis

The figure shows Southern Province having the least water distribution in the country. The boreholes are also sparsely distributed showing the reliance of water supply from SWSC.

The table below indicates the responses received on the effect of climate change on water quality and quantity.

Table 4-2: Climate Change Effect on Water

Effect of Climate Change	Response
Lower water supply	100.00%
Grand Total	**100.00%**

Table 4-3 illustrates the effects of climate change on sanitation in Chirundu's urban area.

Table 4-3: Climate Change Effect on Sanitation

Response	Less water for toilets	Collapsed Pit Latrines due to Floods	Grand Total
Climate change effect on sanitation	24.63%	75.37%	**100.00%**

According to the SWSC Chirundu report, the graph below depicts their operations of 2024. It illustrates the Water Abstraction, Total Produced, Water Billed and the power Consumption Costs.

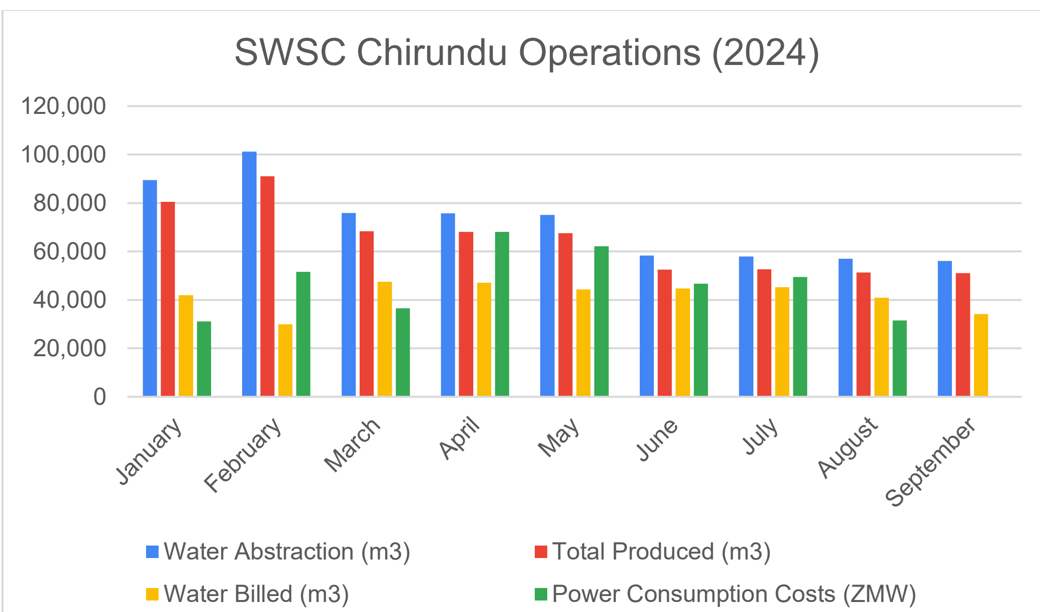

Figure 4-7: SWSC Chirundu Operations 2024

The graph in Figure 4-8 is an illustration of the percentage of NRW for each month of 2024 from January to September.

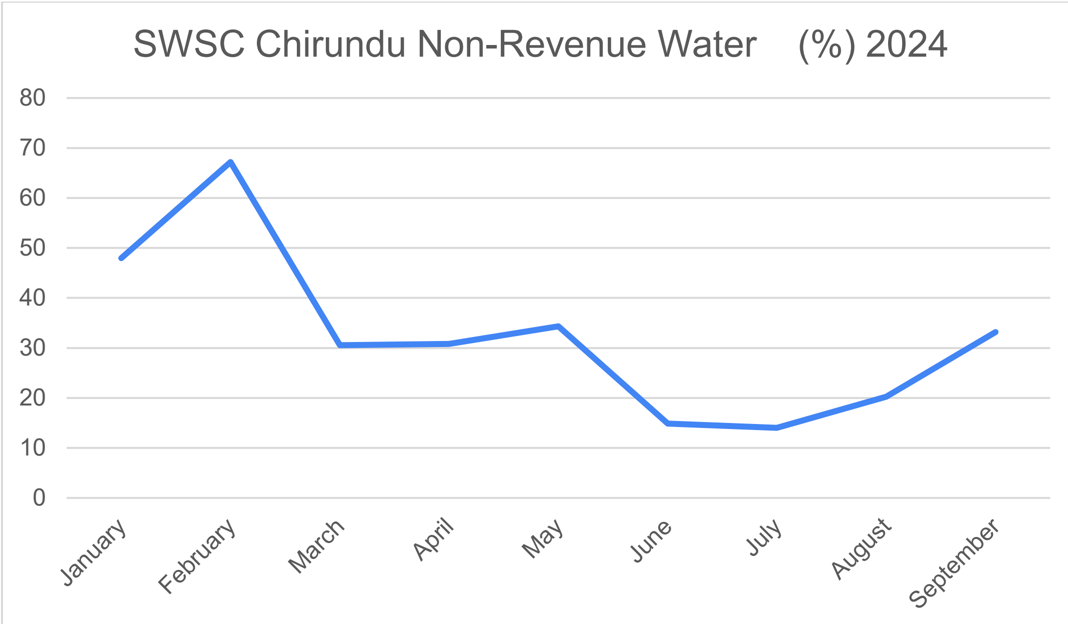

Figure 4-8: SWSC Chirundu Non-Revenue Water 2024

5 Discussion of Findings

The graphs on the average minimum and maximum temperatures indicate an upward trend showing an increase in temperature. This shows the climatic change of the area which cannot be avoided as this leads to events that affect the population of Chirundu's urban area. While an increase in temperature is being experienced, there is a decline in the average precipitation over the years. The increase in temperature and decrease in rainfall patterns has an effect on access to water, sanitation and hygiene. Increase in temperature results in an increased demand for water for daily activities such as drinking and hygiene practices. While the demand is increasing, the precipitations levels are dropping.

Despite having rainfall patterns or being near the Zambezi River, residents complained of the low water supply. Participants indicated having water supply for 6 hours and below per day. It was mentioned that the SWSC water system was established during the construction of the Chirundu Border Facility. The water system was meant to supply water to the border facility and the small population. However, with the growing population and increasing demand for water, the water system is unable to with stand the growing water demands. This coupled with the outdated water system that is not climate resilient makes it difficult to supply water to the households and institutions. For this reason, institutions such as schools and hospitals have diverted from the use of SWSC water supply to creating their own water supply systems such as boreholes that are more reliable. Individuals have also followed suit to avoid water shortages in their homes. However, there were complaints of water salinity from boreholes. Majority of the population do not have the means to have boreholes set up, thus, they are dependent on water supply from SWSC. When engaged, participants indicated that the water supply levels are lower in the hot and dry seasons. This worsens their situation and could go days without water supply. It was also indicated that places with higher terrain have difficulties in accessing water from SWSC as the pressure is insufficient to reach higher ground. They indicated various methods of copying in such periods such as fetching water from nearby schools with boreholes and going down to the Zambezi River to fetch raw water.

Another reason for the low water supply has been attributed to climate change as water supply is reliant on hydroelectric power. The SWSC system is dependent on supplying water to Chirundu's urban area by pumping water from the Zambezi River with the use of hydroelectric power generated from the Kariba Dam. This research took place in 2024, a year in which the country was declared to be in a state of emergency due to drought. This was due to the El Niño being experienced which is a phenomenon that occurs when sea temperatures rise significantly in the Pacific Ocean off South America resulting in dry air which affects the rain formation process. Zambia's Kariba dam had low water levels which resulted in loadshedding throughout the country. SWSC also underwent loadshedding periods. This meant water could not be pumped to houses during these hours. Additionally, the Zambezi River has lower water levels during drought periods. Small islands can be seen during these periods due to water levels dropping. This causes the pumps to draw in muddy water forcing them to deepen their pipes to avoid the muddy water.

Climatic events such as flush floods are common in Chirundu. This was said to hinder access to water as the floods would cause a runoff into the Zambezi River. As Chirundu's urban area is on a downward slope towards the Zambezi River, the runoff carries sediments such as mud and plastic into the Zambezi River. This makes the water brownish and unappealing to use. With the short hours of water supply and the muddy water, it is difficult to access good quality and high quantities of water in Chirundu. According to SWSC Chirundu, households have approximately 50 litres of water per capita per day on average in normal situations (not undergoing a climatic event) thus rating the service level at Intermediate Access to water. Otherwise, during extreme events, people have to make a more than 30 minutes roundtrip to the Zambezi River rating the service level at No Access. Climate change has also affected the water levels of the Zambezi River which force the water utility to extend its fabrication to deeper parts of the river.

Sanitation has also been affected by climate change. Households with flushable toilets do not have enough water to operate their toilets. This has caused them to use buckets turning them into pour flush toilets. Others have resorted to having both flushable toilets and pit latrines. In periods of no water, pit latrines are used due to water rationing. Most households have a ditch in their yards in which they dispose of their waste. Some of these ditches are not deep enough resulting in runoff carrying the waste into the Zambezi River. Others use the contractors for waste disposal. SWSC does not operate waste management but rather uses onsite.

Hygiene practices in the area are well known, however, the limited access to water does not support these practices. Hospitals have a health program which is used to sensitize the public on WASH and public health risk. Despite having the knowledge, residents are unable to practice handwashing due to water shortages. Women in particular have difficulties during menstruation as water is a necessity and are hindered due to limited water supply. Diarrhoea, typhoid and dysentery are the most common diseases in the area with diarrhea being the most common. All of these are water borne diseases further illustrating the water crisis.

However, efforts to lessen the burden are being made, for example, Local Authorities were said to have put up boreholes and hand pumps in various areas as well as conduct sensitization. Adventist Development and Relief Agency (ADRA) was seen to be the most active NGO in the district by providing boreholes and conducting sensitization in communities. The Red Cross was also stated to have aided schools with hand washing basins. Chirundu district has a record of twenty-nine (29) community boreholes with fifteen (15) being in the urban area. Temperatures range from 28°C to 34 °C within the normal range. However, the Electrical Conductivity (EC) of the 68 boreholes in Chirundu district with, 30 boreholes had more than 1000 microsiemens per centimeter (μS/cm) indicating high levels of dissolved solids affecting the appearance and taste (saltiness) of the water.

SWSC in Chirundu district showed a decline in its operations in 2024. This is attributed to the drought experienced in the country. With loadshedding, SWSC Chirundu was unable to supply water at all hours. This caused a water rationing in the district. Despite there being a water shortage, demands for water supply were increasing with SWSC Chirundu having a total of 560 new connections from January to August in 2024. This poses a problem as climate change and climatic events have had significant effects on water supply as evidenced in Figure 4-7 above. Additionally, the water system is unable to sustain the operations of water supply. As seen in the graph, Figure 4-7, the total water produced is twice as much as the total water billed with a ratio of 1:1.60. This coupled with the power consumption expenses with a total of Three Hundred Seventy-Seven Thousand Thirty-Three Zambian Kwacha (ZMW 377,033) for the period of January to August in 2024 indicates the unsustainability of their operations especially in the face of climate change.

The average NRW recoded in January to September 2024 by SWSC Chirundu was 32.57%. The graph in Figure 4-8 has a downward trend. However, this is due to the reduced hours in water supply caused by loadshedding. As seen in the graph, February had 67.19% of NRW before loadshedding was implemented in the country. Additionally, during 2024, SWSC Chirundu had experienced 41 leakage repairs from January to July. SWSC Chirundu is efficient in response to leakages as they have a system in place such as the use of WhatsApp for faulty reporting and technicians are on site within 30 minutes. That means they are reliant on customers reporting faults. Therefore, it is possible that between the time the leaks happen and the time they are reported, there have been substantial water losses incurred. Meaning it could be days before someone reports a leak. Despite having the system in place, NRW is still high and this can be attributed to the old and outdated water system as well as a not so efficient method for leak detection. 32.57% of NRW entails 32.57% of the water supplied has not been billed and the revenue lost cannot be recovered. Such losses hinder the development in the water sector. Therefore, there is need to have more efforts towards the reduction of NRW. This would mean investing in a new system that will enable a reduction in NRW and loss of revenue. Further, results show that systems need to be more efficient and should be made climate resilient to support the growing population.

6 Conclusions and Recommendations

6.1 Conclusions

Access to water is a basic human right and essential to health. Water is needed for day-to-day activities. As seen in this report, climate change has had its effects on WASH which if not given the attention required could lead to detrimental impacts. Building the resilience of the people and the WASH system is imperative for sustainable development. Sustainable Development Goal 6, is to ensure availability and sustainable management of water and sanitation for all. Thus, climate change is a huge threat to the development of WASH. As seen, rising temperatures and dropping precipitation in the past decades shows a decline in water availability. That coupled with weak WASH systems makes it even more difficult for people to access water. Therefore, management and investments into the WASH system play a significant role in achieving universal and equitable access to safe and affordable water.

The current effects of climate change include extreme weather events such as floods and droughts. Chirundu district currently has a high risk of floods, medium risk of drought and high seasonal variability. The district is affected by the El Niño which is brings in dry air from the risen sea temperatures causing dry conditions in the region. In 2023/24, Chirundu district, like the rest of the country, underwent an extreme event, drought, which affected WASH. The drought caused a lower water supply in the distribution system due to loadshedding. Chirundu district has a challenge in water supply which is worsened by the effects of climate change. People only had few hours, less than six (6) hours, of water supplied to their homes. Less water supply additionally affected sanitation and hygiene in the district. Flushable toilets were used as pour flash toilets or abandoned due to low water levels. Others have both flushable toilets and pit latrines for use in such times. Despite having knowledge on hygiene practices, the low water supply made it difficult for the people to have high standards of hygiene due to unavailability of water. This affects the health of the population and women during menstruation.

Future predictions indicate lower water supply in 2030, 2050 and 2080. Further, they show an increase in temperature from the current Average Mean Surface Air Temperature of 2 °C to 3 °C in 2030 to 4 °C in 2050 and 6°C in 2080. With the lowered water supply and increasing temperatures, WASH is highly vulnerable to climate change effects. With the water scarcity currently being experienced, this is seen to worsen over time if nothing is done about it. These conditions will continue to affect the water supply, lowering the amount of water available per capita per day thus affecting access to safe water, thereby further affecting sanitation and hygiene.

Prolonged droughts have impacts on the water supply system as well as floods which overwhelm the water infrastructure causing pollution of the water, thus making it vulnerable to climate change. Pollution of water in the water system causes diseases such as diarrhea, dysentery and typhoid, further making the people vulnerable to climate change effects. Higher temperatures also encourage the growth of microorganisms in water further exposing people to diseases. Water scarcity additionally hinders hygiene practices, worsening diseases in the area. Chirundu's urban area has old water supply infrastructure which makes it weak and vulnerable to climate related stresses. Chirundu has poor sanitation services with households throwing their garbage in pits. Erosion caused by floods pollutes water sources (Zambezi River Basin), therefore more energy and funds for water treatment would be required further stressing water supply. Power cuts disrupt water delivery services making water supply vulnerable to climate change. The current tariffs are extremely inadequate as they are highly regulated, therefore SWSC in Chirundu is operating under hardships.

This study considered the management of NRW as an adaptation measure to climate change. As water is abstracted, treated, produced and distributed, a lot of investment goes into the process. To have a high percentage of NRW means water utilities incur high investment losses. SWSC in Chirundu currently has an average of 32.57% of NRW which is higher than the aspiring 25%. This was mostly attributed to the old infrastructure, leakages due to bad networks (physical water loss) and a low metering ratio (non-physical water loss).

Management of NRW is important for various reasons. Water utilities could improve their service delivery as they would be able to provide water for more hours a day. The revenue earned also makes them more efficient in delivery of services. NRW management allows for expansion as the revenue earned can be re-invested into the WASH system. This could help develop the water supply system as new and improved infrastructure that is climate resilient can be put in place. This protects the water supply to households even during climatic events as strong systems have been established. Management of NRW also helps in making water affordable for the communities. For instance, high NRW means lost revenue, however, to cover the costs of operations of the water systems, households would be charged at a higher rate to keep the water utility running. Therefore, the burden is passed on to the client or the government would have to subsidize the costs when the money could be used to improve the WASH system instead.

Additionally, managing NRW allows for expansion into the rural areas of Chirundu district. The urban area has a water crisis which only means the rural areas are suffering from the same if not worse. Investments in WASH in rural areas could build the resilience of the people and aid them in access to safe drinking water. Rural areas are highly dependent on farming and livestock rearing, without water it makes it difficult for them to sustain their livelihoods.

6.2 Recommendations

Due to the changing climate and erratic climatic events experienced in Chirundu district, it is imperative to have a Meteorological station in the district. As it is a vastly growing area, having data on weather conditions will aid in strengthening climate resilience and reducing vulnerabilities. This data would provide the base for analysis of future climatic events which will help decision makers and developers. Early warnings systems can be effectively and efficiently implemented in the district.

As discussed, innovative technology such as SCADA can be adopted to help reduce water losses. Holistic approaches to reducing NRW such as integrating the strategies into one holistic approach on network monitoring, pressure management, regular analysis and reporting, proactive leak detection and trainings would be the ideal strategy. Although there has been a NRW management strategy, the percentage of NRW is still increasing. The strategy does not anticipate the impacts of climate change and take them into account in order to identify the best solutions for building resilience and reducing NRW and developing sustainable services. Reducing a system’s exposure to climate-related hazards is a vital component of the climate change adaptation approach. The adaptation approach should involve reducing the exposure and vulnerability to climate-related hazards. Mitigation entails a fundamental change to energy systems. Although economic and societal transition is imperative, it requires huge amounts of funding. Adaptation also has an economic cost that developing countries are unable to afford, particularly as they already have other, socio-economic issues to address. As the strategy promotes flexible decision-making and good governance in order to avoid mal-adaptation, it also promotes the innovation and adoption of new technologies that promote and enhance NRW Management. However, it does not highlight climate change and how NRW could be used as an adaptation strategy. Further, the NRW management strategy does not have a Resource Mobilization Strategy and Plan to ensure its implementation. Targets and their costs have been assigned but a strategy to map out or effectively find the funds needed to implement this strategy has not been developed. The Zambia Water Investment Programme (ZIP) has a Resource Mobilization Strategy recently developed in 2024 but looks at the water sector in a wider range. Therefore, a Resource Mobilization Strategy and Plan should be developed specifically to give direction in the financing of the various components under the NRW management strategy. International funds have been set up, such as the Green Climate Fund, created under the United Nations Forum for Climate Change Convention (UNFCCC), and the Adaptation Fund, thus, using NRW management as an adaptation strategy could be used to source these funds. Furthermore, commercial utilities are expected to develop strategies towards NRW management as well as implement them.

The National Adaptation Plan for Zambia is referenced in the ZIP Resource Mobilization Strategy. However, the NAP does not specifically include the management of NRW as an adaptation strategy in the water sector. Deliberate inclusion of NRW management should be made in national adaptation strategies as this would aid in a more sustainable development for the water sector.

Reducing water losses contributes to the conservation of a scarce natural resource (water) and also improves utility financial viability through increased revenue, reduced repair and energy costs. NRW management enables diversification of capital expenditure for new sources and system expansion to provide for the increasing demand, saves energy and reduces carbon emissions. This contributes to mitigating climate change impacts and promoting sustainability. By addressing NRW, countries and organizations can improve water availability, enhanced management of water resources, promotion of climate resilient and sustainable infrastructure and support the broader sustainable development agenda.

7 References

AbuEltayef, H. T., AbuAlhin, K. S. & Alastal, K. M., 2023. Addressing Non-Revenue Water as a Global Problem and its Interlinkages with Sustainable Development Goals. *Water Practice & Technology Vol 18 No 12,* pp. 3175-3202.

Ahmed, Z. Y., 2024. Reducing Non-Revenue Water. *International Journal of Applied Mathematics, Computational Science and Systems Engineering,* Volume VI, pp. 23-29.

Beitzel, M., 2021. *Reducing Urban Water Losses: How Water Utilities Can Improve Efficiency and Meet Future,* s.l.: s.n.

Chirgwin, H., Cairncross, S., Zehra, D. & Waddington, H. S., 2021. *Interventions Promoting Uptake of Water, Sanitation and Hygiene (WASH) Technologies in Low- and Middle-income Countries: An Evidence and Gap Map of Effectiveness Studies,* London: John Wiley & Sons Ltd on behalf of The Campbell Collaboration.

Climate Data, 2019. *Climate Data.* [Online]
Available at: https://en.climate-data.org/africa/zambia/southern-province/chirundu-54402/
[Accessed 5 January 2025].

CRED, 2023. *2023 Disasters in Numbers,* Brussels: Centre for Research on the Epidemiology of Disasters (CRED).

CRIDF, 2016. *Chirundu Water Supply and Sanitation: Feasibility Report,* s.l.: CRIDF.

Crowder, 2024. *5 Strategies to Help Reduce Non-Revenue Water.* [Online]
Available at: https://www.crowderconsult.com/blog/strategies-help-reduce-non-revenue-water
[Accessed 7 January 2025].

Dietz, T., Shwom, R. L. & Whitley, C. T., 2020. Climate Change and Society. *Annual Review of Sociology,* pp. 135-158.

Draganic, I., Bernal, E. & Stordal, L., 2022. *Water and Sanitation Operators Managing and Responding to Natural Disasters in a Changing Climate,* s.l.: UN-Habitat Global Water Operators' Partnerships Alliance.

Fawzy, S., Osman, A. I., Doran, J. & Rooney, D. W., 2020. Strategies for Mitigation of Climate Change: A Review. *Environmental Chemistry Letters,* p. 2069–2094.

GRZ, 2011. *National Urban Water Supply and Sanitation Programme,* Lusaka: MInistry of Local Government and Housing.

GRZ, 2021 b. *Revised Nationally Determined Contribution (NDC) of Zambia,* Lusaka: The Government of the Republic of Zambia.

GRZ, 2021. *National Non-Revenue Water Management Strategy 2022 - 2026,* Lusaka: MWDS.

GRZ, 2022. *Eighth National Development Plan (8NDP) 2022 - 2026,* Lusaka: The Government of the Republic of Zambia.

GRZ, 2023. *The National Adaptation Plan For Zambia,* Lusaka: GRZ.

GRZ, 2024. *National Water Policy 2024,* Lusaka: GRZ.

Hamududu, B. H. & Ngoma, H., 2019. IMPACTS OF CLIMATE CHANGE ON WATER AVAILABILITY IN ZAMBIA: IMPLICATIONS FOR IRRIGATION DEVELOPMENT. *Feed the Future Innovation Lab for Food Security Policy.*

Haque, S. S. & Freeman, M. C., 2021. The Applications of Implementation Science in Water, Sanitation, and Hygiene (WASH) Research and Practice. *Environmental Health Perspectives,* pp. 1-10.

IPCC, 2018. *Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to,* E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp.: Change, Sustainable Development, and Efforts to Eradicate Poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, .

Kingdom, B., Soppe, G. & Sy, J., 2016. *What is non-revenue water? How can we reduce it for better water service?.* [Online]
Available at: https://blogs.worldbank.org/en/water/what-non-revenue-water-how-can-we-reduce-it-better-water-service

Liemberger, R. & Wyatt, A., 2018. Quantifying the Global Non-Revenue Water Problem. *Water Science and Technology Water Supply,* pp. 1-17.

Mackinnon, E. et al., 2019. 21st Century Research in Urban WASH and Health in Sub-Saharan Africa: Methods and Outcomes in Transition. *International Journal of Environmental Health Research,* p. 457–478.

Malek, H. A., Zakaria, M. H., Zulkifli, M. L. & Roslan, N. F., 2021. Determinants of Non-Revenue Water. *Malaysian Journal of Computing , 6 (1),* pp. 642-649.

Megaw, T., Kohlitz, J., Gero, A. & Chong, J., 2020. *Understanding and Responding to Climate Change Impacts in Inclusive WASH Programs - A Conceptual Framework – Learning Paper,* Sydney: Institute for Sustainable Futures, University of Technology Sydney.

MWDS, 2022. *National Non- Revenue Water Management Strategy 2022 - 2026,* Lusaka: The Government of the Republic of Zambia.

Nasara, M. A. et al., 2021. Assessment of Non-Revenue Water Management Practices in NIgeria (A Case Study of Bauchi State Water and Sewerage Cooperation). *American Journal of Engineering Research (AJER),* pp. pp-390-401.

NWASCO, 2023. *Water Supply and Sanitation: Sector Report 2023,* Lusaka: National Water Supply and Sanitation Council.

O'Rourke, E., 1992. The International Drinking Water Supply and Sanitation Decade: Dogmatic Means to a Debatable End. *Wai. Set. Tech. Vol. 26,* pp. 1929-1939.

pS-Eau, 2018. *WASH Services and Climate Change Impacts and Responses,* s.l.: PROGRAMME SOLIDARITÉ EAU.

Ross, A. G. et al., 2020. Can We 'WaSH' Infectious Diseases Out of Slums?. *International Journal of Infectious Diseases,* pp. 130-132.

SIWI, 2019. *Accelerating Climate Action: Building Resilient Cities through Improved Water Governance,* Sweden: Stockholm International Water Institute.

SMM, 2022. *Climate Change, Water, Sanitation and Hygiene and Resilience: A Briefing Paper from SWA Research and Learning Constituency,* s.l.: Sector Ministers' Meeting.

State of Green, 2018. *7 examples of reducing urban water loss and NRW.* [Online]
Available at: https://stateofgreen.com/en/news/7-examples-of-reducing-urban-water-loss/
[Accessed 07 January 2025].

Tarusarira, J., Caroli, G., Medina, L. & Maviza, G., 2023. *When Values Inform Approaches to Climate Security: The Case of Zambia's Southern Province.* [Online]
Available at: https://www.accord.org.za/publication/when-values-inform-approaches-to-climate-security-the-case-of-zambias-southern-province/

UN, 2023. *Sustainable Development Goals: 17 Goals to Transform our World.* [Online]
Available at: https://www.un.org/en/exhibits/page/sdgs-17-goals-transform-world

UN, 2024. *MVI - Preliminary Country Scores.* [Online]
Available at: https://www.un.org/ohrlls/content/mvi-preliminary-country-scores
[Accessed 02 December 2024].

UNEP, 2023. *Emissions Gap Report 2023: Broken Record – Temperatures hit new highs, yet world fails to cut emissions (again),* Nairobi: United Nations Environment Programme.

UNICEF, 2024. *Rising Heat, Drought and Disease: Climate Crisis Poses Grave Risks to Children in Eastern and Southern Africa.* [Online]
Available at: https://www.unicef.org/zambia/press-releases/rising-heat-drought-and-disease-climate-crisis-poses-grave-risks-children-eastern

USAID, 2022. *Financing for Commercial Water Utilities in Zambia,* s.l.: USAID.

WBG, 2024. *What is Climate Change?.* [Online]
Available at: https://climateknowledgeportal.worldbank.org/overview

WBG, 2024. *Zambia.* [Online]
Available at: https://climateknowledgeportal.worldbank.org/country/zambia/climate-data-projections

Weather station: Karoi, Zimbabwe, 2024. *Time and Date.* [Online]
Available at:
https://www.timeanddate.com/weather/@893398/historic?month=12&year=2024
[Accessed 05 January 2025].

WHO, 2011. *Guidelines for Drinking Water Quality: Fourth Edition,* Geneva: World Health Organization.

WRI, 2023. *Water Risk Atlas.* [Online]
Available at: https://www.wri.org/applications/aqueduct/water-risk-atlas/#/?advanced=false&basemap=hydro&geoStore=0103742d088cc8b722ac444ed9163f79&indicator=beca58ab-f8a3-4f46-b790-75951d24456e&lat=-15.998625415960376&lng=-331.248779296875&mapMode=view&month=1&opacity=
[Accessed 02 December 2024].

Yue, X.-L. & Gao, Q.-X., 2018. Contributions of Natural Systems and Human Activity to Greenhouse Gas Emissions. *Advances in Climate Change Research 9,* pp. 243-252.

ZAMSTATS, 2022. *Zambia 2022 Census of Population and Housing,* Lusaka: The Government of the republic of Zambia.

7.1 Similarity Report

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8 Appendices

8.1 Water Quality for Boreholes in Chirundu district

NO.	LATITUDE	LONGITUDE	B.H TYPE	YEAR DRILLED	Temp (°C)	EC (µS/cm)	TDS (ppm)
1	-16.225123	28.54696	Community B.H	1948	30.1	1108	581.5
2	-16.113723	28.725373	Community B.H	1975	30.6	660.8	347.2
3	-16.094634	28.705779		1980	31.2	960.8	505.8
4	-16.114065	28.729428	Community B.H	1994	30.8	783.5	412
5	-16.175272	28.662015	Community B.H	1995	29.1	457.1	240.4
6	-15.989199	28.868029	Community B.H	1998	30.5	335	1760
7	-16.213423	28.569875	Community B.H	1998	30.4	1305	685.2
8	-16.207717	28.574537	Community B.H	1998	31.3	1492	783.5
9	-16.202817	28.582647	School B.H	1998	31.5	1483	779.5
10	-16.079574	28.698144		1999	30.4	2.28	1206
11	-15.938744	28.898651	Community B.H	2005			
12	-16.065131	28.840793		2008	31.9	861.1	452.4
13	-16.184365	28.611527	Community B.H	2010	29.6	1747	917.7
14	-15.998858	28.86273	Community B.H	2011	29.3	1528	803.1
15	-16.173358	28.660532	Community B.H	2012	29.8	676.4	355.4
16	-15.95709	28.891528	Community B.H	2012	31.1	2470	1301
17	-16.062188	28.838757	Community B.H	2013	30.6	863.1	454
18	-16.112917	28.728245		2013	30.6	944.8	496.3
19	-15.96496	28.88474	Non Commercial	2013	30	1175	617
20	-16.06091	28.835245	Community B.H	2014	31.6	723.6	380.4
21	-16.034677	28.755892	Community B.H	2014	30.1	588.4	309.4
22	-15.961133	28.88686	Community B.H	2014	30.2	5390	2831
23	-16.01689	28.853882	Non Commercial	2014	30.3	1221	641.5
24	-16.079662	28.83409	Community B.H	2015	30.8	970.5	509.9
25	-16.062956	28.83165	School B.H	2015	30.7	795.9	418.1
26	-16.111211	28.722565		2015	31.1	2260	1182
27	-16.17737	28.657378	Community B.H	2015	28.6	462	242.7
28	-15.985053	28.868265	Community B.H	2015	30.3	2240	1176
29	-16.16281	28.665134	Community B.H	2016	30.7	825.3	452.3
30	-16.02685	28.700195	Community B.H	2016	30.8	1200	632.3
31	-16.027575	28.8445865	Non Commercial	2016	30.5	781.2	410
32	-16.022116	28.824581		2016	31	785.2	413.2
33	-16.163075	28.66237	Community B.H	2016	31.6	1121	586.5
34	-16.092197	28.837347	School B.H	2017	30.8	4020	2113
35	-16.205295	28.58209		2017	31.5	1456	765.1
36	-16.036432	28.745202	Non Commercial	2017	30.4	557.9	293.1
37	-15.962408	28.81211	Non Commercial	2017	31.4	1925	1011
38	-15.962408	28.81211	Non Commercial	2017	31.4	1665	875.8
39	-16.112358	28.722045	School B.H	2018	30.4	1038	544.9

40	-16.1812	28.61381	Community B.H	2018	29.9	532.7	279.7
41	-16.10211	28.692857		2018	29.5	583.1	305
42	-15.960812	28.851855	Non Commercial	2018	28.1	1322	699.4
43	15.99306	28.865417		2018	30.6	1287	676.2
44	15.99306	28.865417		2018	30.4	1312	689
45	-16.08815	28.698585		2019	31.1	4610	2418
46	-16.01706	28.831125	Non Commercial	2019	32.6	851.3	447.2
47	-16.069817	28.835757	Community B.H	2020	31.1	949.2	498.6
48	-16.207603	28.583962	Community B.H	2020	30.3	1131	595.2
49	-16.174152	28.623918		2020	30.3	991.1	519.9
50	-16.038922	28.75634	Non Commercial	2020	29.8	580	304.6
51	-16.074468	28.833537	Community B.H	2021	30.8	1029	541.2
52	-16.177004	28.636786	Community B.H	2021	29.6	2730	1437
53	-16.035061	28.745405	Non Commercial	2021	29.4	1254	649.5
54	-16.0115538	28.826493	Non Commercial	2021	31.7	897.5	471.3
55	-15.935472	28.907012	Community B.H	2022			
56	-16.106605	28.694455			29.4	214.5	112.9
57	-16.099748	28.704318			29.8	648	340.3
58	-16.103423	28.697737			29.1	475.5	249
59	-16.091427	28.70138			29.4	808.1	424.6
60	-16.099038	28.69955	School B.H		28.3	727.7	382
61	-16.090518	28.700352			29.8	951.5	503.3
62	-16.091823	28.69846	School B.H		29.3	973.4	510.8
63	-16.08956	28.699483	School B.H		29.1	973.8	514.6
64	-16.08769	28.703773			30.3	1141	599.2
65	-16.078147	28.69672			30.8	2780	4560
66	-16.023747	28.711091			29.4	985.4	517.3
67	-15.93506	28.938777	Community B.H		32.4	1078	566
68	-16.021268	28.831037	Non Commercial		34.2	859.9	457.1