CHARACTERISATION OF SURFACE WATER QUALITY IN THE LUAPULA RIVER BASIN AND DEVELOPING A WQI_{min} MODEL FOR POTENTIAL INTER-BASIN WATER TRANSFER TO THE KAFUE RIVER BASIN

By

JOVITA KAZEKULA

A thesis submitted to the University of Zambia in fulfilment of the requirements for the degree of Master of Science in Integrated Water Resources Management

THE UNIVERSITY OF ZAMBIA

LUSAKA

2025

DECLARATION

I, Jovita Kazekula, declare that this is my work and that the thesis has neither in part nor in whole been presented as substance for an award of any degree to this university or any other university. Acknowledgement has been made where other people's work has been drawn upon.

Signature of Author…………………………………………………………………………

Date………………………………………………………………………………………

APPROVAL

This thesis of Jovita Kazekula is approved as fulfilling the requirements of the Degree of Master of Science in Integrated Water Resources Management of the University of Zambia.

Name	Signature	Date
Chairperson		
1st Examiner		
2nd Examiner		
External Examiner		

ABSTRACT

This study underscored the importance of water quality, providing insights for sustainable resource management in decision-making and development planning. The study focused on the Luapula River Basin (LRB) in Zambia, a potential donor for inter-basin water transfers to the Kafue River Basin (KRB). The research objectives included establishing baseline data on surface water quality and developing a cost-effective Water Quality Index model (WQI_{min}) for regular monitoring. Data was collected during both the dry and wet seasons of 2022 and 2023, respectively. Two triplicate samples were collected from each sampling point using the grab sampling method from 57 sampling points in the dry season and 91 sampling points in the dry and wet seasons. The samples were analysed according to the standard methods for the examination of water and wastewater. In the dry season, Electrical conductivity (EC) ranged from 8 µs/cm to 225 µs/cm, Total dissolved solids (TDS) values ranged from 5 mg/L to 162 mg/L, pH values ranged from 6.19 to 8.4 and temperature ranged from 18.5^0C to 28.1^0C, potassium ranged from 1.7 mg/L to 12 mg/L, sodium ranged from 5.3 mg/L to 36.3 mg/L, chloride ranged from 8 mg/L to 55 mg/L, turbidity ranged from 1.39 NTU to 37.2 NTU, iron ranged from <0.002 mg/L to 2.234 mg/L, calcium hardness ranged from 6 $mgCaCO_3$/l to 30 mgCaCO3/l and total hardness ranged from 20 $mgCaCO_3$/l to 106 $mgCaCO_3$/l. In the wet season, EC ranged from 6 µs/cm to 78 µs/cm, TDS ranged from 2 mg/L to 50 mg/L, pH ranged from 5.97 to 8.23 and temperature ranged from 20.8^0C to 28.8^0C, potassium ranged from < 0.01 mg/L to 2.4 mg/L, chloride ranged from 2 mg/L to 14 mg/L, turbidity ranged from 0.3 NTU to 24.9 NTU and iron ranged from <0.002 mg/L to 1.4 mg/L. Calcium and total hardness values were all below the detection limit of 1 $mgCaCO_3$/l in the wet season. Total and faecal coliforms ranged from 0 CFU/100 ml to > 200 CFU/100 ml in both seasons. The concentrations of nitrate, phosphate and sulphate were below the detection limit of 0.01 mg/L. Similarly, the levels of manganese and lead were below the detection limits of <0.002 mg/L and <0.01 mg/L, respectively, in both seasons. The spatial-temporal variations were influenced by precipitation patterns, geological factors and anthropogenic activities, notably evidenced by elevated coliforms, iron, turbidity, sodium and chloride levels in specific areas. Hydro-chemical analysis characterised the surface water as a calcium–magnesium–bicarbonate type, indicating underlying geological geology rich in silicates. The WQI indicated that nine per cent of the sampling points in the LRB were unsafe, seven per cent were very poor, four per cent were poor, 2 per cent were good and 58 per cent were excellent for ambient purposes. The poor and unsafe WQIs in specific locations were mainly attributed to iron and turbidity. However, the overall WQI for the LRB was 38 per cent, indicating that the LRB has good-quality water making the implementation of inter-basin water transfer to the KRB feasible. A multi-linear regression model was developed for predicting the WQI value based on only five parameters (the WQI_{min} value). The use of WQI_{min} has the potential to save on the costs and time associated with water-quality monitoring. This model has the potential to aid in understanding challenges linked to inter-basin transfer and support the formulation of management strategies prioritizing water availability and ecosystem and livelihood sustainability.

Keywords:
Hydro-chemical analysis, Luapula River Basin, Spatial-temporal variations, Water Quality Index, WQI_{min} model, Zambia.

To my late mother, Christine Kazani, husband, children and family, whose love and support inspired me to work hard.

ACKNOWLEDGEMENTS

I thank the Oliver and Adelaide Tambo Foundation and the Oliver Tambo Africa Research Chairs Initiative (ORTARChi) for their financial support. I would also like to extend my gratitude to Professor Imasiku A. Nyambe, Professor Kawawa Banda and Stanley Hantambo, a PhD student, for guiding me during the supervision of this thesis. Special thanks go to my husband, Mwewa A. Lwanga, for his unwavering support throughout my study.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ACRONYMS

8NDP	8th National Development Plan
Ca	Calcium
CaH	Calcium Hardness
Cl^-	Chloride
CRB	Congo River Basin
DO	Dissolved Oxygen
EC	Electrical Conductivity
EDTA	Ethylenediaminetetraacetic Acid
FAO	Food And Agriculture Organisation
FC	Faecal Coliforms
Fe	Iron
GPS	Global Positioning System
ICMM	International Council on Mining and Metals
IFC	International Finance Corporation
ISO	International Organization for Standardization
ITCZ	Intertropical Convergence Zone
IWRM	Integrated Water Resources Management
JICA	Japan International Cooperation Agency
K	Potassium
KRB	Kafue River Basin
LRB	Luapula River Basin
MDG	Millennium Development Goals
MEWD	Ministry of Energy and Water Development
MFNP	Ministry of Finance and National Planning
Mg	Magnesium
Mn	Manganese
MWDSEP	Ministry of Water Development, Sanitation and Environmental Protection
Na	Sodium

NASREC	Natural and Applied Sciences Research Ethics Committee
NER	No Effect Range
NO_3	Nitrate
NRWSSP	National Rural Water Supply and Sanitation Programme
NTU	Unity of Turbidity
NUWSSP	National Urban Water Supply and Sanitation Programme
NWASCO	National Water Supply and Sanitation Council
NYSDH	New York State Department of Health
ORTARChI	Oliver Tambo Africa Research Chairs Initiative
Pb	Lead
pH	Potential Hydrogen
PO_4	Phosphate
PPE	Personal Protective Equipment
SDG	Sustainable Development Goals
SO_4	Sulphate
T	Temperature
TC	Total Coliforms
TDS	Total Dissolved Solids
TH	Total Hardness
TNTC	Too Numerous To Count
TWQR	Target Water Quality Range
UN	United Nations
UNICEF	United Nations Children's Fund
WARMA	Water Resources Management Authority
WHO	World Health Organisation
WQI	Water Quality Index
WWF	World Wildlife Fund
ZABS	Zambia Bureau Of Standards
ZEMA	Zambia Environmental Management Agency
ZRB	Zambezi River Basin
ZWIP	Zambia Water Investment Programme

1.0 INTRODUCTION

1.1 Background

Surface water is a vital natural renewable resource and a necessity for the survival of both humans and animals (Abanyie *et al*., 2023). Safe and adequate water contributes to a country's economic growth and development by promoting human welfare, disease prevention and poverty reduction (Abanyie *et al*., 2023). However, most countries have an uneven distribution of water over time and space, which often limits its use and availability (Ngoma and Hamududu, 2019). In addition to the uneven distribution of water resources, population growth, urbanisation and climate change have a significant impact on the amount of water available (Molekoa *et al*., 2021). These variables increase the stress associated with water resource distribution, which leads to water scarcity, which is a serious worldwide issue that can have an impact on ecosystems, communities and economies (UN-Water, 2019; WWF, 2016).

To address water scarcity and other water-related issues, many countries, including China, the United States, Australia, India, Russia, Brazil and South Africa, have implemented inter-basin water transfer schemes (Gurung, 2015). According to the Ministry of Finance and National Planning (MFNP, 2022), Zambia is among the countries that are considering implementing inter-basin water transfer to address water scarcity and enhance the management and productive use of water resources. Inter-basin water transfer is the movement of water from a basin with a surplus, to a basin with a shortage to alleviate water scarcity in the recipient basin (CTCN, 2016). However, the implementation of inter-basin water transfer poses some socio-economic, ecological and public health implications (Laassilia *et al.*, 2021). Therefore, implementing inter-basin water transfer calls for effective water resource management and monitoring. Frequent surface water quality monitoring is essential in inter-basin water transfer projects to detect and manage pollutants, ensure ecological balance, protect public health and guarantee the availability of high-quality water for all uses (Fathi *et al*., 2018). Water quality is the measure of water for a particular, use based on physio-chemical, chemical and biological characteristics (USGS, 2018). Surface-water-quality monitoring also plays a vital role in the identification of possible sources of pollution that can be associated with anthropogenic activities and result from industrial processes, agricultural runoff and domestic wastewater (Syeed *et al*., 2023). In addition to anthropogenic activities, pollution also comes from natural phenomena driven by hydrological processes (Bortoletto *et al.*, 2015; Shil *et al.*, 2019). Water quality monitoring also helps in determining the treatment process required for the water (American Public Health Association *et al.*, 2017). Therefore, water quality monitoring provides important information that helps in river basin management and conservation.

This research was part of the Oliver Tambo Africa Research Chairs Initiative (ORTARChI), a water conservation project whose theme was enhancing catchment protection and management in the Upper Zambezi and Luapula River basins. The project was launched on March 4, 2022. The objective of the project was to improve water management in the Upper Zambezi and Luapula River basins in the framework of Integrated Water Resources Management (IWRM). This would be achieved by creating knowledge through studies on the water and stream sediment quality and quantity, inter-basin water transfers between the two basins and the development of site-specific remediation technologies. Therefore, the results of the study will help to determine the characteristics of surface water quality in the Luapula River Basin (LRB), remedial action for pollution and the implications for inter-basin water transfers.

The main objective of this study was to establish baseline data on the quality of surface water in the LRB for domestic and ambient purposes and to develop a $\mathrm{WQI}_{\mathrm{min}}$ model to be used for regular water quality monitoring in the LRB in line with inter-basin water transfer from the LRB to the Kafue River Basin (KRB). The specific objectives of the study included determining spatial-temporal variations of surface water quality parameters, evaluating the hydro-chemical characteristics of surface water and establishing the Water Quality Index (WQI) for the LRB using the Zambian Bureau of Standards (ZABS, 2021) guidelines on ambient water. The World Health Organisation (WHO, 2017) guidelines for drinking water were also incorporated as domestic use was identified as the best water use in the LRB (ZABS, 2021).

1.2 Problem Statement

Water scarcity poses a critical global challenge and can affect ecosystems, communities and economies (UN-Water, 2019). Water scarcity increases reliance on alternative water sources, whose quality might be compromised due to pollution. This often leads to diseases such as cholera and diarrhoea, which are the leading causes of death in children under five (World Bank, 2020). In Zambia, water scarcity is a significant issue despite the country's abundant water resources (Maluleke, 2024). Challenges arise due to uneven distribution, variable rainfall and increasing demand for water (Ngoma and Hamududu, 2019). The KRB, which includes the capital city of

Lusaka, is the most water-stressed basin in the country. This is because it is the most urbanised and houses over 50 per cent of Zambia's population (WARMA, 2022). The situation in the KRB is of concern because it plays a major role in the country's economy as it has the most water use activities (WARMA, 2022). Addressing water scarcity through inter-basin water transfer in Zambia, particularly from the LRB to the KRB, is a feasible solution. However, it must be approached cautiously, considering the challenges associated with the environmental, economic, political and social aspects of such projects while ensuring water quality and safety throughout the transfer process (Wilson *et al*., 2017). This brings about the need for regular water quality monitoring in both the donor and receiver basins before and after inter-basin water transfer is implemented. Therefore, the development of a cost-effective method for regular monitoring is essential.

1.3 Objectives

The main objective of this study was to establish baseline data on the quality of surface water in the LRB, with the following specific objectives:

I. To determine spatial-temporal variations in surface water quality parameters;
II. To determine the hydro-chemical characteristics of surface water quality in the LRB; and
III. To develop a WQI_{min} model to be used for regular water quality monitoring for possible inter-basin water transfers.

1.4 Research Questions

The research questions for this study are:

I. What are the spatial-temporal variations of surface water in the LRB?
II. What are the hydro-chemical characteristics of surface water quality in the LRB? and
III. How can a WQI_{min} model be developed for regular water quality monitoring in inter-basin transfers?

1.5 Significance of the Study

The implementation of inter-basin water transfer in Zambia would address water scarcity in the KRB and promote the government's mandate of providing safe and adequate water to reduce disease and enhance economic growth. This study envisages providing information for decision-making concerning inter-basin water transfer in Zambia, specifically from the LRB to the KRB.

The findings of this study will provide information on whether it is possible to implement inter-basin water transfer from the LRB to the KRB, based on the quality of surface water in the LRB. The findings of this study were also used as input for a PhD study on inter-basin water transfer from the LRB to the KRB. The findings could also be helpful to the people of the LRB and the KRB, water utility companies, the agricultural sector, the metrological department, various industries and regulatory institutions such as the Water Resources Management Authority (WARMA), the Zambia Environmental Management Agency (ZEMA), the National Water Supply and Sanitation Council (NWASCO) and communities of the two basins and Zambia. The knowledge and skills acquired will also benefit future researchers in similar fields.

2.0 LITERATURE REVIEW

2.1 General Remarks

This chapter describes surface water quality, how it affects human welfare and its implications for inter-basin water transfer. The chapter also describes the water quality parameters that were analysed.

2.2 Sustainable Development Goals on Water

The 17 Sustainable Development Goals (SDGs) were agreed in 2015 by the United Nations General Assembly (UNGA) to be a blueprint for achieving a better and more sustainable future for all by the year 2030 (UN, 2017). The SDGs on water and sanitation, SDG No. 6, aims at ensuring the availability and sustainable management of water and sanitation for all. The SDGs have many targets set to achieve the different goals; target 6.4 of SDG No. 6 addresses water stress and the efficient use of water (UN-Water, 2018a). Target 6.4 aims at substantially increasing water-use efficiency and ensuring sustainable withdrawals and supplies of freshwater to address water scarcity (UN-Water, 2018a). In 2006, the Zambian government implemented Vision 2030 for the development of the country which included addressing water needs (MWDSEP, 2019). The Zambian government also launched the 8th National Development Plan (8NDP) for the period 2022–2026, whose main objective is social-economic transformation for improved livelihoods (MFNP, 2022). The 8NDP recognizes increased access to improved water sources and sanitation as one of the means of improving livelihoods in Zambia (MFNP, 2022). Zambia is considering implementing inter-basin water transfer to address water scarcity and enhance the management and productive use of water resources (MFNP, 2022). In 2022, the government of Zambia also launched the Zambia Water Investment Programme (ZWIP), which aims at providing access to clean water and decent sanitation and creating hundreds of thousands of jobs by 2030. Studies on water quality and the implementation of inter-basin water transfer aim at contributing towards the SDGs and an overall improvement of livelihood through safe and adequate water.

2.3 Access to Water

According to UNICEF (2019) and WHO (2019), one in three people cannot access safe drinking water worldwide. However, in Zambia, substantial progress has been made in increasing access to safe and adequate water, improving access from 63 per cent of the population in 1992 to 72 per cent in 2018. (ZSA *et al.*, 2019). Of the 72 per cent of people using basic drinking water services, 92 per cent are in urban areas, while 58 per cent are in rural areas (ZSA *et al.,* 2019). The Ministry of Finance and National Development (MFNP, 2022) attributes this improvement to consistent public sector investments in water and sanitation, together with support from cooperating and development partners.

In 2006, the government of Zambia implemented the National Rural Water Supply and Sanitation Programme (NRWSSP), which aimed at increasing rural water coverage from 37 per cent to 75 per cent by 2015. However, the programme only managed to achieve coverage of 44 per cent by 2015. This was mainly attributed to insufficient funding for the project (World Bank, 2020). Phase 3 of the NRWSSP was implemented in 2019 to increase rural water coverage from 44 per cent to 100 per cent by 2030 (MWDSEP, 2019). In the LRB, the water coverage by the utility company is only 37 per cent (Kumamaru, 2019; World Bank, 2020). Most people in Zambia rely on the closest water for domestic and livestock consumption, this includes shallow wells and streams; this subjects communities to the risks of polluted water, putting them at risk of water-borne diseases (Petrie *et al*., 2016). In 2015, Zambia was one of the countries that missed the Millennium Development Goals (MDGs) on water and sanitation and is again on track to miss the more ambitious SDGs (World Bank, 2020). Access rates have remained almost stagnant over the past 15 years, with six per cent of water samples in urban areas failing bacteriological tests as sanitation, sewer collection and treatment remain poor (World Bank, 2020).

2.4 Water Scarcity

There are two types of water scarcity: economic water scarcity and physical water scarcity. Zambia can be classified as a country of economic water scarcity. This is because, despite the country's abundant water resources, limiting institutional, technical and financial capacity hinders the effective use of the resources for the development goals of the country (Maluleke, 2024). Physical water scarcity occurs when over 75 per cent of surface water is allocated to industries, agriculture and or domestic purposes (Britannica, 2024). Water scarcity poses a critical global challenge and can affect ecosystems, communities and economies (UN-Water, 2019; WWF, 2016). Damania *et al.* (2019) also highlighted the unwanted economic effects of water scarcity on industries such as agriculture, energy production and manufacturing.

In Zambia, the KRB is known to be water-stressed (WARMA, 2022). Water stress occurs when the quality of water prevents it from being used or when water demand exceeds supply for a given period. The water scarcity in the KRB has negative effects on the Zambian economy and livelihood (WWF, 2018). This is because the basin plays a major role in the country's economy as it has the most water-use activities (WARMA, 2022). Zambia depends on the KRB for hydropower, mining, industry, agriculture and fisheries (WWF, 2021). The agriculture industry is affected by water stress due to the reduction in crop and food production, leading to food shortages (Falkenmark and Rockstrom, 2013). The droughts and irregular rainfall patterns in the KRB have negative effects on livelihoods as most Zambians depend on agriculture (Petrie *et al.*, 2016). Hydropower in Zambia has been affected by water scarcity. The reduction in water flows in the KRB can result in energy shortages that often lead to long hours of load shedding (Kozacek, 2015). The quality of water also plays a part in hydropower generation because nutrient pollution from agriculture promotes the growth of the water hyacinth, which causes blockages in the turbines for energy production (WWF, 2016). Water scarcity can also harm aquatic ecosystems and wildlife, leading to habitat loss and reduced biodiversity. The reduction in water flows can lead to habitat degradation, reduced fish stocks and disruption of aquatic biodiversity in the KRB (Chomba and Nkhata, 2016).

Human health is also at risk because the lack of clean and safe water due to pathogenic microorganisms can lead to diseases such as cholera and dysentery (Prüss-Ustün *et al*., 2019). In Zambia, inadequate water supply and sanitation services are common; these often lead to health risks and unwanted effects on livelihoods (WWF, 2018). The Zambia Statistics Agency (ZSA *et al*., 2019) reports that 42 per cent of rural households obtain water from unimproved water sources, while eight per cent of urban households obtain water from unimproved sources. The World Bank (2020) reported that Zambia's inadequate water supply and sanitation are partly responsible for 40 per cent of stunted children. Inadequate water supply and sanitation increases the prevalence of disease, malnutrition and poor hygiene, all of which impede normal growth and development. It further adds that insufficient water, sanitation and hygiene are also the leading cause of infections, such as cholera and diarrhoea as well as the leading cause of death in children under the age of five. This could be related to the Japan International Cooperation Agency's (JICA, 2014) findings that the major diseases that affect households in the LRB are malaria, respiratory illnesses and intestinal infections such as dysentery, diarrhoea and cholera. Waterborne diseases have had a devastating impact on communities and the economy in Zambia, specifically the KRB (Costanzo *et al*., 2020). The 2017 cholera outbreak in Lusaka resulted in 5,900 cases, which claimed 114 lives and caused economic disruption (World Bank, 2020). Furthermore, the 2023 to 2024 cholera outbreak in Lusaka had recorded over 21,007 cases and over 702 deaths as of 6th March, 2024 (ReliefWeb, 2024). In addition to the economic, ecosystem and health effects, water scarcity can also bring about increased competition for water and potential conflict among users (UN-Water, 2018). This is evident in the conflicts in Syria over water resources (Gleick, 2014). Therefore, water scarcity brings about the need for effective management policies for the supply and demand of water to improve livelihoods and ensure environmental protection and the preservation of ecosystem well-being and adaptability (UN-Water, 2018).

2.5 Inter-Basin Water Transfer

Inter-basin water transfer is the movement of water from a basin with a surplus, to a basin with a shortage to alleviate water scarcity in the recipient basin (CTCN, 2016). The implementation of inter-basin water transfer poses some socio-economic, ecological and public health challenges, necessitating the use of criteria that should be met before the implementation of inter-basin water transfer projects (Laassilia *et al.*, 2021). These justification criteria are:

I. There must be proof of both present and future water scarcity in the receiver basin (Sinha *et al.*, 2020);

II. There must be surplus water in the donor basin after meeting its present and future water demands (Laassilia *et al.*, 2021);

III. The project should be backed by a comprehensive assessment involving multiple disciplines, aiming to minimize negative effects, enhance advantages and showcase equitable distribution among the basins involved (Laassilia *et al.*, 2021);

IV. The benefits of the project should be shared equitably between the donor and the receiver basin (Laassilia *et al.*, 2021); and

V. There has to be a proper governance and participatory approach focused on establishing a stable legal and institutional framework involving collaboration and coordination among decision-makers, designers, scientists and the population impacted by the decisions (Laassilia *et al.*, 2021).

Inter-basin water transfer is usually implemented to address water scarcity and ensure the availability of water for economic development. Many countries have implemented inter-basin water transfer projects to address various water-related challenges, including China, the United States, Australia, India, Russia, Brazil and South Africa (Gurung, 2015). In China, water was diverted from the Yangtze River in the southern region of China to the water-scarce northern region (Zhang *et al*., 2021). South Africa also implemented the Lesotho highlands water project to address water scarcity by transferring water from the highlands of Lesotho to the Gauteng area (Haas *et al*., 2010).

In Zambia, the need to implement inter-basin water transfer projects is a growing concern. This is prompted by the uneven distribution of water resources, population growth, urbanisation and climate change (Ngoma and Hamududu, 2019). The KRB of Zambia is the most urbanised with a lot of industrial activities and 50 per cent of the country's population (WARMA, 2022). The basin plays a major role in the country's economy as it has the most water-use activities (WARMA, 2022). Climate change has also affected the KRB as it is met with declining water resources during droughts, which negatively affect the livelihoods of the population (Petrie *et al*., 2016). In addition, the KRB is situated farther south of the Intertropical Convergency Zone (ITCZ), which means it receives less rainfall (AfDB, 2013). These factors have left the KRB water-stressed (Petrie *et al*., 2016; WWF, 2016). Further studies indicate a projected nine per cent reduction in water resources by 2080 in the KRB from the current 11 000 m^3 to 10 000 m^3 (Ngoma and Hamududu, 2019). This reduction in water resources has been attributed to Zambia's current development trend and might lead to possible depletion in the future (WWF, 2018). The LRB, on the other hand, has a high availability of surface water and rainfall because it is part of the Congo River Basin (CRB), which is located near the ITCZ. Ngoma and Hamududu (2019) projected that the water resources in the northern part of Zambia, where the LRB is situated, will remain the same by 2080 despite climate change. It is for this reason that the aspect of inter-basin water transfer from the LRB to the KRB is being studied.

2.6 Quality of Surface Water in Zambia

Little is known about the quality of surface water in the LRB as most studies on surface water quality in Zambia have been focused on the KRB. The concern over the quality of water in the KRB is increasing due to mining and other effluents discharged into the Kafue River (Petrie *et al.*, 2016). Zambia depends on the KRB for hydropower, mining, industry, agriculture and fisheries (WWF, 2021). The Kafue River drains the Copperbelt Province, which is one of the greatest stratiform metallogenic provinces in the world (Kříbek *et al.*, 2023). In surface water in the Copperbelt Province, there have been detections of heavy metals like copper, cobalt, lead, manganese and sediments in surface water that result from mining activities (Kříbek *et al*., 2014). Similarly, in Kabwe District, the mining activities from the abandoned Kabwe Mine have led to the lead and zinc contamination of the local population, the water, the soil and food (Mwandira *et al*., 2020). Despite the contamination of surface water, the effects of mining on the Kafue River are minimal due to the high neutralising capacity of the mining wastes because of the rapid precipitation of iron oxides and hydroxides, together with the absorption and/or co-precipitation of copper and cobalt (Sracek, 2012). There are, however, potential environmental risks such as degradation of water quality and potential human health hazards that may arise due to the high metal content in stream sediments when enough metals in sediments can be remobilised (Sracek, 2012).

There has been an increase in the import and use of pesticides for public health and agriculture purposes in Zambia (Petrie *et al*., 2016). Large-scale agricultural industries in Zambia and small-scale farmers use pesticides and artificial fertilisers for farming. For example, commercial sugar farming in Mazabuka uses large amounts of fertilizers and pesticides, leading to water pollution and pest resistance (Petrie *et al*., 2016). The water in Mazabuka also has high nutrient loads, which lead to the proliferation of aquatic weeds (Winton *et al*., 2020). Surface water in some areas of Zambia is under threat due to non-point pollution sources, which include the leaching of chemicals from farming activities, industrial effluents, land erosion and sewage effluents (Mwaba, 2019). Activities like deforestation and land clearing for agriculture also contribute to the decline in the quality of water. This is because when the roots that hold the soil in place are removed, the soil is easily washed into nearby streams (Browder *et al.* 2019). This also promotes long range soil transportation by wind.

2.7 Surface Water Pollution

Water pollution is any direct or indirect contamination of water that may result in the alteration of the water's biological, chemical or physio-chemical properties, affecting its colour, odour, taste, temperature or turbidity (MEWD, 2010). Surface water is more prone to pollution than groundwater because it is unprotected. Pathogens, nutrients, chemicals, heavy metals, pesticides and plastics often cause surface water pollution (Borthakur and Singh, 2020). The significant sources of water pollution include, but are not limited to; agricultural fertilisers, open defecation, industrial by-products, poorly maintained sewerage systems, littering, poor waste disposal and natural phenomena driven by hydrological processes (Bortoletto *et al*., 2015; Shil *et al*., 2019). Different pollutants pose different environmental effects. For example, excess nutrients result in eutrophication, pathogens affect human health negatively and chemical pollution could have toxic effects. Flooding can also lead to pollution as the water spreads across areas that are usually not exposed to water. In Zambia, surface water is at risk of pollution due to the dumping of solid waste, industrial effluents and poor sanitation (Savage *et al*., 2015). This is more common in the KRB due to the high population and industrialisation (Petrie *et al.*, 2016). In the LRB, the water coverage by the utility company is only 37 per cent of the entire population (Kumamaru, 2019; World Bank, 2020). This drives people to use water from alternative sources, which might be contaminated putting them at risk of water-borne diseases (Petrie *et al.*, 2016).

2.8 Ambient Water Quality Guidelines

The Zambia Bureau of Standards (ZABS, 2021) has put in place guidelines for the basic requirements and the standards for ambient water for each basin (Table 1). Ambient water describes water naturally present in the environment, incorporating both surface area water and groundwater. These standards provide a legal basis for pollution control as well as ensure that the water quality is maintained in the no-effect-range (NER) (ZABS, 2021). The NER is also referred to as the target water quality name (TWQR) (ZABS, 2021). The water in the LRB and KRB has many designated uses, which include domestic purposes, aquatic ecosystems, recreational and navigational purposes, mining and industrial purposes and agricultural purposes. However, domestic use was identified as the best water use in both basins and so standards were established with the need to protect this use (ZABS, 2021). Thus, the ZABS (2010) and the WHO (2017) domestic/drinking water standards are also discussed in this thesis.

Table 1: Guidelines for ambient (ZABS, 2021) and drinking water (ZABS, 2010; WHO, 2017) for the LRB.

Parameter	Ambient water guidelines	Drinking water guidelines	
		ZABS	WHO
pH	5.5 – 8	6.5 – 8.0	6.5 – 8.5
Temperature (^{0}C)	23.5	-	-
Electrical Conductivity (µMhos/cm)	100	1500	1500
TDS (mg/L)	50	1000	1000
Turbidity (NTU)	10	5	5
Total hardness, (mg$CaCO_3$/L)	250	500	500
Calcium hardness (mg$CaCO_3$/L)	_	500	500
Chloride, Cl_{-} (mg/L)	30	250	250
Nitrate (as NO_{3-} N mg/L)	6	10	10
Phosphate, PO_4^{3-} (mg/L)	0.04	-	6
Sulphate, SO_{4-} (mg/L)	20	400	250
Sodium, Na^+ (mg/L)	5	200	200
Potassium, K^+ (mg/L)	_	200	200
Iron, Fe^{3+} (mg/L)	0.7	0.3	0.3
Manganese, Mn^{4+} (mg/L)	0.001	0.1	0.4
Lead, Pb (mg/L)	2	0.01	0.05
Total coliforms (CFU/100ml)	200	0	0
Faecal coliforms (CFU/100ml)	50	0	0

2.9 Measured Water Quality Parameters and their Significance

The water quality parameters that were analysed in this study were in three distinct groups, which were: physio-chemical parameters; chemical parameters; and microbial parameters. The physio-chemical parameters include potential hydrogen (pH), temperature (T), electrical conductivity (EC), total dissolved solids (TDS) and turbidity. The chemical parameters include Total Hardness (TH), calcium hardness (CaH), chloride (Cl), nitrate (NO_3), phosphate (PO_4), sulphate (SO_4), sodium (Na), potassium (K), iron (Fe), manganese (Mn) and lead (Pb). The microbial parameters include total coliforms (TC) and faecal coliforms (FC). The parameters were selected based on their ability to comprehensively represent the key aspects of water quality as well as the various social and economic activities in the LRB.

2.9.1 Potential Hydrogen

Potential Hydrogen (pH) is a scale ranging from 0 to 14 used to specify the acidity or alkalinity of water. This is a measure of the concertation of hydrogen and hydroxyl ions. The hydroxyl ions are lower when the hydrogen ions are higher and vice versa. Water with a pH less than seven is acidic, while a pH greater than seven indicates alkaline water. Water is neutral when the pH is seven. pH ranges from 5 to 9 in natural waters (WHO, 2017). pH has great significance in water as it is usually used for characterising the water and has a lot of influence on the biological and chemical processes (UN-Water, 2018). pH affects the corrosiveness of water. Acidic water is more corrosive than alkaline water. It also has a strong control over the oxidation state and degree of dissolution of metal contaminants. It also affects the microbiological processes in water and water treatment processes such as softening, coagulation, removal of iron and manganese disinfection with chlorine (WHO, 2017).

2.9.2 Temperature

Temperature is a physical quantity that expresses the water's degree of hotness or coldness (Arora, 2017). The temperature impacts other inorganic and chemical contaminants, which may affect the taste of water (ZABS, 2010). High water temperatures promote the growth of microorganisms, which affect taste, colour, odour and corrosion. Water with lower temperatures is more palatable than warm water (WHO, 2017).

2.9.3 Electrical Conductivity and Total Dissolved Solids

The electrical conductivity (EC) of water is a measure of its ability to conduct electricity, the total ionic concentration of water (UN-Water, 2018). These ions are sodium, potassium, calcium, sulphate, nitrate, chloride, magnesium carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-).

Total dissolved solids (TDS) are also referred to as the mineral content of water because they consist of mineral components of soil dispersed in water (Arora, 2017). The amount of TDS is generally lower in surface waters than in groundwater because groundwater is richer in minerals due to longer interaction with the underlying geology. The amount of TDS in water depends on the solubility of the materials with which the water comes into contact (ZABS, 2021). TDS is significant in water as it affects the physical properties such as viscosity, density, freezing point and boiling point. TDS also alters the chemical properties of water. Higher values of TDS give water a salty or bitter taste, making it brackish and causing intestinal problems (WHO, 2017). EC and TDS are directly related. TDS can be estimated using Equation 1 (ZABS, 2021).

$$\boldsymbol{TDS}\ (\boldsymbol{mg/l}) = \boldsymbol{EC}\ (\mathbf{\mu mhos/cm}) * \mathbf{0.65} \qquad \text{(Equation 1)}$$

This computation can also verify the accuracy of the equipment used if both EC and TDS values are known. However, there is a need to determine the conversion factor for specific runoff events and sites if accuracy is required (ZABS, 2021).

2.9.4 Turbidity

Turbidity is water's cloudiness caused by suspended solids like clay and silt, organic particles like plant debris, organisms and chemical precipitates such as iron and manganese (Arora, 2017). High turbidity levels have undesirable effects on water, including interference with water treatment processes and staining of clothes and materials exposed to water with high turbidity (Damania *et al*., 2019). Turbidity values higher than 4 NTU affect the colour of the water because it forms a visible milky-white, muddy, black or red-brown suspension. The acceptability of the water is also affected because most people consider turbid water to be unsafe to drink (WHO, 2017).

2.9.5 Total Hardness

Total hardness is a measure of the concentration of ions of calcium and magnesium. Calcium and magnesium in the water occur due to the underlying geology (Afiukwa *et al*., 2012). Calcium ions usually occur in water due to the dissolution of limestone, dolomite and/or gypsum in the underlying geology, while dolomite and magnesite are the significant suppliers of magnesium ions. Usually, the amount of calcium ions is higher than that of magnesium ions and surface water is either soft or moderately high (Arora, 2017). These ions can have undesirable effects on water. They form insoluble compounds with palmitate, a component of soap that results in higher soap consumption. High concentrations of magnesium may weaken concrete and cause intestinal disorders when present with sulphate as magnesium sulphate ($MgSO_4$) is a purgative. Despite the undesirable effects of hardness, evidence exists that water with moderate hardness has more health benefits than soft water. Cardiovascular diseases seem to be more prevalent in areas with soft water (Bykowska-Derda *et al*., 2023). Table 2 shows the rating of water from soft to extremely hard depending on the concentrations of total hardness (WHO, 2017).

Table 2: Hardness ratings based on total hardness concentration (WHO, 2017).

Hardness concentration (mg $CaCO_3$/l)	**Hardness rating**
0-60	Soft
60-119	Moderately hard
120-180	Hard
>180	Very hard

2.9.6 Chloride

Chloride has many sources and is usually present in all natural waters, with values ranging from 10 to 20 mg/L in surface water. It is a major component of the salinity of water and is one of the significant components of TDS. In natural waters, chloride is produced from sodium chloride, which is formed from the dissolution of rocks and soil (Al-Mashagbah, 2015). Sodium chloride is a major component of many rock types. Sources of chloride also include sewerage and animal feeds and can indicate contamination (Hong *et al.*, 2023). High chloride values (200–300 mg/L) give water a salty taste and may intensify its corrosiveness and values above 600 mg/L cause health complications, especially in hypertensive individuals (WHO, 2017).

2.9.7 Nitrate

Nitrate is formed by the oxidation of nitrogen and occurs more frequently in groundwater due to its solubility than in surface water. The sources of nitrate in fresh surface water include decayed organic matter, sewage and faecal matter and fertilisers (WHO, 2017). Nitrates occur due to the oxidation of nitrogen. Nitrate is a strong indicator of contamination. It has undesirable effects as it can cause methemoglobinemia, which is also referred to as blue baby syndrom. It is a fatal disease in infants under one year. Nitrate has also been suspected to be carcinogenic (Karwowska and Kononiuk, 2020).

2.9.8 Phosphate

Phosphate usually occurs as a result of geological formations, sewerage discharge, fertilizers and the intrusion of detergents into water (Al-Mashagbah, 2015). If the sources are geological, then the concentrations are typically less than 0.1 mg/L. If the phosphate occurs with nitrates and nitrites, it results from sewerage (ZABS, 2021). Polyphosphates indicate that the source is detergents. High values indicate pollution and contamination; they can cause eutrophication by promoting algae growth, which has undesirable effects such as oxygen depletion. However, small amounts can be useful in corrosion control and the prevention of scale formation in hard water (WHO, 2017).

2.9.9 Sulphate

Sulphate in water occurs mainly from gypsum ($CaSO_4$) and occurs in all natural waters. When magnesium ions are also present, high concentrations of sulphate may cause gastrointestinal irritations, causing diarrhoea. High values of sulphate may also be corrosive to concrete, causing cement bacillus (WHO, 2022).

2.9.10 Sodium and Potassium

Sodium and potassium ions are found in all ground and surface waters; they form strong alkaline hydroxides of sodium and potassium and are known as ions of alkali metals (Banerjee and Prasad, 2020). Sodium and potassium ions form very soluble salts and therefore precipitation of sodium and potassium salts rarely occurs (Banerjee and Prasad, 2020). Sodium is significant in water because it negatively affects hypertensive individuals and high values can give rise to taste in water (WHO, 2017).

2.9.11 Iron and Manganese

Iron and manganese occur in surface water as colloidal oxides. They also occur in low dissolved oxygen waters and mostly in deep groundwater as Fe^{2+} and Mn^{2+} and often occur together (Dvorak and Schuerman, 2021). Because of their lower solubility, iron and manganese are less common in water than sodium, potassium, magnesium and calcium and may be absent in natural waters. If they occur in natural waters, it is in minimal amounts. Iron concentrations greater than 3 mg/L are considered very high. The same can be said for manganese concentrations greater than 1 mg/L (Wang *et al*., 2016). When water containing iron and manganese encounters oxygen, the iron ions (Fe^{2+}), become oxidised to ferric oxide (Fe_2O_3) and ferrous oxide (FeO) and the water turns yellow-brownish and later forms a brown iron oxide precipitate. The precipitate has strong similarities to rust. Manganese ions (Mn^{2+}) also react similarly to iron and can be oxidised to Mn^{4+}. In the case of manganese, oxidation to Mn^{4+} is difficult; it takes longer and requires a higher pH. Manganese ions form a dark brown or black precipitate, a more complicated structure than the iron precipitate (Campbell, 2022). Iron and manganese have undesirable effects on water, including discolouration, turbidity, staining of clothes and formation of encrustations in pipes; they also affect the taste of water and may cause gastrointestinal irritation (WHO, 2017).

2.9.12 Lead

Lead is one of the most common heavy water on earth (Jaishankar *et al.*, 2014). Most of the lead present in surface water occurs because of geological formations and mining activities. Lead is more corrosive when it occurs with copper. Lead has unwanted effects on pregnant women, the foetus and children under six. High blood lead levels of 100 – 120 µg/dl in adults and 80 – 100 µg/dl in children affect the brain with acute intoxication, restlessness, poor attention span, dullness, headaches, irritability, loss of memory, hallucinations, muscle tremors and abdominal problems (WHO, 2017). However, even low levels of lead in the blood can have profound and lasting effects on health such as anaemia, making it essential to minimize exposure (Hsieh *et al.*, 2017).

2.9.13 Total Coliforms and Faecal Coliforms

The New York State Department of Health (NYSDH, 2023) defines total coliforms as a combination of all forms of bacteria in water, while faecal coliforms refer to specific microorganisms in human or animal excreta. Total and faecal coliforms are indicator microorganisms showing water contamination levels (WHO, 2017). Therefore, if total and faecal coliforms are low, the risk to human health is low. Similarly, if total and faecal coliforms are high, the risk to human health is high. The standard for total and faecal coliforms in drinking water is 0/100ml (WHO, 2017).

2.10 Water Quality Analysis Techniques

There are many different techniques used to assess the quality of surface water. This study used spatial-temporal variation analysis, the Piper Diagram, the Gibbs Plot and the WQI. Spatial-temporal variation analysis involves monitoring water quality at multiple locations and over different periods to understand how water quality changes across space and time. It helps identify areas or periods with water quality issues (Li and Heap, 2011). This method provides insights into the patterns of water quality changes and helps in targeting specific areas or periods for remediation, thereby supporting the development of effective water management strategies (Li and Heap, 2011). This method, however, requires extensive data collection and analysis as it might be hard to identify pollution sources without additional investigation (Li and Heap, 2011).

The Piper Diagram is a graphical method used to classify and visualise the hydro-chemical characteristics of water. It categorises water samples into different hydro-chemical facies based on the concentration of major ions, e.g., Na, K, Ca, Mg, Cl, SO_4 and HCO_3 (Piper, 1944). This method provides a quick visual representation of the water chemistry and helps in identifying the dominant ions in water (Piper, 1944). This method may not capture trace elements as it is limited to major ion concentrations, it also does not provide a quantitative measure of water quality. The Gibbs Plot is a graphical tool that is also used to understand the hydro-geochemical processes affecting water quality (Gibbs, 1970). It relates the ratios of major ions in water to their concentration, allowing the identification of controlling processes such as rock weathering, evaporation and precipitation (Gibbs, 1970). This method helps in understanding the dominant processes influencing water chemistry, it is also useful for identifying natural and anthropogenic influences. This method also may not capture trace elements as it is limited to major ion concentrations, it also requires some expertise in interpreting the plot.

The WQI has been adopted and modified by different scholars, including Brown *et al.* (1970) and Cude (2001), since it was developed by Horton (1965). The WQI is used to compute a single value from multiple test results and multiple parameters (Adelagun *et al*., 2021). It is for this reason that the WQI is globally used because it can easily be understood by non-technical individuals. The WQI, despite being a useful tool, has some limitations. The WQI is not an absolute measure of pollution because it cannot outline all water quality hazards; it gives an idea of the state of the water. It lacks accuracy and precision in the classification of the parameters evaluated (Nong *et al.*, 2020). This is because there is no single WQI that has been globally accepted, making WQIs source-specific (Banda and Kumarasamy, 2020). These limitations have prompted the development of a modified WQI, WQI_{min}. The WQI_{min} uses the measured parameters to determine key parameters with the most influence on the WQI. This reduces redundancy and lowers the monitoring costs for water quality, making the WQI_{min} economical and effective. The WQI_{min} method has been used by various scholars (Nong *et al.*, 2020; T. Wu *et al.*, 2021; Z. Wu *et al.*, 2021) due to the high correlations between the WQI and the $WQI_{min.}$ It is necessary, however, to develop a suitable WQI_{min} for a specific area based on the research background of the area (Avigliano and Schenone, 2016). The research background involves the types of economic activities, land use and geological formations in an area. These inform the types of parameters that are selected for analysis.

2.11 Summary

Many studies indicate that the KRB's lack of safe and adequate water is a significant concern (Petrie *et al*., 2016; Maluleke, 2024; WWF, 2021). The World Bank, UN-Water, World Wildlife Fund (WWF) and JICA share the same insight on this matter. Projects such as the National Urban Water Supply and Sanitation Programme (NUWSSP), National Rural Water Supply and Sanitation Programme (NRWSSP), JICA and Vision 2030 show continued efforts to improve the situation (MWDSEP, 2019; World Bank, 2020). No studies have been undertaken on inter-basin water transfers in Zambia. Many studies have been conducted to assess water quality in Zambia, with the majority in the KRB (World Bank, 2020). However, there is no systematic data set on the quality of water in rural areas in Zambia, where the LRB is situated (World Bank, 2020). In addition, most of the population in the LRB only have access to unimproved ground or surface water sources, putting them at risk of waterborne diseases. This brings about the need to assess whether the water that is readily available to the population is safe for consumption.

Takam *et al.* (2024), Kwambana (2022) and Nguvulu *et al*. (2021) are among the different scholars who have computed the WQI using the WHO drinking water standards. However, this study focused on baseline data on the quality of water in the LRB and developed the $\mathrm{WQI}_{\mathrm{min}}$ using the ZABS (2021) guidelines for ambient water. The study also incorporated the WHO (2022) guidelines for drinking water because domestic use was identified as the best water use in the LRB (ZABS, 2021).

3.0 DESCRIPTION OF THE STUDY AREA

3.1 Location

The LRB is in northern Zambia, between latitudes 8-12 degrees South and 28-30 degrees East (Figure 1). The LRB covers the Central, Luapula and Northern provinces. The districts within the basin include Serenje, Chitambo, Chembe, Chiengi, Chipili, Kawambwa, Lunte, Milenge, Mporokoso, Mwense, Nchelenge, Mwansabombwe, Kancibiya, Chilubi, Nsama, Lavushi Manada, Samfya, Kaputa, Luwingu and Mansa (WARMA, 2022). The LRB is part of the Congo River System and is 615 km long with an area of 113, 323 km^2. The Luapula River is an international river shared between Zambia and Congo. It originates from Lake Bangweulu and the Chambeshi River and flows southward to Mukuku. It then turns westwards and northwards until it falls into Lake Mweru, forming the border between Zambia and Congo. The LRB has several waterfalls and wetlands. These include the Lumangwe Falls, the Kabwelume Falls, the Ntumbachushi Falls, the Musonda Falls, the Mambilima Falls and the Bangweulu wetlands (Luapula Provincial Administration, 2018).

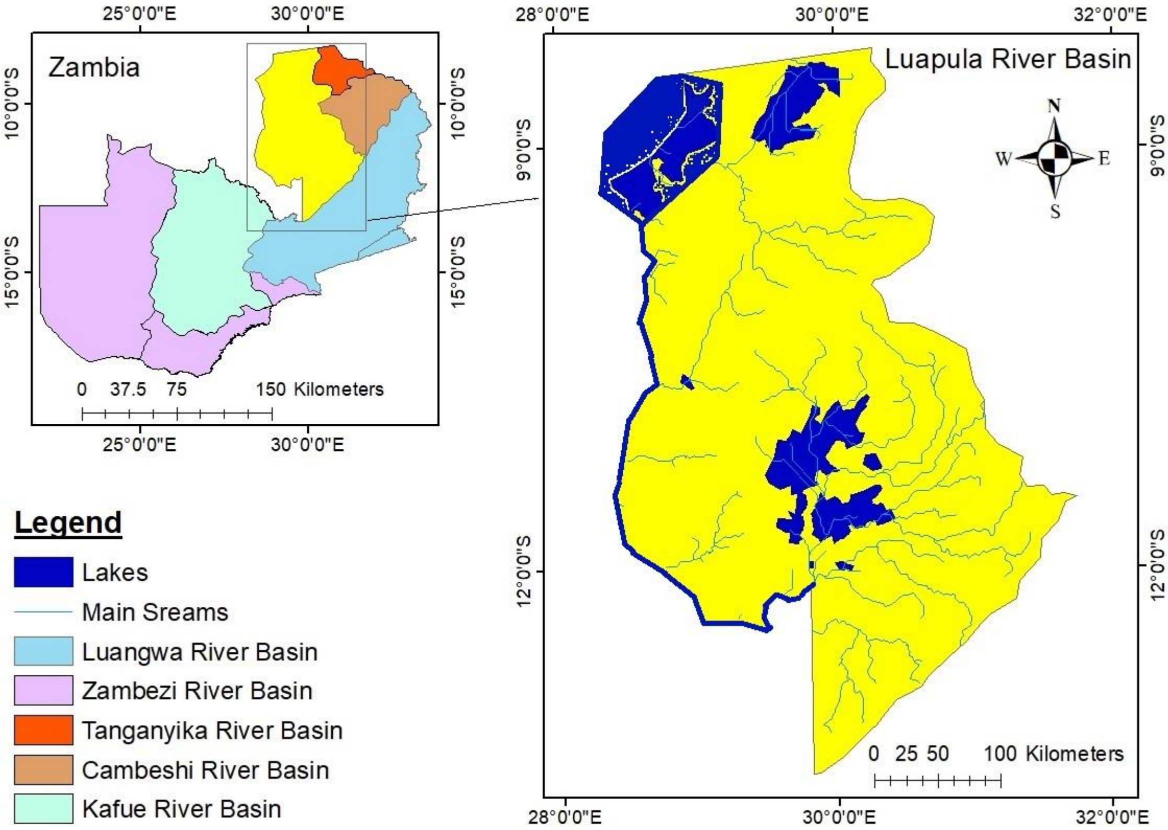


Figure 1: Location of the LRB in Central, Luapula and Northern provinces, Zambia.

3.2 Topography

The elevations in the LRB range from 900 to 1500 m above sea level (Figure 2) (FAO, 2021). The marshlands are a prominent feature of the landscape; these are shallow depressions on the Central African Plateau. These marshlands are covered in grass, do not have trees or border drainage lines and are usually waterlogged throughout the year, most often with a stream in the centre. These areas receive water by seepage from sub-surface drainage and rainwater runoff from surrounding higher grounds (FAO, 2021).

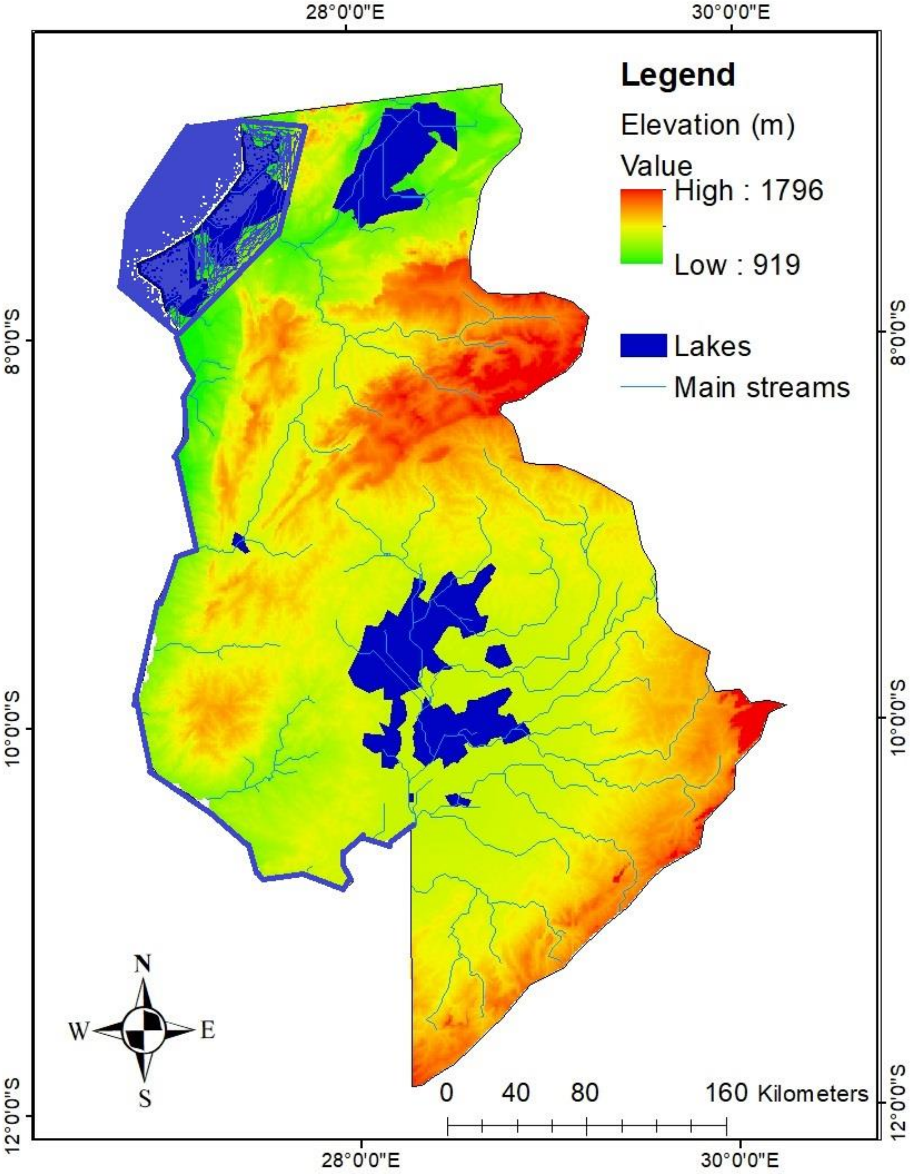


Figure 2: Topographic map of the LRB in Central, Luapula and Northern provinces, Zambia.

3.3 Soils and Geology

The LRB is dominated by loamy sand and heavily leached soils. These soils are characterised by moderate to severe acidity. The acidity of the marshy soils, rich in organic matter, varies between pH 3.7 to 4.7 (FAO, 2021). The LRB is mainly in the Bangweulu Block with a distribution of Basement rocks, Muva Supergroup, Katanga Supergroup and alluviums (JICA, 2014) (Figure 3 and Table 3).

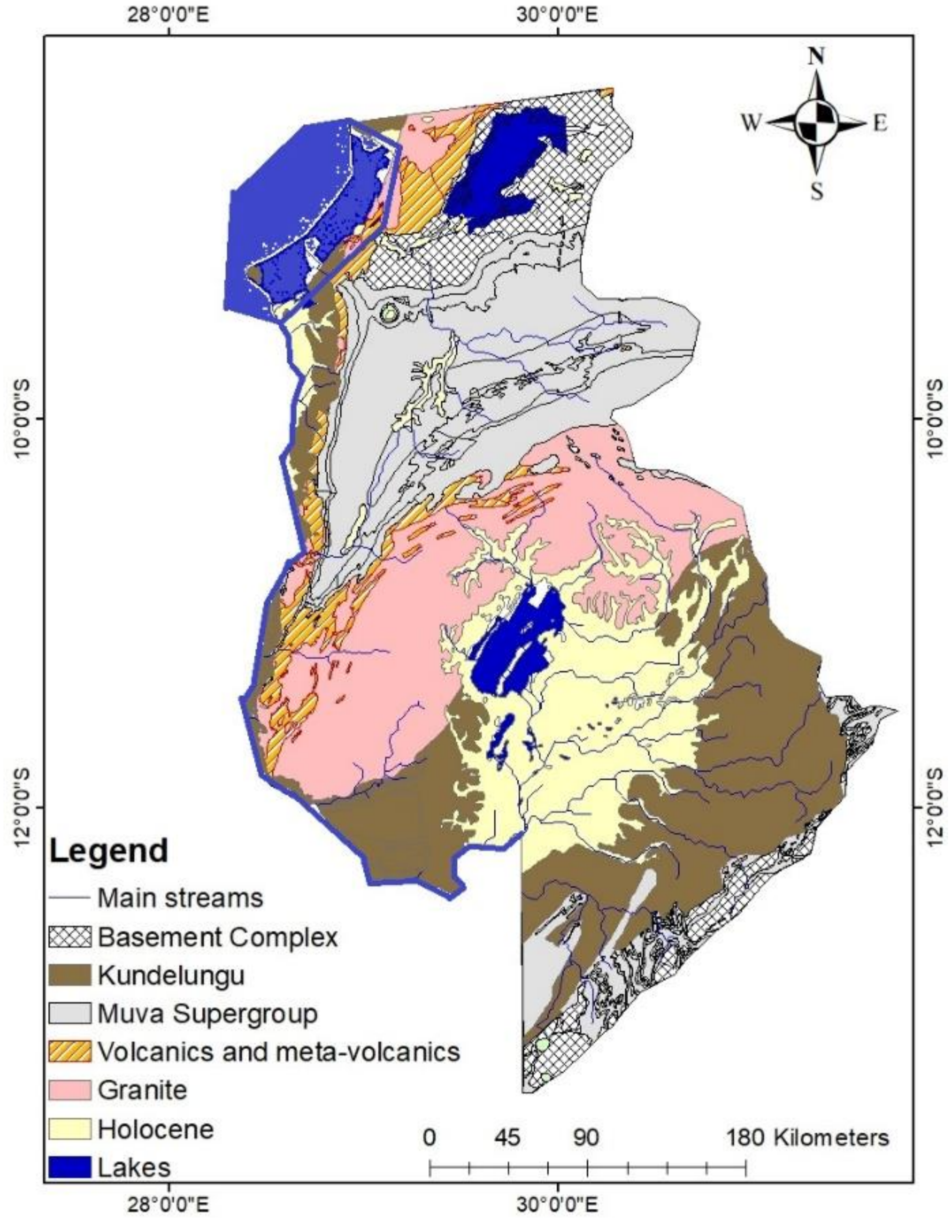


Figure 3: Geological supergroups and compositions of the LRB in Central, Luapula and Northern provinces, Zambia (Bäumle *et al.*, 2018).

Table 3: Geological supergroups and compositions of the LRB in Central, Luapula and Northern provinces, Zambia (JICA, 2014; Nyambe and Phiri, 2010).

Geological Name	Composition
Holocene	Alluvium, colluvium and laterite.
Kundelungu Supergroup	Sandstone, mudstone, conglomerate, shales, carbonates, tillites, mixtites, psammite and rudite formations.
Muva Supergroup	Sandstone, mudstone, quartzite, siliceous schist and shales.
Basement Complex	Granitic rocks, gneiss, metamorphic igneous rocks, schist, basalt and amphibolite.

3.4 Climate

The LRB has a tropical climate with three distinct seasons: the cold-dry season from April to August, the hot-dry season from August to October and the warm-wet season from November to April. The LRB is part of agro-ecological Zone III (Figure 4) and has high rainfall levels, with the annual rainfall recorded ranging from 1100 mm to 1500 mm per annum and the average exceeding 1000 mm (World Bank, 2019). The average monthly temperature is 21.4 ^{0}C and ranges from 9.7 ^{0}C in June to 32 ^{0}C in October (WARMA, 2022). The LRB is one of many sub-basins that make up the CRB (Luapula Provincial Administration, 2018).

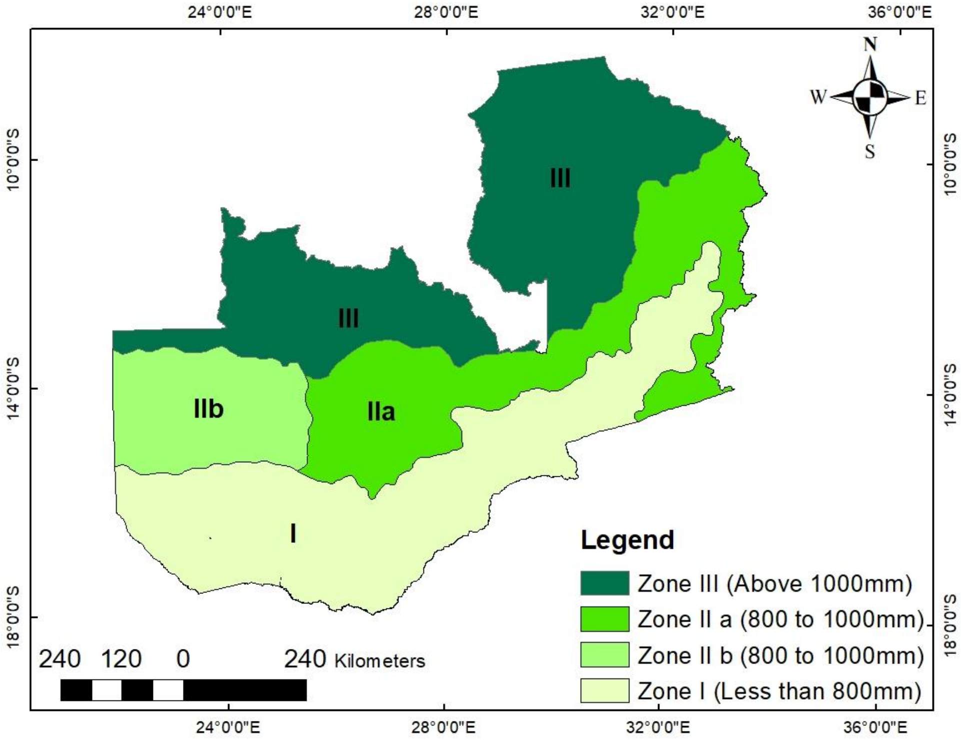


Figure 4: Agro-ecological Zones of Zambia (SASSCAL, 2017).

3.5 Landcover

Grasslands cover over 50 per cent of the LRB, followed by the Miombo woodlands (WARMA, 2022), (Figure 5). Mansfield *et al.* (1975) indicated that the LRB is characterised by Chipya Vegetation, which includes species like *Diplorhynchus condylocarpon*, *Hymenocardia acida*, *Maprounea Africana* and *Syzgium guineense subsp. Macrocarpum*. The Mbala-Kawambwa Plateau as part of the LRB, is rich in the *Brachystegia-Julbernadia* woodlands. Ecological groups of shrubs such as *Bridelia cathartica*, *Bridelia duvigneaudii* and *Protea petiolaris* are also prominent.

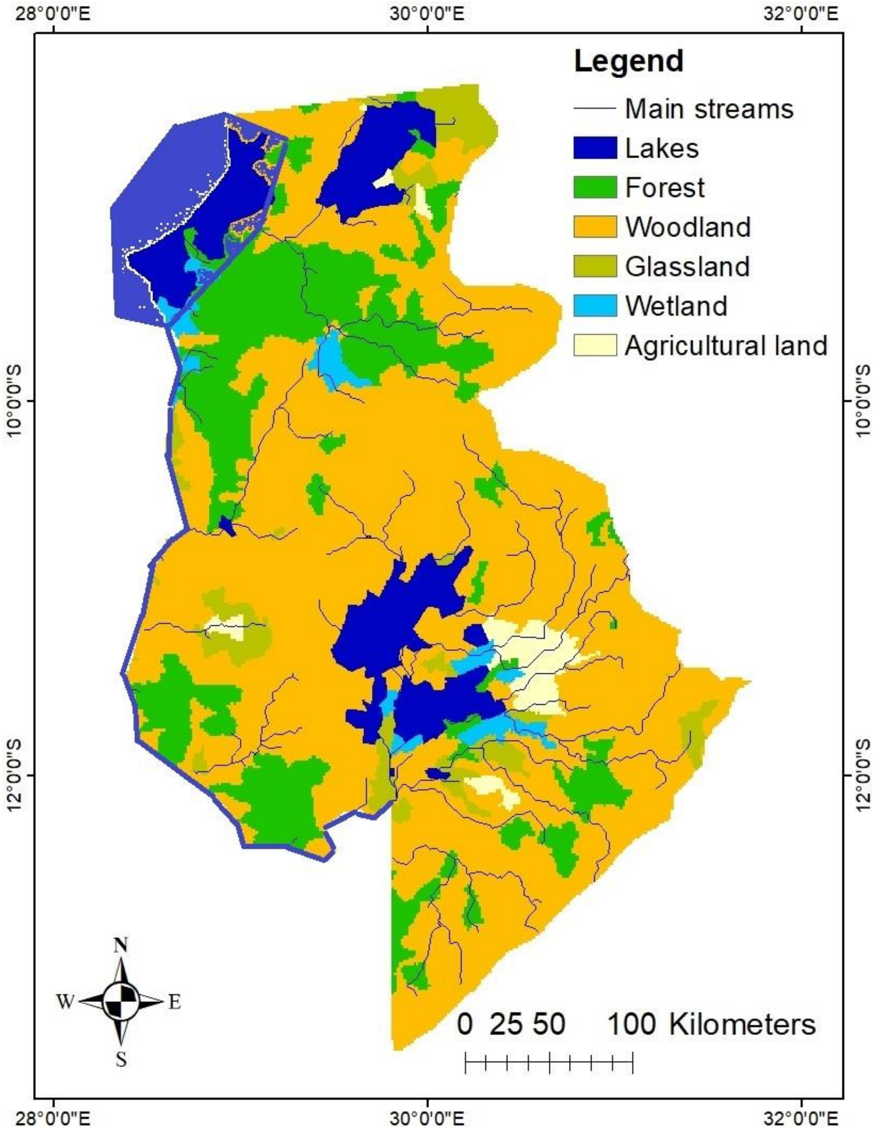


Figure 5: Land use and landcover map of the LRB in Central, Luapula and Northern provinces, Zambia (HydroATLAS-Zambia, 2023).

3.6 Population

The 2022 census recorded the population of Luapula to be 1,514,011 with 743,962 males and 770,049 females, showing an increase of 52.6 per cent from the 2010 population of 991,927 (ZSA, 2022). An estimated 84 per cent of the population in Luapula lives in rural areas (FAO, 2021). Most of the population is concentrated around the lakes and river valleys for fishing and the main roads for easy access to the transportation of farm produce (FAO, 2021).

3.7 Economic Activities

Fishing and agriculture are the main economic activities in the basin (FAO, 2021). Other activities include transport, tourism, hydropower, forestry, mining and manufacturing. The LRB has three hydropower stations: the Chishimba Power Station, which produces an average of 6 MW, the Musonda Power Station, which produces an average of 5 MW and the Shiwang'andu Power Station, which produces an average of 1 MW (ZESCO, 2022). According to the Luapula Provincial Administration (2018), mining is a growing sector in the LRB and the minerals mined include copper, iron, manganese, lime, gemstones and gold.

3.8 Culture and Language

The LRB is rich in culture; the main ethnic groups are the Bwila, Swila and Lunda, found around Mwense and the Luapula River. The Chisalunga are found on the Kawambwa Plateau and the Chushi, Ngumba, Kabende and Baunga are found in Samfya District and Lake Bangweulu areas (FAO, 2021). The people have various cultural dances, such as the imfunkutu, akalela, ichilumwa-lumwa and icinkwasa, which are performed during the Mutomboko Ceremony by the Mwata Kazembe of the Lunda people (Luapula Provincial Administration, 2018).

4.0 METHODOLOGY

4.1 General Remarks

This chapter describes the methods that were used to collect primary and secondary data to achieve the study's objectives. The tools and calculations that were used to analyse that data to answer each research question have also been outlined.

4.2 Ethical Clearance

Ethical clearance was sought from the University of Zambia Natural and Applied Sciences Research Ethics Committee (NASREC) before engaging in fieldwork (Appendix 1).

4.3 Primary Data Sources

Acquiring primary data involved the collection of water samples in the LRB in the 2022 dry and 2023 wet seasons. Samples were collected from Serenje District to Lake Mweru. The area of interest was the Luapula River, from its source at Lake Bangweulu to Lake Mweru; this included streams that feed into it. Other areas of interest were in Central Province, covering Serenje and Chitambo districts as part of the inter-basin water transfer area of the LRB. The covered districts included Serenje District, Chitambo District, Samfya District, Mansa District, Chembe District, Mwense District, Mwansabombwe District and Nchelenge District. The International Standards (ISO 5667-3, 2012) guidelines on sampling and testing procedures were followed. Proper Personal Protective Equipment (PPE) were used during sampling and in situ testing.

Fifty-seven (57) locations were sampled in September and November 2022 for the dry season data, while ninety-one (91) points were sampled in March 2023 for the wet season data in the LRB. Out of the 91 points sampled in the wet season, only 57 that had the same coordinates as those of the dry season were used in data analysis and mapping. The coordinates for each sampling point were captured using the Global Positioning System (GPS) and recorded, then used to plot the sampling points using Q-GIS (Figure 6). The date, time, weather, elevation, human activities, the name of the stream and its symbol were also recorded.

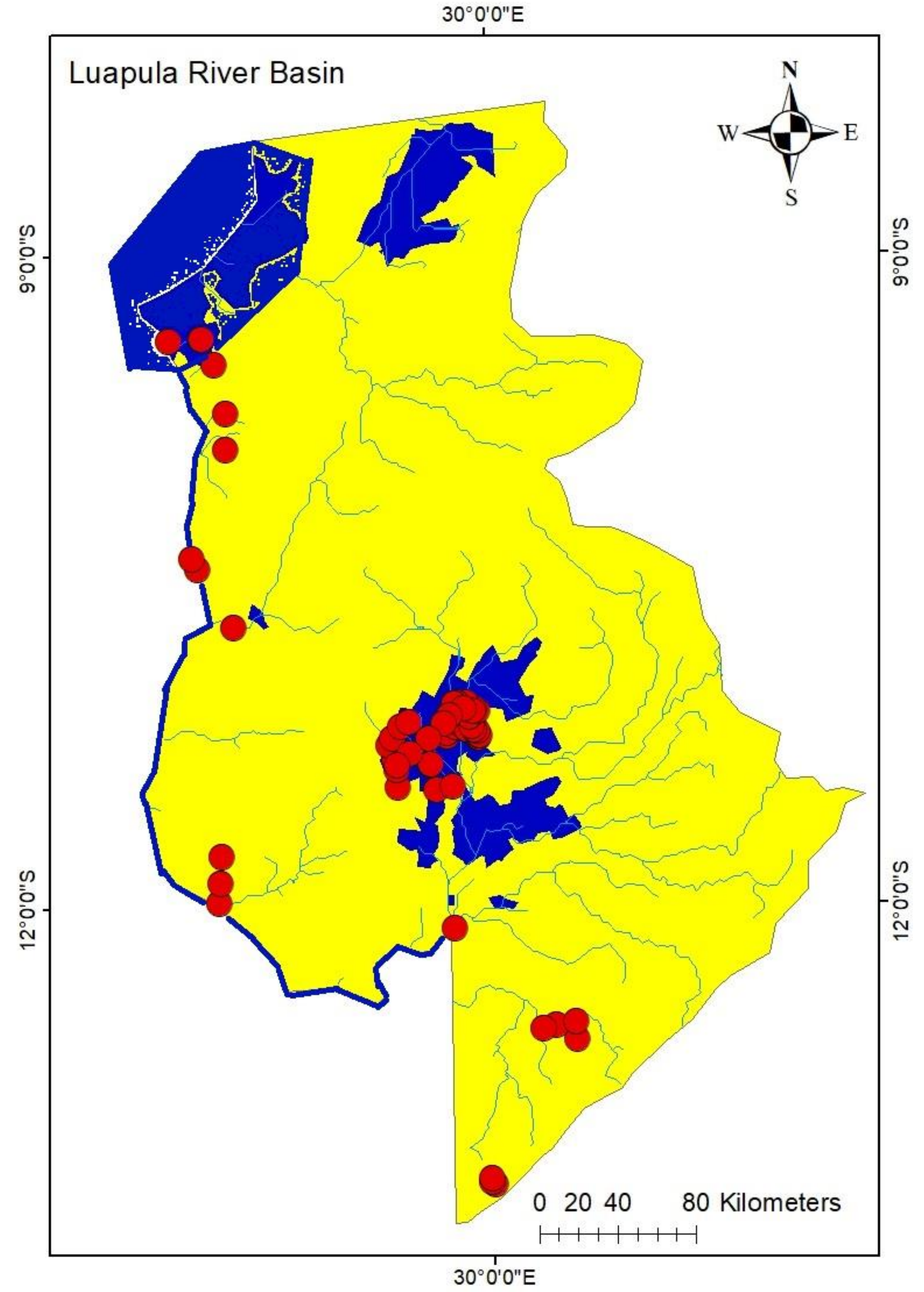


Figure 6: Location of the sampling points in Central, Luapula and Northern provinces, Zambia.

4.3.1 Sample Collection

Two triplicate samples were collected from each sampling point for validation purposes. The first sample was used to analyse for nutrients (phosphate and nitrate), total and faecal coliforms, total hardness, calcium hardness, turbidity and major anions and cations, including sulphate, chloride, sodium and potassium. The second sample was for analysis of heavy metals including iron, manganese and lead. EC, TDS, temperature and pH were tested in situ using the YSI ProDSS multi-meter. The values of calcium (Ca), magnesium (Mg), bicarbonate (HCO_3) and carbonate (CO_3) were derived from the values of known parameters because they were not tested but were necessary for data analysis.

Water samples were collected using the grab sampling method, capturing the water quality at various locations and times for subsequent analysis. Random sampling was employed to select sampling points, with final sampling points informed by the accessibility of various streams within the LRB. Most samples were collected by physically going into the water at the mid-point of the stream and facing in the direction of flow to avoid any contamination from substrate disturbance. In other cases, ropes on bridges and boats were used for safety.

To collect the samples, the lids of the sampling containers were removed to ensure no contact with the internal surfaces of the container or lid. The containers were fully inverted and submerged 0.2 m below the water surface. The containers were rinsed three times by filling them with at least one-third of the container volume, replacing the lid, shaking gently and then pouring the water downstream of the sample collection point. The rinsed containers were filled with water, ensuring they did not fill to the brim to avoid suffocating the oxygen-dependent microorganisms.

After the samples were collected, the ones for heavy metals were acidified using nitric acid to prevent precipitation, sorption to the container walls and microbial activity. The volume of acid added was one per cent of the total volume of the sampling container, in this case, one per cent of 500 ml, which was 5 ml. All samples were preserved using ice packs and kept on-site at 4 ^{0}C before testing in the laboratory. The samples were promptly sent to the laboratory by bus and arrived within 24 hours of collection for analysis.

4.3.2 Tests for Physio-Chemical and Chemical Parameters

The analysis of Physio-chemical and chemical parameters was according to the standard methods for the examination of water and wastewater by the American Public Health Association *et al.* (2017). The Electrical conductivity (EC), TDS, temperature and pH were tested in situ using the YSI ProDSS multi-meter (Figure 7). The testing for turbidity was conducted at the Civil and Environmental Engineering laboratory in the School of Engineering using a Hach 2100N turbidimeter (Figure 7).

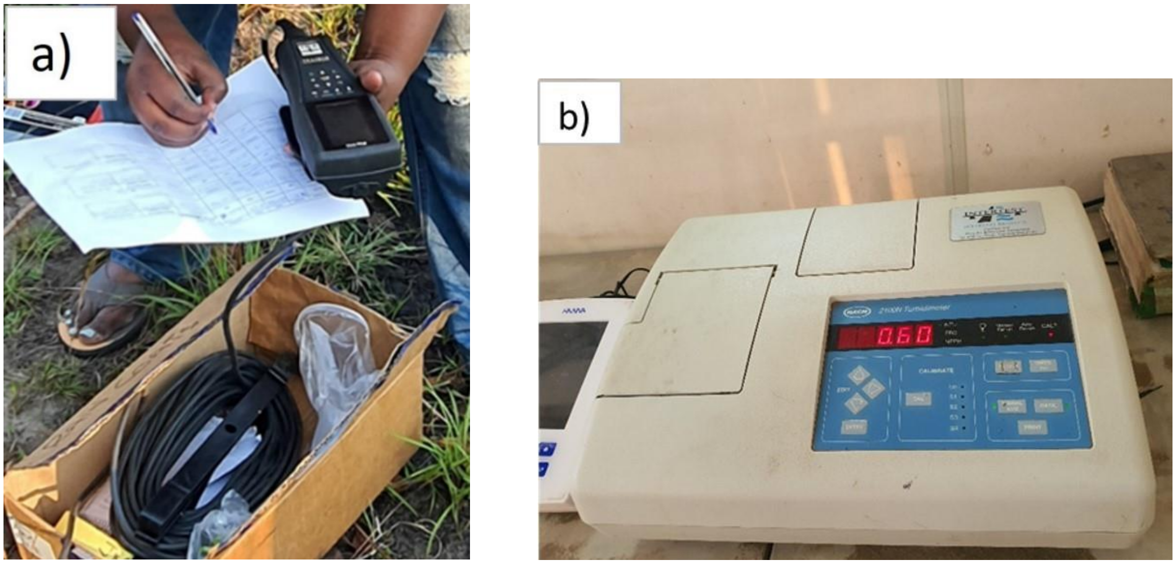


Figure 7: a) YSI ProDSS multi-meter for testing physio-chemical parameters, b) Hach 2100N turbidimeter used for the laboratory testing of turbidity.

A SP-UV-D1.8 spectrophotometer was used to test for phosphate, sulphate, sodium, potassium and nitrate (Figure 8).

Figure 8: The SP-UV-D1.8 Spectrophotometer for the laboratory testing of phosphate, sulphate, sodium, potassium and nitrate.

The titrimetric method was used to test for chloride, calcium and total hardness (Figure 9).

Figure 9: Titrimetric analysis using the volumetric method for the laboratory testing of chloride, calcium and total hardness.

Manganese, iron and lead testing was conducted at the Geo-chemical Laboratory in the School of Mines using the Varian 55 Atomic Absorption Spectrophotometer (AAS), a heavy metal analyser (Figure 10).

Figure 10: Laboratory testing of manganese, iron and lead using the Varian 55 Atomic Absorption Spectrophotometer.

4.3.3 Laboratory Tests for Microbial Parameters

Total and faecal coliforms were measured at the Civil and Environmental Engineering Laboratory in the School of Engineering using the membrane filter method (Figure 11). In this procedure, 100 ml of the sample was poured into a filtration bottle with filter paper to absorb microorganisms. The filter paper was then removed using sterile forceps, placed onto a nutrient media in a petri dish and incubated for 24 hours at 44 ^{0}C for faecal coliforms and 37 ^{0}C for total coliforms. This analysis was according to the standard methods for the examination of water and wastewater by the American Public Health Association *et al.* (2017).

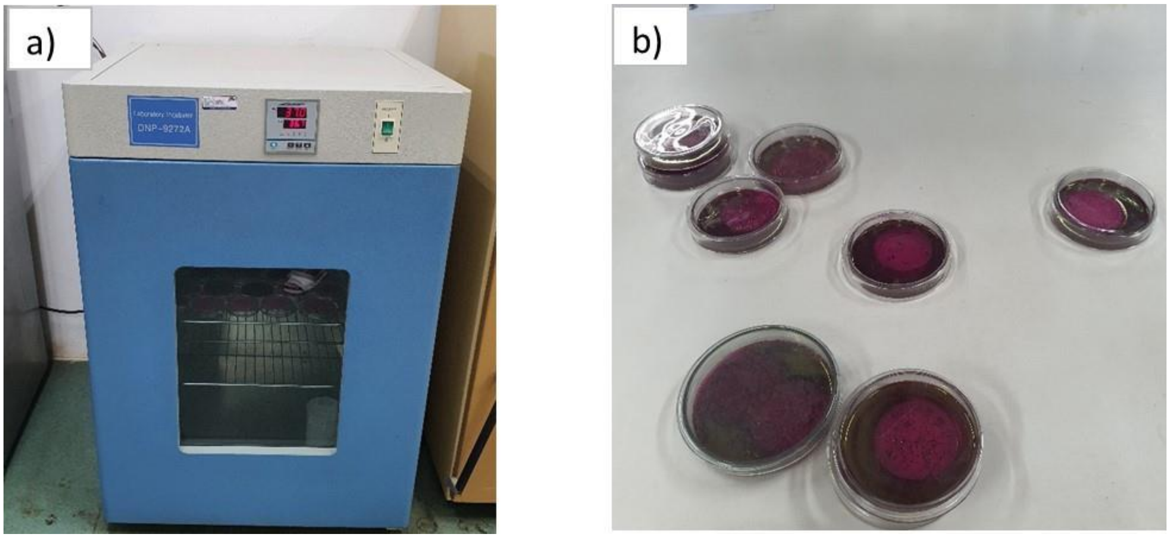


Figure 11: a) DNP-9272A incubator for coliforms and b) membrane filters after coliform incubation.

To avoid cross-contamination, all the equipment used was sterilised before use, especially when moving from one sample to the next. After incubation of the coliform, the number of coliforms was counted on the filter paper.

4.4 Spatial-Temporal Variation Analysis

The water-quality data were divided into two temporal groups, dry season and wet season; and three geographic groups: upstream from Lake Bangweulu to Mpanta, midstream from Mukuku Bridge to Muongo River and downstream from Kashiba Bay to Lake Mweru. For parameters that had values below the detection limit of the equipment, an arbitrary value of one-half the detection limit was assumed. For the coliforms, any number of CFU/100 ml greater than 200 was considered too numerous to count (TNTC). Therefore, for the sake of graphs and computations, TNTC was assigned a numerical value of 999 as a placeholder. Statistical analysis was conducted to determine the minimum, maximum and median values of each parameter. The minimum is the smallest value in a data set, the maximum is the largest value and the median is the middle value in a data set when the values are arranged in ascending or descending order.

A Gibbs Plot was used to determine whether the processes in the water were influenced by evaporation dominance, rock dominance or precipitation dominance (Gibbs, 1970). The diagram entails plotting the TDS values on the y-axis against the dividend of sodium and the sum of sodium and calcium, which is Na/(Na + Ca) on the x-axis on one plot and TDS on the y-axis against the dividend of chloride and the sum of chloride and bicarbonate, which is $Cl/(Cl + HCO_3)$ on the x-axis on the other.

4.5 Hydro-Chemical Characteristics Analysis

Concentrations of major cations and anions in meq/l were plotted on Piper diagrams to help examine the data for spatial and temporal patterns. Several calculations were performed to convert the measured concentrations into the appropriate units (Appendix 2). The values of calcium and magnesium were derived from the values of total and calcium hardness using Equations 2 and 3, respectively.

$$\boldsymbol{Ca = CaH * 0.4} \qquad \text{(Equation 2)}$$

$$\boldsymbol{Mg = (TH - CaH) * 0.24} \qquad \text{(Equation 3)}$$

The alkalinity, which is the sum of HCO_3^- and CO_3^{2-} was derived from the ionic balance formula (Equation 4).

$$\boldsymbol{Ca^+ = An^-} \qquad \text{(Equation 4)}$$

where; Ca^+ is the sum of the major cations in meq/l, An^- is the sum of the major anions in meq/l. The units of values of the major cations and anions were converted from mg/L to meq/l using Equation 5.

$$\boldsymbol{\left(\frac{Vn}{M}\right) * charge} \qquad \text{(Equation 5)}$$

where; Vn is the measured value of each parameter in mg/L, M is the molar mass of the parameter and charge is the ionic charge of the parameter.

4.6 Water Quality Index Computation

There are several water quality indices; however, this study applied the weighted arithmetic sum method. This study infused the ZABS (2021) guideline for ambient water into the index. The parameters used in computing the WQI were selected based on their ability to give an overall depiction of the status of water. These parameters were EC, TDS, temperature, pH, total hardness, turbidity, total coliforms and iron. Dissolved oxygen (DO) is also a vital parameter in the depiction of the status of water; however, the results for DO were discarded because of a mistake in the measuring process.

The following procedure was used to compute the WQIs:

The unit weight factor, Wn for each parameter was calculated using Equation 6;

$$\boldsymbol{Wn = K/Sn} \qquad \text{(Equation 6)}$$

where; K=1/(∑1/Sn) and Sn is the ZABS guideline for ambient water for each parameter.

The sub-index, Qn for each parameter was calculated using Equation 7;

$$\boldsymbol{Qn = 100(Vn - Vo)/(Sn - Vo)} \qquad \text{(Equation 7)}$$

where; Vn is the measured value of each parameter and Vo is the ideal value of each parameter in pure water (Vo is usually 0 for all the other parameters except dissolved oxygen and pH, Vo is 8 and 7, respectively).

The WQI for each sampling point is computed using Equation 8;

$$\boldsymbol{WQI = \sum(Wn * Qn) / \sum Wn} \qquad \text{(Equation 8)}$$

where; the summation of the unit weight factors ($\sum Wn$) of all parameters is 1.

The WQIs were used to classify the water quality according to Table 4. The mean of the WQIs from the different sampling points was computed to determine the average overall WQI for the LRB.

Table 4: Water quality ratings used in this study depending on WQI values (Brown *et al*., 1970; Kwambana, 2022).

WQI (%)	0-25	26-50	51-75	76-100	>100
WQI Ratings	Excellent	Good	Poor	Very poor	Unsafe

To identify which of the eight parameters used in the WQI computation are most influential in predicting the WQI values, stepwise multiple linear regression was performed in Minitab 18. This technique was used to determine which parameters best explain the variability in the WQI values. This involved adding or removing parameters based on statistical criteria to find the most significant predictors. In this study, the WQI values for each sampling point were regarded as the dependent variable and the eight water quality parameters used in WQI computation were considered as the independent variables. Therefore, the WQI values were regressed against the eight parameters. The stepwise regression process helps in selecting the subset of parameters that best explains the WQI values, resulting in the final model with fewer, more significant predictors; key parameters. After the selection of the key parameters, the WQI values for each WQI_{min} model were calculated using Equations 6 to 8 above.

To determine how well the WQI_{min} values predicted by the model correspond to the actual WQI values, correlation analysis was performed. This helps in evaluating the performance of the WQI_{min} model in replicating or predicting water quality as measured by the original WQI. This was done by plotting the WQI values against the WQI_{min} values on a scatter plot. This visual representation helps to see if there's a linear relationship between the two sets of values. The correlation analysis produced a Pearson Correlation Coefficient for each WQI_{min} model, which is a statistical measure that calculates the strength and direction of the linear relationship between two continuous variables. Pearson Correlation Coefficient ranges from -1 to 1. Therefore; a Pearson Correlation Coefficient between 0 and 1 represents a perfect positive linear correlation, between -1 and 0 represents a perfect negative linear correlation and a Pearson Correlation Coefficient equal to zero means no linear correlation.

5.0 RESULTS AND DISCUSSION

5.1 General Remarks

The minimum, maximum and median values for each parameter from 57 sampling points in the dry season and 91 sampling points in the wet season are presented (Table 5). The values were compared against the ZABS (2021) guidelines for ambient water as well as the ZABS (2010) and WHO (2017) guidelines for drinking water. The detailed results are attached in Appendices 3 and 4 for the dry and wet seasons, respectively. It should be noted that only the dry season values were used for the Gibbs Diagram, the Piper Diagram and the WQI computation because of high levels of dilution in the wet season. The dry season values are less affected by dilution, which provides a more accurate representation of the water's natural chemical composition. This provides a better understanding of geochemical processes and more reliable assessments of water quality. In addition, the missing wet season values of sodium were due to faulty equipment at the laboratory.

5.2 Electrical Conductivity and Total Dissolved Solids

The median of electrical conductivity (EC) in the dry season was 27 µs/cm, with the lowest being 8 µs/cm at Mbereshi River and the highest being 225 µs/cm at Kasanka River in Kasanka National Park. In the wet season, EC values ranged from 6 µs/cm at Mun'gona River to 78 µs/cm at Lake Mweru and the median was 23 µs/cm (Table 5). TDS values ranged from 5 mg/L at Mbereshi River to 162 mg/L at Kasanka River, with a median of 17 mg/L in the dry season. In the wet season, the values ranged from 2 mg/L at Muongo River to 50 mg/L at Lake Mweru, with a median of 15 mg/L (Table 5). The dry season values were higher than the wet season values in most points upstream and midstream (Figure 12). This is because, in the dry season, much of the surface water is baseflow as it comes from the groundwater system, therefore, it is higher in EC and TDS. In the wet season, more of the water comes from rain which has lower EC and TDS. However, this is the opposite downstream, where the wet season values were higher than the dry season values. This can be attributed to the increased water flow due to rainfall and runoff in the wet season which introduce additional inputs of dissolved solids and salts from the entire catchment area. Xu *et al*. (2022) also indicated that the amount of water in a river or stream influences the variations of certain parameters, such as EC and TDS, alluding to higher values downstream in the wet season. In addition, Banda *et al*. (2023) attributed this to hydrological flow regimes that cause the deposit of large amounts of sediment from upstream. EC values at some points in the dry season were higher than the permissible limit of 100 µs/cm for ambient water (ZABS, 2021) but below the permissible limit of 1500 µs/cm for drinking water (WHO, 2017). The TDS values for the dry season in most areas failed to meet the permissible limit of 50 mg/L for ambient water (ZABS, 2021) but fell within the limit of 1000 mg/L for drinking water (WHO, 2017).

Table 5: Summary of the values of water quality parameters for the dry and wet seasons in the LRB, in Central, Luapula and Northern provinces, Zambia.

Parameter	**Units**	**Dry season**			**Wet season**			**ZABS (2021)**	**ZABS (2010)**	**WHO (2017)**
		Min.	**Max.**	**Median**	**Min.**	**Max.**	**Median**			
EC	(µs/cm)	8	225	27	6	78	23	100	1500	1500
pH	–	6.2	8.4	7.26	6	8.2	7.625	5.5 – 8	6.5 – 8.0	6.5 – 8.5
Temp.	(C)	18.5	28.1	24.9	20.8	28.8	25.8	23.5	-	-
TDS	mg/L	5	162	17	2	50	15	50	1000	1000
Calcium hardness	mg/L	6	30	0.5	<1	<1	0.5	–	500	500
Total hardness	mg/L	20	106	0.5	<1	<1	0.5	250	500	500
Potassium	mg/L	1.7	12	2.49	<0.01	2.4	0.83	_	200	200
Sodium	mg/L	5.3	36.3	7.555	_	_	_	5	200	200
Nitrate	mg/L	<0.01	<0.01	0.005	<0.01	<0.01	0.005	6	10	10
Phosphate	mg/L	<0.01	<0.01	0.005	<0.01	<0.01	0.005	0.04	-	6
Sulphate	mg/L	<0.01	<0.01	0.005	<0.01	<0.01	0.005	20	400	250
Chloride	mg/L	8	55	11.5	2	14	6	30	250	250
Turbidity	NTU	1.4	37.2	4.7	0.3	24.9	1.68	10	5	5
Iron	mg/L	<0.002	2.2	0.073	<0.002	1.4	0.001	0.7	0.3	0.3
Manganese	mg/L	<0.002	<0.002	0.001	<0.002	<0.002	0.001	0.001	0.1	0.4
Lead	mg/L	<0.01	<0.01	0.005	<0.01	<0.01	0.005	2	0.01	0.05
Total coliforms	CFU/100ml	0	TNTC	40	0	TNTC	15	200	0	0
Faecal coliforms	CFU/100ml	0	TNTC	20	0	TNTC	29	50	0	0

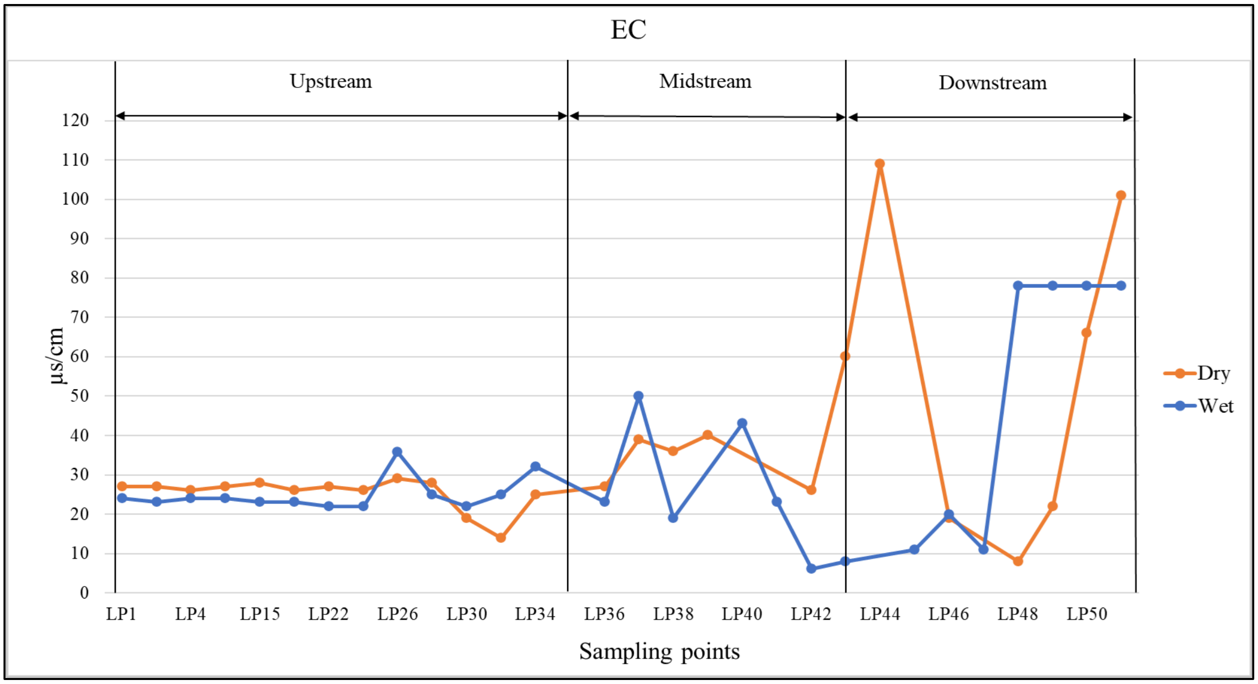


Figure 12: Spatial-temporal variations of EC from upstream, midstream and downstream in the LRB in Central, Luapula and Northern provinces, Zambia.

5.3 pH

The pH values for the dry season ranged from 6.19 at the Mbereshi River to 8.4 at the Bangweulu Swamps and the median was 7.26. In the wet season, pH ranged from 5.97 at Kashiba Bay to 8.23 at Mbabala, with a median value of 7.63 (Table 5 above). The results show that the pH in both seasons ranged from slightly acidic to slightly alkaline, with the average being neutral. The variations in pH can be attributed to the observed fishing camps with improper sanitation throughout the basin. Nguvulu *et al.* (2021) found similar results in the Upper Chongwe River Catchment in Zambia and attributed the decrease in pH to the increase in the discharge of untreated sewage into the catchment. The wet season values upstream were alkaline compared to the dry season values, which varied from acidic to alkaline (Figure 13). The midstream and downstream values, on the other hand, both varied from slightly acidic to slightly alkaline. Nyoni (2014) had similar findings on the Zambezi and Kafue rivers, where there was no significant difference between the dry and wet season values of pH. This is common in natural waters as pH tends to range from 5 to 9 and the ideal pH for biological productivity should be between 7 and 8.5 (WHO, 2017). Mataa (2022) recorded alkaline pH values upstream and downstream of the Barotse Floodplain in Zambia and attributed them to the soils and subsurface minerals.

The pH values at some points in both seasons exceeded the upper limit of the 5.5 to 8.0 guidelines for ambient water (ZABS, 2021) but were within the permissible limits of 6.5 to 8.5 for drinking water (WHO, 2017).

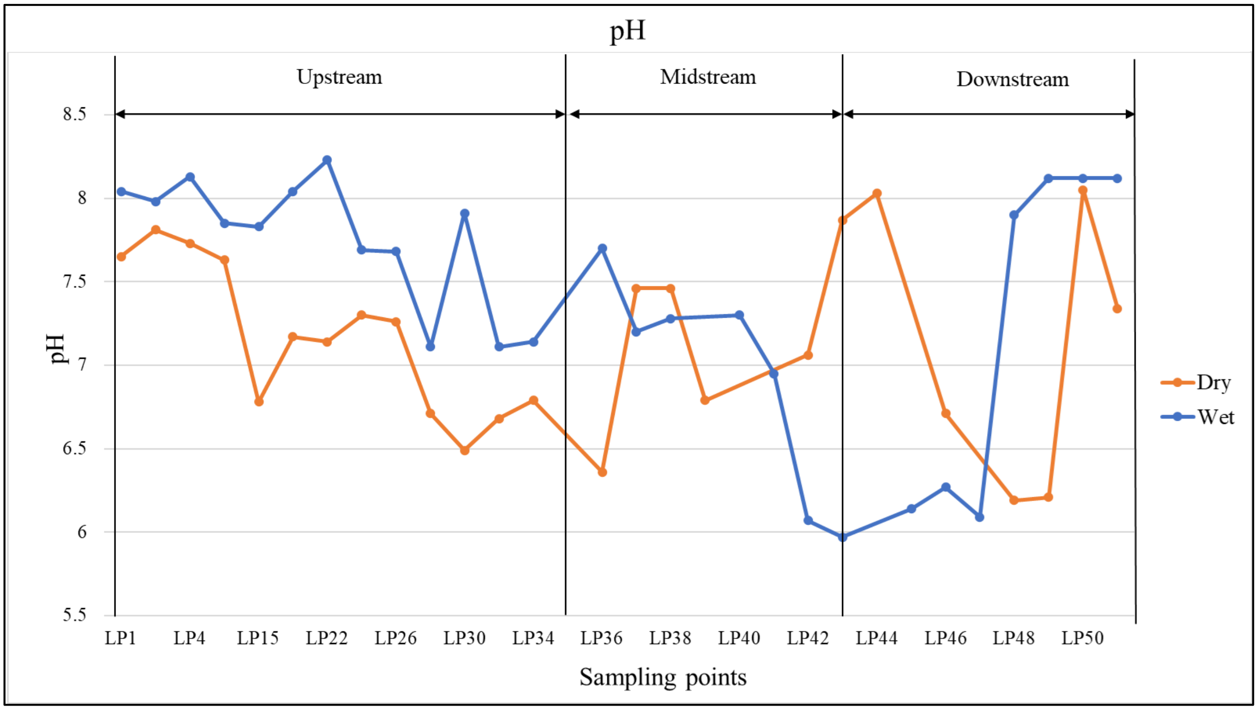


Figure 13: Spatial-temporal variations of pH from upstream, midstream and downstream in the LRB in Central, Luapula and Northern provinces, Zambia.

5.4 Temperature

Temperature is a constantly varying parameter. In the dry season, the temperature ranged from 18.5 ^{0}C to 28.1 ^{0}C with a median of 24.9 ^{0}C. In the wet season, it ranged from 20.8 ^{0}C to 28.8 ^{0}C with a median of 25.8 ^{0}C (Table 5 above). The wet season values midstream and downstream were higher than the dry season values at most points (Figure 14). The water temperature was generally higher from mid-morning to late afternoons as compared to early mornings and late evenings. Nyambe *et al*. (2018) also found fluctuating temperatures in the Barotse Floodplain in Western Zambia. The temperature variations were attributed to the weather as well as changes in air temperature because the temperature of water is highly affected by the atmospheric temperature (Xu *et al*., 2022).

The temperature at more than 21 points failed to meet the ZABS (2021) guideline on temperature for ambient water, which is 23.5 ^{0}C in both seasons.

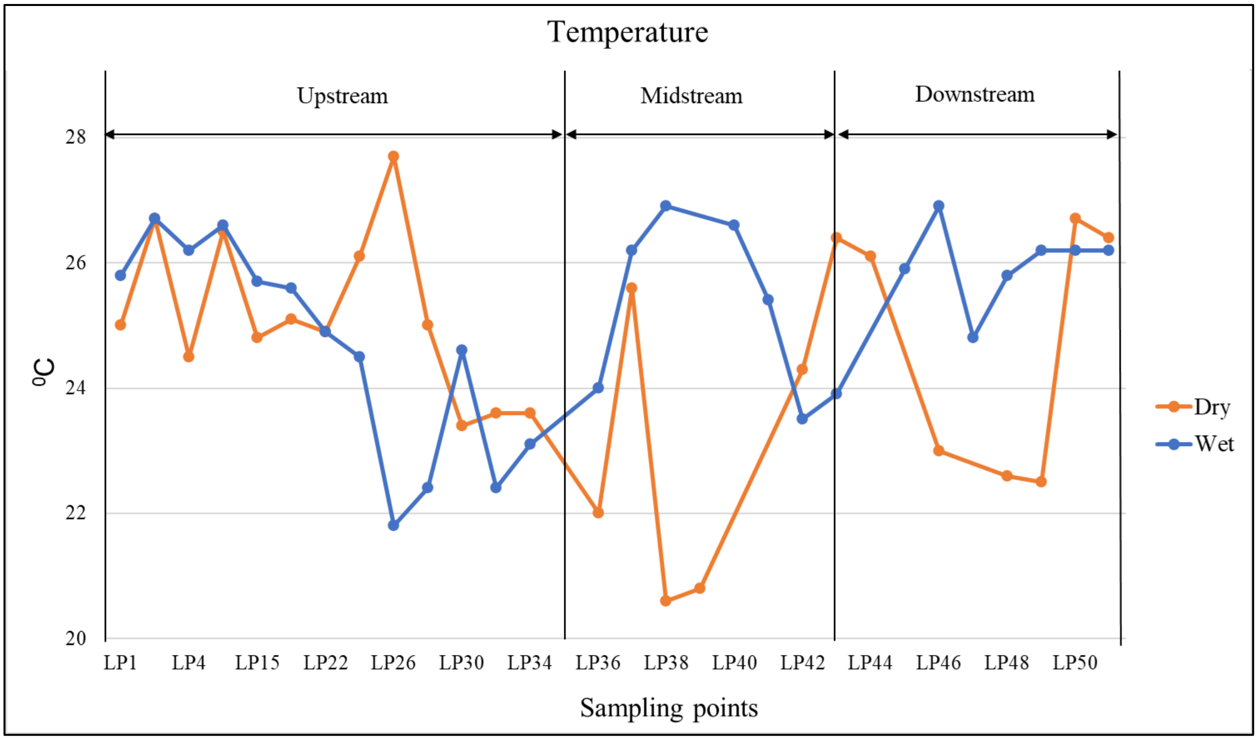


Figure 14: Spatial-temporal variations of temperature from upstream, midstream and downstream in the LRB in Central, Luapula and Northern provinces, Zambia.

5.5 Turbidity

The turbidity ranged from 1.39 NTU at Lake Chifunabuli to 37.2 NTU at Lake Bangweulu and the median was 4.7 NTU in the dry season. In the wet season, values ranged from 0.3 NTU at Lake Chifunabuli to 24.9 NTU with a median of 1.68 NTU (Table 5 above). The values of turbidity in the wet season were lower than the dry season values in most points (Figure 15). High values of turbidity coincided with points with high iron. This is because turbidity is also caused by suspended solids like clay and silt and chemical precipitates of iron which are affected by rainfall dilution.

The values of turbidity at some points in both seasons did not meet the ZABS (2021) guidelines of 10 NTU for ambient water. The values of turbidity at these points also exceeded the guideline of 5 NTU for drinking water (WHO, 2022). Nguvulu *et al*. (2021) found similar results in the Upper Chongwe River Catchment in Zambia and attributed it to effluent from the Sewage Treatment Plant and Stabilisation Ponds in the area.

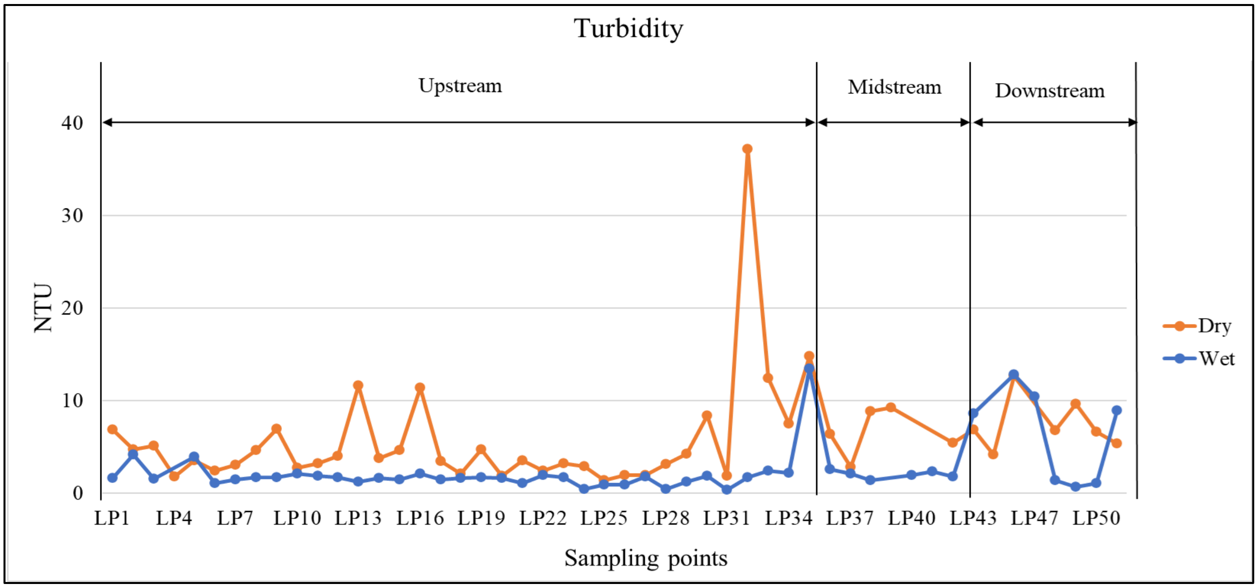


Figure 15: Spatial-temporal variations of turbidity from upstream, midstream and downstream in the LRB in Central, Luapula and Northern provinces, Zambia.

5.6 Nutrients

For both seasons, the values of nitrate, phosphate and sulphate were all below the detection limit of 0.01mg/L. This means that these three parameters fell within the ZABS (2021) permissible limits for ambient water (Table 5 above).

5.7 Calcium Hardness and Total Hardness

Calcium hardness in the dry season had a median of 0.5 $mgCaCO_3/l$, ranging from 6 $mgCaCO_3/l$ at Chisangwa Stream to 30 mgCaCO3/l at Kasanka River, Kasengo Bay and Lake Mweru. Total hardness ranged from 20 $mgCaCO_3/l$ at Mbereshi, Lufubu and Mukuku Bridge to 106 $mgCaCO_3/l$ at Musonda Falls Bridge, with a median of 0.5 $mgCaCO_3/l$ in the dry season (Table 5 above). There is evidence of dilution from rainwater as the wet season values of calcium and total hardness values were all below the detection limit of 1 $mgCaCO_3/l$ (Figures 16 and 17). These findings are supported by Banda *et al.* (2023) and Nyambe *et al.* (2018), who attributed the variations in calcium and total hardness to hydrological flow regimes that cause deposits of sediments from upstream. They also attributed the variations of calcium and total hardness to the plant's uptake of calcium to form new plant tissues. Nyambe *et al.* (2018) also found that the points with lower pH coincided with points with high calcium in the dry season, attributing the variations to pH as well. This is similar to the findings of this study. This is because low pH favours the dissolution of calcium. The variations in calcium and total hardness were also a result of leaching from the underlying geology in the basin, which includes rocks like igneous, volcanic and metamorphic rocks rich in silicates.

The values of total hardness in both seasons met the permissible limit of 250 mg$CaCO_3$/l for ambient water; however, there is currently no guideline for calcium hardness in the ZABS standards for ambient water (ZABS, 2021). The permissible limit for calcium and total hardness in drinking water is 500 mg $CaCO_3$/l (WHO, 2017). The values of calcium and total hardness in most points were lower than 60 mg$CaCO_3$/l, making the water soft (WHO, 2017). Soft water can lead to environmental issues like increased corrosivity and altered aquatic ecosystems, as well as health risks such as nutrient deficiencies due to the lack of calcium and magnesium (Lesimple *et al.*, 2020).

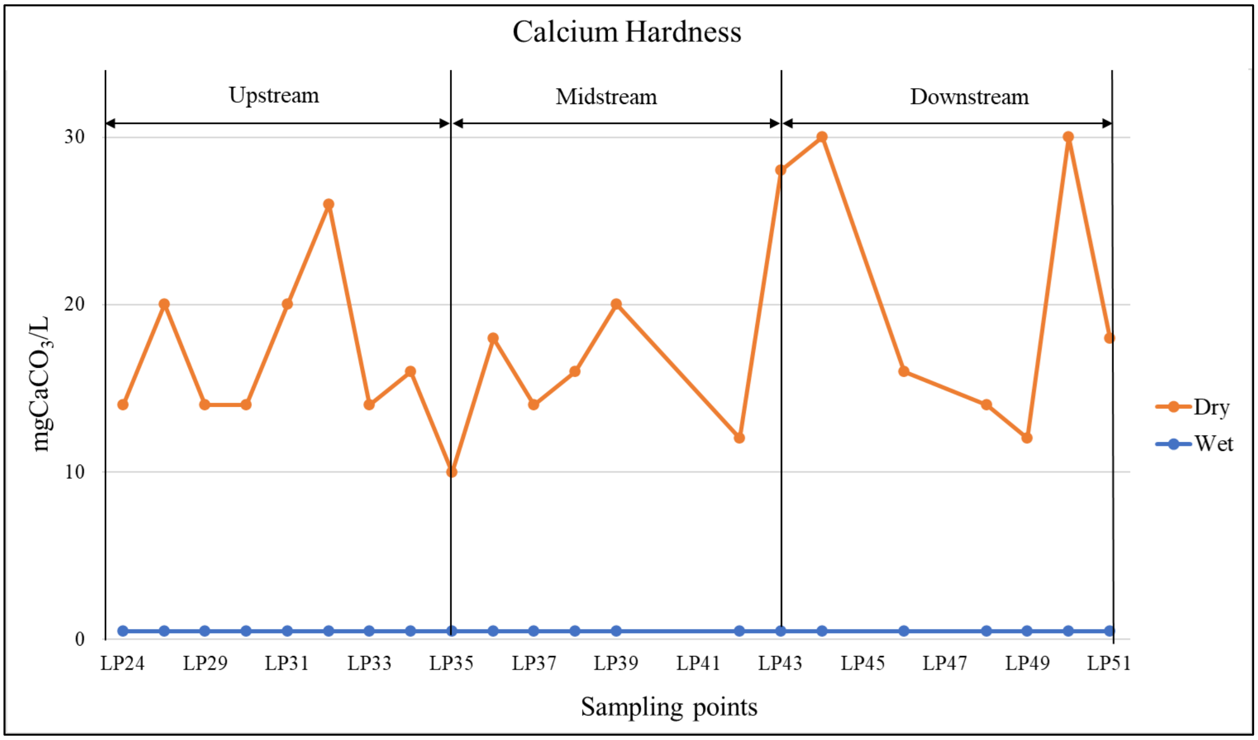


Figure 16: Spatial-temporal variations of calcium hardness from upstream, midstream and downstream in the LRB in Central, Luapula and Northern provinces, Zambia.

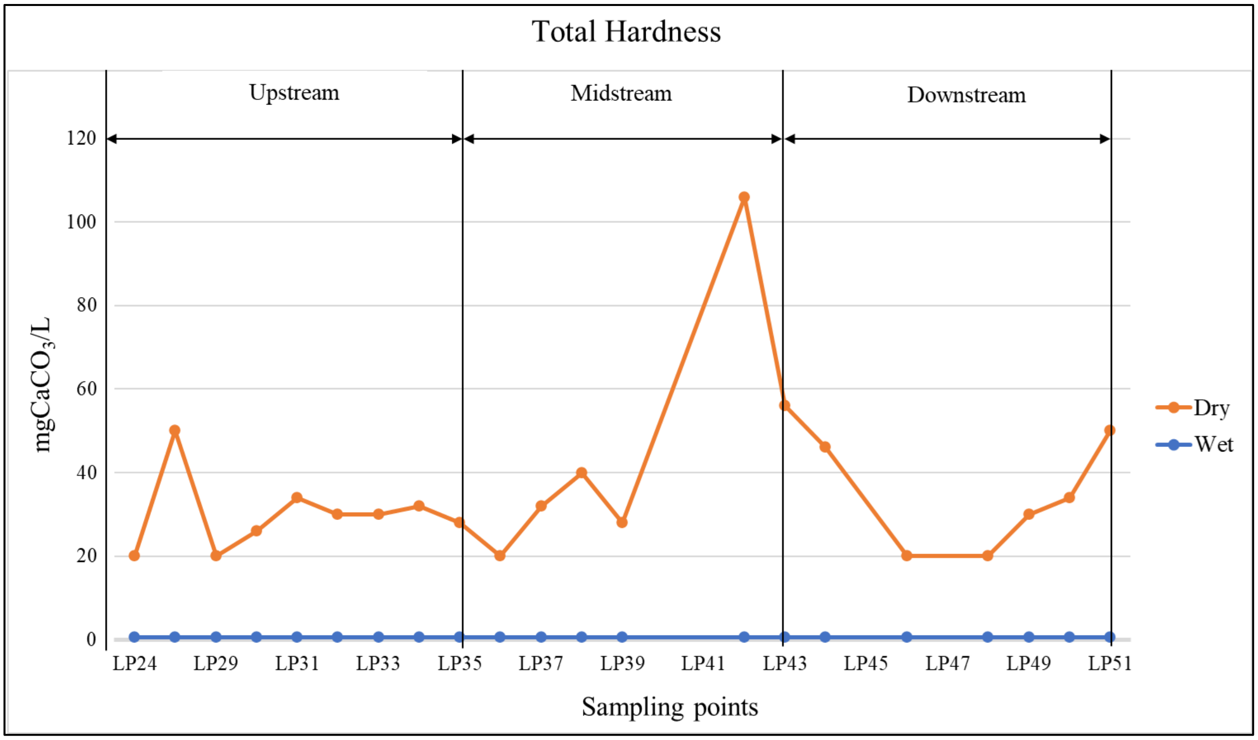


Figure 17: Spatial-temporal variations of total hardness from upstream, midstream and downstream in the LRB in Central, Luapula and Northern provinces, Zambia.

5.8 Potassium

Potassium in the dry season had a median value of 2.49 mg/L and ranged from 1.7 mg/L to 12 mg/L. In the wet season, potassium ranged from < 0.01 mg/L in Serenje at Chisangwa to 2.4 mg/L in Chembe, with a median of 0.83 mg/L (Table 5 above). The graphs show dilution from rainwater in the values of potassium as the wet season values were all lower than the dry season values (Figure 18). However, Mataa (2022) recorded an increase in potassium in the wet season in the Barotse Floodplain and attributed it to flooding over pastureland that leads to an increase in nutrients. Anthropogenic activities such as gardening, washing and the presence of fishing camps without toilets which promote open defecation along the streams (Figure 19) also played a role in the variation of potassium. This is because of the introduction of fertilizers, soaps, detergents and human waste that contain potassium. These activities were observed throughout the LRB and were very prominent at Musanfwe and Chisangwa streams in Serenje District, Nkulumanshima Bridge in Chitambo District, Katansha Bridge and Mpanta at the source of the Luapula River in Samfya District, Mukuku Bridge in Samfya District, Muongo River in Mansa District and Nshinda Stream in Nchelenge District. The variations in potassium can also be attributed to the presence of siltstones and granite that contain potassium feldspars. There is currently no guideline for potassium in the ZABS (2021) standards for ambient water, however, it met the WHO (2022) guidelines for drinking water.

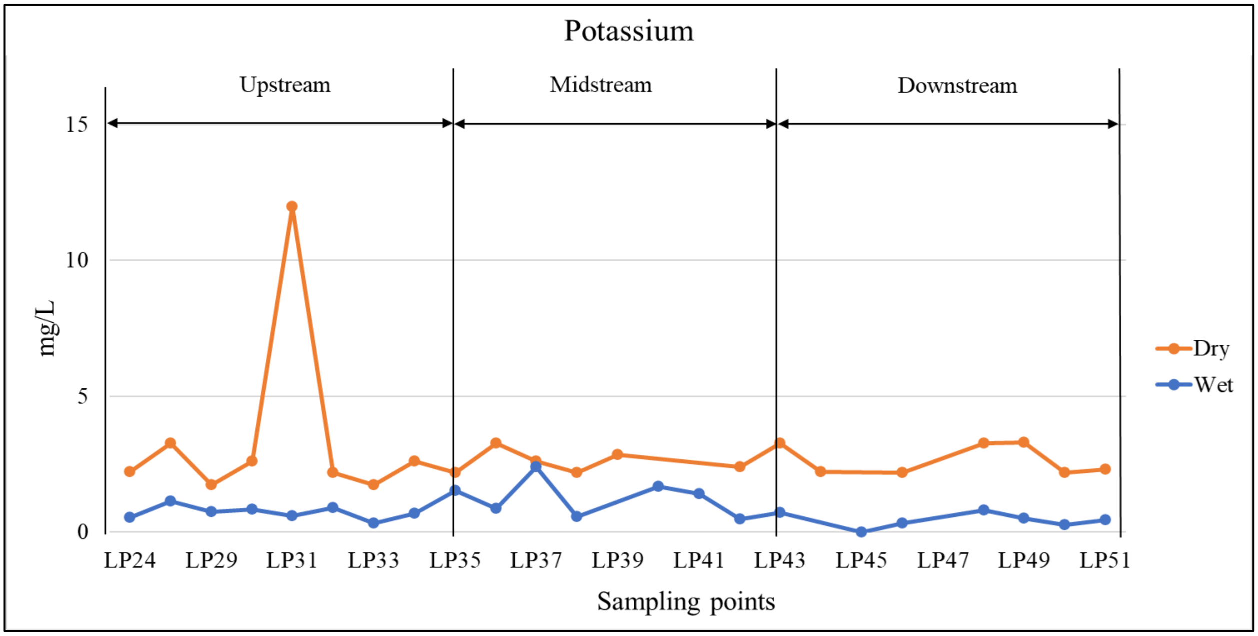


Figure 18: Spatial-temporal variations of potassium from upstream, midstream and downstream in the LRB in Central, Luapula and Northern provinces, Zambia.

5.9 Sodium

The values of sodium in the dry season ranged from 5.3 mg/L to 36.3 mg/L and the median was 7.555 mg/L (Table 5 above). Sodium was not tested in the wet season due to faulty equipment at the laboratory. The variations in the values of sodium can be attributed to the presence of siltstones and granite that contain sodium feldspars and anthropogenic activities such as gardening. Gardening influences the variation of sodium due to the use of sodium-containing fertilizers and pesticides (Figure 19). Nyambe *et al*. (2018) also indicated that the variations of sodium in the dry season in the Baroste Floodplain in western Zambia are due to intensive anthropogenic activities such as gardening. The values of sodium were all above the ZABS (2021) guideline of 5 mg/L for ambient water (Figure 20). High sodium values can harm aquatic life, alter water chemistry, negatively impact vegetation, disrupt ecosystem balance and lead to soil degradation. High values of sodium also indicate contamination because sodium is not typically present in high concentrations in fresh water. However, sodium did not exceed the permissible limit of 200 mg/L for drinking water, according to (WHO, 2022).

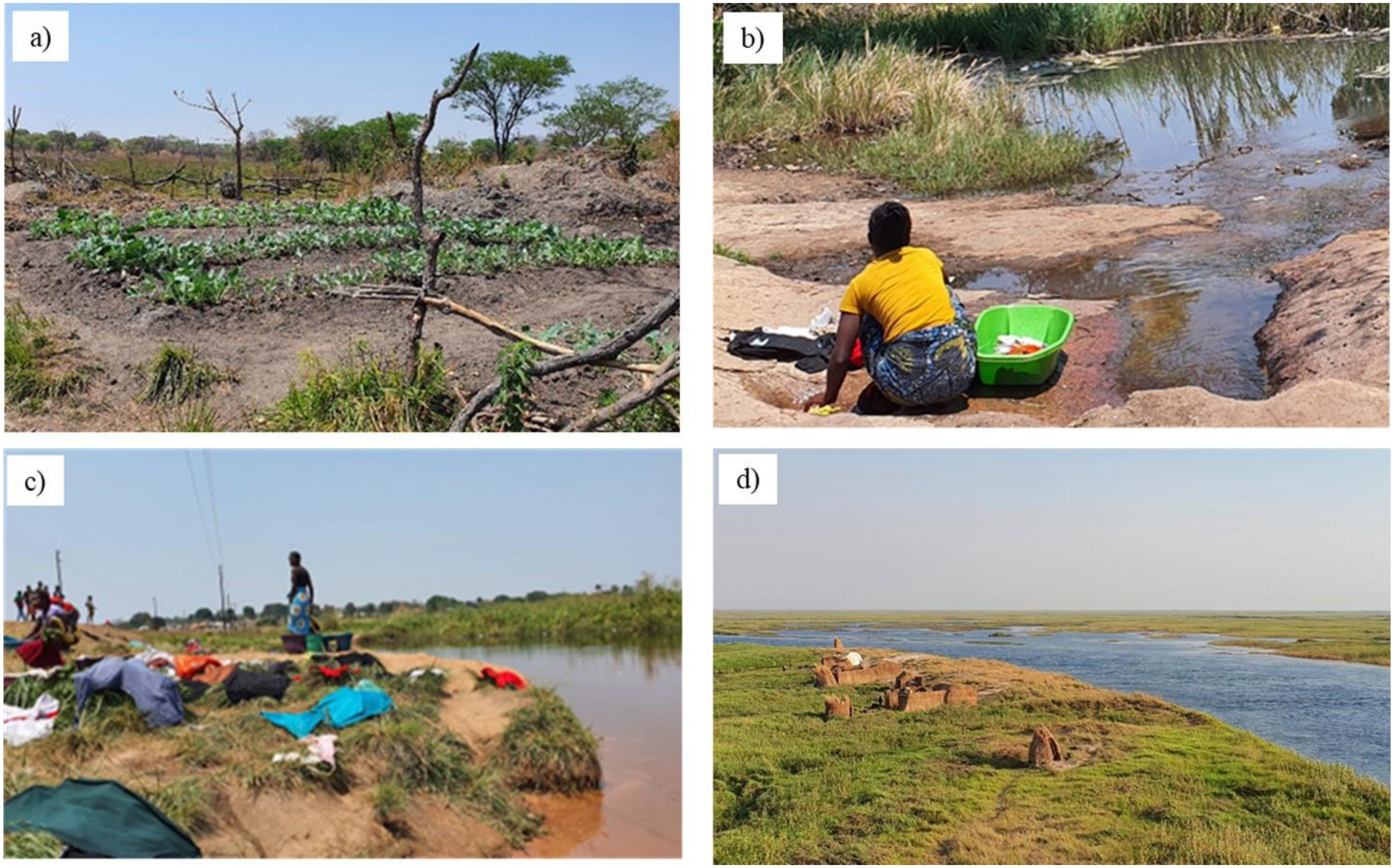


Figure 19: Observed anthropogenic activities; (a and b) Vegetable gardens and washing along Musanfwe Stream in Serenje District, (c) washing at Nshinda Stream in Nchelenge District and (d) fishing camps at Mukuku Bridge in Samfya District, Zambia.

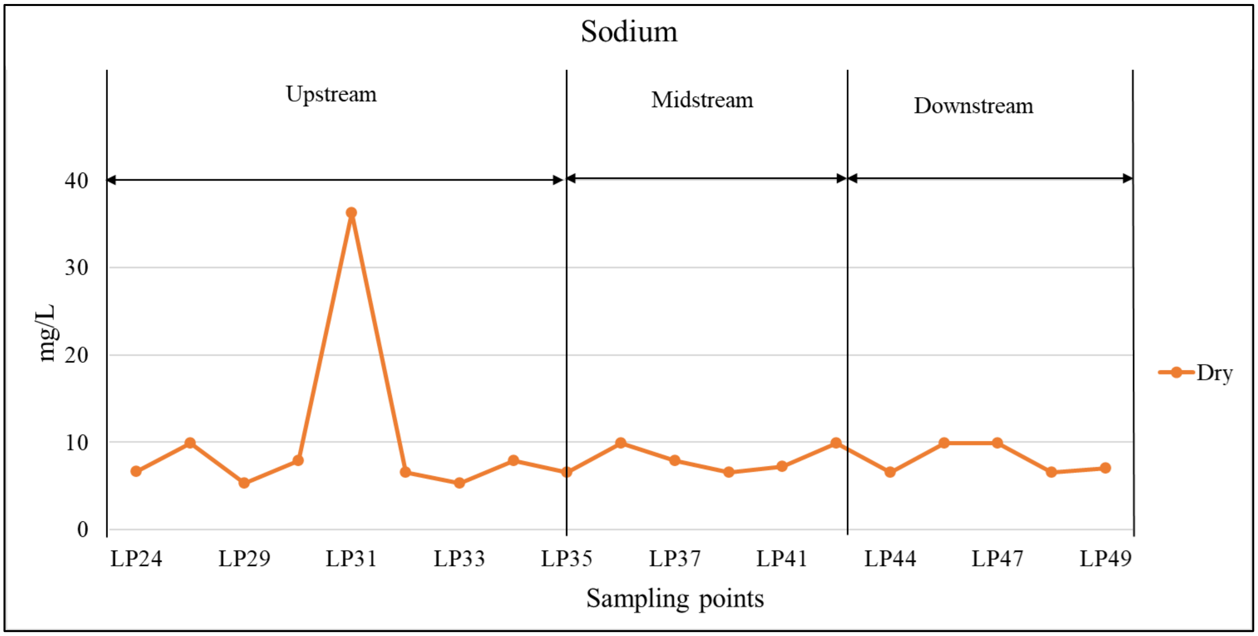


Figure 20: Spatial-temporal variations of Sodium from upstream, midstream and downstream in the LRB in Central, Luapula and Northern provinces, Zambia.

5.10 Chloride

Chloride ranged from 8 mg/L to 55 mg/L and the median was 11.5 mg/L in the dry season. In the wet season, however, chloride ranged from 2 mg/L in Lake Mweru, Kalungwishi Bridge and Chinweshiba to 14 mg/L at Kashiba Bay with a median of 6 mg/L (Table 5 above). Values of chloride in the wet season values were lower than the dry season values at most sampling points (Figure 21). Chloride concentrations in most natural surface waters range from 10 to 20 mg/L; values higher than 20 mg/L indicate contamination (Hong *et al.*, 2023). This supports that the observed anthropogenic activities (Figure 19 above) also played a role in the variation of chloride. This is because chloride-containing fertilizers, pesticides, herbicides and washing products find themselves in the water due to runoff.

The values of chloride in the dry season exceeded the ZABS (2021) permissible limits of 30 mg/L for ambient water at some points. However, the 250mg/L limit for chloride in drinking water (WHO. 2022) was never exceeded.

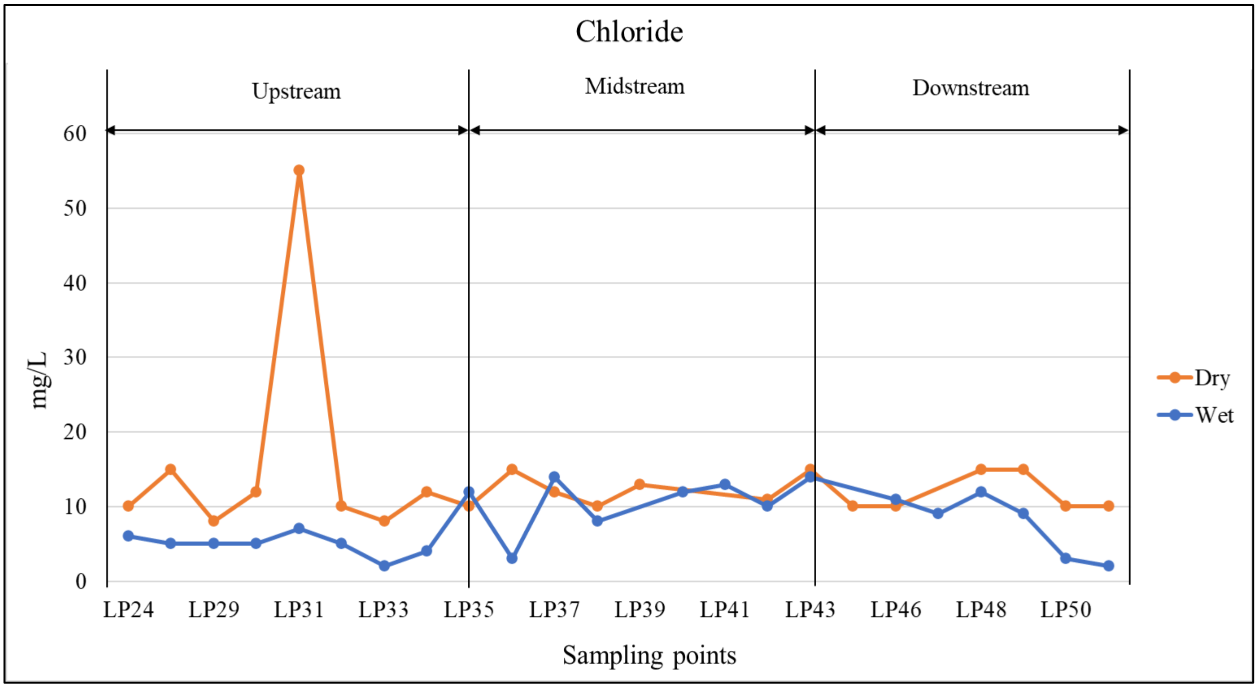


Figure 21: Spatial-temporal variations of chloride from upstream, midstream and downstream in the LRB in Central, Luapula and Northern provinces, Zambia.

5.11 Heavy Metals

The values of manganese and lead in both seasons were below the detection limit and fell within the ZABS (2021) permissible limits for ambient water.

The values of iron in the dry season ranged from <0.002 mg/L to 2.234 mg/L at Nkulumanshima Bridge, with a median of 0.073 mg/L. In the wet season, values ranged from <0.002 mg/L to 1.4 mg/L at Njerere, with a median of 0.001 mg/L (Table 5 above). In the upstream and downstream sections, the dry season values were higher than the wet season values, showing evidence of dilution from rainwater. However, this was the opposite for the midstream section as the wet season values were generally higher than the dry season values at some points (Figure 22). It was observed that the values of iron were higher in Serenje District, Chitambo District and areas near Lake Mweru that have manganese mining activities. This is because iron usually occurs together with manganese and is more common in groundwater than surface water because it is present in silicates, laterite and siltstones in the underlying geology of the LRB. Therefore, the recorded high values of iron can be a result of mining waste, where manganese is extracted but the iron minerals are discarded and later find themselves on the surface due to sediment deposits. Sracek *et al.* (2012) also found high values of heavy metals including iron in the Kafue River in Zambia and indicated that they may pose potential environmental risks in acid spikes due to acid mine drainage. Takam *et al.* (2024) also found high values of iron in the streams and rivers surrounding the Kansanshi Mine in Solwezi District, North-Western Province of Zambia. Takam *et al.* (2024) attributed this to anthropogenic activities such as mining and farming in the district. These activities open the iron-rich soils of Solwezi District (Lweya *et al*., 2015), which may lead to the increase of iron in the rivers through soil erosion (Takam *et al.*, 2024).

Some values of iron in both seasons did not meet the ZABS (2021) guidelines of 0.7 mg/L for ambient water, with most exceeding the WHO (2022) guideline of 0.3 mg/L for drinking water. Iron has undesirable effects on water, including discolouration, which causes turbidity, staining of clothes and formation of encrustations in pipes. It also affects the taste of water and may cause gastrointestinal irritation (WHO, 2017).

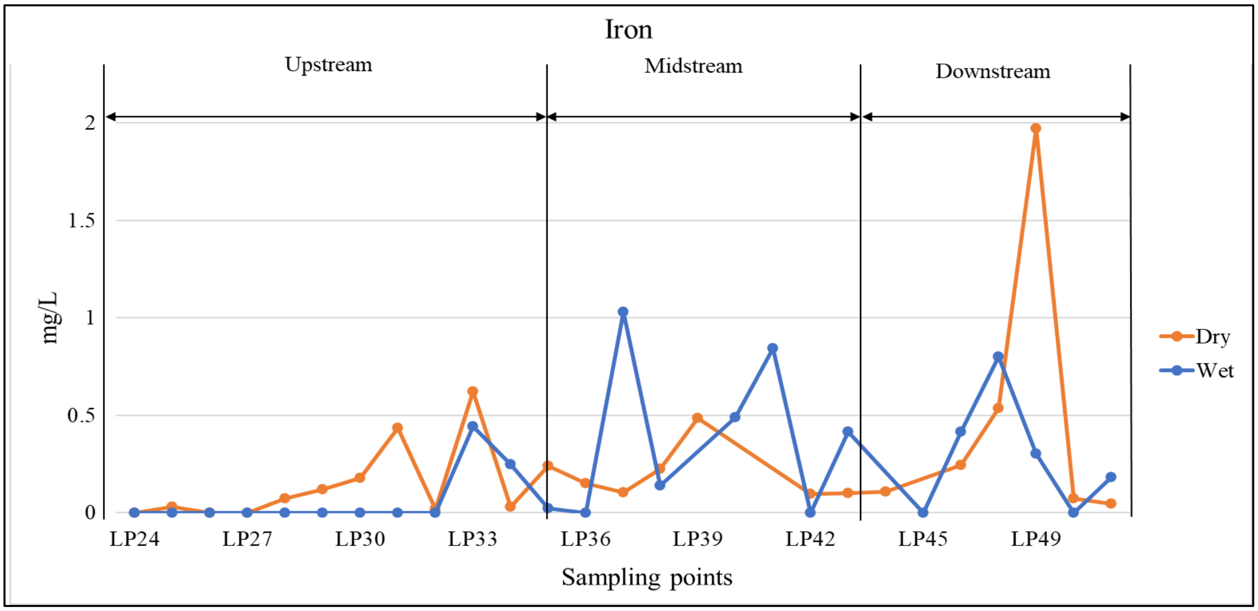


Figure 22: Spatial-temporal variations of iron from upstream, midstream and downstream in the LRB in Central, Luapula and Northern provinces, Zambia.

5.12 Microbial Parameters

Total coliforms ranged from 0 CFU/100 ml to >200 CFU/100 ml which was designated as TNTC, with a median of 40 CFU/100 ml in the dry season. In the wet season, total coliforms ranged from 0 CFU/100 mL to TNTC, with a median of 15 CFU/100 ml (Table 5 above). Faecal coliforms ranged from 0 CFU/100 ml to >200 CFU/100 ml which was designated as TNTC, with a median of 20 CFU/100 ml in the dry season. In the wet season, the values ranged from CFU/100 mL to

TNTC in Mbabala, with a median of 29 CFU/100 ml (Table 5 above). Therefore, both total and faecal coliforms in both seasons ranged from 0 to TNTC (Figures 23 and 24). The values of total and faecal coliforms were a result of increased anthropogenic activities in the basin. Some of the observed anthropogenic activities included washing on the banks of streams, livestock rearing, bathing and the presence of fishing camps without toilets which promote open defecation along the streams (Figure 19 above). Nyambe *et al*. (2018) found similar results in the Barotse Floodplain in western Zambia and also attributed the elevated values of coliforms to increased anthropogenic activities, especially near settled areas.

Most values of total coliforms and faecal coliforms did not meet the required standards. The guideline for coliforms in drinking or domestic water is 0 CFU/100 ml (WHO, 2017).

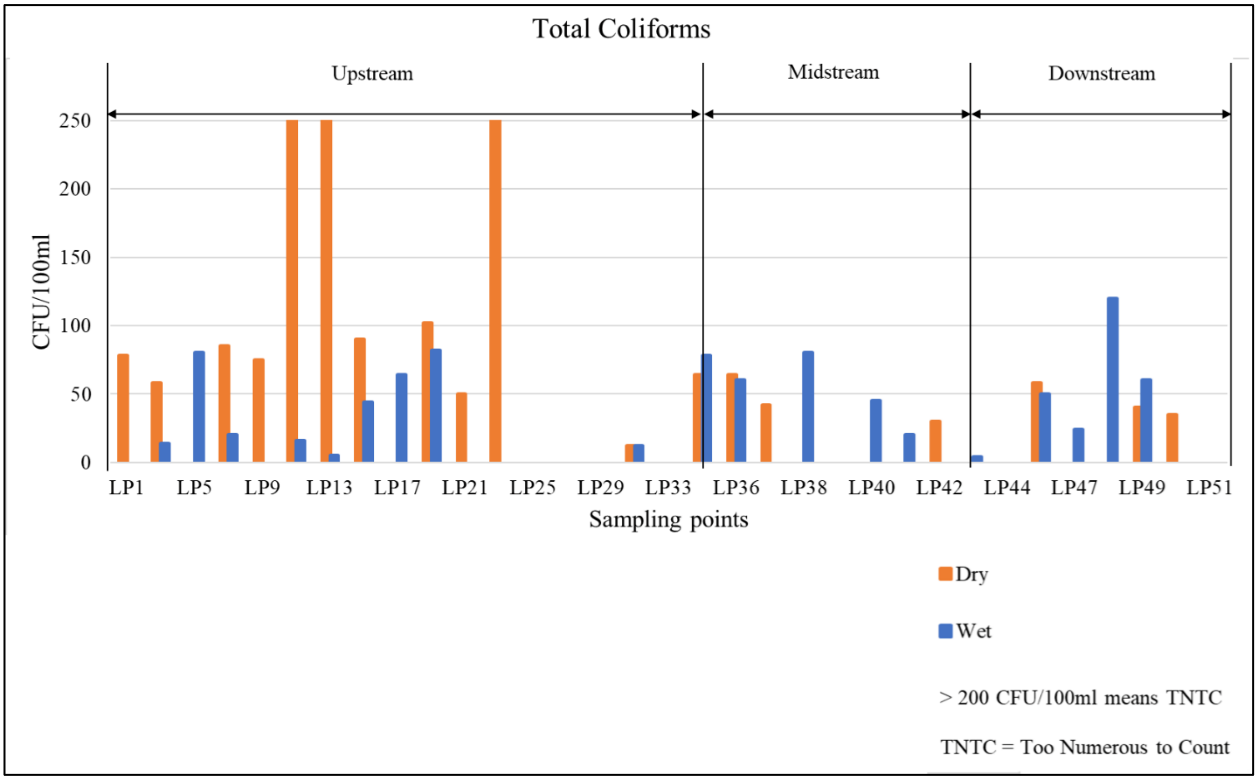


Figure 23: Spatial-temporal variations of total coliforms from upstream, midstream and downstream in the LRB in Central, Luapula and Northern provinces, Zambia.

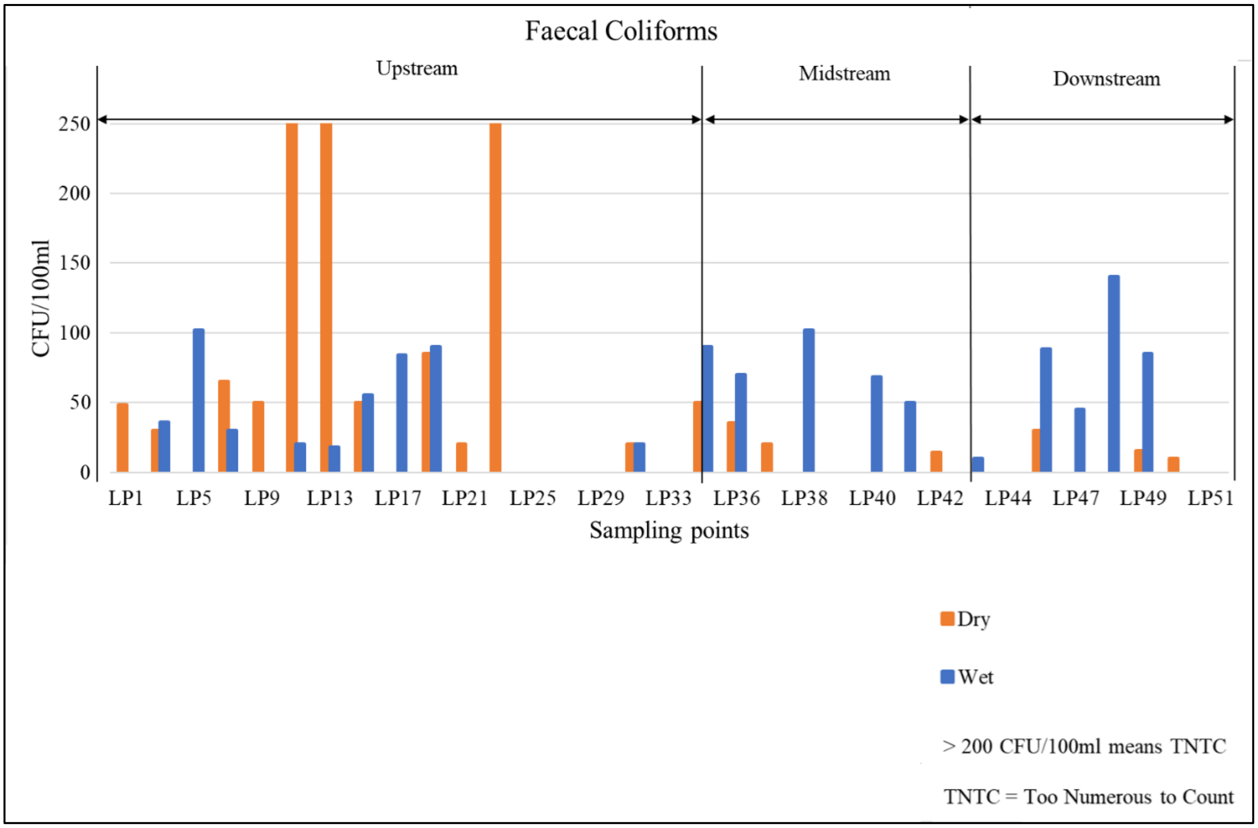


Figure 24: Spatial-temporal variations of faecal coliforms from upstream, midstream and downstream in the LRB in Central, Luapula and Northern provinces, Zambia.

5.13 Gibbs Plot

The Gibbs Plot (Figure 25) performed to determine the major causes of the variations showed that precipitation dominance was the major cause of variations in the values of the parameters in the LRB. However, at the Kasanka River in Chitambo District, the water quality was only characterised by rock dominance. Nearly all the other samples fell within the precipitation dominance suggesting weathering and precipitation (Figure 25). Banda *et al.* (2023a) found similar results in the Barotse Floodplain; the quality of the water was characterised by precipitation and rock weathering.

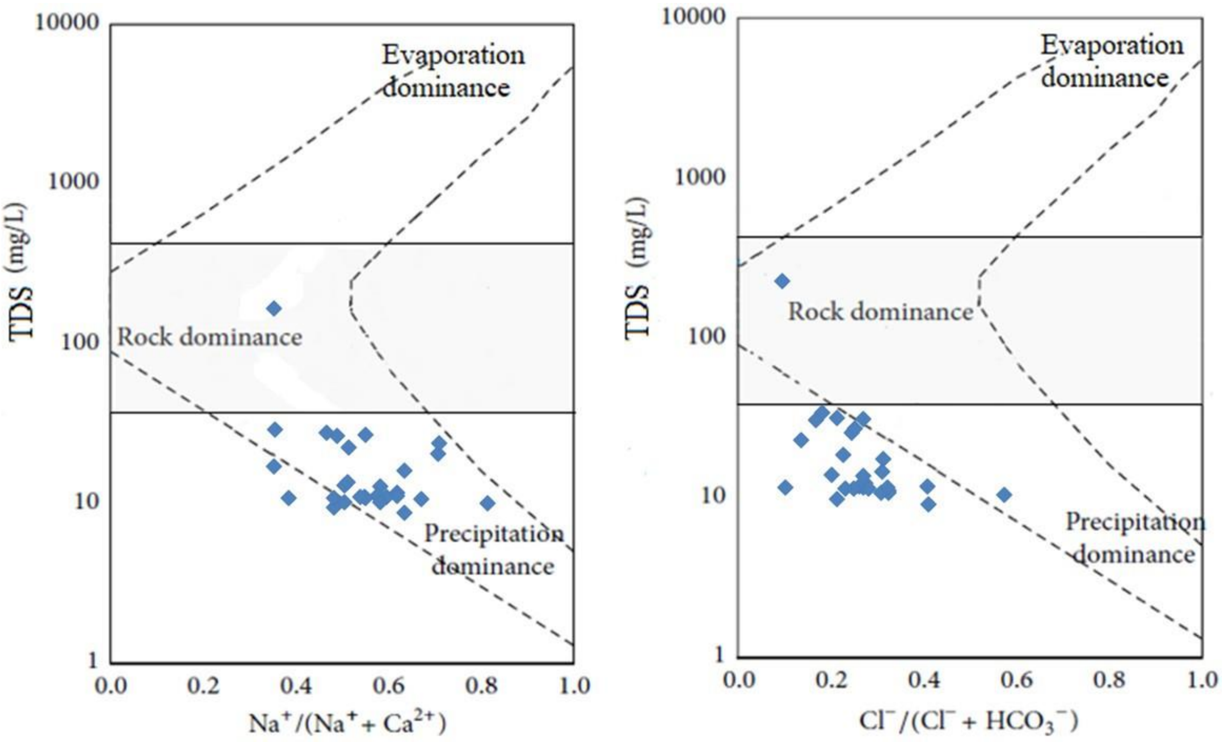


Figure 25: Gibbs Diagram showing the major causes of variations in the LRB in Central, Luapula and Northern provinces, Zambia.

5.14 Hydro-Chemical Characteristics

The dry season data was used to evaluate the hydro-chemical characteristics of the water in the LRB because of the dilution in the wet season. As indicated earlier, the major cations and anions were plotted on a Piper Diagram to classify the surface water in the LRB (Figure 26). These cations and anions included calcium, magnesium, sodium, potassium, chloride, sulphate and bicarbonate. There was no dominant ion among the cations as most samples fell within the centre (no dominant type), with two points under the mixed and the sodium-potassium-chloride-sulphate types, respectively. The anions fell within the bicarbonate-type zone, with one point in the chloride-type zone. Therefore, the hydro-chemical facies of surface water in the LRB were characterised by calcium-magnesium-bicarbonate (Ca^{2+}-Mg^{2+}-HCO_3^-) water types. Similar studies, like that of Banda *et al*. (2023a) in the Barotse Floodplain, found the order of the ionic abundance for cations to be $Ca^{2+} > Na^+ > Mg^{2+} > K^+$ with HCO^{3-} dominating among the anions and the water is characterised by calcium-magnesium-bicarbonate (Ca^{2+}-Mg^{2+}-HCO_3^-) facies. Azhari *et al.* (2022) used the Piper Diagram and found similar results in the Oued Laou Watershed in Morocco and attributed the chemical changes to anthropogenic sources, irrigation returns, rock-water interactions and chemical fertilisers.

Calcium, sodium and magnesium are influenced by the presence of igneous, metamorphic and volcanic rocks that contain silicates in the underlying geology in the LRB. Bicarbonate is a result of dissolved carbonic acid from atmospheric carbon dioxide and humic acids from soils or weathered silicates (Ye *et al*., 2022). The bicarbonate can also be a result of leaching from carbonate rocks in the underlying geology of the LRB.

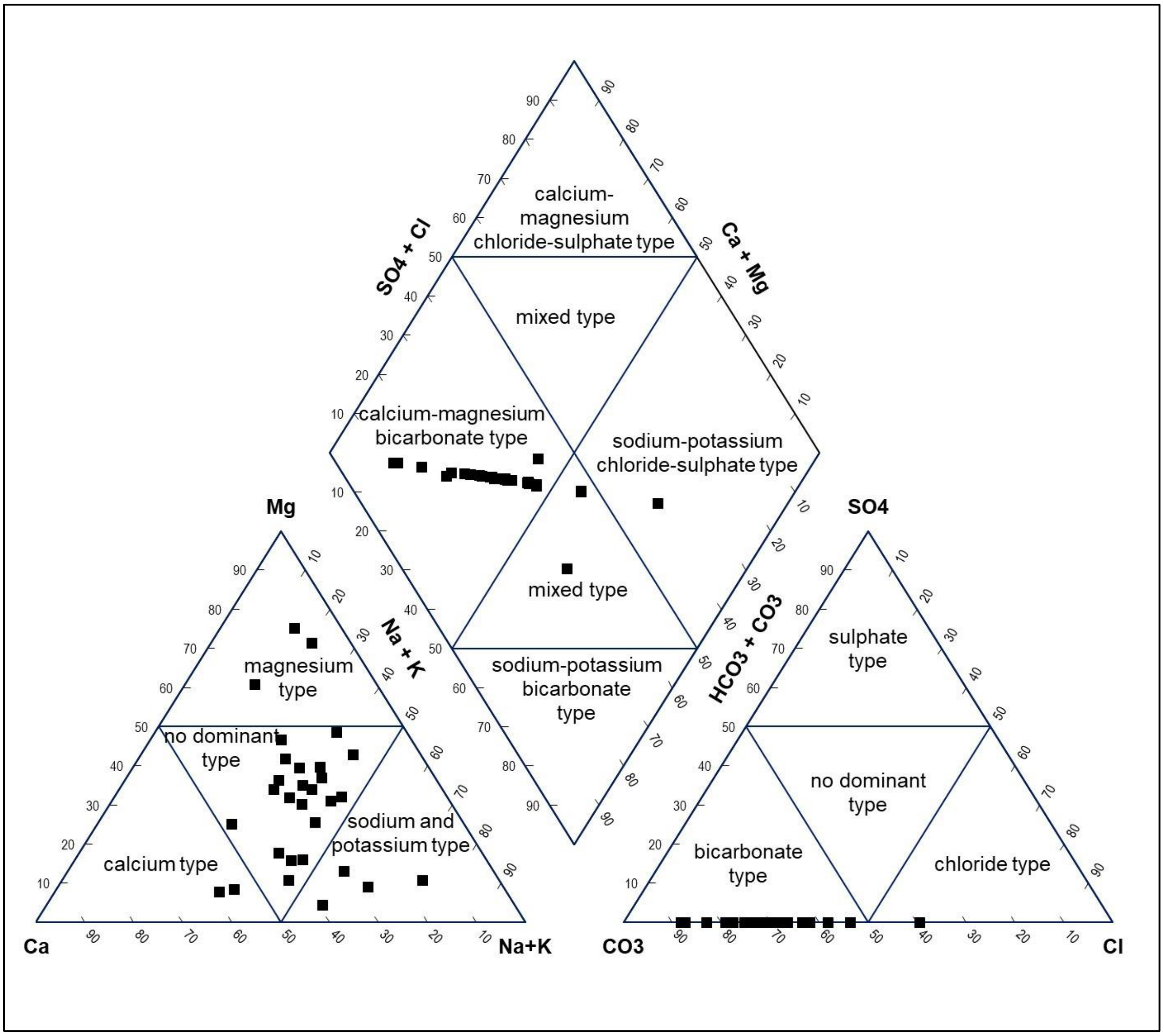


Figure 26: Piper Diagram showing the hydro-chemical facies of surface water in the LRB in Central, Luapula and Northern provinces, Zambia.

5.15 Water Quality Index

The Water Quality Index (WQI) was computed from the dry season values of EC, TDS, temperature, pH, total hardness, turbidity, total coliforms, faecal coliforms and iron. These parameters were selected based on their ability to give an overall depiction of the state of the water. The different WQI ratings from each sampling point in the LRB are indicated in Appendix 5. The WQIs for LRB indicated that nine per cent of the sampling points were unsafe, seven per cent were very poor, four per cent were poor, 22 per cent were good and 58 per cent were excellent for consumption (Figure 27 and Table 6). The average WQI for the LRB was found to be 38 per cent. The WQI was unsafe in areas with high levels of iron and turbidity, which exceeded the ZABS (2021) guidelines for ambient water. This is supported by the results of the WQI_{min} model, which showed that iron and turbidity were key parameters in the WQI.

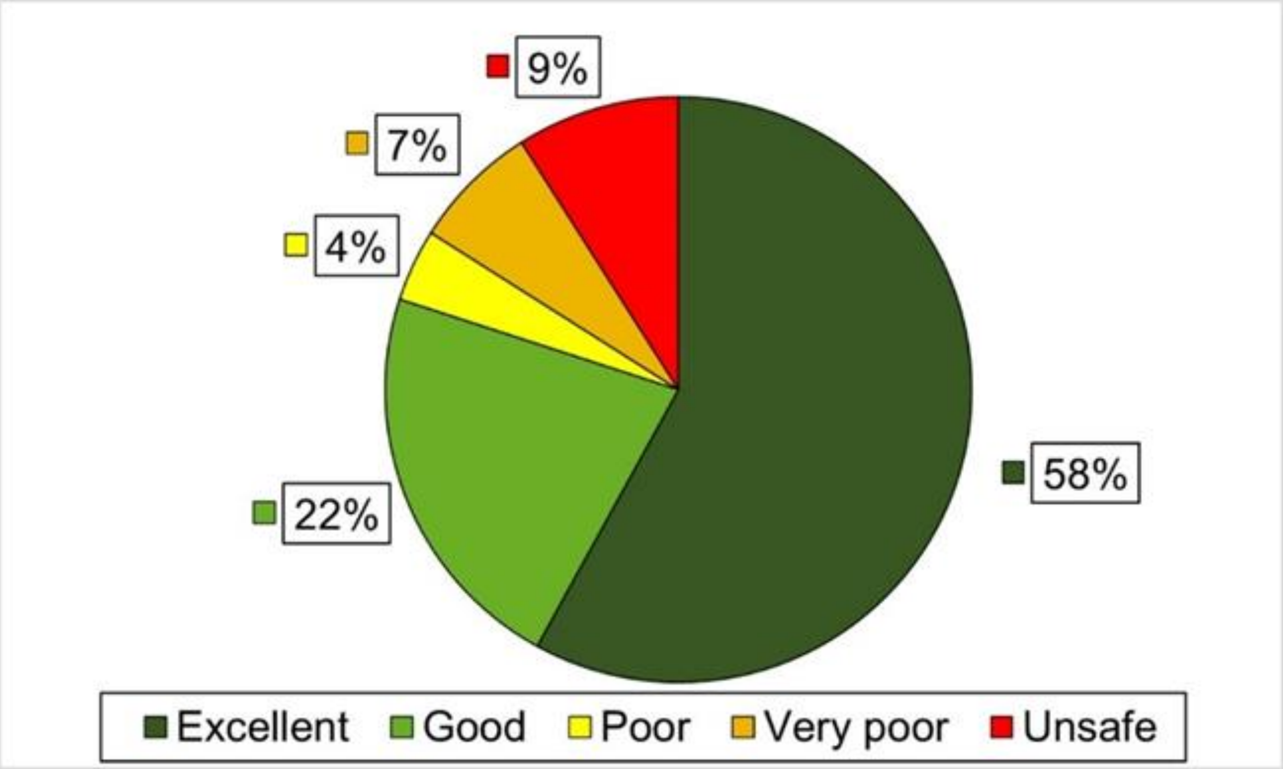


Figure 27: The WQI percentages in the LRB in Zambia.

Table 6: Proposed uses of water in the LRB based on water quality index ratings used in this study (Paneerselvam *et al*., 2020; Brown *et al*., 1970).

WQI (%)	**Water Quality**	**No. of samples**	**%**	**Uses**
0-25	Excellent	33	58	Drinking, Industrial and Irrigation
26-50	Good	13	22	Drinking, Industrial and Irrigation
51-75	Poor	2	4	Industrial and Irrigation
76-100	Very poor	4	7	Irrigation
>100	Unsafe	5	9	Proper treatment before use
Average WQI		**38%**		

The proposed uses for water based on the WQI ratings are listed in Table 6 above. Therefore, excellent water and good quality water can be used for drinking, industrial and irrigation purposes. Poor-quality water can be used for industrial and irrigation purposes without treatment. Very poor-quality water can only be used for irrigation purposes. Finally, proper treatment is required before using unsafe water (Paneerselvam *et al.*, 2020).

The different WQI ratings were also depicted on maps of the LRB (Figure 28). The most unsafe and very poor points in the LRB were in the Serenje and Chitambo districts as well as at Nshinda Stream, Mulembo Stream, Lake Chifunabuli and Mberishi River, which had high values of iron. Miyenge Stream in Chembe and Lake Chifunabuli had poor WQIs (Appendix 5). Some points with good WQIs were on Lake Wasa, the Luapula River in Mpanta and Kashiba Bay, the Luwo Stream in Chembe, Lake Bangweulu, Lake Chifunabuli, Lufubu River and Kasengo Bay. Excellent points were at Lake Bangweulu, Lake Chifunabuli, Lake Mweru, Luapula River in Chembe, Katansha Bridge in Samfya and Muongo River in Mansa. Takam *et al.* (2024) used the WQI index to assess the effects of mining activities and land use change on water quality in Solwezi District, North-western Province, Zambia. His study found that the water quality of most rivers was safe for human and animal consumption. Nguvulu *et al.* (2021) also used the WQI to assess the quality of surface water in response to land use and land cover change in the Upper Chongwe River Catchment of the KRB in Zambia. Nguvulu *et al*. (2021) compared results from 2006 to 2017 and found that the WQI went from very bad to unsuitable for drinking. They also attributed this to pollution from the increased anthropogenic activities in the catchment. Kwambana (2022) also applied the weighing factor method to compute the WQI for the Upper Vaal River Catchment in Johannesburg, South Africa. Kwambana (2022) found that the WQI values increased from upstream to downstream due to the cumulative effect of pollution sources. This was also true for this study, except for the streams near the manganese mines in Serenje District, Chitambo District and areas near Lake Mweru where the underlying geology contributed to high iron levels. However, the underlying geology could also be a contributing factor.

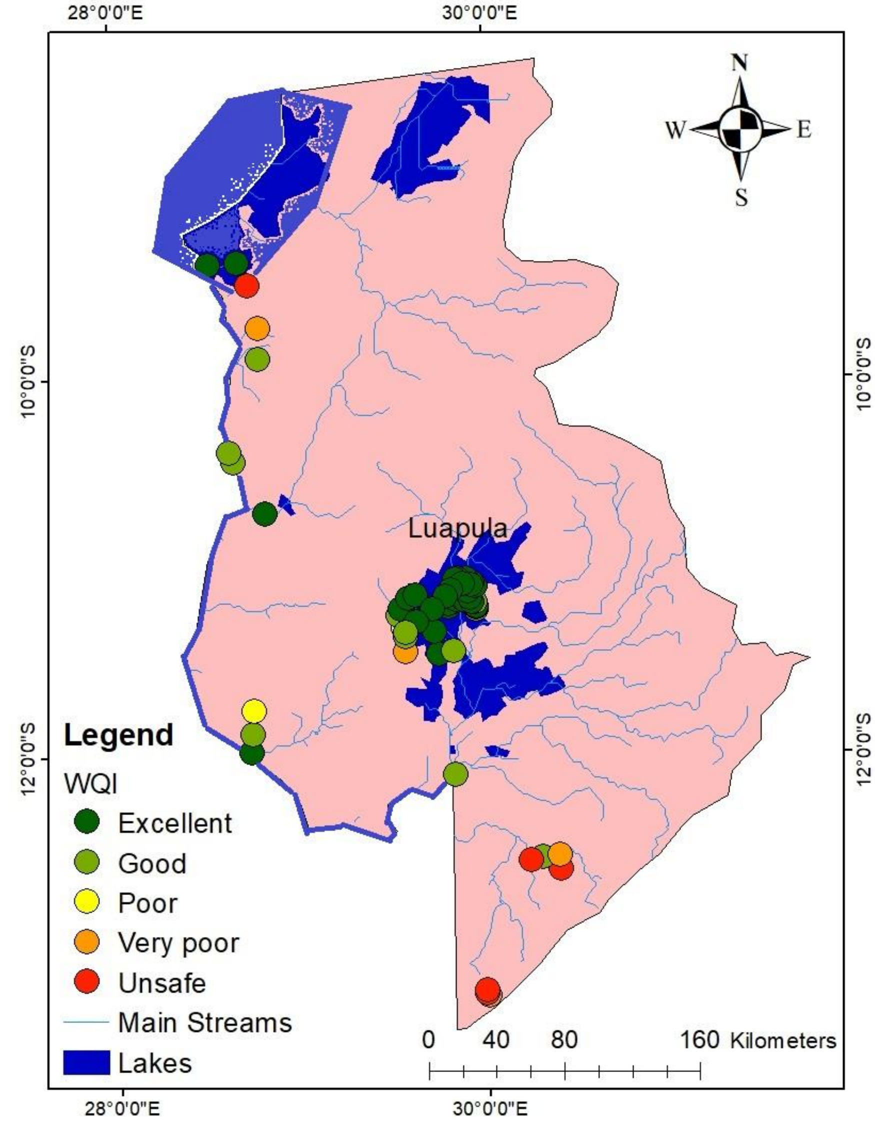


Figure 28: Map showing the distribution of WQI percentages in the LRB in Central, Luapula and Northern provinces, Zambia.

The results of the stepwise multiple linear regression showed total coliform and EC had the least contribution to the WQI calculation and were therefore considered non-key parameters by the model. The stepwise regression produced seven models. The correlation analysis of these models against the WQI showed that all the models had a positive linear relationship with the WQI, with Pearson correlation coefficients ranging from 0.999 to 1. All the models had a P value of < 0.001. The best-performing model was determined by comparing the values of the P value, S, R^2, adjusted R^2 and the Pearson Correlation Coefficient. The best-performing model was one with the highest R^2 and adjusted R^2 and the lowest S value. Furthermore, the difference between the WQI and WQI_{min} was also used to determine the best-performing model using the average values. The average values were; WQI_{min1} (28 per cent), WQI_{min2} (31 per cent), WQI_{min3} (35 per cent), WQI_{min4} (37 per cent), WQI_{mi5} (38 per cent), WQI_{min6} (35 per cent) and WQI_{min7} (35 per cent) (Table 7). Model WQI_{min5} had the same average value as the overall WQI (38 per cent). Therefore, Model WQI_{min5} was found to be the best-performing model with an S value of 0.54, an R^2 of 1 and an adjusted R^2 of 1. The model shows that iron, turbidity, pH, temperature and TDS are key parameters in the computation of WQI.

Table 7: Results of the stepwise multiple linear regression and correlation analysis.

Model	**R2 (%)**	**R2 adj. (%)**	**S**	**P value**	**Pearson Coefficient**	**WQI_{min}**
WQI_{min} 1	99.4	99.4	4.2	< 0.001	0.997	28%
WQI_{min} 2	99.8	99.8	2.5	< 0.001	0.999	31%
WQI_{min} 3	100	100	0.9	< 0.001	1	35%
WQI_{min} 4	100	100	0.9	< 0.001	1	37%
WQI_{min} 5	100	100	0.5	< 0.001	1	38%
WQI_{min} 6	99.8	99.8	2.4	< 0.001	0.999	35%
WQI_{min} 7	99.8	99.8	2.4	< 0.001	0.999	35%

5.16 Inter-Basin Water Transfer

From the WQI, most of the sampling points in the LRB were excellent for ambient purposes. The points that recorded poor, very poor and unsafe WQIs in the LRB were attributed to the high levels of iron and turbidity. However, the average rating of 38 per cent represents good quality water.

The economic benefits associated with inter-basin water transfer to the KRB, however, are significant and can positively impact various industries in Zambia. Various scholars like Wilson *et al*. (2017), Gao and Yu (2018) and Wu *et al.* (2020) have studied the economic benefits of inter-basin water transfer projects. These scholars evaluated the economic benefits of the South-to-North Water Diversion Project in China, the findings indicated positive impacts on agricultural productivity, industrial development and overall economic growth in the northern regions. Therefore, in Zambia, the mining industry would benefit from the reliable water supply from inter-basin transfer, which will ensure sustained mining operations through a constant power supply. The International Council on Mining and Metals (ICMM) and the International Finance Corporation (IFC) (ICMM and IFC, 2017) highlight the importance of adequate water availability in mineral processing activities, which enhances the efficiency and sustainability of mining operations. The agricultural sector would benefit from the increased water availability through inter-basin water transfer by providing a consistent and reliable water source for irrigation and food production. This, in turn, contributes to enhanced agricultural productivity and economic growth in the agricultural sector (FAO, 2017). The energy sector, particularly hydropower generation, can benefit from inter-basin water transfer by ensuring a stable water supply for power generation, thus reducing the long hours of load shedding experienced in Zambia. Reliable water sources are essential for maintaining consistent energy production, reducing disruptions and supporting the overall energy industry (ICMM and IFC, 2017). The implementation of inter-basin water transfer to the KRB would also ensure a stable water supply for industrial activities, supporting manufacturing operations and promoting economic growth in the manufacturing sector (United Nations Industrial Development Organization, 2018). However, while the economic benefits are evident, it is crucial to balance these advantages with environmental considerations and the potential costs associated with water monitoring. Thus, the developed WQI_{min} model as utilized by scholars such as T. Wu *et al*. (2021), Z. Wu *et al*. (2021), Wang *et al*. (2022) and Nong *et al*. (2020), can play a vital role in monitoring water quality, reducing testing costs and informing management strategies that prioritize ecosystem sustainability, livelihoods and water availability across various industries. This is because the developed WQI_{min} indicates a reduction in the number of parameters from eight to five while maintaining the same average WQI and WQI ratings. This means that the WQI_{min} can be used as a more efficient method to monitor water quality in the LRB. This will reduce the cost of testing for parameters and encourage frequent water quality monitoring. The WQI_{min} model for the LRB will also help to understand the water quality challenges that might arise from the implementation of inter-basin water transfer.

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This study aimed to assess the surface water quality in the LRB to establish baseline data for potential inter-basin water transfers. Water samples were collected during the dry season of 2022 (September to November) and the wet season of 2023 (March), with a focus on eighteen selected parameters. In the dry season, EC ranged from 8 µs/cm to 225 µs/cm, TDS values ranged from 5 mg/L to 162 mg/L, pH values ranged from 6.19 to 8.4 and temperature ranged from 18.5^0C to 28.1^0C. Potassium ranged from 1.7 mg/L to 12 mg/L, sodium ranged from 5.3 mg/L to 36.3 mg/L, chloride ranged from 8 mg/L to 55 mg/L, turbidity ranged from 1.39 NTU to 37.2 NTU, iron ranged from <0.002 mg/L to 2.234 mg/L, calcium hardness ranged from 6 $mgCaCO_3$/l to 30 mgCaCO3/l and total hardness ranged from 20 $mgCaCO_3$/l to 106 $mgCaCO_3$/l, in the dry season. In the wet season, EC ranged from 6 µs/cm to 78 µs/cm, TDS ranged from 2 mg/L to 50 mg/L, pH ranged from 5.97 to 8.23 and temperature ranged from 20.8^0C to 28.8^0C. Potassium ranged from < 0.01 mg/L to 2.4 mg/L, chloride ranged from 2 mg/L to 14 mg/L, turbidity ranged from 0.3 NTU to 24.9 NTU and iron ranged from <0.002 mg/L to 1.4 mg/L in the wet season. Calcium and total hardness values were all below the detection limit of 1 $mgCaCO_3$/l in the wet season. Total and faecal coliforms ranged from 0 CFU/100ml to TNTC in both seasons. The concentrations of nitrate, phosphate and sulphate were found to be below the detection limit of 0.01 mg/L, similarly, the levels of manganese and lead were below the detection limits of <0.002 and <0.01, respectively, in both seasons.

Variations in water quality were primarily influenced by precipitation patterns and anthropogenic activities. The influence of anthropogenic activities was indicated by elevated levels of coliforms, iron, turbidity, sodium and chloride in specific areas. Additionally, the underlying geology in the LRB like igneous, volcanic and metamorphic rocks rich in silicates also played a role in the variations of calcium hardness, total hardness and iron.

Analysis using the Piper Diagram indicated that there was no dominant ion among the cations and all the anions were bicarbonate-type. The hydro-chemical facies of LRB surface water were characterised by calcium-magnesium-bicarbonate ($Ca^{2+-}Mg^{2+}$-HCO_3^-) compositions, suggesting the prevalence of igneous, volcanic and metamorphic rocks rich in silicates in the underlying geology of the LRB. The presence of bicarbonate was attributed to dissolved carbonic acid from atmospheric carbon dioxide and humic acids originating from soils or weathered silicates. The bicarbonate can also be a result of leaching from carbonate rocks in the underlying geology of the LRB.

The WQI indicated that nine per cent of the water samples in the LRB were unsafe, seven per cent were very poor, four per cent were poor, 22 per cent were good and 58 per cent were excellent for ambient purposes. The average WQI for the LRB was 38 per cent, indicating good water. Poor WQIs were mainly due to elevated iron and turbidity levels. From the multiple linear regression analysis, model $WQI_{min}5$ was found to be the best-performing model with an S value of 0.54, an R2 of 1 and an adjusted R2 of 1. All the models had a P value of < 0.001. Model $WQI_{min}5$ shows that iron, turbidity, pH, temperature and TDS are key parameters in the computation of WQI.

The potential of inter-basin water transfer to the KRB prompts consideration of water monitoring costs despite significant potential economic benefits to various industries in Zambia. Therefore, the developed WQI_{min} model offers a cost-effective and economical alternative for frequent water quality monitoring in the LRB. This is because the model reduces the number of parameters to five key parameters. Therefore, this model will aid in understanding challenges linked to inter-basin transfer and support the formulation of management strategies prioritizing water availability and ecosystem and livelihood sustainability.

Therefore, the findings establish crucial baseline data for potential inter-basin water transfers. This provides a detailed understanding of the current water quality in the LRB and offers a reference point against which future changes can be measured. This baseline is essential for assessing the impacts of water transfers on both the LRB and the KRB, ensuring that the transfers do not degrade water quality or disrupt ecosystems. It also helps in making informed decisions on the suitability of water for various uses, such as drinking, irrigation and industrial processes, in the context of water management.

6.2 Recommendations

The study recommends:

- The implementation of inter-basin water transfer to the KRB because water in the LRB has an average WQI rating of 38 per cent (good) and 58 per cent of the sampling had excellent water;
- Implementation of strategies to mitigate the impact of anthropogenic activities on water quality by WARMA and ZEMA, especially in areas with elevated levels of coliforms, iron, turbidity, sodium and chloride;
- Regular water quality monitoring using cost-effective methods such as the WQI_{min} model by WARMA in both basins; and
- Future studies to develop hydrological models to predict the quality of water in the LRB and the KRB after the implementation of inter-basin water transfer. This can aid in predicting the transport of pollutants and assessing the potential implications of inter-basin water transfer on the water quality.

REFERENCES

Abanyie, S.K., Ampadu, B., Frimpong, N.A., Yahans Amuah, E.E., 2023. Impact of improved water supply on livelihood and health: Emphasis on Doba and Nayagnia, Ghana. Innovation and Green Development 2, 100033. https://doi.org/10.1016/j.igd.2023.100033

Adelagun, R.O.A., Etim, E.E., Godwin, O.E., Adelagun, R.O.A., Etim, E.E., Godwin, O.E., 2021. Application of water quality index for the assessment of water from different sources in Nigeria, in promising techniques for wastewater treatment and water quality assessment. IntechOpen. https://doi.org/10.5772/intechopen.98696. 20p.

AfDB, 2013. Strategic Environmental and Social Assessment (SESA) - Strengthening Climate Resilience in The Kafue Basin project (SCRIKA) [WWW Document]. URL https://www.afdb.org/sites/default/files/documents/environmental-and-social-assessments/zambia_-_strengthening_climate_resilience_in_the_kafue_basin_-_executive_sesa_summary.pdf (accessed 6.1.22). 24p.

Afiukwa, J., Afiukwa, C., Oti, W., 2012. Determination of calcium, magnesium and total hardness concentrations in drinking water supply in Ebonyi State, Nigeria. Continental J. Water, Air and Soil Pollution 3. https://doi.org/10.5707/cjwasp.2012.3.1.12.16. 5p.

Al-Mashagbah, A.F., 2015. Assessment of surface water quality of King Abdullah Canal, using physico-chemical characteristics and water quality index, Jordan. JWARP 07, pp. 339–352. https://doi.org/10.4236/jwarp.2015.74027

American Public Health Association, American Water Works Association, Water Environment Federation, 2017. Standard methods for the examination of water and wastewater. 23rd edition. American Public Health Association, 800 I Streat, NW, Washington, DC, America. 1504 p.

Arora, P., 2017. Physical, chemical and biological characteristics of water. https://www.researchgate.net/publication/322419790_Physical_Chemical_and_Biological_Characteristics_of_Water_e_Content_Module. 17p.

Avigliano, E. & Schenone, N., 2016. Water quality in the Atlantic Rainforest Mountain Rivers (South America): quality indices assessment, nutrients distribution and consumption effect. Environmental Science and Pollution Research. 23 (15), pp. 15063-15075. 10.1007/s11356-016-6646-9.

Azhari, H.E., Cherif, E.K., Sarti, O., Azzirgue, E.M., Darak, H., Yachou, H., Esteves da Silva, J.C.G., Salmoun, F., 2022. Assessment of surface water quality using the Water Quality Index (IWQ), Multivariate Statistical Analysis (MSA) and Geographic Information System (GIS) in Oued Laou Mediterranean Watershed, Morocco. Water 2023, 15, 130. https://doi.org/10.3390/ w15010130. 34p.

Banda, K., Mulema, M., Chomba, I., Chomba, M., Levy, J., Nyambe, I., 2023(a). Investigating groundwater and surface water interactions using remote sensing, hydrochemistry and stable isotopes in the Barotse Floodplain, Zambia. Geology, Ecology and Landscapes, pp. 1–16. https://doi.org/10.1080/24749508.2023.2202450.

Banda, K., Ngwenya, V., Mulema, M., Chomba, I., Chomba, M., Nyambe, I., 2023. Influence of water quality on benthic macroinvertebrates in a groundwater-dependent wetland. Front. Water 5, 1177724. https://doi.org/10.3389/frwa.2023.1177724. 11p.

Banda, T.D., Kumarasamy, M.V., 2020. Development of Water Quality Indices (WQIs): A review. Polish journal of environmental studies. 29, 2011–2021. https://doi.org/10.15244/pjoes/110526. 12p.

Banerjee, P., Prasad, B., 2020. Determination of concentration of total sodium and potassium in surface and groundwater using a flame photometer. Appl Water Sci 10, pp. 113-120. https://doi.org/10.1007/s13201-020-01188-1

Bäumle, R., El-Fahem, T., Karen, M., 2018. Hydrogeological map of Zambia 1:1,500,000 [WWW Document]. URL https://www.deutscher-rohstoffeffizienz-preis.de/EN/Themen/Wasser/Projekte/abgeschlossen/TZ/Zambia/map_hygeo_zambia.pdf;jsessionid=2AF0DAF379263DE3062FE102C197291C.internet001?__blob=publicationFile&v=3 (accessed 12.16.23).

Borthakur, A. and Singh, P., 2020. Sustainability science: below and above the ground per the United Nation's sustainable development goals. Climate Change and Soil Interactions, pp. 453–471. https://doi.org/10.1016/B978-0-12-818032-7.00017-5.

Bortoletto, E. C., Silva, H. A., Bonifácio, C. M. & Tavares, C. R. G., 2015. Water quality monitoring of the Pirapó River Watershed, Paraná, Brazil. Brazilian Journal of Biology 75 (4), pp. 148–177. http://dx.doi.org/10.1590/1519-6984.00313suppl.

Britannica, 2023. Intertropical convergence zone (ITCZ) [WWW Document]. URL https://www.britannica.com/science/intertropical-convergence-zone (accessed 11.7.23).

Britannica, 2024. Water scarcity | Description, Mechanisms, Effects, & Solutions | Britannica [WWW Document]. URL https://www.britannica.com/topic/water-scarcity (accessed 8.10.24).

Browder, G., Ozment, S., Bescos, I.R., Gartner, T., Lange, G.-M., 2019. Integrating green and grey: Creating next generation infrastructure. Washington, DC: World Bank and World Resources Institute. https://openknowledge.worldbank.org/handle/10986/31430. 140p.

Brown, R.M., McClelland, N.I., Deininger, R.A., & Tozer, R.G., 1970. Water quality index - do we dare? *Water Sewage Works*, 117 (10), pp. 339–343.

Bykowska-Derda, A., Spychala, M., Czlapka-Matyasik, M., Sojka, M., Bykowski, J., Ptak, M., 2023. The Relationship between Mortality from Cardiovascular Diseases and Total Drinking Water Hardness: Systematic Review with Meta-Analysis. Foods 12, 3255. 12p. https://doi.org/10.3390/foods12173255.

Campbell, B., 2022. Manganese in Drinking Water: What It Is, How It Gets There, and More [WWW Document]. WaterWorld. URL https://www.waterworld.com/residential-commercial/article/14306308/manganese-in-drinking-water-what-it-is-how-it-gets-there-and-more (accessed 8.15.24).

Chomba, M.J. and Nkhata B.A. (2016) Water Security on the Kafue Flats of Zambia. Technical Report of the International Water Security Network, Water Research Node, Monash South Africa, Johannesburg. 39p.

Climate Technology Centre & Network (CTCN), 2016. Inter-basin transfers | Document]. URL https://www.ctc-n.org/technologies/inter-basin-transfers (accessed 9.20.23). The Climate Technology Centre and Network (CTCN), UN City, Marmorvej 51, 2100 Copenhagen, Denmark.

Costanzo, S., Kelsey, H., Mbewe, J., Chivava, F., Mwale, C., Katiyo, L., Mwanza, O., 2020. Lower Kafue River Report Card – Methodology Report. World Wildlife Fund, Washington, D.C., United States. 30p.

Cude, C. (2001) Oregon Water Quality Index: A Tool for Evaluating Water Quality Management Effectiveness. Journal of the American Water Resources Association, 37, pp. 125-137. http://dx.doi.org/10.1111/j.1752-1688.2001.tb05480.x

Damania, R., Desbureaux, S., Rodella, A.-S., Russ, J., Zaveri, E., 2019. Quality Unknown: The Invisible Water Crisis. Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-1459-4. 142p.

Dvorak, B., Schuerman, B., 2021. Drinking Water: Iron and Manganese. G1714: Natural Resources, Water Management**.** [WWW Document]. URL https://extensionpublications.unl.edu/assets/html/g1714/build/g1714.htm (accessed 11.27.23).

Falkenmark, M., Rockström, J., 2013. Balancing water for humans and nature: The new approach in ecohydrology. Earthscan. 10.4324/9781849770521, pp. 74-89.

FAO, 2017. Water for Sustainable Food and Agriculture: A report produced for the G20 Presidency of Germany. Food and Agriculture Organization of the United Nations, Rome. 33p.

FAO, 2021. Report prepared for the aquaculture for local community development programme https://www.fao.org/3/ac987e/AC987E09.htm.

Fathi, E., Zamani-Ahmadmahmoodi, R. & Zare-Bidaki, R., 2018. Water quality evaluation using water quality index and multivariate methods, Beheshtabad River, Iran. Applied Water Science 8 (210), pp. 1–6. https://doi.org/10.1007/s13201018-0859-7.

Gao, Y., Yu, M., 2018. Assessment of the economic impact of South-to-North Water Diversion Project on industrial sectors in Beijing. Economic Structures 7, 4. https://doi.org/10.1186/s40008-018-0104-4. 17p.

Gibbs, R.J., 1970. Mechanisms controlling world water chemistry. Science, New Series 170, pp. 1088–1090.

Gleick, P.H., 2014. Water, Drought, Climate Change and Conflict in Syria. Weather, Climate and Society 6, pp. 331–340. https://doi.org/10.1175/WCAS-D-13-00059.1

Gurung, P., 2015. Inter-basin Water Transfer: Is this a Solution for Water Scarcity? 23p. https://doi.org/10.13140/RG.2.1.3592.5607

Haas, L.J.M., Mazzei, L., O'Leary, D., 2010. Lesotho highlands water project: communication practices for governance and sustainability improvement, World Bank Working Papers. The World Bank. 60p. https://doi.org/10.1596/978-0-8213-8415-2

Hong, Y., Zhu, Z., Liao, W., Yan, Z., Feng, C., Xu, D., 2023. Freshwater Water-Quality Criteria for Chloride and Guidance for the Revision of the Water-Quality Standard in China. Int J Environ Res Public Health 20, 11p. https://doi.org/10.3390/ijerph20042875

Horton, R.K., 1965. An index number system for rating water quality. J Water Pollution Control Fed, pp. 300-306. https://doi.org/10.1080/07900627.2010.488853

Hsieh, N.-H., Chung, S.-H., Chen, S.-C., Chen, W.-Y., Cheng, Y.-H., Lin, Y.-J., You, S.-H., Liao, C.-M., 2017. Anemia risk in relation to lead exposure in lead-related manufacturing. BMC Public Health 17, 389. https://doi.org/10.1186/s12889-017-4315-7

HydroATLAS-Zambia, 2023. HydroATLAS-Zambia [WWW Document]. HydroATLAS-Zambia. URL https://hydroatlas-zambia.weebly.com/ (accessed 8.15.24).

International Council on Mining and Metals (ICMM), International Finance Corporation (IFC), 2017. Shared Water, Shared Responsibility, Shared Approach: Water in the Mining Sector [WWW Document]. URL https://www.icmm.com/website/publications/pdfs/environmental-stewardship/2017/research_shared-water-shared-responsibility.pdf (accessed 2.7.24). 48p.

ISO 5667-3, 2012. International Standard: ISO 5667-3:2012(E). Fourth edition. ISO copyright office, Case postale 56, CH-1211 Geneva, Switzerland. Tel. + 41 22 749 01 11 Fax + 41 22 749 09 47 E-mail copyright@iso.org Web www.iso.org. 50p.

Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B.B., Beeregowda, K.N., 2014. Toxicity, mechanism and health effects of some heavy metals. Interdiscip Toxicol 7, pp. 60–72. https://doi.org/10.2478/intox-2014-0009

Japan International Cooperation (JICA) Agency, 2014. Preparatory survey report on the project for groundwater development in Luapula Province phase 3 in the republic of Zambia. 42p.

Karwowska, M., Kononiuk, A., 2020. Nitrates/Nitrites in Food—Risk for Nitrosative Stress and Benefits. Antioxidants (Basel) 9, 241. https://doi.org/10.3390/antiox9030241. 17p.

Kozacek, C., 2015. Zambia electricity shortage highlights Africa’s hydropower shortfalls [WWW Document]. Circle of Blue. URL https://www.circleofblue.org/2015/world/zambia-electricity-shortage-highlights-africas-hydropower-shortfalls/ (accessed 11.27.23).

Křibek, B., Majer, V., Knésl, I., Nyambe, I., Mihaljevič, M., Ettler, V., Sracek, O., 2014. Concentrations of arsenic, copper, cobalt, lead and zinc in cassava (Manihot esculenta Crantz) growing on uncontaminated and contaminated soils of the Zambian Copperbelt. Journal of African Earth Sciences, Special Volume of the 24th Colloquium of African Geology 99, 713–723. https://doi.org/10.1016/j.jafrearsci.2014.02.009

Křibek, B., Nyambe, I., Sracek, O., Mihaljevič, M., Knésl, I., 2023. Impact of Mining and Ore Processing on Soil, Drainage and Vegetation in the Zambian Copperbelt Mining Districts: A Review. Minerals 13, 384, 40p. https://doi.org/10.3390/min13030384

Kumamaru, K., 2019. A Comparative Assessment of Communal Water Supply and Self Supply Models for Sustainable Rural Water Supplies: A Case Study of Luapula, Zambia. PhD Thesis, Loughborough University. 357p.

Kwambana, G.K., 2022. Water Quality Index in the Upper Vaal River Catchment. Masters' Thesis, University of the Witwatersrand, Johannesburg. 89p.

Laassilia, O., Ouazar, D., Bouziane, A., Hasnaoui, M.D., 2021. Justification criteria for Inter-Basin Water Transfer Projects. E3S Web Conf. 314, 06001. https://doi.org/10.1051/e3sconf/202131406001. 6p.

Lesimple, A., Ahmed, F.E., Hilal, N., 2020. Remineralization of desalinated water: Methods and environmental impact. Desalination 496, 114692. https://doi.org/10.1016/j.desal.2020.114692

Li, J. and Heap, A.D., 2011. A Review of Comparative Studies of Spatial Interpolation Methods in Environmental Sciences: Performance and Impact Factors. Ecological Informatics, 6, pp. 228-241. https://doi.org/10.1016/j.ecoinf.2010.12.003

Luapula Provincial Administration, 2022. About Luapula – Luapula Province Administration. URL https://www.lua.gov.zm/?page_id=1637 (accessed 11.27.23).

Lweya, C., Jessen, S., Banda, K., Nyambe, I., Koch, C.B., Larsen, F., 2015. Groundwater transport of Cu in laterites in Zambia. Applied Geochemistry 56, 94–102. https://doi.org/10.1016/j.apgeochem.2015.02.002

Maluleke, L., 2024. Water, water everywhere but Zambia is water insecure. Good Governance Africa. URL https://ggamall.azurewebsites.net/water-water-everywhere-but-zambia-is-water-insecure/ (accessed 8.10.24).

Mansfield, J E., Bennett, J G., King, D M., Lawton R M., 1975. Land resources of the Northern and Luapula provinces, Zambia – a reconnaissance assessment, Volume 1. Land Resources Division, Ministry of Overseas Development Tolworth Tower, Surbiton, Surrey KT6 7 DY, England. 64p.

Mataa, M., 2022. Assessment of river-groundwater interactions in the Barotse Floodplain, western, Zambia. Masters' Thesis. The University of Zambia, Lusaka. 142p.

Ministry of Energy and Water Development (MEWD), 2010. National Water Policy. Ministry of Energy and Water Development, Zambia. 53p.

Ministry of Finance and National Planning (MFNP), 2022. 8th National Development Plan: Socio-economic transformation for improved livelihoods. Ministry of Finance and National Planning P O Box 50062 Lusaka, ZAMBIA Tel: +260-211-252395. 105p.

Ministry of Water Development, Sanitation and Environmental Protection (MWDSEP), 2019. National Rural Water Supply and Sanitation Programme (NRWSSP) 2019 – 2030. Ministry of Water Development, Sanitation and Environmental Protection, Lusaka, Zambia. 112p.

Molekoa, M.D., Avtar, R., Kumar, P., Thu Minh, H.V., Dasgupta, R., Johnson, B.A., Sahu, N., Verma, R.L., Yunus, A.P., 2021. Spatio-temporal analysis of surface water quality in Mokopane Area, Limpopo, South Africa. Water 2021, 13, 220. https://doi.org/10.3390/w13020220. 15p.

Mwaba, K., 2019. Water Pollution in Zambia. Texila International Journal of Public Health 94–98. https://doi.org/10.21522/TIJPH.2013.SE.19.02.Art015

Mwandira, W., Nakashima, K., Kawasaki, S., Arabelo, A., Banda, K., Nyambe, I., Chirwa, M., Ito, M., Sato, T., Igarashi, T., Nakata, H., Nakayama, S., Ishizuka, M., 2020. Biosorption of Pb (II) and Zn (II) from aqueous solution by Oceanobacillus profundus isolated from an abandoned mine. Sci Rep 10, 21189. https://doi.org/10.1038/s41598-020-78187-4. 9p.

New York State Department of Health (NYSDH), 2023. Coliform Bacteria in Drinking Water Supplies. [WWW Document]. URL https://www.health.ny.gov/environmental/water/drinking/coliform_bacteria.htm (accessed 11.27.23).

Ngoma, H., Hamududu, B.H., 2019. Impacts of climate change on water availability in Zambia: implications for irrigation development. Department of Agricultural, Food and Resource

Economics, Michigan State University, Justin S. Morrill Hall of Agriculture, 446 West Circle Dr., Room 202, East Lansing, Michigan 48824, USA. 41.N.), pp. 96-105, Biodiversity & Ecology, 6, Klaus Hess Publishers, Göttingen & Windhoek. doi:10.7809/b-e.00310

Nguvulu, A., Shane, A., Mwale, C.S., Tena, T.M., Mwaanga, P., Siame, J., Chirambo, B., Lungu, M., Mudenda, F., Mwelwa, D., Chinyanta, S., Kawala, J., Bowa, V.M., Mutambo, L.S., Okello, N., Musonda, C., 2021. Surface Water Quality Response to Land Use Land Cover Change in an Urbanizing Catchment: A Case of Upper Chongwe River Catchment, Zambia. JGIS 13, pp. 578–602. https://doi.org/10.4236/jgis.2021.135032

Nong, X., Shao, D., Zhong, H., Liang, J., 2020. Evaluation of water quality in the South-to-North Water Diversion Project of China using the water quality index (WQI) method. Water Research 178, 115781. 15p. https://doi.org/10.1016/j.watres.2020.115781

Nyambe, I., Chabala, A., Banda, K., Zimba, H. & Phiri, W. (2018) Determinants of spatio-temporal variability of water quality in the Barotse Floodplain, western Zambia. In: Climate change and adaptive land management in southern Africa – assessments, changes, challenges and solutions (ed. by Revermann, R., Krewenka, K.M., Schmiedel, U., Olwoch, J.M., Helmschrot, J. & Jürgens, N.), pp. 96-105, Biodiversity & Ecology, 6, Klaus Hess Publishers, Göttingen & Windhoek. doi:10.7809/b-e.00310

Nyambe, I., Phiri, C., 2010. Database of mineral resources of Zambia. International workshop on UNFC-2009 Warsaw. 29p.

Nyoni, F., 2014. Carbon dynamics of two river systems in Zambia: A comparative study of the Zambezi and the Kafue rivers. Masters' thesis, The University of Zambia. 117p.

Paneerselvam, B., Kumar, P., Karuppannan, S., Ravichandran, N., Vijayasurya, K., 2020. Non-Carcinogenic Risk Assessment of Groundwater in the southern part of Salem District in Tamil Nadu, India. Journal of the Chilean Chemical Society 65, 4697. 12p. https://doi.org/10.4067/S0717-97072020000104697

Petrie, B., Petrik, D., Martin, L., Chapman, A., Davies, R., Blignaut, J.N. 2016. Strengthening Climate Resilience in the Kafue Sub-basin (SCRiKA) Project: Final Report. OneWorld Sustainable Investments, Cape Town, South Africa. 119p.

Piper, A.M, 1994. A graphic procedure in the geochemical interpretation of water analyses. Eos Trans. Am. Geophys. 25, pp. 914–928.

Prüss-Ustün, A., Bartram, J., Clasen, T., Colford, J.M., Cumming, O., Curtis, V., Bonjour, S., Dangour, A.D., De France, J., Fewtrell, L., Freeman, M.C., Gordon, B., Hunter, P.R., Johnston, R.B., Mathers, C., Mäusezahl, D., Medlicott, K., Neira, M., Stocks, M., Wolf, J., Cairncross, S., 2014. Burden of disease from inadequate water, sanitation and hygiene in low- and middle-income settings: a retrospective analysis of data from 145 countries. Trop Med Int Health 19, pp. 894–905. https://doi.org/10.1111/tmi.12329

Ram, A., Tiwari, S.K., Pandey, H.K., Chaurasia, A.K., Singh, S., Singh, Y.V., 2021. Groundwater quality assessment using water quality index (WQI) under GIS framework. Appl Water Sci 11, 46. 20p. https://doi.org/10.1007/s13201-021-01376-7

ReliefWeb, 2024. UNICEF Zambia Flash Update (Cholera) - 07 March 2024 [WWW Document]. URL https://reliefweb.int/report/zambia/unicef-zambia-flash-update-cholera-07-march-2024 (accessed 8.10.24).

Savage, M., Mujica, A., Chiappe, F., Ross, I., 2015. Climate finance and water security. Oxford Policy Management Limited, 6 St Aldates Courtyard Tel +44 (0) 1865 207 300 38 St Aldates Fax +44 (0) 1865 207 301 Oxford OX1 1BN Email admin@opml.co.uk Registered in England: 3122495 United Kingdom Website www.opml.co.uk 30. 30p.

Shil, S., Singh, U. K. & Mehta, P., 2019. Water quality assessment of a tropical river using water quality index (WQI), multivariate statistical techniques and GIS. Applied Water Science 9 (168), pp. 1–21. https://doi.org/10.1007/s13201-019-1045-2

Sinha, P., Rollason, E., Bracken, L.J., Wainwright, J. and Reaney, S.M., 2020. A new framework for integrated, holistic and transparent evaluation of inter-basin water transfer schemes. Science of The Total Environment, 721, p.137646. 64p.

Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL), 2017. Data and Information Portal [WWW Document]. URL http://data.sasscal.org/metadata/view.php?view=geodata&id=5722 (accessed 11.29.23).

Sracek, Ondra & Křibek, Bohdan & Mihaljevič, Martin & Majer, Vladimir & Veselovský, František & Vencelides, Zbynek & Nyambe, Imasiku. (2012). Mining-related contamination of surface water and sediments of the Kafue River drainage system in the Copperbelt district, Zambia: An example of a high neutralisation capacity system. Fuel and Energy Abstracts. 112. 10.1016/j.gexplo.2011.08.007, pp. 174-188.

Syeed, M.M.M., Hossain, M.S., Karim, M.R., Uddin, M.F., Hasan, M., Khan, R.H., 2023. Surface water quality profiling using the water quality index, pollution index and statistical methods: A critical review. Environmental and Sustainability Indicators 18, 100247. https://doi.org/10.1016/j.indic.2023.100247

Takam, X.T., Kalaba, F.K., Nyirenda, V.R., 2024. Temporal Analysis of Surface Water Quality Trends in Zambia's Solwezi Mining District (preprint). SSRN. https://doi.org/10.2139/ssrn.4707111. 21p.

UNICEF, WHO, 2019. https://www.who.int/news/item/18-06-2019-1-in-3-people-globally-do-not-have-access-to-safe-drinking-water-unicef-who .

United Nations Industrial Development Organization, 2018. Industrial Development Report 2018: Demand for Manufacturing - Driving Inclusive and Sustainable Industrial Development, Industrial Development Report. UN. https://doi.org/10.18356/b0cad365-en. 274p.

United Nations (UN), n.d. THE 17 GOALS | Sustainable Development [WWW Document]. URL https://sdgs.un.org/goals (accessed 11.15.24).

United States Geological Survey (USGS), 2018. Water Quality Information by Topic [WWW Document]. URL https://www.usgs.gov/special-topics/water-science-school/science/water-quality-information-topic#overview (accessed 10.12.23).

UN-Water, 2018. Progress on ambient water quality: Piloting the monitoring methodology and initial findings for SDG 6 indicator 6.3.2 [WWW Document]. URL https://www.unwater.org/sites/default/files/app/uploads/2018/12/SDG6_Indicator_Report_632_Progress-on-Ambient-Water-Quality_ENGLISH_2018-1.pdf (accessed 11.22.23). 60p.

UN-Water, 2018. Progress on level of water stress: Global baseline for SDG indicator 6.4.2 [WWW Document]. URL https://www.unwater.org/sites/default/files/app/uploads/2018/08/642-progress-on-level-of-water-stress-2018.pdf (accessed 11.7.23). 60p.

UN-Water, 2019. UN-Water Annual Report. UN-Water 7 bis, Avenue de la Paix, 1202 Geneva, Switzerland Tel: +41 22 730 8636 Email: unwater@un.org Web: www.unwater.org. 38p.

Wang, A., Duncan, S.E., Dietrich, A.M., 2016. Effect of iron on taste perception and emotional response of sweetened beverage under different water conditions. Food Quality and Preference 54, pp. 58–66. https://doi.org/10.1016/j.foodqual.2016.06.016

Water Resources Management Authority (WARMA), 2022. Kafue Catchment. Accessed on the 1st of June 2022. https://www.warma.org.zm/catchments-zambia/kafue-catchment-2/.

Water Resources Management Authority (WARMA), 2022. Luapula Catchment. Accessed on the 1st of June 2022. https://www.warma.org.zm/catchments-zambia/lapula-catchment/.

Wilson, M., Li, X.-Y., Ma, Y.-J., Smith, A., Wu, J., 2017. A Review of the Economic, Social, and Environmental Impacts of China's South–North Water Transfer Project: A Sustainability Perspective. Sustainability 9, 1489. https://doi.org/10.3390/su9081489. 11p.

Winton, R.S., Kleinschroth, F., Calamita, E., Botter, M., Teodoru, C.R., Nyambe, I., Wehrli, B., 2020. Potential of aquatic weeds to improve water quality in natural waterways of the Zambezi catchment. Sci Rep 10, 15467. https://doi.org/10.1038/s41598-020-72499-1

World Bank, 2019. Climate-Smart Agriculture in Zambia [WWW Document]. URL https://climateknowledgeportal.worldbank.org/sites/default/files/2019-06/CSA%20_Profile_Zambia.pdf (accessed 11.7.23). 25p.

World Bank, 2020. Zambia Water Supply and Sanitation Sector Diagnostic. World Bank, Washington, DC. https://doi.org/10.1596/34067. 64p.

World Health Organisation (WHO), 2011. Guidelines for drinking-water quality - 4th ed. Regional Office for the Eastern Mediterranean. Eastern Mediterranean Health Journal; 22, 564p.

World Health Organisation (WHO), 2017. Guidelines for drinking-water quality: fourth edition incorporating the first addendum. World Health Organisation, Geneva. 631p.

World Health Organisation (WHO), 2022. Compendium of WHO and other UN guidance on health and environment. 2022 update. Geneva: World Health Organisation; 2022 (WHO/HEP/ECH/EHD/22.01). Licence: CC BY-NC-SA 3.0 IGO. 200p.

Wu, L., Bai, T., Huang, Q., 2020. Tradeoff analysis between economic and ecological benefits of the inter basin water transfer project under changing environment and its operation rules. Journal of Cleaner Production 248, p119294. https://doi.org/10.1016/j.jclepro.2019.119294.

Wu, T., Wang, S., Su, B., Wu, H., Wang, G., 2021. Understanding the water quality change of the Yilong Lake based on comprehensive assessment methods. Ecological Indicators 126, 107714. 9p. https://doi.org/10.1016/j.ecolind.2021.107714

Wu, Z., Lai, X., Li, K., 2021. Water quality assessment of rivers in Lake Chaohu Basin (China) using water quality index. Ecological Indicators 121, 107021. 8p. https://doi.org/10.1016/j.ecolind.2020.107021

WWF, 2016. Water in the Zambian economy: Exploring shared risks and opportunities in the Kafue Flats. WWF-World Wide Fund for Nature (Formerly World Wildlife Fund), Zambia. 64p.

WWF, 2018. Water Situational Analysis of the Lower Kafue Basin. Socio-Economic Development and Climate Change: Risks and Opportunities. WWF-World Wide Fund for Nature (Formerly World Wildlife Fund), Zambia. 48p.

WWF, 2021. Why Protecting the Kafue Flats is a big deal for Zambia [WWW Document]. URL https://africa.panda.org/?34542/Kafue-flats-big-deal-for-Zambia (accessed 11.20.23).

Xu, W., Duan, L., Wen, X., Li, H., Li, D., Zhang, Y., Zhang, H., 2022. Effects of Seasonal Variation on Water Quality Parameters and Eutrophication in Lake Yangzong. Water 14, 2732. 18p. https://doi.org/10.3390/w14172732

Ye, X., Zhou, Y., Lu, Y., Du, X., 2022. Hydrochemical Evolution and Quality Assessment of Groundwater in the Sanjiang Plain, China. Water 14, 16p. https://doi.org/10.3390/w14081265

Zambia Bureau of Standards (ZABS), 2010. Drinking water quality-specification. ZS 190. First revision. Zambia Bureau of Standards, Lechwe House, Freedom Way South-end P.O. Box 50259. 14p.

Zambia Bureau of Standards (ZABS), 2021. Ambient Water Quality – Specifications. ZS 1182: 2021 ICS 13.060.10. First edition. Zambia Bureau of Standards, Lechwe House, Freedom Way South-end P.O. Box 50259. 31p.

Zambia Bureau of Standards, 2021. Ambient Water Quality – Guidelines. ZS 1182: 2021 ICS 13.060.10. First edition. Zambia Bureau of Standards, Lechwe House, Freedom Way South-end P.O. Box 50259. 45p.

Zambia Statistics Agency, 2022. 2022 Census of population and housing preliminary report. Zambia Statistics Agency, Corner Nationalist/John Mbita Roads P O Box 31908 Lusaka, Zambia. 39p.

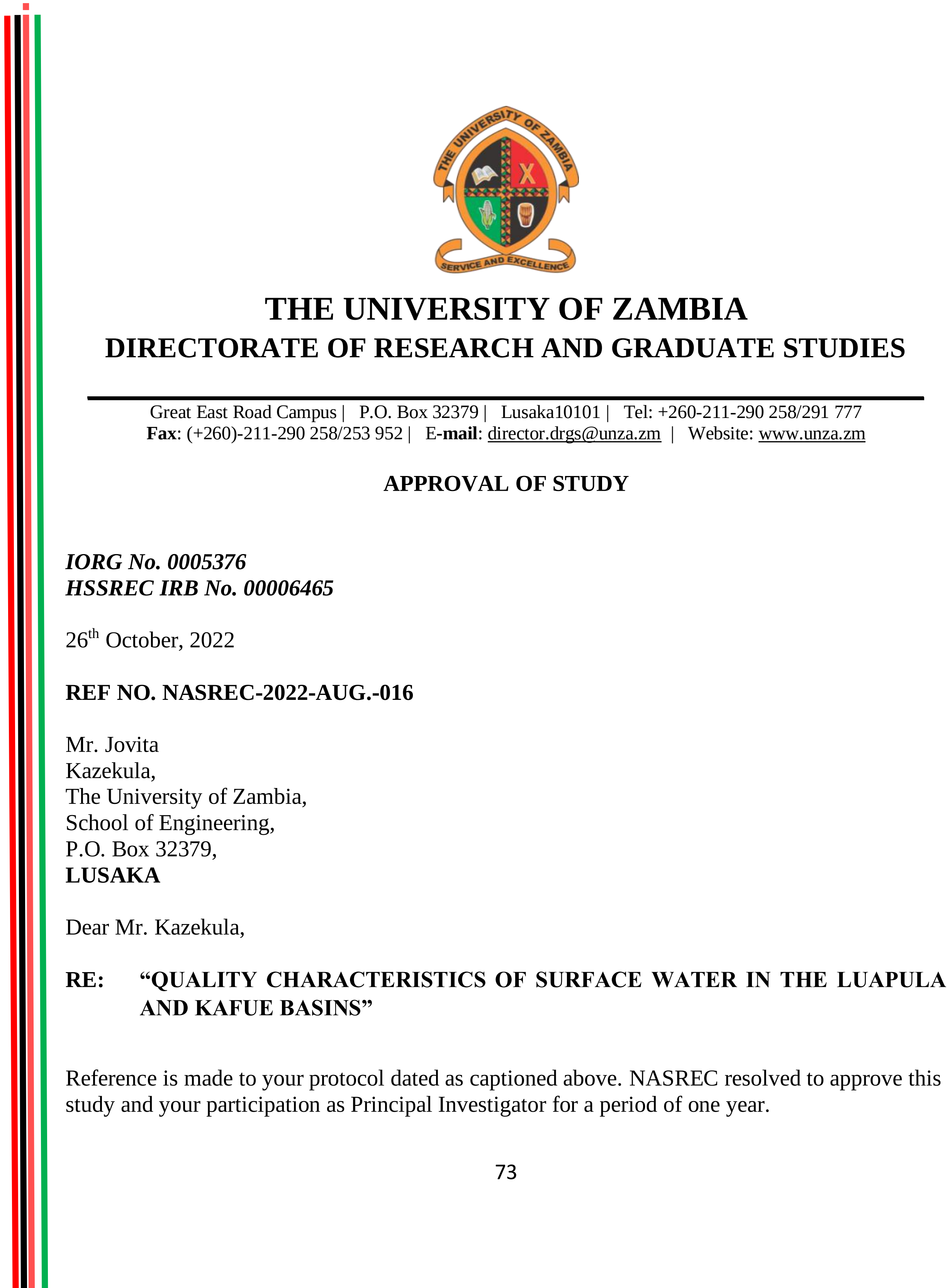
Zambia Statistics Agency, Ministry of Health (MOH) and ICF, 2019. Zambia Demographic and Health Survey 2018. Lusaka, Zambia and Rockville, Maryland, USA: Zambia Statistics Agency, Ministry of Health and ICF. 581p.

ZESCO Limited [WWW Document], n.d. URL https://www.zesco.co.zm/generation.php (accessed 12.7.23).

Zhang, C., Duan, Q., J.-F. Yeh, P., Pan, Y., Gong, H., Moradkhani, H., Gong, W., Lei, X., Liao, W., Xu, L., Huang, Z., Zheng, L., Guo, X., 2021. Sub-regional groundwater storage recovery in North China Plain after the South-to-North water diversion project. Journal of Hydrology 597, 126156. 38p. https://doi.org/10.1016/j.jhydrol.2021.1261

APPENDICES

Appendix 1: Letter of approval of study and ethical clearance.



THE UNIVERSITY OF ZAMBIA
DIRECTORATE OF RESEARCH AND GRADUATE STUDIES

Great East Road Campus | P.O. Box 32379 | Lusaka10101 | Tel: +260-211-290 258/291 777
Fax: (+260)-211-290 258/253 952 | E-**mail**: director.drgs@unza.zm | Website: www.unza.zm

APPROVAL OF STUDY

IORG No. 0005376
HSSREC IRB No. 00006465

26th October, 2022

REF NO. NASREC-2022-AUG.-016

Mr. Jovita
Kazekula,
The University of Zambia,
School of Engineering,
P.O. Box 32379,
LUSAKA

Dear Mr. Kazekula,

RE: “QUALITY CHARACTERISTICS OF SURFACE WATER IN THE LUAPULA AND KAFUE BASINS”

Reference is made to your protocol dated as captioned above. NASREC resolved to approve this study and your participation as Principal Investigator for a period of one year.

REVIEW TYPE	**ORDINARY REVIEW**	**APPROVAL NO.** **NASREC-2022-AUG.-016**
Approval and Expiry Date	Approval Date: 26th October,, 2022	Expiry Date: 25th October, 2023
Protocol Version and Date	Version - Nil.	25th October, , 2023
Information Sheet, Consent Forms and Dates	• English.	To be provided
Consent form ID and Date	Version - Nil	To be provided
Recruitment Materials	Nil	Nil
Other Study Documents	Questionnaire.	

Specific conditions will apply to this approval. As Principal Investigator it is your responsibility to ensure that the contents of this letter are adhered to. If these are not adhered to, the approval may be suspended. Should the study be suspended, study sponsors and other regulatory authorities will be informed.

CONDITIONS OF APPROVAL

- No participant may be involved in any study procedure prior to the study approval or after the expiration date.
- All unanticipated or Serious Adverse Events (SAEs) must be reported to NASREC within 5 days.
- All protocol modifications must be approved by NASREC prior to implementation unless they are intended to reduce risk (but must still be reported for approval). Modifications will include any change of investigator/s or site address.
- All protocol deviations must be reported to NASREC within 5 working days.
- All recruitment materials must be approved by NASREC prior to being used.
- Principal investigators are responsible for initiating Continuing Review proceedings. NASREC will only approve a study for a period of 12 months.
- It is the responsibility of the PI to renew his/her ethics approval through a renewal application to NASREC.
- Where the PI desires to extend the study after expiry of the study period, documents for study extension must be received by NASREC at least 30 days before the expiry date. This is for the purpose of facilitating the review process. Documents received within 30 days after expiry will be labelled “late submissions” and will incur a penaltyfee of K500.00. No study shall be renewed whose documents are submitted for renewal 30 days after expiry of the certificate.
- Every 6 (six) months a progress report form supplied by The University of Zambia Natural and Applied Sciences Research Ethics Committee as an IRB must be filled in and submitted to us. There is a penalty of K500.00 for failure to submit the report.

- When closing a project, the PI is responsible for notifying, in writing or using the Research Ethics and Management Online (REMO), both NASREC

- and the National Health Research Authority (NHRA) when ethics certification is no longer required for a project.

- In order to close an approved study, a Closing Report must be submitted in writing or through the REMO system. A Closing Report should be filed when data collection has ended and the study team will no longer be using human participants or animals or secondary data or have any direct or indirect contact with the research participants or animals for the study.

- Filing a closing report (rather than just letting your approval lapse) is important as it assists NASREC in efficiently tracking and reporting on projects. Note that some funding agencies and sponsors require a notice of closure from the IRB which had approved the study and can only be generated after the Closing Report has been filed.

- A reprint of this letter shall be done at a fee.

- All protocol modifications must be approved by NASREC by way of an application for an amendment prior to implementation unless they are intended to reduce risk (but must still be reported for approval). Modifications will include any change of investigator/s or site address or methodology and methods. Many modifications entail minimal risk adjustments to a protocol and/or consent form and can be made on an Expedited basis (via the IRB Chair). Some examples are: format changes, correcting spelling errors, adding key personnel, minor changes to questionnaires, recruiting and changes, and so forth. Other, more substantive changes, especially those that may alter the risk-benefit ratio, may require Full Board review. In all cases, except where noted above regarding subject safety, any changes to any protocol document or procedure must first be approved by NASREC before they can be implemented.

Should you have any questions regarding anything indicated in this letter, please do not hesitate to get in touch with us at the above indicated address.

On behalf of NASREC, we would like to wish you all the success as you carry out your study.

Yours faithfully,

Dr. Mususu Kaonda

VICE-CHAIRPERSON
THE UNIVERSITY OF ZAMBIA NATURAL AND APPLIED SCIENCES RESEARCH ETHICS COMMITTEE - IRB

cc: Director, Directorate of Research and Graduate Studies
Assistant Director (Research), Directorate of Research and Graduate Studies
Assistant Registrar (Research), Directorate of Research and Graduate Studies

Appendix 2: Conversion of major cations and anions to meq/l and calculation of HCO_3 in the LRB, Zambia.

Ca (mg/L)	K (mg/L)	Na (mg/L)	SO4 (mg/L)	Cl (mg/L)	Na (meq/l)	Mg (meq/l)	Ca (meq/l)	K (meq/l)	Cations	SO4 (meq/l)	Cl (meq/l)	Anions			HCO_3 (mg/L)
					22.99	12.15	20.04	39.1		16.03	35.45	Sum	HCO_3 (meq/l)	Total	0.02
8	2.83	8.58	<0.01	13	0.37	0.40	0.40	0.07	1.24	0.00	0.37	0.37	0.87	1.24	53.26
8	3.27	9.9	<0.01	15	0.43	0.40	0.40	0.08	1.31	0.00	0.42	0.42	0.89	1.31	54.00
2.4	1.96	5.94	<0.01	9	0.26	1.07	0.12	0.05	1.49	0.00	0.25	0.25	1.24	1.49	75.71
4	2.18	6.6	<0.01	10	0.29	0.32	0.20	0.06	0.86	0.00	0.28	0.28	0.58	0.86	35.15
4	3.28	9.93	<0.01	15	0.43	0.67	0.20	0.08	1.39	0.00	0.42	0.42	0.96	1.39	58.79
12	2.19	6.64	<0.01	10	0.29	1.46	0.60	0.06	2.41	0.00	0.28	0.28	2.12	2.41	129.54
5.6	3.27	9.9	<0.01	15	0.43	0.36	0.28	0.08	1.15	0.00	0.42	0.42	0.73	1.15	44.29
6.4	2.6	7.89	<0.01	12	0.34	0.32	0.32	0.07	1.05	0.00	0.34	0.34	0.71	1.05	43.10
4	2.18	6.6	<0.01	10	0.29	0.36	0.20	0.06	0.90	0.00	0.28	0.28	0.62	0.90	37.56
5.6	2.61	7.92	<0.01	12	0.34	0.36	0.28	0.07	1.05	0.00	0.34	0.34	0.71	1.05	43.17
6.4	2.18	6.6	<0.01	10	0.29	0.47	0.32	0.06	1.14	0.00	0.28	0.28	0.85	1.14	52.10
8	2.83	8.51	<0.01	13	0.37	0.16	0.40	0.07	1.00	0.00	0.37	0.37	0.63	1.00	38.61
4.8	2.38	7.22	<0.01	11	0.31	1.86	0.24	0.06	2.47	0.00	0.31	0.31	2.16	2.47	131.83
11.2	3.27	9.9	<0.01	15	0.43	0.55	0.56	0.08	1.63	0.00	0.42	0.42	1.20	1.63	73.39
12	2.2	6.68	<0.01	10	0.29	0.32	0.60	0.06	1.26	0.00	0.28	0.28	0.98	1.26	59.75
12	2.18	6.6	<0.01	10	0.29	0.08	0.60	0.06	1.02	0.00	0.28	0.28	0.74	1.02	45.05
7.2	2.31	7	<0.01	10	0.30	0.63	0.36	0.06	1.35	0.00	0.28	0.28	1.07	1.35	65.44
4.8	3.28	9.94	<0.01	15	0.43	0.36	0.24	0.08	1.11	0.00	0.42	0.42	0.69	1.11	41.97
5.6	3.27	9.9	<0.01	15	0.43	0.12	0.28	0.08	0.91	0.00	0.42	0.42	0.49	0.91	29.82
6.4	2.18	6.6	<0.01	10	0.29	0.08	0.32	0.06	0.74	0.00	0.28	0.28	0.46	0.74	28.00
7.2	3.27	9.92	<0.01	15	0.43	0.04	0.36	0.08	0.91	0.00	0.42	0.42	0.49	0.91	29.93
5.6	1.74	5.28	<0.01	8	0.23	0.32	0.28	0.04	0.87	0.00	0.23	0.23	0.64	0.87	39.27
10.4	2.17	6.57	<0.01	10	0.29	0.08	0.52	0.06	0.94	0.00	0.28	0.28	0.66	0.94	40.08
8	11.98	36.3	<0.01	55	1.58	0.28	0.40	0.31	2.56	0.00	1.55	1.55	1.01	2.56	61.58
5.6	2.61	7.92	<0.01	12	0.34	0.24	0.28	0.07	0.93	0.00	0.34	0.34	0.59	0.93	35.93
5.6	1.74	5.28	<0.01	8	0.23	0.12	0.28	0.04	0.67	0.00	0.23	0.23	0.45	0.67	27.22
8	3.27	9.9	<0.01	15	0.43	0.59	0.40	0.08	1.51	0.00	0.42	0.42	1.08	1.51	66.06
5.6	2.2	6.66	<0.01	10	0.29	0.12	0.28	0.06	0.74	0.00	0.28	0.28	0.46	0.74	28.16

Appendix 3: Data for the 2022 dry season in the LRB, Zambia.

No.	Symbol	Date	Time	EC (µs/cm)	pH	Temp. (C)	TDS (mg/L)	Calcium hardness (mg CaCO3/l)	Total hardness (mg CaCO3/l)	Mg (mg/L)	Ca (mg/L)	K (mg/L)	Na (mg/L)	NO_3 (mg/L)	PO_4 (mg/L)	SO_4 (mg/L)	Cl (mg/L)	Turbidity (NTU)	Total coliforms (CFU/100ml)	Faecal coliforms (CFU/100ml)	Fe (mg/L)	Mn (mg/L)	Pb (mg/L)
1	JK001	23/09/2022	10:50	79	6.73	22.1	55	20	40	4.8	8	2.83	8.58	<0.01	<0.01	<0.01	13	2.98	5	0	0.582	<0.002	<0.01
2	JK002	23/09/2022	14:55	90	7.18	20.2	65	20	40	4.8	8	3.27	9.9	<0.01	<0.01	<0.01	15	12	21	10	1.092	<0.002	<0.01
3	JK003	23/09/2022	16:35	67	7.02	18.6	50	6	60	13	2.4	1.96	5.94	<0.01	<0.01	<0.01	9	11.2	35	10	0.938	<0.002	<0.01
4	JK004	24/09/2022	10:15	27	6.36	18.5	20	10	26	3.84	4	2.18	6.6	<0.01	<0.01	<0.01	10	12.7	0	0	2.234	<0.002	<0.01
5	JK005	24/09/2022	12:28	86	6.85	23	58	10	44	8.16	4	3.28	9.93	<0.01	<0.01	<0.01	15	6.85	74	50	0.296	<0.002	<0.01
6	JK006	24/09/2022	13:45	225	7.35	19.8	162	30	104	17.8	12	2.19	6.64	<0.01	<0.01	<0.01	10	19.2	0	0	0.82	<0.002	<0.01
7	JK007	24/09/2022	16:01	51	7.38	20.1	37	14	32	4.32	5.6	3.27	9.9	<0.01	<0.01	<0.01	15	9.13	0	0	0.58	<0.002	<0.01
8	JK008	25/09/2022	11:13	25	6.79	23.6	17	16	32	3.84	6.4	2.6	7.89	<0.01	<0.01	<0.01	12	7.49	0	0	0.031	<0.002	<0.01
9	JK009	25/09/2022	13:23	28	7.21	24.8	18	10	28	4.32	4	2.18	6.6	<0.01	<0.01	<0.01	10	14.8	64	50	0.242	<0.002	<0.01
10	JK010	26/09/2022	14:34	39	7.46	25.6	25	14	32	4.32	5.6	2.61	7.92	<0.01	<0.01	<0.01	12	2.8	42	20	0.106	<0.002	<0.01
11	JK011	26/09/2022	16:14	36	7.46	20.6	26	16	40	5.76	6.4	2.18	6.6	<0.01	<0.01	<0.01	10	8.82	0	0	0.225	<0.002	<0.01
12	JK012	26/09/2022	17:03	40	6.79	20.8	28	20	28	1.92	8	2.83	8.51	<0.01	<0.01	<0.01	13	9.23	0	0	0.485	<0.002	<0.01
13	JK015	27/09/2022	11:33	26	7.06	24.3	17	12	106	22.6	4.8	2.38	7.22	<0.01	<0.01	<0.01	11	5.4	30	14	0.095	<0.002	<0.01
14	JK016	27/09/2022	13:06	60	7.87	26.4	66	28	56	6.72	11.2	3.27	9.9	<0.01	<0.01	<0.01	15	6.84	0	0	0.102	<0.002	<0.01
15	JK017	27/09/2022	13:58	109	8.03	26.1	69	30	46	3.84	12	2.2	6.68	<0.01	<0.01	<0.01	10	4.13	0	0	0.11	<0.002	<0.01
16	JK018	28/09/2022	16:06	66	8.05	26.7	40	30	34	0.96	12	2.18	6.6	<0.01	<0.01	<0.01	10	6.61	35	10	0.073	<0.002	<0.01

Appendix 3, cont.: Data for the 2022 dry season in the LRB, Zambia.

No.	Symbol	Date	Time	EC (μs/cm)	pH	Temp. (C)	TDS (mg/L)	Calcium hardness (mg CaCO3/l)	Total hardness (mg CaCO3/l)	Mg (mg/L)	Ca (mg/L)	K (mg/L)	Na (mg/L)	NO$_3$ (mg/L)	PO$_4$ (mg/L)	SO$_4$ (mg/L)	Cl (mg/L)	Turbidity (NTU)	Total coliforms (CFU/100ml)	Faecal coliforms (CFU/100ml)	Fe (mg/L)	Mn (mg/L)	Pb (mg/L)
17	JK019	28/09/2022	17:22	101	7.34	26.4	64	18	50	7.68	7.2	2.31	7	<0.01	<0.01	<0.01	10	5.29	0	0	0.046	<0.002	<0.01
18	JK020	29/09/2022	09:38	22	6.21	22.5	15	12	30	4.32	4.8	3.28	9.94	<0.01	<0.01	<0.01	15	9.65	40	15	1.973	<0.002	<0.01
19	JK021	29/09/2022	10:37	8	6.19	22.6	5	14	20	1.44	5.6	3.27	9.9	<0.01	<0.01	<0.01	15	6.77	0	0	0.538	<0.002	<0.01
20	JK022	29/09/2022	11:42	19	6.71	23	13	16	20	0.96	6.4	2.18	6.6	<0.01	<0.01	<0.01	10	12.6	58	30	0.246	<0.002	<0.01
21	JK023	06/10/2022	07:15	27	6.36	22	18	18	20	0.48	7.2	3.27	9.92	<0.01	<0.01	<0.01	15	6.34	64	35	0.151	<0.002	<0.01
22	MC14	Oct-22	–	14	6.68	23.6	9	14	30	3.84	5.6	1.74	5.28	<0.01	<0.01	<0.01	8	12.4	0	0	0.623	<0.002	<0.01
23	MC15	Oct-22	–	25	6.73	23.9	16	26	30	0.96	10.4	2.17	6.57	<0.01	<0.01	<0.01	10	37.2	TNTC	TNTC	0.018	<0.002	<0.01
24	MC16	Oct-22	–	18	6.82	24.5	12	20	34	3.36	8	12	36.3	<0.01	<0.01	<0.01	55	1.83	12	20	0.436	<0.002	<0.01
25	MC17	Oct-22	–	19	6.49	23.4	13	14	26	2.88	5.6	2.61	7.92	<0.01	<0.01	<0.01	12	8.36	32	44	0.177	<0.002	<0.01
26	MC18	Oct-22	–	25	6.9	24.9	16	14	20	1.44	5.6	1.74	5.28	<0.01	<0.01	<0.01	8	4.24	0	0	0.121	<0.002	<0.01
27	MC19	Oct-22	–	26	7.19	25	16	20	50	7.2	8	3.27	9.9	<0.01	<0.01	<0.01	15	1.39	0	0	0.031	<0.002	<0.01
28	MC20	Oct-22	–	26	7.26	26.9	17	14	20	1.44	5.6	2.2	6.66	<0.01	<0.01	<0.01	10	2.84	0	0	<0.002	<0.002	<0.01
29	R2-1	Nov-22	–	28	6.71	25	18	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	1.9	0	0	<0.002	<0.002	<0.01
30	R2-2	Nov-22	–	29	7.26	27.7	18	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	1.9	0	0	<0.002	<0.002	<0.01
31	R2-3	Nov-22	–	27	7.14	24.9	17	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	2.4	TNTC	TNTC	<0.002	<0.002	<0.01
32	R2-4	Nov-22	–	26	7.17	25.1	17	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	2.1	60	20	<0.002	<0.002	<0.01
33	R2-5	Nov-22	–	26	7.31	25.1	17	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	1.4	95	80	<0.002	<0.002	<0.01
34	R2-6	Nov-22	–	27	7.36	26.6	17	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	2.6	85	50	<0.002	<0.002	<0.01
35	R2-7	Nov-22	–	27	7.36	26.6	17	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	2.67	TNTC	TNTC	<0.002	<0.002	<0.01
36	R2-8-1	Nov-22	–	27	7.52	25.5	18	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	3.2	TNTC	TNTC	<0.002	<0.002	<0.01

Appendix 3, cont.: Data for the 2022 dry season in the LRB, Zambia.

No.	Symbol	Date	Time	EC (µs/cm)	pH	Temp. (C)	TDS (mg/L)	Calcium hardness (mg CaCO3/l)	Total hardness (mg CaCO3/l)	Mg (mg/L)	Ca (mg/L)	K (mg/L)	Na (mg/L)	NO_3 (mg/L)	PO_4 (mg/L)	SO_4 (mg/L)	Cl (mg/L)	Turbidity (NTU)	Total coliforms (CFU/100ml)	Faecal coliforms (CFU/100ml)	Fe (mg/L)	Mn (mg/L)	Pb (mg/L)
37	R2-8-2	Nov-22	–	27	7.62	25.4	17	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	4	TNTC	TNTC	<0.002	<0.002	<0.01
38	R2-9	Nov-22	–	27	7.71	25.3	18	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	3.7	70	58	<0.002	<0.002	<0.01
39	R2-10	Nov-22	–	28	7.05	25.1	18	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	3.5	50	20	0.187	<0.002	<0.01
40	R2-11	Nov-22	–	24	6.92	24.4	16	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	1.8	TNTC	TNTC	0.226	<0.002	<0.01
41	R2-12	Nov-22	–	24	6.98	23.3	16	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	4.7	102	85	0.053	<0.002	<0.01
42	R2-13	Nov-22	–	25	6.6	24.6	17	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	11.4	88	65	0.154	<0.002	<0.01
43	R2-14	Nov-22	–	28	6.78	24.8	20	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	4.64	90	50	0.083	<0.002	<0.01
44	R2-15	Nov-22	–	26	8.4	26.4	17	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	11.6	TNTC	TNTC	<0.002	<0.002	<0.01
45	R2-16	Nov-22	–	27	8.08	26.8	17	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	4.62	TNTC	TNTC	<0.002	<0.002	<0.01
46	R2-17	Nov-22	–	25	7.43	24.9	16	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	3	85	65	<0.002	<0.002	<0.01
47	R2-18	Nov-22	–	26	7.73	24.5	17	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	1.74	0	0	<0.002	<0.002	<0.01
48	R2-19	Nov-22	–	27	7.65	25	17	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	6.8	78	48	0.034	<0.002	<0.01
49	R2-20	Nov-22	–	27	8.03	26.6	17	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	5.1	58	30	<0.002	<0.002	<0.01
50	R2-21	Nov-22	–	27	7.63	26.5	17	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	2.41	20	0	<0.002	<0.002	<0.01
51	R2-22	Nov-22	–	26	7.76	24.7	17	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	3.49	0	0	<0.002	<0.002	<0.01
52	R2-23	Nov-22	–	27	7.81	26.7	17	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	4.7	62	40	<0.002	<0.002	<0.01
53	R2-24	Nov-22	–	27	7.86	27	17	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	6.9	75	50	0.019	<0.002	<0.01
54	R2-25	Nov-22	–	26	7.67	25.8	17	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	3.4	0	0	<0.002	<0.002	<0.01
55	R2-26	Nov-22	–	26	7.3	26.1	17	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	3.2	TNTC	TNTC	<0.002	<0.002	<0.01
56	R2-27	Nov-22	–	27	7.8	26	17	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	3.11	0	0	0.074	<0.002	<0.01
57	R2-28	Nov-22	–	40	7.15	28.1	25	<1	<1	<0.1	<0.1	_	_	<0.01	<0.01	<0.01	_	10.41	TNTC	TNTC	0.214	<0.002	<0.01

Appendix 4: Data for the 2023 wet season in the LRB, Zambia.

No.	Symbol	Temp. (C)	pH	EC (µs/cm)	TDS (mg/L)	Calcium hardness (mgCaCO3/l)	Total hardness (mg CaCO3/l)	Mg (mg/L)	Ca (mg/L)	K (mg/L)	NO$_3$ (mg/L)	PO$_4$ (mg/L)	SO$_4$ (mg/L)	Cl (mg/L)	Turbidity (NTU)	Total coliforms (CFU/100ml)	Faecal coliforms (CFU/100ml)	Fe (mg/L)	Mn (mg/L)	Pb (mg/L)
1	SH001	_	_	_	_	<1	<1	<0.1	<0.1	0.451	<0.01	<0.01	<0.01	2	8.87	0	0	0.183	<0.002	<0.01
2	Mweru	25.7	8.08	68	44	<1	<1	<0.1	<0.1	_	<0.01	<0.01	<0.01	2	1.46	0	0	_	_	_
3	Mweru	25.7	8.08	68	44	<1	<1	<0.1	<0.1	_	<0.01	<0.01	<0.01	_	_	_	_	_	_	_
4	Mweru	27.4	7.84	75	46	<1	<1	<0.1	<0.1	_	<0.01	<0.01	<0.01	_	_	_	_	_	_	_
5	Mweru	27.8	8.04	74	46	<1	<1	<0.1	<0.1	_	<0.01	<0.01	<0.01	_	_	_	_	_	_	_
6	Mweru	27.7	7.97	72	45	<1	<1	<0.1	<0.1	_	<0.01	<0.01	<0.01	_	_	_	_	_	_	_
7	Mweru	27.4	8.14	70	44	<1	<1	<0.1	<0.1	_	<0.01	<0.01	<0.01	_	_	_	_	_	_	_
8	Mweru	26.8	7.84	65	41	<1	<1	<0.1	<0.1	_	<0.01	<0.01	<0.01	_	_	_	_	_	_	_
9	Mweru	27.4	7.74	65	40	<1	<1	<0.1	<0.1	_	<0.01	<0.01	<0.01	_	_	_	_	_	_	_
10	Mweru	26.1	8	71	45	<1	<1	<0.1	<0.1	_	<0.01	<0.01	<0.01	_	_	_	_	_	_	_
11	SH002	26.2	8.12	78	49	<1	<1	<0.1	<0.1	0.253	<0.01	<0.01	<0.01	3	1	0	0	<0.002	<0.002	<0.01
12	SH003	26.2	8.12	78	49	<1	<1	<0.1	<0.1	0.505	<0.01	<0.01	<0.01	9	0.65	60	85	0.301	<0.002	<0.01
13	Mbereshi	25.8	8.01	72	50	<1	<1	<0.1	<0.1	_	<0.01	<0.01	<0.01	_	_	_	_	_	_	_
14	SH005	25.8	7.9	78	50	<1	<1	<0.1	<0.1	0.81	<0.01	<0.01	<0.01	12	1.39	120	140	0.8	<0.002	<0.01
15	SH006	24.8	6.09	11	7	<1	<1	<0.1	<0.1		<0.01	<0.01	<0.01	9	10.4	24	45	_	_	_
16	SH007	26.9	6.27	20	12	<1	<1	<0.1	<0.1	0.331	<0.01	<0.01	<0.01	11	12.8	50	88	0.415	<0.002	<0.01
17	SH008	25.9	6.14	11	7	<1	<1	<0.1	<0.1	_	<0.01	<0.01	<0.01	_	_	_	_	_	_	_
18	SH009	23.9	5.97	8	5	<1	<1	<0.1	<0.1	0.726	<0.01	<0.01	<0.01	14	8.62	4	10	0.417	<0.002	<0.01
19	SH011	23.5	6.07	6	4	<1	<1	<0.1	<0.1	0.481	<0.01	<0.01	<0.01	10	1.78	0	0	<0.002	<0.002	<0.01
20	Musonda	23.6	6.8	13	9	<1	<1	<0.1	<0.1	_	<0.01	<0.01	<0.01	_	_	_	_	_	_	_
21	SH035	24.4	6.66	29	10	<1	<1	<0.1	<0.1	_	<0.01	<0.01	<0.01	_	_	_	_	_	_	_
22	WS1	26.6	7.29	60	38	<1	<1	<0.1	<0.1	0.7663	<0.01	<0.01	<0.01	4	0.34	5	12	<0.002	<0.002	<0.01
24	SH010	26.9	7.28	19	12	<1	<1	<0.1	<0.1	0.573	<0.01	<0.01	<0.01	8	1.39	80	102	0.138	<0.002	<0.01
25	SH013	25.4	6.95	23	15	<1	<1	<0.1	<0.1	1.401	<0.01	<0.01	<0.01	13	2.28	20	50	0.843	<0.002	<0.01
26	SH014	26.6	7.3	43	23	<1	<1	<0.1	<0.1	1.662	<0.01	<0.01	<0.01	12	1.94	45	68	0.491	<0.002	<0.01
27	SH015	27.7	7.5	30	19	<1	<1	<0.1	<0.1	1.531	<0.01	<0.01	<0.01	12	13.4	78	90	0.021	<0.002	<0.01
28	WS2	22.8	7.37	21	21	<1	<1	<0.1	<0.1	0.993	<0.01	<0.01	<0.01	3	0.7	80	110	<0.002	<0.002	<0.01
23	SH012	26.2	7.2	50	2	<1	<1	<0.1	<0.1	2.401	<0.01	<0.01	<0.01	14	2.03	0	0	1.03	<0.002	<0.01

Appendix 4, cont.: Data for the 2023 wet season in the LRB, Zambia.

No.	Symbol	Temp. (C)	pH	EC (µs/cm)	TDS (mg/L)	Calcium hardness (mgCaCO3/l)	Total hardness (mg CaCO3/l)	Mg (mg/L)	Ca (mg/L)	K (mg/L)	NO_3 (mg/L)	PO_4 (mg/L)	SO_4 (mg/L)	Cl (mg/L)	Turbidity (NTU)	Total coliforms (CFU/100ml)	Faecal coliforms (CFU/100ml)	Fe (mg/L)	Mn (mg/L)	Pb (mg/L)
29	SH020	23.1	7.14	32	21	<1	<1	<0.1	<0.1	0.677	<0.01	<0.01	<0.01	4	2.14	20	50	0.25	<0.002	<0.01
30	SH016	22.4	7.11	25	17	<1	<1	<0.1	<0.1	0.334	<0.01	<0.01	<0.01	2	2.36	0	0	0.444	<0.002	<0.01
31	WS14	24.7	7.9	23	15	<1	<1	<0.1	<0.1	0.7471	<0.01	<0.01	<0.01	5	1.18	0	0	<0.002	<0.002	<0.01
32	WS15	22.4	7.11	25	17	<1	<1	<0.1	<0.1	0.8389	<0.01	<0.01	<0.01	6	1.78	0	0	<0.002	<0.002	<0.01
33	WS16	24.5	7.69	22	15	<1	<1	<0.1	<0.1	0.902	<0.01	<0.01	<0.01	5	1.68	120	TNTC	<0.002	<0.002	<0.01
34	WS17	26.6	7.75	14	9	<1	<1	<0.1	<0.1	0.844	<0.01	<0.01	<0.01	6	1.74	0	0	<0.002	<0.002	<0.01
35	WS18	24.7	7.9	23	7.9	<1	<1	<0.1	<0.1	0.8449	<0.01	<0.01	<0.01	5	1.93	40	50	<0.002	<0.002	<0.01
36	WS19	24.6	7.91	22	14	<1	<1	<0.1	<0.1	0.8473	<0.01	<0.01	<0.01	5	1.86	60	75	<0.002	<0.002	<0.01
37	WS20	24.5	7.69	22	15	<1	<1	<0.1	<0.1	0.844	<0.01	<0.01	<0.01	7	1.7	0	0	<0.002	<0.002	<0.01
38	WS21	24.9	8.23	22	15	<1	<1	<0.1	<0.1	0.8176	<0.01	<0.01	<0.01	6	1.93	14	20	<0.002	<0.002	<0.01
39	WS22	25.6	8.04	23	15	<1	<1	<0.1	<0.1	0.9281	<0.01	<0.01	<0.01	6	1.57	190	TNTC	<0.002	<0.002	<0.01
40	WS23	25.7	7.83	23	15	<1	<1	<0.1	<0.1	0.878	<0.01	<0.01	<0.01	7	1.46	44	55	<0.002	<0.002	<0.01
41	WS25	26.6	7.85	24	15	<1	<1	<0.1	<0.1	0.289	<0.01	<0.01	<0.01	4	1.02	80	90	<0.002	<0.002	<0.01
42	WS28	26.7	7.98	23	15	<1	<1	<0.1	<0.1	0.9141	<0.01	<0.01	<0.01	7	4.13	10	30	<0.002	<0.002	<0.01
43	WS34	25.8	8.04	24	15	<1	<1	<0.1	<0.1	0.8326	<0.01	<0.01	<0.01	7	1.6	0	0	<0.002	<0.002	<0.01
44	Mukuku	27.7	6.89	21	13	<1	<1	<0.1	<0.1	_	<0.01	<0.01	<0.01	_	_	_	_	_	_	_
45	Tuta	24.6	7.47	23	15	<1	<1	<0.1	<0.1	_	<0.01	<0.01	<0.01	_	_	_	_	_	_	_
46	SH027	24	7.7	23	15	<1	<1	<0.1	<0.1	0.872	<0.01	<0.01	<0.01	3	2.51	60	70	<0.002	<0.002	<0.01
47	SH028	_	_	_	_	<1	<1	<0.1	<0.1	0.503	<0.01	<0.01	<0.01	3	6.19	10	20	0.045	<0.002	<0.01
48	SH029	27	7.33	40	25	<1	<1	<0.1	<0.1	0.775	<0.01	<0.01	<0.01	_	_	_	_	1.375	<0.002	<0.01
49	SH030	28.8	7.41	34	21	<1	<1	<0.1	<0.1	0.607	<0.01	<0.01	<0.01	_	_	_	_	<0.002	<0.002	<0.01
50	SH031	27	6.98	22	14	<1	<1	<0.1	<0.1	0.234	<0.01	<0.01	<0.01	3	2.27	40	70	0.095	<0.002	<0.01
51	SH032	21.3	7.55	31	22	<1	<1	<0.1	<0.1	<0.01	<0.01	<0.01	<0.01	4	6.41	0	0	0.007	<0.002	<0.01
52	SH033	23	7.22	25	17	<1	<1	<0.1	<0.1	0.825	<0.01	<0.01	<0.01	4	6.15	60	85	0.71	<0.002	<0.01
53	SH024	20.8	7.16	15	10	<1	<1	<0.1	<0.1	0.632	<0.01	<0.01	<0.01	14	1.53	5	10	0.117	<0.002	<0.01
54	SH025	21	7.57	46.9	33	<1	<1	<0.1	<0.1	0.329	<0.01	<0.01	<0.01	12	1.45	8	14	<0.002	<0.002	<0.01
55	SH026	21.6	7.95	46.4	32	<1	<1	<0.1	<0.1	0.261	<0.01	<0.01	<0.01	10	1.26	6	10	<0.002	<0.002	<0.01
56	WS 3	21.8	7.68	35.8	25	<1	<1	<0.1	<0.1	1.1432	<0.01	<0.01	<0.01	4	0.88	TNTC	TNTC	<0.002	<0.002	<0.01
57	WS 4	26.4	7.85	27	17	<1	<1	<0.1	<0.1	1.1461	<0.01	<0.01	<0.01	5	0.86	0	0	<0.002	<0.002	<0.01
58	WS 5	26.6	7.75	40	9	<1	<1	<0.1	<0.1	0.3047	<0.01	<0.01	<0.01	4	0.38	6	10	<0.002	<0.002	<0.01
59	WS 6	26	7.5	13	9	<1	<1	<0.1	<0.1	0.286	<0.01	<0.01	<0.01	6	0.34	9	15	<0.002	<0.002	<0.01
60	WS 7	25.4	7.12	18	11	<1	<1	<0.1	<0.1	0.5211	<0.01	<0.01	<0.01	6	0.37	20	28	<0.002	_	_
61	WS 8	25.3	7.01	13	10	<1	<1	<0.1	<0.1	0.6034	<0.01	<0.01	<0.01	7	0.35	12	20	<0.002	_	_

Appendix 4, cont.: Data for the 2023 wet season in the LRB, Zambia.

No.	Symbol	Temp. (C)	pH	EC (μs/cm)	TDS (mg/L)	Calcium hardness (mgCaCO3/l)	Total hardness (mg CaCO3/l)	Mg (mg/L)	Ca (mg/L)	K (mg/L)	NO_3 (mg/L)	PO_4 (mg/L)	SO_4 (mg/L)	Cl (mg/L)	Turbidity (NTU)	Total coliforms (CFU/100ml)	Faecal coliforms (CFU/100ml)	Fe (mg/L)	Mn (mg/L)	Pb (mg/L)
62	WS 9	26.7	7.18	16	10	<1	<1	<0.1	<0.1	0.5459	<0.01	<0.01	<0.01	6	2.64	48	88	<0.002	_	_
63	WS 10	26.6	7.17	16	10	<1	<1	<0.1	<0.1	0.4494	<0.01	<0.01	<0.01	5	1.64	0	0	<0.002	_	_
64	WS 11	27.8	7.92	25	16	<1	<1	<0.1	<0.1	0.8848	<0.01	<0.01	<0.01	5	2.13	10	18	<0.002	_	_
65	WS 12	28.2	7.61	24	15	<1	<1	<0.1	<0.1	0.9021	<0.01	<0.01	<0.01	6	0.92	4	15	<0.002	_	_
66	WS 13	28	7.5	22	14	<1	<1	<0.1	<0.1	0.8395	<0.01	<0.01	<0.01	5	1.71	44	80	<0.002	_	_
67	WS 24	25.8	7.34	21	13	<1	<1	<0.1	<0.1	0.3822	<0.01	<0.01	<0.01	5	1.04	0	0	<0.002	_	_
68	WS 26	26	7.41	23	15	<1	<1	<0.1	<0.1	0.8186	<0.01	<0.01	<0.01	5	1.45	64	84	<0.002	_	_
69	WS 27	26.6	7.32	24	15	<1	<1	<0.1	<0.1	0.9112	<0.01	<0.01	<0.01	6	2.04	100	120	<0.002	_	_
70	WS 29	24.7	7.17	23	15	<1	<1	<0.1	<0.1	0.9314	<0.01	<0.01	<0.01	7	1.41	20	30	<0.002	_	_
71	WS 30	24.7	7.59	23	15	<1	<1	<0.1	<0.1	0.9545	<0.01	<0.01	<0.01	6	1.52	14	36	<0.002	_	_
72	WS 31	25.3	7.71	24	15	<1	<1	<0.1	<0.1	0.9599	<0.01	<0.01	<0.01	7	3.92	80	102	<0.002	_	_
73	WS 32	26.6	7.56	23	15	<1	<1	<0.1	<0.1	0.9439	<0.01	<0.01	<0.01	6	1.68	20	35	<0.002	_	_
74	WS 33	25	7.8	24	15	<1	<1	<0.1	<0.1	0.9454	<0.01	<0.01	<0.01	7	1.6	12	20	<0.002	_	_
75	WS 34	24.9	7.7	23	15	<1	<1	<0.1	<0.1	0.8326	<0.01	<0.01	<0.01	7	1.6	0	0	<0.002	_	_
76	WS 35	24.9	8.15	23	15	<1	<1	<0.1	<0.1	0.8332	<0.01	<0.01	<0.01	5	1.65	82	90	<0.002	_	_
77	WS 36	25.4	7.64	23	15	<1	<1	<0.1	<0.1	0.8748	<0.01	<0.01	<0.01	7	2.05	4	15	<0.002	_	_
78	WS 37	25.3	7.96	23	15	<1	<1	<0.1	<0.1	0.9114	<0.01	<0.01	<0.01	7	1.22	5	18	<0.002	_	_
79	WS 38	26.1	7.91	23	15	<1	<1	<0.1	<0.1	0.8704	<0.01	<0.01	<0.01	6	1.84	16	20	<0.002	_	_
80	WS 39	25.6	8.15	23	15	<1	<1	<0.1	<0.1	0.8326	<0.01	<0.01	<0.01	6	1.65	0	0	<0.002	_	_
81	WS 40	25.8	7.94	23	15	<1	<1	<0.1	<0.1	0.7075	<0.01	<0.01	<0.01	6	1.67	0	0	<0.002	_	_
82	WS 41	27	7.52	29	18	<1	<1	<0.1	<0.1	1.088	<0.01	<0.01	<0.01	7	8.55	55	75	<0.002	_	_
83	SH004	_	_	_	_	<1	<1	<0.1	<0.1	0.242	<0.01	<0.01	<0.01	5	1.34	50	68	0.765	_	_
84	SH018	_	_	_	_	<1	<1	<0.1	<0.1	0.221	<0.01	<0.01	<0.01	5	24.9	74	88	0.057	_	_
85	SH019	_	_	_	_	<1	<1	<0.1	<0.1	0.539	<0.01	<0.01	<0.01	7	2.59	60	75	1.006	_	_
86	LM 7	_	_	_	_	<1	<1	<0.1	<0.1	_	<0.01	<0.01	<0.01	14	1.17	4	12	_	_	_
87	MB 1	_	_	_	_	<1	<1	<0.1	<0.1	_	<0.01	<0.01	<0.01	12	2.11	6	12	_	_	_
88	Council	_	_	_	_	<1	<1	<0.1	<0.1	_	<0.01	<0.01	<0.01	12	1.89	28	50		_	_
89	SH021	_	_	_	_	<1	<1	<0.1	<0.1	1.131	<0.01	<0.01	<0.01	11	15.4	80	106	0.133	_	_
90	Marne	_	_	_	_	<1	<1	<0.1	<0.1	_	<0.01	<0.01	<0.01	12	1.53	64	88	_	_	_

Appendix 5: WQI ratings for each sampling point in the LRB, Zambia.

No.	Symbol	Name	District	WQI (%)	WQI
1	JK001	Musanfwe	Serenje	76	Very poor
2	JK002	Chisangwa		141	Unsafe
3	JK003	Chisangwa		121	Unsafe
4	JK004	Nkulumanshima Bridge	Chitambo	277	Unsafe
5	JK005	Lake Wasa		44	Good
6	JK006	Kasanka River		117	Unsafe
7	JK007	Mulembo		79	Very poor
8	JK008	Katansha Bridge	Samfya	13	Excellent
9	JK009	Luapula River		42	Good
10	JK010	Luapula River	Chembe	21	Excellent
11	JK011	Luwo		38	Good
12	JK012	Miyenge		67	Poor
13	JK015	Muongo River	Mansa	18	Excellent
14	JK016	Luapula River	Mwense	27	Good
15	JK017	Kasengo		28	Good
16	JK018	Lake Mweru Chimbofuma	Nchelenge	24	Excellent
17	JK019	Luapula River		16	Excellent
18	JK020	Nshinda		246	Unsafe
19	JK021	Mbereshi	Mwansabombwe	76	Very poor
20	JK022	Lufubu	Mansa	41	Good
21	JK023	Luapula River	Samfya	29	Good
22	MC14	Lake Chifunabuli		85	Very poor
23	MC15			30	Good
24	MC16			57	Poor
25	MC17			32	Good
26	MC18			21	Excellent
27	MC19			9	Excellent
28	MC20			7	Excellent
29	R2-1	Lake Bangweulu		6	Excellent
30	R2-2	Lake Bangweulu		7	Excellent
31	R2-3	Lake Bangweulu		7	Excellent
32	R2-4	Lake Bangweulu		6	Excellent
33	R2-5	Lake Bangweulu		6	Excellent
34	R2-6	Lake Bangweulu		8	Excellent
35	R2-7	Lake Bangweulu		9	Excellent
36	R2-8-1	Lake Bangweulu		10	Excellent
37	R2-8-2	Lake Bangweulu		12	Excellent
38	R2-9	Lake Bangweulu		11	Excellent
39	R2-10	Lake Bangweulu		28	Good
40	R2-11	Lake Bangweulu		33	Good
41	R2-12	Lake Bangweulu		12	Excellent
42	R2-13	Lake Bangweulu		31	Good
43	R2-14	Lake Bangweulu		17	Excellent
44	R2-15	Lake Bangweulu		22	Excellent
45	R2-16	Lake Bangweulu		15	Excellent
46	R2-17	Lake Bangweulu		8	Excellent
47	R2-18	Lake Bangweulu		9	Excellent
48	R2-19	Lake Bangweulu		16	Excellent
49	R2-20	Lake Bangweulu		14	Excellent
50	R2-21	Lake Bangweulu		9	Excellent
51	R2-22	Lake Bangweulu		11	Excellent
52	R2-23	Lake Bangweulu		12	Excellent
53	R2-24	Lake Bangweulu		16	Excellent
54	R2-25	Lake Bangweulu		10	Excellent
55	R2-26	Lake Bangweulu		9	Excellent
56	R2-27	Lake Bangweulu		20	Excellent
57	R2-28	Lake Bangweulu		37	Good