ASSESSMENT OF POTENTIAL HEALTH RISKS OF DOMESTIC WATER SOURCES IN MATATANI VILLAGE, LIMPOPO PROVINCE, SOUTH AFRICA

BY

NDOU PFUNZO

STUDENT NUMBER: 18004501

Supervisor: PROF R. MAKUNGO

Co – Supervisor: DR T.P. MALIMA

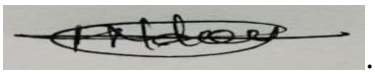
A dissertation submitted to the Department of Earth Science at the University of Venda in fulfillment of the requirements of the degree of Master of Earth Science in Hydrology and Water Resources

MARCH 2025

© University of Venda

DECLARATION

I, Ndou Pfunzo, 18004501 declare that this research dissertation is my original work and has not been submitted for any degree at any other university or institution. The dissertation does not contain another persons' writing unless specifically acknowledged and referenced accordingly.

Signed (Student): ..... Date: 21/03/2025... .

© University of Venda

DEDICATION

It is with sincere gratitude that I dedicate this work to my mother Ms Musiwalo Caroline Ndou and my whole family.

© University of Venda

ACKNOWLEDGEMENTS

I would like to begin by expressing my sincere gratitude to my supervisors, Prof. R. Makungo and Dr. T.P. Malima, for their patience and generosity. This work would not have been possible without your expert guidance and advice throughout the study. I am also immensely grateful to the Energy and Water Sector Education and Training Authority and the Water Research Commission for their funding and for providing me with the opportunity to learn.

I would like to express my heartfelt gratitude to my parents, Ms. M.C. Ndou and Mr. T.R. Musetsho, for their unwavering love, encouragement, and support. I am deeply thankful to my entire family for motivating me to reach this point, especially my grandmother, Mrs. T.M. Ndou, and my uncle, Mr. H.S. Ndou.

I am grateful to Ms. S.G. Mukwevho and Mrs. E. Tshivhase for their support throughout my studies. Lastly, I extend my appreciation to the chief of Matatani Village for granting me permission to conduct this research in his village, as well as to the community members, including Ms. R. Mutele, who assisted with my fieldwork, and the households that kindly allowed me to collect rainwater samples.

© University of Venda

ABSTRACT

Poor water quality is associated with adverse health outcomes worldwide. In many developing countries, access to clean and safe water remains limited, forcing individuals to depend on available water sources despite their poor quality. This study evaluated the potential human health risks associated with domestic water sources at Matatani Village, Limpopo Province, South Africa. Field observations were conducted to identify the available water sources and the potential contaminants present for each source. Water samples were collected during both wet and dry seasons from the primary sources used by the residents, including boreholes, springs, and a river. Rainwater samples from various roof types were also collected during the rainfall season. The physical parameters including pH, electrical conductivity (EC), and total dissolved solids (TDS) were measured using standardized multi-meter. Turbidity was measured using turbidity meter. Microbiological parameters such as total coliforms and *Escherichia coli* (*E.coli*) were analyzed using membrane filtration method. Metals such as sodium (Na), magnesium (Mg), potassium (K), iron (Fe), lead (Pb), manganese (Mn), cadmium (Cd), arsenic (As), aluminium (Al), copper (Cu) and zinc (Zn) were analyzed using inductively coupled plasma optical emission spectrophotometer (ICP-OES) . The non-metals such as chloride (Cl), fluoride (F), phosphate (PO_4) and sulphate (SO_4) were analyzed using the DR 3900 Laboratory spectrophotometer. Health risk assessment was conducted for non-carcinogenic and carcinogenic risk through ingestion based on the United States Environmental Protection Agency (USEPA) method. The pH for groundwater and river water was within the recommended guideline. The turbidity and TDS were above the guidelines for river and groundwater. For rainwater water, the EC and TDS were within the recommended guidelines while the turbidity was above the recommended guideline. The total coliform and *E.coli* were both above the recommended guidelines for the majority of the samples. Metals such as As, Mn, Cd, Pb, Zn, Mn, Al, and Fe were above the recommended guidelines for surface and groundwater and rainwater, respectively. They metals ranged from 0.60 to 6.88, 1.54 to 6.51, 0 to 16.61, 1.63 to 7.63, 1.54 to 10.59, 4.22 to 5.74, 0.36 to 7.86 for As, Mn, Cd, Pb, Zn, Mn, Al, and Fe, for all sources respectively. The presence of these metals in water sources can cause adverse effects on human health. Non-metals such as from 0.1 to 5.7 and 0 to 89 for F and SO4, they were within the recommended guidelines for groundwater, river water, and rainwater. The non-carcinogenic hazard index (HI) ranged from 4.20 to 18.3 for river and groundwater while it ranged from 0.52 to 3.11 for rainwater for both adults and children, respectively. The HI for river and groundwater was greater than 1 for children and adults indicating significant health risk. The HI for children only exceeded 1 for rainwater meaning that

© University of Venda

the children are at risk. The carcinogenic risk for Pb, Cd and As ranged between 0.09 to 4.26 and 0.09 to 0.96 for groundwater, river water, and rainwater for adults and children, respectively. Identified microbial health risks include nausea, vomiting, abdominal cramps, cholera and typhoid fever. These findings highlighted the severe risk of diseases for the residents of Matatani Village. They also confirmed that water in Matatani Village is unsafe for human use. It is recommended that residents have to use the sources of water such as municipal water which consistently show lower contamination levels and boil water before use to minimize contamination risk. Residents have to minimize pollution by implementing stricter regulations to reduce the discharge of various elements into the environment.

© University of Venda

University of Venda
Creating Future Leaders

TABLE OF CONTENTS

Contents

DECLARATION i
DEDICATION ii
ACKNOWLEDGEMENTS iii
ABSTRACT iv
LIST OF FIGURES x
LIST OF TABLES xii
LIST OF ABBREVIATIONS xiii
1.1 Background of the study 1
1.2 Statement of the problem 3
1.3 Motivation 4
1.4 Research objectives 5
1.4.1 Main objective 5
1.4.2 Specific objectives 5
1.5 Research questions 5
1.6 Characteristics of the study area 6
1.6.1 Location and hydrology 6
1.6.2 Climate of the study area 7
2.1 Preamble 8
2.2 Water quality status of rural areas 8
2.3 Potential sources of pollution/contamination in rural areas 9
2.4 Challenges of accessing safe drinking water in rural areas 11
2.5 Previous studies 11
2.6 Water quality parameters 15
2.6.1 Physical water quality parameters 15
2.6.2 Chemical water quality parameters 17
2.6.3 Microbiological parameters 21
2.7 Methods of analyzing microbial water quality parameters 22
2.8 Methods of analyzing chemical water quality parameters 23
2.9 Water quality indices (WQIs) 25
2.9.1 Types of WQIs 27

© University of Venda

2.10 Health risk assessment 32
2.11 Summary 33
CHAPTER THREE: METHODS AND MATERIALS 34
3.1 Preamble 34
3.2 Water pollutants related to domestic water supply 34
3.3 Water sampling 34
3.3.1 Samples quality control 36
3.4 Analysis of water quality parameters 36
3.4.1 Measurement of physical quality water parameters 36
3.4.2 Metals analysis 36
3.4.3 Non-metal analysis 37
3.5 Microbiological analysis 38
3.6 Determination of WQIs 39
3.7 Health risk assessment procedures 40
3.7.1 Non-carcinogenic risk assessment procedures 40
3.7.2 Carcinogenic risk ($CR_{ingestion}$) 41
3.8 Summary 42
CHAPTER 4: RESULTS AND DISSCUSSION 43
4.1 Preamble 43
4.2 Water sources available and identified potential pollutants 43
4.3 Water quality results for river water and groundwater 51
4.3.2 Microbiological water quality parameters 54
4.3.3 Chemical water quality parameters 56
4.4 Water quality results for rainwater 69
4.4.1 Physical water quality parameters 69
4.4.2 Chemical water quality parameters 71
4.5 Results on WQIs 78
4.6 Health risk assessment results 80
4.6.1 Non carcinogenic and microbial health risks 80
4.6.2 The carcinogenic and microbial health risks 83
4.7 Summary 86
CHAPTER 5: CONCLUSION AND RECOMMENDATIONS 88
5.1 Conclusion 88

© University of Venda

5.2 Recommendations 89
REFERENCES 90

© University of Venda

LIST OF APPENDICES

Appendix 1: Physical water quality parameters for the wet season 120

Appendix 2: Physical water quality parameters for the dry season..... 121

Appendix 3: Microbiological parameters for wet and dry season in cfu/100ml 121

Appendix 4: Non -metals concentrations for dry and wet seasons in mg/L 122

Appendix 5: Metals concentrations for wet season in mg/L 123

Appendix 6: Metals concentration for dry season in mg/L 124

Appendix 7: Metals concentration for dry season in mg/L 126

Appendix 8: Water quality index for river water and groundwatwer 127

Appendix 9: Water quality index for rainwater 130

Appendix 10: Non-carcinogenic risk estimations for groundwater, river water and rainwater 132

Appendix 11: Carcinogenic risk estimations for groundwater, river water and rainwater..... 136

Appendix 12: Concentrations of Fe, Cu, Zn, Pb, Al, Cd, Mn, As for all sources in both dry and wet seasons. 138

© University of Venda

LIST OF FIGURES

Figure 1.1: Map of the study area 6

Figure 3.1: Map of the sources of the study area 35

Figure 3.2: Roof types for rainwater harvesting 35

Figure 4.1: Functional water sources of the study area..... 43

Figure 4.2: Non-functional water sources of the study area 45

Figure 4.3: Identified roof types of rainwater 45

Figure 4.6: Washing and bathing area in the downstream point of Mutale 46

Figure 4.7: Potential contaminants for the spring 47

Figure 4.4: Potential water contaminants for the upstream point of Mutale River 47

Figure 4.5: Potential contaminants for the downstream point of Mutale River 48

Figure 4.8: Potential contaminats for BH2 49

Figure 4.9: Elevation maps for BH1 50

Figure 4.10: pH values for groundwater and river water 51

Figure 4.11: Turbidity values for groundwater and river water 53

Figure 4.12: EC values for groundwater and river water 53

Figure 4.13: TDS values for groundwater and river water 54

Figure 4.14: E.coli counts for groundwater and river water 55

Figure 4.15: Total coliform counts for groundwater and river water 56

Figure 4.16: Cu concentration for groundwater and river water 57

Figure 4.17: As concentrations for groundwater and river water 58

© University of Venda

Figure 4. 18: K concentrations for groundwater and river water 59

Figure 4.19: Al concentrations for groundwater and river water 59

Figure 4.20: Mg concentrations for groundwater and river water 60

Figure 4. 21: Na concentrations for groundwater and river water 61

Figure 4.22: Zn concentrations for groundwater and river water 62

Figure 4.23: Mn concentrations for groundwater and river 62

Figure 4. 24: Pb concentrations for groundwater and water 63

Figure 4.25: Cd concentrations for groundwater and river water 64

Figure 4. 26: Fe concentrations for groundwater and river water 65

Figure 4. 27: Ca concentrations for groundwater and river water 66

Figure 4. 28: Cl concentrations for groundwater and river water 67

Figure 4. 29: F concentrations for groundwater and river water 68

Figure 4. 30: SO_4 concentrations for groundwater and river water 68

Figure 4. 31: PO_4 concentrations in groundwater and river water 69

Figure 4.32: pH, TDS, EC and Turbidity values for rainwater 71

Figure 4.33: Mg, K, Ca, and Na concentrations for rainwater 73

Figure 4.34: Zn, Cu, Al and Fe concentrations for rainwater 74

Figure 4.35: As, Mn, Cd and Pb concentrations for rainwater 76

Figure 4.36: F, Cl, SO_4, PO_4 concentrations for rainwater 78

Figure 4.37: WQIs for groundwater and river water 79

Figure 4.38: WQIs for rainwater 80

© University of Venda

LIST OF TABLES

Table 2.1 NSFWQI rating of water quality.....27

Table 2.2: OWQI ratings of water quality.....29

Table 2.3: WAWQI for water quality 32

Table 3.1: Calibration standard solutions for non –metals……..…...38

Table 3.2: Adopted values for non-carcinogenic health risk assessment.....41

Table 4.1: Indicators of non-carcinogenic health risk assessment for groundwater and river water……..……83

Table 4.2: Indicators of non-carcinogenic health risk assessment for rainwater 83

Table 4.3 Indicators of carcinogenic health risk assessment for groundwater and river water ..85

Table 4.4: Indicators of carcinogenic health risk assessment for rainwater.....85

Table 4.5: Potential health risk for microbiological parameters in water sources 86

© University of Venda

University of Venda
Creating Future Leaders

LIST OF ABBREVIATIONS

AAS	Atomic Absorption spectrometry
ADD	Average daily dose
Al	Aluminium
As	Arsenic
BH1	Borehole 1
BH2	Borehole 2
BW	Body weight
Ca	Calcium
Cd	Cadmium
CFU	Colony Forming Unit
CSF	Cancer slope factor
Cl	Chloride
Cu	Copper
DI	Daily intake
DWAF	Department of Water Affairs and Forestry
E.Coli	Escherichia Coliform
EC	Electrical Conductivity
EPA	Environmental Protection Agency
Fe	Iron
Fl	Fluoride
HI	Hazard Index
HQ	Hazard quotient
IC	Iron Chromatography
IC-PMS	Inductively Coupled Plasma Mass Spectrometry
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometry
K	Potassium
Mg	Magnesium
Mn	Manganese
Na	Sodium
NSF	National Sanitation Foundation Water Quality Iindex
NO_3	Nitrate
NTU	Nephelometric Turbidity Unit

© University of Venda

OWQI	Oregon Water Quality Index
Pb	Lead
PO_4	Phosphate
RfD	Reference dose
SANS	South African National Standard
SO_4	Sulfate
TC	Total Coliform
TDS	Total dissolved solids
USEPA	United States of Environmental Protection Agency
WAWQI	Weighted Arithmetic Water Quality Index
WHO	World Health Organization

© University of Venda

CHAPTER 1: INTRODUCTION

1.1 Background of the study

The consumption of safe and uncontaminated water has been associated with improved health outcomes and enhanced well-being among households worldwide (WHO, 2004). Despite the rise in population size and access to clean and safe water, people still experience different avoidable health issues from consuming polluted water (Edokpayi *et al.*, 2018a). The utilization of untreated or insufficiently treated water remains a significant public health issue, posing ongoing risks to communities, leading to waterborne illnesses such as cholera, typhoid fever, cryptosporidiosis, poliomyelitis, and dysentery (Edokpayi *et al*., 2021). Water-related illnesses have persistently been the main contributor to increased mortality rates among children under the age of five worldwide (Adimalla and Qian, 2019). It is essential to mitigate the effects of diseases resulting from an insufficient water supply system. This can be done by ensuring that communities receive clean and reliable water for household use.

According to Ahmed *et al.* (2020a), the limited availability of freshwater resources constitutes a significant global issue, in areas characterized by arid and semi-arid climates experiencing the most severe impacts. In addition, this is driven by population growth, rising water pollution from human activities, and fluctuations in weather and climate conditions. Human and natural factors such as agricultural runoff, mining activities, sewage and wastewater discharge, soil erosion, and weathering of rocks have the potential to contribute to the elevation of contamination levels in freshwater sources (Strehmel *et a*l., 2016). Human activities, such as urban expansion, industrial development, and agricultural practices, have contributed to the degradation of water quality in rivers, streams, and dams. These activities introduce pollutants and disrupt natural processes, leading to contamination and environmental harm (Madilonga *et al*., 2021). In numerous developing nations, water is predominantly sourced from rivers, lakes, and reservoirs, often being used without adequate treatment, posing a significant public health risk to households (Li *et al.*, 2010). In numerous rural regions of developing countries, the widespread use of contaminated water for activities such as drinking, bathing, laundry, swimming, and irrigation is prevalent, primarily due to restrictions to access to reliable sources of clean and safe water. This practice significantly adversely affects the health of households (Olasoji *et al*., 2019). As reported by the World Health Organization (WHO, 2019), 785 million people still lack basic drinking water infrastructure with 144 million depending on surface water for their basic water needs and

© University of Venda

others relying on groundwater sources for their needs. There is a need to ensure that quality water supply is realized to minimize water-related diseases which threaten people's lives.

In South Africa, surface water bodies, including rivers, lakes, ponds, and streams, play a crucial role as primary sources of water supply, especially in areas where multiple dams support local communities according to Madilonga *et al*. (2021). Around 5% of the population in South Africa continues to face insufficient access to water supply services, with the majority of these households located in rural areas, and this forces households to use unprotected water sources which result in ill health (Magonono, 2017). In sub-Saharan Africa, health expenditures for treating waterborne diseases such as malaria, diarrhea, and worm infections constitute more than one-third of the income of low-income households (Matta and Kumar, 2017). According to Sobsey *et al*. (2008), rural areas often experience unreliable availability of safe drinking water, leading communities to depend on alternative sources of water.

Surface water is typically the first option, as it is easily accessible and simple to use. Shortage of water resources limited budget, industrial pollution, and poor proper waste management in South Africa reduce water quality and result in health risks to households (Nekhavhambe *et al*., 2014). The enhancement of sources of water is critical for improving the health standards of communities. Contaminated water plays a significant role in the transmission of diseases, including diarrhea, cholera, giardiasis, dysentery, typhoid, and polio (Khan *et al*., 2023). Vhembe District is one of the regions in Limpopo Province, which is one of the most rural and economically disadvantaged areas in South Africa which lacks water safety plans, risk management or even monitoring programs, that could help alleviate the challenges of poor water quality (Luvhimbi *et al*., 2022). Furthermore, households are at risk of waterborne diseases and other related water-related illnesses.

Groundwater is a vital freshwater resource, supplying nearly one-third of the world's population for domestic use, agricultural, and industrial activities according to Li *et al.* (2021). Furthermore, groundwater is an essential resource in arid and semi-arid regions, where surface water and rainfall are limited (Enitan-Folami *et al*., 2020). In countries with developing economies, nearly 90% of wastewater is released untreated into aquatic environments which increases water pollution and the risk contracting waterborne diseases. The sewage discharge, pollute water and which result in the treated water not meeting the defined standards by the WHO (Luvhimbi *et al*., 2022).

© University of Venda

1.2 Statement of the problem

In South Africa, access safe drinking water is a basic human right and crucial for the health of its people (DWAF, 2004). Despite this South African households experience inequalities in access to safe drinking water. Although access to potable water is a right as stipulated in the South African constitution (Act 108) (1996), numerous communities in the Vhembe District still depend on untreated river water sources and borehole water for their domestic needs which has health implications (Traoré *et al*., 2016). Furthermore, research findings have demonstrated that most river water in this region possesses a poor microbiological quality, making it unfit for human consumption. Luvhimbi *et al*. (2022) also indicated that communities from the District Municipality of Vhembe rely on drinking water with a higher risk of waterborne diseases. Matatani, a village in the Vhembe District Municipality, encounters difficulties associated with the dependence on untreated water as a result of limited access to municipal water supply. This makes the community to be vulnerable to health risks.

In many provinces of South Africa, the water resources available in rural settlements are of poor quality (Bessong *et al.,* 2014). According to Khabo-Mmekoa and Momba (2019), the provinces in South Africa with the least availability of clean water and adequate sanitation are Eastern Cape, KwaZulu-Natal, and Limpopo. These provinces are predominantly home to rural communities, where most residents depend on unsafe drinking water. The Vhembe District Municipality, including the study area, cannot be excluded from poor water sources that negatively affect households' health when used for domestic needs. The water provided by local treatment facility to around fifty-five communities in the Thulamela Local Municipality, located within the District of Vhembe in Limpopo Province, has been identified as salty and not fit for human consumption according to Nthunya *et al.* (2018). Runa *et al.* (2022) confirmed that prolonged and excessive consumption of salty drinking water can lead to significant health problems, including impaired cellular osmosis, hypertension, and an increased risk of renal and cardiovascular diseases.

A report by South African Council for Scientific and Industrial Research revealed that around 2.11 million individuals in South Africa do not have access to reliable water infrastructure, and the use of untreated water from these inadequate sources poses a considerable public health threat (Edokpayi *et al*., 2018b). Due to the long distances required to access water sources and the irregular availability of water, households depend on storing water in various containers.

© University of Venda

However, these storage practices increase residents' vulnerability to waterborne contaminants, which can result in gastrointestinal diseases like diarrhea, helminthiasis, and cholera, and are a major contributor to water quality-related health issues (Potgieter *et al*., 2020).

Musina, located in the Limpopo Province of South Africa where Matatani Village is located, is profoundly affected by both historical and ongoing copper mining activities that have significantly impacted the local environment and water quality. The legacy of these mining operations, particularly the presence of abandoned copper mine tailings and has contributed to elevated concentrations of heavy metals such as copper (Cu), lead (Pb), and arsenic (As) in the surrounding soils, sediments, and groundwater (Singo and Kramers, 2020; Singo, 2013). These metals pose substantial environmental and public health risks due to their persistence, bioavailability, and toxicity within the ecosystem and human populations dependent on these water resources.

1.3 Motivation

South Africa is a semi-arid country with scarce water resources, and ensuring the availability of sufficient water supply systems continues to be a major challenge (Edokpayi *et al.*, 2018b). Ensuring a safe potable water supply is one of the key factors for a country's sustainable development. However, water quality is significantly threatened by urbanization, agricultural activities, industrial processes, and climate change (Foster and Chilton, 2003). Contaminants, including heavy metals, hydrocarbons, trace organic compounds, pesticides, nanoparticles, microplastics, and other emerging pollutants, pose substantial risks to human health, ecosystem stability, and long-term socioeconomic development (Li *et al*., 2021). Enitan- Folami *et al*. (2020) stated that South Africa is experiencing water stress due to the growing demand for potable water, irregular rainfall patterns, and elevated evaporation rate which negatively impact the health of households. This study, which evaluates the health risks of household water sources in Vhembe District, is essential for mitigating potential health impacts associated with water supply systems.

The provision of reliable access to clean and safe water remains unfulfilled in numerous rural areas of South Africa (Edokpayi *et al*., 2022). An estimated 2.3 billion people globally are impacted by waterborne diseases (Wang and Yang, 2016). Consuming unsafe drinking water poses significant health risks (Chowdhary *et al*., 2020). Excessive exposure to mercury (Hg), fluoride (F), As, Pb, cadmium (Cd), and nitrate (NO_3) in contaminated water sources can result in various health issues, including cancer, dental and skeletal fluorosis,

© University of Venda

acute nausea, memory impairments, renal failure, anemia, and skin rashes (Chouhan and Flora, 2010). Health risk assessment is therefore crucial to identify potential risk faced by residents from Matatani Village. Evaluating the quality of domestic water sources is crucial for determining their water quality and assessing their suitability for consumption. Several studies have been conducted in the Thulamela Municipality, Limpopo Province, including water quality assessments and evaluations of health risks associated with drinking water sources and point of use, as reported by Luvhimbi *et al.* (2022). Additionally, Mutileni (2021) conducted an assessment of health risks associated with groundwater in the Collins Chabane and Makhado Municipalities in Vhembe District, there is still lack of studies in remote areassuch as Matatani Village. This creates a gap in knowledge concerning the assessment of health risks in remote rural communities within the Vhembe District Municipality. The majority of the studies do not consider rainwater for health risk assessment. This study is important as it will highlight the potential health risks in Matatani Village and suggest possible mitigating strategies to address water provision and improve the health of households.

1.4 Research objectives

1.4.1 Main objective

The main objective of the study was to assess the potential human health risks of domestic water sources at Matatani Village and recommend strategies to mitigate health of risks. The main objective was achieved by the following specific objectives of the study

1.4.2 Specific objectives

- To identify water sources and potential pollutants within Matatani Village.
- To determine the water quality status of domestic water sources at Matatani Village.
- To assess the potential human health risk associated with each water source at Matatani Village.

1.5 Research questions

- What are the potential pollutants of domestic water sources at Matatani Village?
- What is the quality status of domestic water sources at Matatani Village?
- What are the health risks assessment associated with each source at Matatani Village?

© University of Venda

1.6 Characteristics of the study area

1.6.1 Location and hydrology

Matatani Village is situated within the Musina Local Municipality (Figure 1.1) in the Vhembe District Municipality, situated in the northeastern region of Limpopo Province. It shares its northern border with Zimbabwe and its eastern boundary with Mozambique (Ramaano, 2022). Matatani is an exceedingly rural community situated in the northern part of the LimpopoProvince, South Africa, with geographic coordinates at latitude 22°34.3′ S and longitude 30°48.2′ E. (Madziga and Mansoor, 2018).

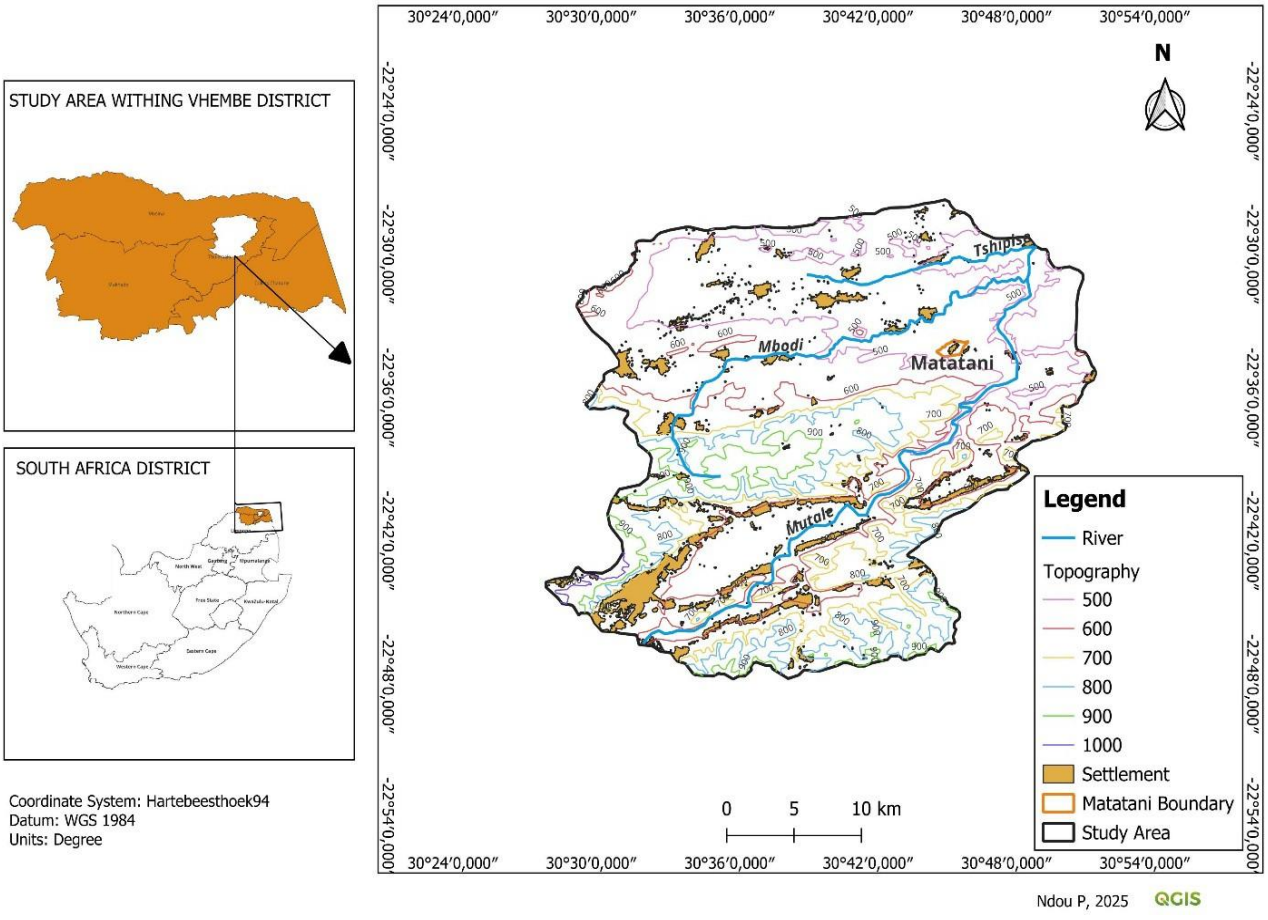


Figure 1.1: Map of the study area

© University of Venda

1.6.2 Climate of the study area

The Musina area experiences a climate with mild, dry winters and hot, humid summers. The mean temperature varies from a maximum of 24.6°C and a minimum of 6.7°C in July, to a maximum of 32.8°C and a minimum of 20.8°C in January. During the summer, daily maximum temperatures often exceeds 35°C (Dirk *et al*., 2010). The area's long-term average annual temperature is 22.3°C, with average highest and lowest temperatures of 29.6°C and 15.1°C, (Grobbelaar, 2009). The Musina area receives a mean annual rainfall of 464.1 mm, the majority of which occurs during the hot summer months (Ramaano, 2022). In this region, the wet season begins in October and gradually ends in April, followed by a transitional period in winter with minimal precipitation (Andrews *et al.,* 2024). The Musina region has an average annual potential evaporation reaching 2.274 mm annually, with an average yearly soil moisture load (percentage of days when evaporation demand exceeded twice the soil moisture input) of 84%. Usually, a total number of 168 days per year with maximum air temperatures above 30°C occurs in the region, even during the very dry winter months. Maximum air temperatures above 35°C often occur throughout the year.

© University of Venda

CHAPTER 2: LITERATURE REVIEW

2.1 Preamble

The chapter provides literature review on the physical, microbial, and chemical quality of domestic water, along with health risk assessments. It also examines the quality of water in rural areas, identifies potential sources of pollution affecting these regions, and reviews methods for analyzing physio-chemical and microbiological parameters.

2.2 Water quality status of rural areas

Water is vital for human survival; however, many individuals lack access to reliable and safe drinking water and suffer fatal consequences from preventable waterborne diseases (Akyuz, 2020). Ensuring access to clean and safe drinking water is essential for maintaining human health, it is recognized as a fundamental human right, and is a vital component of effective health protection policies (WHO, 2017). The Constitution of South Africa (1996) guarantees access to clean and safe drinking water as a human right for all citizens. However, millions of people still lack adequate access to a reliable potable water supply in South Africa (South African Government, 1996). According to Haseena *et al*. (2017), 3.1% of deaths result from contamination and the poor quality of water. In developing countries, inadequate water quality is the primary factor of numerous waterborne diseases impacting households. The quality of water in developing countries is of low quality and has been the cause of many waterborne diseases affecting households (Chalchisa *et al*., 2018).

In some areas lack of adequate funding from the government restricts access to proper water treatment of water services which forces communities to depend on untreated groundwater without considering the potential sources of contamination (Makungo and Odiyo, 2018). Ndubuisi *et al.* (2021) conducted a study to assess the water quality and composition of the benthic fauna of the Amuzuta Stream in Umuahia, located in Southeast Nigeria. The findings revealed elevated levels of bacterial and fecal contamination, exceeding the WHO limits, indicating the presence of possible disease-causing pathogens and rendering water unsafe for drinking. Edokpayi *et al.* (2018b) conducted an assessment of the various factors affecting the quality of water and associated water-use practices in rural areas of the Province of Limpopo. The study found that microbiological quality of water poses a greater risk to consumers of untreated natural water, as Escherichia coliform (*E. coli)* was detected in all natural water sources.

© University of Venda

The water quality of sources available in rural areas across most provinces of South Africa is poor (Munyai *et al.*, 2021). The majority of people in rural areas rely on untreated groundwater for household purposes (Carrard and Willetts, 2019). These rural areas face frequent exposure to elevated concentrations of heavy metals as a result of their dependence on and consumption of untreated water. Rural communities are forced to utilize unprotected sources due to the absence of enough water sources in their areas (Hossain *et al*., 2022). Edokpayi *et al.* (2018a) stated that rural areas struggle with proper water supply, leaving residents to resort to having to collect water from wells, ponds, springs, rivers, and rainwater to satisfy their residential water demands. In addition, water obtained from these sources is used without any treatment. This has a significant negative effect on public health and overall well-being. The WHO has also reported that around 80% of illnesses are transmitted by using contaminated water (Bharadwaj, 2018).

Exposure to contaminated water during pregnancy increases the risk for women of chemical exposure, which is associated with a higher incidence of low birth weight, which subsequently impacts their health (Currie *et al*., 2013). Cancer mortality rates occur more frequently in rural regions compared to urban areas, primarily because urban populations have access to treated drinking water, while rural communities depend on untreated water sources. Disadvantaged and rural communities are at a higher risk of disease due to inadequate sanitation, hygiene, and water supply (Haseena *et al*., 2017). With significant advancements in enhancing water accessibility, sanitation, and hygiene facilities, global morbidity and death rates can potentially decrease by about 9.1% and 6.3%, respectively (Kaur, 2020).

2.3 Potential sources of pollution/contamination in rural areas

Water in South Africa is very scarce as there are factors reducing the water quality such as nature and climate, and population growth which needs economic development (Raimi *et al*., 2019). Akhtar *et al.* (2021b) stated that domestic sewage, industrialization, pesticides and fertilizers are also factors that degrade the water quality. Increase population growth plays a huge role in deteriorating water quality due to an increase of solid waste generation (Abdel-Shafy and Mansour, 2018). The waste produced in solid form that is discharged into the rivers and reduces the quality of the water (Dutta *et al*., 2020). The population growth leaves the government incapable of supplying essential needs to citizens such as portable water to citizens (Edokpayi *et al*. 2020).

As stated by Basu *et al.* (2022), water is also polluted by human waste due to a substantial

© University of Venda

quantity of domestic sewage being released into rivers, and almost all of it is untreated. Domestic sewage solid waste contains toxic substances, solid waste, plastic debris, bacterial contaminants, and harmful metals that significantly degrade water quality, making it unsafe for use (Chowdhary *et al*., 2020). Various industrial liquid waste drained into rivers without being treated is the primary cause of water quality degradation (Yohannes and Elias *et al*., 2017). Hazardous substances discharged from industries contribute to the contamination of surface water and groundwater, respectively. In agriculture, pesticides used to eliminate bacteria, pests, and other harmful organisms contain chemicals that enter water sources directly, impacting water quality. Dharminder *et al*. (2019) reported that only 60% of fertilizers are absorbed by the soil, with the excess chemicals being carried into river water through flooding, heavy rainfall, and over-irrigation, eventually entering the food chain. The chemicals pollute the water and are very harmful to living organisms.

West and Central African countries are developing countries with limited access to safe drinking water and sanitation services (Dube *et al*., 2015). Water pollution caused by human activities has become a widespread global issue, with the quality of rivers in Africa, Asia, and Latin America declining since the 1990s (UNEP, 2016). In less developed countries, surface water degradation is primarily driven by pollution from urban populations rather than from agricultural or industrial sources (Chen *et al*., 2022). The water quality degradation in the uMngeni River in KwaZulu Natal, South Africa is caused by increased population pressures, and the improvement of living standards (Namugize *et al*., 2018). Edokpayi *et al*. (2018b) the study evaluated all factors affecting the water quality and related water use practices in rural communities of Limpopo Province. It found that microbiological water quality issues pose a greater risk to individuals consuming untreated natural water, as *E. coli* was identified in each freshwater source.

The quality of water in some areas downstream of Mokopane, Limpopo Province showed degradation as contaminants built up with the river flow. Over four years of study, the water quality for streams either remained the same or worsened. Dorps River and Dithokeng Dam displayed no change between 2016 and 2019, and the assessed water quality was determined to be likely unfit for drinking (Molekoa *et al*., 2021). Makungo and Odiyo (2018) conducted a study in Siloam Village, Limpopo Province to determine the water quality status of individual boreholes and their problems. They reported that in some boreholes EC, turbidity, chloride (Cl), iron (Fe), and nitrate exceeded the recommended guidelines, they indicated that elevated nitrate concentrations were associated with groundwater contamination due to faecal matter from pit

© University of Venda

latrines. Furthermore, they also showed that the high fluoride concentrations make the people from Siloam village to be exposed to health risks.

2.4 Challenges of accessing safe drinking water in rural areas

Potable water is water that poses no significant health risks when consumed, including changing sensitivities that could arise across phases of life (WHO, 2022). Safe drinking water is appropriate for all common household needs, including personal hygiene (WHO, 2017). In 2010, it was estimated that around 1.8 billion people worldwide were consuming unsafe water for their well-being (Hutton and Chase, 2016). According to Khwaja and Aslam (2018), the WHO reported that 80% of diseases are waterborne. A large majority of these illnesses are related to diarrhea, causing approximately 1.9 million deaths and 4 billion new episodes of diarrhea each year, with a particularly high impact on children under five years old (Joshi and Amadi, 2013). Poor water quality has significant implications for human health, leading to diseases caused by microorganisms and vectors, such as infectious and chronic diarrhea, as well as exposure to chemical contaminants that can contribute to non-diarrheal health issues.

The availability of safe and clean drinking water remains a critical public health concern in Pakistan, with the country facing challenges related to both water quality and quantity, as documented in various studies (Fida *et al*., 2022). In Pakistan, microbiological contamination of drinking water has been identified as a primary contributor to the spread of diseases and mortality among people, particularly children (Daud *et al*. 2017). Fitri *et al*. (2020) stated that the increase of development activities and land use changes in Kelantan city from 2012 to 2018 decreased the water quality downstream of Kelantan River, Peninsular Malaysia.

Pollution of water sources is a global issue that limits access to safe water from these sources for home consumption daily. The deteriorating status of wastewater treatment works infrastructure from the municipality in South Africa is the primary contributor to the country's environmental concerns, as well as the primary contributor to health problems in disadvantaged communities (Sibanda *et al.,* 2015). Sindane and Modley (2022) showed that poor water quality problems create unsafe living conditions for Emfuleni residents and damages the environment.

2.5 Previous studies

The quality of drinking water is one of the most crucial factors affecting human health (Wątor *et al*., 2021). Muhammad *et al*. (2011) study in Pakistan, discovered concentrations of nickel (Ni) and chromium (Cr) in water which were higher than their respective permissible limits in surface

© University of Venda

and groundwater samples, respectively. It was further stated that water contamination was responsible for diseases such as diarrhea and viral hepatitis, headaches, liver and kidney problems.

Njoku *et al.* (2024) evaluated groundwater quality in selected rural communities of Ijebu-North Local Government Area, Ogun State, Nigeria. The investigation focused on boreholes and hand-dug wells, analyzing key parameters such as NO_3, Fe, Cd and coliform bacteria. Results showed that a significant number of samples exceeded WHO drinking water standards, especially for NO_3 and Cd both of which pose health risks. The Water Quality Index (WQI) calculated in the study classified approximately 75% of the samples as unsuitable for drinking purposes. The health risk assessment further identified children as the most vulnerable group, due to their increased sensitivity to contaminants like nitrate and heavy metals. The findings underscore the need for regular water quality monitoring, as well as the implementation of treatment and public health interventions to ensure the safety of groundwater sources in rural Nigerian communities.

Nazwaz *et al*. (2023) assessed the quality of drinking water across in urban areas of Lahore, Pakistan, revealing widespread contamination with As, F, TDS, residual chlorine, and *E. coli*. Most samples exceeded WHO and national standards, with WQI values above 100, indicating the water was unfit for human consumption. Health risk assessment showed elevated non-carcinogenic and carcinogenic risks, particularly from As exposure, with children identified as the most vulnerable group. The study stressed the urgent need for water treatment, regular monitoring, and provision of safer alternatives to mitigate public health threats in urban areas.

Bahetnur and Lee (2023) conducted a detailed assessment of heavy metal contamination in the Esil River, a major water body in Kazakhstan, Central Asia. The study focused on four toxic metals including Cr, As, Pb, and Cd and analyzed their concentrations across 15 sampling sites between 2014 and 2019. Results showed that the levels of these metals exceeded national and international safety standards at several locations, primarily due to industrial activities and untreated municipal wastewater discharges. Using both deterministic and probabilistic health risk assessments, the study found that non-carcinogenic risks (hazard index > 1) and carcinogenic risks (up to 7.22×10^{-4}) were particularly high for children. It was concluded that there is a critical need for pollution control and health protection measures to reduce human exposure to toxic metals in the region's water sources.

© University of Venda

Ghoderao *et al.* (2022) assessed groundwater quality across five sites in Jabalpur District, Madhya Pradesh, India, and using the WQI methodology. Analyses of parameters including EC, Cr, alkalinity, NO_3, and hardness revealed WQI values ranging from excellent (17.9) to poor (176.9). Sites with high EC, total alkanity, and Cr were unfit for consumption without treatment. Principal component analysis identified Cr as the primary driver of variance (31%), indicating its critical role in water degradation. The study emphasized the importance of localized groundwater management, targeted monitoring, and intervention strategies to mitigate health risks.

Hassan (2023) examined heavy metal concentrations in rainwater collected from the industrial area of Kwashe and the natural area of Gara in the Duhok Governorate, Iraq, during January and February 2023. Seven samples were analyzed using atomic absorption spectrophotometry (ASS), with results indicating that Pb (1.446 mg/L) and Cd (0.331 mg/L) concentrations in Kwashe exceeded the WHO drinking water guidelines (0.01 mg/L and 0.003 mg/L, respectively) by approximately 145 and 110 times. Other metals, including Zn, Ni, Cr, Mn, Cu, and Fe, remained within permissible guidelines, and Co was not detected. In Gara, metal concentrations were generally lower, although Pb (0.083 mg/L) and Cd (0.0077 mg/L) still exceeded WHO guidelines. The study concludes that industrial operations in Kwashe are likely a major contributor to Pb and Cd contamination in local rainwater.

Anabtawi *et al.* (2022) evaluated heavy metal concentrations in harvested rainwater from 74 household cisterns in Yatta Town, Hebron, Palestine, using ICP-MS and comparing results to WHO and Palestinian drinking water standards. All Cd concentrations were within safe guidelines, while Pb, Cr, and Ni exceeded guidelines in two samples each, and Zn exceeded the WHO limit in one sample. Mn, Co, and Cu remained within permissible limits. Source analysis linked Pb and Zn to roofing materials and storage tanks, Cr to road and brake dust, and Ni to leaching from metallic fittings. Health risk assessment (HRA) indicated no significant non-carcinogenic risks, though the study recommended ongoing monitoring and infrastructure maintenance to reduce contamination.

Edokpayi *et al.* (2014) detected the occurrence of heavy metals including Fe, zinc (Zn), aluminium (Al), manganese (Mn), Pb, and Cr, in concentrations higher than the recommended guideline set by DWAF, except Cu. This elevated concentration of heavy metals presents a threat to domestic and aquatic life, respectively. The study suggested that river water requires proper treatment before being used for domestic purposes to reduce potential health risks. A study by Edokpayi *et al.* (2018a) in Muledane revealed that 87.5% of borehole water contained elevated

© University of Venda

levels of NO_3, Fe, and Mn among the examined anions and heavy metals. The concentrations of Cr, Fe, and Mn in certain boreholes exceeded the recommended guidelines set by the WHO and the Department of Water Affairs and Forestry (DWAF). Furthermore, the study highlighted that the consumption of water from the analyzed boreholes poses a carcinogenic risk (CRing) due to the estimated concentrations of manganese, Fe, and Cu for children and adults, respectively.

Madilonga *et al.* (2021) conducted a study that found turbidity, Pb, Cd, and fecal coliform levels exceeded the threshold limits set by South African National Standard (SANS) and the WHO. The study indicated that the downstream section of the river showed higher contamination levels than the upstream and midstream areas. As a result, the study emphasized the need for proper treatment of water from this river before use. Mandindi *et al.* (2022) evaluated the concentrations of major and trace metals, along with metalloids, in the drinking water of Romanslaagte village, Whittlesea, Eastern Cape, South AfricaThe study found that most of the metals analyzed, including As, Al, Cd, Cr, Mn, Pb, Sb, and Se, were present at levels exceeding the allowable limits for drinking water established by SANS and WHO.

Makungo and Odiyo (2018) conducted a study in Siloam Village, Limpopo Province, to assess the water quality status of individual boreholes and their problems. Their findings revealed that in certain boreholes, EC, turbidity, chloride (Cl), Fe, and NO_3 values and concentrations exceeded the recommended guidelines. They also highlighted that elevated nitrate concentrations were linked to groundwater contamination from fecal matter originating from pit latrines. Furthermore, they also showed that the high fluoride concentrations expose the people from Siloam village to health risks.

Luvhimbi *et al.* (2022) assessed the physical, chemical, and microbiological quality of municipal water supplied in Thulamela, analyzing its quality from the source to the point of use for consumption. The study identified elevated levels of Pb at household taps and storage containers, which were attributed to the materials used in the pipes and containers. Adults and children were found to be at the highest risk for cancer. The study recommended maintaining adequate residual free chlorine levels at distribution points and improving the reliability of the treated water supply in the rural areas of Thulamela Municipality.

Olowoyo *et al.* (202) assessed the health hazards associated with trace metals and physical and chemical parameters in bottled mineral water in South Africa. The results showed that mineral water does not have any cancer-causing and non-cancer-causing effects from the sampled water, the HI and HQ in the study were < 1. Similarly, Moradnia *et al.* (2024) conducted a study to assess the cancerous and non-cancerous risks in drinking water of Isfahan in Iran and the results

© University of Venda

demonstrated a negligible non-cancerous health risk to the residents due to the HI value < 1.

2.6 Water quality parameters

Water quality parameters are classified into physical, chemical, and microbiological characteristics according to established criteria. These parameters are closely linked to water consumption and its safety for human use, offering crucial insights into the suitability of a water body for use. Furthermore, water quality parameters are utilized to assess the suitability of water for drinking purposes (Acharya *et al*., 2018). Domestic water should not only be free of chemicals and micro-organisms but should also be of acceptable quality in terms of taste and odour (Gerber and Chen, 2011).

2.6.1 Physical water quality parameters

- **pH**

pH is the measure of the acidity of a solution of water (Pye *et al*., 2020). The pH is a key parameter in water quality, representing the negative logarithm of the hydrogen ion concentration (Omer, 2019). According to Solomon *et al*. (2007) water that is acidic contains a lot of hydrogen (H) ions and water that is basic contains a lot of hydroxyls (OH) ions. The scale of the pH ranges from 0.00-14.00 and pH of 7.00 is neutral, any pH lower than 7 is acidic whereas any pH exceeding 7 is basic (Westcott, 2012). Pure water is considered neutral, having a pH of 7 at 25°C. For domestic use, the pH of water should range between 6 to 9 (Obiefuna and Sheriff, 2011). Similarly, Islam *et al.* (2017) state that the safe pH range for drinking water intended for residential use is between 6.5 and 8.5.

Eyankware *et al*. (2022) indicated that more acidic water is related to heavy metals dissolving from host rocks into groundwater. Lei *et al*. (2021) supported that water of acidic water corrodes metals and other substances. Acidic pH values were recorded by Mukonazwothe *et al.* (2022) in boreholes in Nwanedi village found in Musina Local Municipality. A pH lower than 4 can cause skin and eye irritation, and a pH higher than 11 can also irritate due to the corrosive effects of low pH levels. Stamatas and Tierney (2014) indicated that health effects are found in extreme pH and also gave a warning that extreme pH can worsen existing skin conditions. Furthermore, a pH above 8.5 affectsthe taste of water and gives it a soapy taste (Wolfrum *et al*., 2016).

© University of Venda

- **Turbidity**

Turbidity is an indicator of water's clarity or transparency, and since water is typically colorless, contamination can be easily observed in terms of turbidity. Ilori *et al.* (2019) describe turbidity as an indicator of the light-scattering characteristics of water, with the test serving to evaluate the quality of wastewater discharge in relation to colloidal substances. The turbidity level of water is determined by the concentration of solid particles suspended in. Turbidity is typically expressed in Nephelometric Turbidity Units (NTU), with water quality considered good if the turbidity is below 1 NTU. A turbidity value greater than 1 NTU indicates poor water quality.

- **Electrical Conductivity (EC)**

Electrical conductivity (EC) is an indicator of water's capacity to transmit an electric current, reflecting the concentration of dissolved ions in the water, and it is also a tool for assessing water purity (Al-Mussawi, 2014). Belov *et al.*, (2019) defined Conductivity as a numerical representation of an aqueous solution's capacity to conduct electricity. The electrical conductivity of water is influenced by various factors, including the presence of ions, their concentration, mobility, valence, relative abundance, and the temperature of the water. EC measure a solution's capacity to conduct an electric current, which is largely determined by the ionic composition of the water (Meride and Ayenew, 2016). Pure water, being a poor conductor, acts as an insulator, while an increase in ion concentration enhances its conductivity (Guo and Keppler, 2019). The EC is typically determined by the concentration of dissolved solids in the water. According to WHO (2021) guidelines, the EC of drinking water should not exceed 400 µS/cm. Oyem *et al.* (2014) suggested that water temperature has a direct impact on EC, as the temperature increases, so does the EC, and when the temperature decreases also the EC decreases.

- **Total dissolved solids (TDS)**

Weber-Scannell *et al.* (2007) defined TDS as the total concentration of dissolved substances in water, encompassing both inorganic salts and other compounds, a key factor in determining water quality and organic matter. Corwin and Yemoto (2020) postulated that as TDS is measured the salinity of the water is also automatically measured, and we are also automatically measuring the salinity of the water.

© University of Venda

TDS are directly related to conductivity and influence pH levels and when TDS increases, conductivity also rises, while pH will be more likely to decrease, increasing the acidity of water (Arega *et al.*, 2019). Poursaeid *et al.* (2020) also noted that Total Dissolved Solids (TDS) indicates the overall salinity levels of water. According to Rahman and Rahman (2018), water containing TDS less than 1000 mg/L is safe for drinking and poses no harm to the public. However, if the TDS exceeds 1000 mg/L, the water has a high salt content, which poses a risk to public health and cannot be utilized for drinking purposes as it causes harm to the public (Asare *et al.*, 2016). Water with high TDS values has a salty taste and produces scales on cooking vessels and boilers and it also indicates that the water is highly mineralized.

2.6.2 Chemical water quality parameters

- **Magnesium (Mg)**

The Mg is a plentiful and an important nutritional requirement for people, it is essential for normal functioning of the muscles. An amount of 0.3-0.5 g/day is required per day in the human body. It represents the second primary factor contributing to hardness, comprising 15-20% of the overall hardness, which is expressed as calcium carbonate $CaCO_3$ (Sharma *et al.*, 2016). The body of a human has about 25g of Mg, 60% in bones and 40% in muscles and tissues (Meride and Ayenew, 2016). According to Krishnan *et al.* (2007) the allowed value of Mg in water should be less than 50 mg/l. Furthermore, Zavitsanou and Drigas (2021) stated that deficiency of mg in the human body has been linked to significant mental health issues, including major depression, including low intelligence quotient is of great public health concern.

- **Sodium (Na)**

Na is a cation found in common salt that contributes to a salty taste in water when its concentration exceeds 250 mg/L (Beyene, 2015). Na is required to maintain the electrolyte balance in the body (DWAF, 1998). High sodium concentrations in drinking water should be taken into account by individuals on low-sodium diets, as it may lead to hypertension (Shammi *et al.*, 2019). A slight taste may be evident above 100 mg/L. High Na concentration in infants can put stress on the kidneys and heart, potentially causing severe disruptions in the body's salt balance (DWAF, 1998).

© University of Venda

- **Calcium (Ca)**

Ca is defined as an element found in the Earth's crust, essential for human cell function and bone health. According to Meride and Ayenew (2016) 95 % of Ca in the human body is stored in bonesand teeth. Lewiński and Skowrońska-Jóźwiak (2014) highlighted that a significant deficiency of Ca in the human body can lead to conditions such as rickets, poor blood clotting, and increased susceptibility to bone fractures. On the other hand, excessive Ca concentrations have been linked to cardiovascular diseases. According to the WHO (WHO, 2011), the permissible concentration of Ca in drinking water should not exceed 75 mg/L.

- **Potassium (K)**

K is a silver-white alkali metal that reacts readily with water. It plays a crucial role in the functioning of living organisms and is found in all human and animal tissues, with a particularly high concentration in plant cells (Soetan *et al*., 2010). The overall quantity of K in the human body varies between 110 and 140 g (Mohsin *et al*., 2013). K is essential for various bodily functions, including heart protection, regulating blood pressure, aiding protein metabolism, supporting muscle contractions, and facilitating nerve signaling. (Lajçi *et al*., 2017). According to Ismail and Ismail (2016) shortage of K is unlikely to occur but it may result in depression, muscle weakness, and heart rhythm disorder if it occurs. The permissible amount of K according to WHO (2011) guideline is 12 mg/L.

- **Cadmium (Cd)**

Cd is defined as the soft blush white metal that is chemically like Zn but very toxic to living organisms and its presence in water or the aquatic environment is very dangerous as it builds up in an organism after some time (DWAF, 1996). Its permissible limit in drinking water by SANS 241 (2015) is 0.03 mg/L. At higher concentrations, Cd causes acute health effects like nausea, vomiting, and diarrhea, its long-term exposures result in kidney damage and bone pain (DWAF, 1998).

- **Iron (Fe)**

Fe is silvery in colour which appears to be greyish black. The Fe is considered a vital micronutrient necessary for the survival of all living organisms (DWAF, 1996).

© University of Venda

Fe is essential for producing the hemoglobin, the red blood pigment responsible for carrying oxygen. The Fe concentration in water increases by corrosion of pipes and by of Fe present in soil by acidic water (Petersen and Melchers, 2012). High ingestion can cause hemochromatosis and can also stain enameled surfaces such as baths, laboratory bowls, and laundry (DWAF, 1998).

- **Aluminium (Al)**

Al is described as a silvery white soft light metal that is resistant to corrosion. Al is the most abundant metal in the Earth's crust, making up approximately 8% of its composition (DWAF, 1998). The required Al in water should be 0.15 mg/L by DWAF (1996) and at higher concentrations, it results in Alzheimer's and dialysis dementia.

- **Manganese (Mn)**

A grey-white brittle metal which is also regarded as an important for both people and animals, is essential for maintaining cartilage heath (DWAF, 1998). The permissible concentration of Mn in drinking water is 0.05 mg/L, and it should not exceed 0.15 mg/L (DWAF, 1996). A low concentration of Mn results is anemia and skeletal abnormalities (DWAF, 1996).

- **Zinc (Zn)**

A metallic element that is important in plants and animals is required to maintain healthy skin and cell membrane and a proper functioning of the immune system (DWAF, 1998).

According to DWAF (1996) the allowed concentration of Zn in drinking water is 3 mg/L In and it is caused by the leaching of galvanized plumbing fittings. Excess concentrations result in water having a bitter taste and having a milky appearance (DWAF, 1996).

- **Lead (Pb)**

Pb is a very soft metal that is highly malleable and ductile, it reduces corrosion (DWAF, 1998). The required concentration of SANS 241 (2015). Exposure to a Pb, most especially in young children, causes neurological impairment and affects their intelligence quotient, in adults it leads to anemia (DWAF, 1996).

© University of Venda

- **Copper (Cu)**

Cu is defined as an orange-coloured metal that conducts heat and electricity effectively and is also regarded as a vital element for humans, plants, and animals (DWAF, 1998). An acceptable Cu concentration in water is 1mg/L by DWAF (1996) and the most vulnerable group to the health effects of copper effects are individuals with a rare genetic disorder called Wilson's disease. High concentration causes gastrointestinal disturbances and possible liver, kidney, and red blood damage (DWAF, 1996).

- **Arsenic (As)**

As can be defined as greying semi-metal that is widespread in the environment and has a concentration of about 2 mg/kg (DWAF, 1996). According to DWAF (1998), as is a semi-toxic metal that may be used as a rat poison sometimes. It is required in the body of a human being only in small concentration, it helps sustain the integrity of the human system and contributes to the health of both the skin and hair (DWAF, 1998). The permissible concentration allowed by SANS 241 (2015) in drinking water is 0.01 mg/L. Increased As concentrations may occur due to pollution from mines and cattle dips (DWAF, 1996). High concentrations of as may result in cancer (DWAF, 1996).

- **Chloride (Cl)**

Cl originates from the dissolution of salts, such as hydrochloric acid (HCl) and sodium chloride (NaCl), as well as from sodium carbonate (Na2CO3). It is also present in industrial waste and sewage and seawater (Ahmed *et al.*, 2020b). Surface water bodies frequently contain lower concentrations of Cl as compared to groundwater (K'oreje *et al*., 2016). Cl is essential for metabolism activity in the body of a human being. High chloride concentration destroys metallic pipes and structures and damages growing plants (Hwang *et al*., 2017). According to WHO standards, the Cl concentration should not exceed 250 mg/l (Meride and Ayenew, 2016).

- **Nitrate (NO_3)**

Nitrate (NO_3) is a significant water quality parameter, particularly associated with health issues such as blue baby syndrome in infants. NO_3 sources include the nitrogen cycle, industrial waste, and the use of nitrogen fertilizers. The concentration of NO_3 in drinking water should not exceed

© University of Venda

45 mg/L according to WHO (2011). The health of the elderly and children can have a negative effect if high NO_3 water is used for a long time without proper treatment.

2.6.3 Microbiological parameters

Microbiological water contaminants are organisms, including protozoa, bacteria, and viruses, that are too small to be seen without a microscope and may be found in drinking water (Kristanti *et al*., 2022). The microbes are most often related to the spread of waterborne diseases caused by infectious agents such as gastroenteritis and cholera (Baker-Austin *et al*., 2017). Organisms used to measure levels of microbial contaminants are fecal indicators, and those that show contamination in feces from animal or human waste (Leeming *et al*., 1996). Due to the difficulty in detecting some of these pathogens, microbial indicators of recent faecal contamination are commonly used to evaluate the risk of waterborne infectious diseases (Medema *et al*, 2003). The presence of pathogenic organisms is typically indicated through tests for total coliforms, fecal coliforms, or specifically for *Escherichia coli* (*E. coli*).

- **Total Coliform (TC)**

Total coliforms (TC) are organisms that can grow at 37 °C, produce β-galactosidase, and belong to the Enterobacteriaceae (Leclerc *et al*. 2001). Motlagh and Yang (2019) stated that total coliforms are indicator organism's tests that are frequently utilized to detect the presence of pathogens in water. According to SANS 241 (2015), total coliform found in water should not exceed 10 cfu/100ml. Total coliform (TC) counts are widely utilized to evaluate the general hygienic quality of water, the effectiveness of water treatment processes, and the condition of the distribution system (Ahmed *et al*., 2015). TC counts suggest poor treatment, contamination after treatment or growth, or high levels of nutrients (Markou *et al*., 2018). In certain situations, TC can signal the existence of a pathogen enabling the spread of infectious diseases.

Duressa (2019) reported the TC counts for bacteriological quality in household tap in Nekemte, Oromia, Ethiopia .In that study, TC counts in household tap water ranged from **12** to 120 cfu/100 mL, with 37% of the samples positive for fecal coliforms, confirming microbial intrusion into the distribution system, likely due to pipeline integrity issues or insufficient disinfection (Duressa et al., 2019). It was also observed that the TC counts in tap water were lower than those in water samples taken from the main distribution tank after treatment,

© University of Venda

suggesting that the treatment system effectively reduced the microbial load in the water.

- **Escherichia coliform (*E. coli*)**

Escherichia coliform (E. coli) is a bacterial species commonly utilized and recognized globally as a standard indicator organism for assessing water quality. Its presence in water is often used to signal potential contamination, making it a key parameter in water quality testing (Wen *et al*., 2020). Yasir *et al.* 2020 identified *E. coli* as the dominant organism in the microbial world. Its presence has been shown to be the most dependable sign of faecal contamination, especially in open-source water supplies such as rivers (Sorensen *et al*., 2015). Waterborne diseases, particularly intestinal and diarrheal illnesses, are a leading cause of morbidity and mortality among young children in developing countries (Ugboko *et al.,* 2020). According to Pachepsky *et al.* (2016), the detection of *E. coli* in water samples serves as an indicator of potential contamination by other fecal-related bacterial pathogens. The presence of *E. coli* in water suggests contamination from both human and animal feces, which, if ingested, can lead to serious diseases such as diarrhea, typhoid, and giardiasis. (Pal *et al.,* 2018).

2.7 Methods of analyzing microbial water quality parameters

- **Membrane filtration method**

This is the process used to analyze the microbiological properties of water samples in laboratory settings. This technique is widely used to detect coliform and other bacteria in water. Water is filtered through the membrane size of 0.45 µm which keeps the bacteria. The membrane is transferred to a selective agar medium and then incubated allow colony formation allowing direct enumeration of bacteria (American Society for Microbiology, 2016). A membrane is a physical barrier that permits substances to pass through based on their size (Cabral, 2010). The pores of the filtration membrane usually range in size from 0.05 µm to 1.0 µm. This technique enables the testing of large volumes of water and provides results within 24 hours (Rompre *et al.*, 2002). Its advantage it is ability to process the large samples volumes and also providing higher sensitivity and yielding quantitative results. Its drawback is that high turbid samples can clog the membrane filter which makes it less effective for some environmental or wastewater samples (Pinto *et al.*, 2012).

- **The Multiple tube fermentation**

© University of Venda

This is a traditional method used for detecting coliform bacteria, particularly in drinking water and wastewater to calculate the most likely quantity of coliforms in the water samples. The procedure involves three stages, the presumptive test where the gas formation in the lactose broth shows potential coliform presence (Allen *et al.,* 2004). The confirmed test uses selective lactose bike broth and the completed test where verification is done using the methylene blue agar. Its major advantage is its ability to check viable but non-culturable bacteria which might not be capable of growing on solid media (Pinto *et al.,* 2012). Its limitation is that it is time-consuming, and it takes about 48 hours to obtain the bacteria. Another limitation is that it is a statistical estimation rather than a direct count which may include variability in results (Sutton, 2011).

- **Spread plate technique**

Spread plate technique is a simple and widely used method for enumerating viable microorganisms in various samples. A small volume of a diluted sample of about (0.1 mL) is uniformly over the surface of a solid agar medium using a sterile glass or plastic spreader. After incubation colonies are counted and reported as cfu|10ml (Allen *et al.,* 2004). The method is straightforward to use and it is not expensive and it also allows for the isolation of individual colonies which can be further tested for microbial identification. Its limitation is its difficulty in handling highly concentrated samples and it cannot detect viable but non-culturable bacteria unlike multiple tube fermentation (Madigan *et al.,* 2018).

2.8 Methods of analyzing chemical water quality parameters

- **Atomic emission spectroscopy (AES)**

The analyte concentration is measured quantitatively using optical emission spectroscopy (AES or OES), which measures the optical emission from excited atoms (Khan *et al.,* 2022). This is one of the methods used physically to examine water samples. When it comes to trace elements, it permits the determination of several components simultaneously, increasing its efficiency (Research Gate, 2025). The AES can analyze metals, metalloids, and non-metals, unlike ion chromatography. Its drawback is needing people who are skilled in operating it and it is very expensive to use it due to the use of argon gas needed to operate it (Research Gate, 2025). Its historical evolution is connected to the sixteen advancements in our basic knowledge of structural matters and the makeup of atomic spectra.

© University of Venda

- **Inductively coupled plasma-optical emission spectrometry (ICP-OES)**

Kmiecik *et al*. (2016) defined ICP-OES spectrometry as a valuable technique used to identify metals in water samples. Liquid samples are introduced into argon plasma, created by radiofrequency (RF) with temperatures ranging from 6.000 to 7.000°K, using various nebulizers or sample delivery methods. 1 According to Kashani. (2011), samples are nebulized at a rate of approximately 0.4 ml per minute, generating a fine mist of droplets within the chamber now picks the smallest droplets that will be analyzed at about <5 microns. The ICP-OES has a detection limit of elements which is from 1-100ng/ml in solution, for elements like beryllium (Be), lithium (Li), calcium (Ca), magnesium (Mg), titanium (Ti), scandium (Sc), strontium (Sr), yttrium (Y), copper (Cu), and barium (Ba) (Mutileni, 2021). The advantage of this method is that it can analyze many elements at the same time, and it has high productivity. When comparing this to the ICP-MS, this method is less sensitive and does not give out isotope-specific information (Vanhaecke and Degryse, 2012).

- **Ion chromatography (IC)**

The IC is an analytical technique that involves passing a liquid through a stationary phase to separate and produce ionic solutions (approximately 5 µm in diameter), which then flow through a detector (Liu *et al.*, 2015). It is mainly utilized for determining the concentration of metals and essential anions including Fluoride (F), Nitrate (NO_3), and Chloride (Cl). The method was developed around 1975, and a portion of its benefits is that this technique can viewed as one of the most remarkable strategies with regards to the division of charged particles (Cutsail and DeBeer, 2022). IC is very versatile as it does not only analyze the environment, it also includes food and beverages, and biological specimens (Yashin and Yashin, 2004). It can measure major concentrations such as F, Cl, NO_3, NO_2, and SO_4 and cations such as Li, Na, K, Ca, and Mg (Mutileni, 2021). IC can detect and quantify various ranges of ions, it also allows the analysis of multiple ions at once which saves resources and time (Chromatography Today, 2022). IC is capable of detecting ions in very low concentration, often in parts-per-billion (ppb) or parts-per-trillion (ppt) levels.

According to Chromatography Today (2022), it needs very little sample preparation which helps prevent contamination and analyte loss which assists in the reduction of errors. Despite these advantages, the equipment and consumables are highly expensive making it

© University of Venda

hard to afford, and their maintenance may need expertise and specialized training (Microbe Notes, 2021). Another drawback of this technique is that it is only suitable to dissociate charged particles and it is not unable to separate nonionic species (Microbe Notes, 2021).

- **Inductively coupled plasma mass spectrometry (ICP-MS)**

ICP-MS is recognized as the most efficient tool for detecting trace metals and is capable of analyzing nearly every metal. The technique transfers liquids from a vial to the nebulizer at a steady temperature throughout the analysis, which reaches around 6000°C. The analytical process consists of four phases: sample introduction, interface, and mass spectrometry and ICP torch. The technique has very good detection limits for most elements with it being able to analyze all samples in < 1 min in the region of nanograms per liter to 10 or 100 ml per liter about 8 orders of magnitudes of concentration units (Howard, 2000; Mutileni, 2021). This method benefits from ionization happening in a chemically stable environment, preventing oxide formation, and resulting in more thorough ionization. Another advantage of this technique is that it is very sensitive, it can detect both trace elements and ultra-trace metals (PubMed Central, 2025). ICP-MS also allows exact isotopic ratio measurement and can also be used in forensic and geological studies (PubMed Central, 2025). Despite the advantages, its setback is that it can be easily affected by spectral and non-spectral interferences which require advanced correction techniques. Another limiting factor is that the cost of instrumentation is high, reducing its widespread use (PubMed Central, 2025).

2.9 Water quality indices (WQIs)

The WQIs is a numerical scale that synthesizes data from various physical, chemical, and biological parameters into a single, composite value (Sánchez *et al*., 2007). The WQI serves as a singular, aggregated numerical value that encapsulates the overall quality of a water sample, derived from the analysis of multiple water quality parameters(Cude, 2001). This index facilitates the assessment and categorization of water suitability for various intended uses, such as drinking, by integrating diverse measurements into a comprehensive score (Juwana *et al.*, 2012). This score facilitates the interpretation of water quality conditions for decision-makers, water resource managers, and the general public (Abbasi and Abbasi, 2012).

The concept of the WQI was initially proposed by Horton (1965) in the United States and has since undergone significant development and regional adaptation. One of the most influential models

© University of Venda

derived from Horton's framework is the National Sanitation Foundation Water Quality Index (NSFWQI), developed in the early 1970s. This model incorporates a set of core parameters including pH, dissolved oxygen, turbidity, total solids, and faecal coliforms (Brown *et al.,* 1970). Subsequent refinements to the index have included additional variables such as nitrate, heavy metals, and temperature to address location-specific environmental and public health concerns (Pesce and Wunderlin, 2000).

The methodology for calculating WQI typically involves the selection of relevant water quality parameters, followed by the assignment of weights that reflect their relative importance to human and ecological health. These parameters are then transformed into sub-indices and aggregated to generate a final composite index. The resultant values are often interpreted using categorical classifications such as "excellent," "good," "poor," or "unsuitable" for human consumption or ecological function (Abbasi and Abbasi, 2012).

Numerous studies have demonstrated the applicability of WQI in assessing both spatial and temporal variations in water quality. For example, Bordalo *et al.* (2001) utilized WQI to evaluate seasonal trends in surface water quality in Vietnam, highlighting the index's usefulness in identifying pollution episodes. Similarly, Sharma and Kansal (2011) applied the index to assess water quality along the Yamuna River in India, effectively pinpointing areas heavily impacted by anthropogenic activities and untreated wastewater discharges.

The primary strength of WQI lies in its ability to simplify and standardize the presentation of multi-parameter data, thereby improving the accessibility of water quality information across various stakeholder groups (Sutadian *et al.,* 2016). Several reviews have cautioned that WQI can potentially obscure specific pollutant impacts, particularly when high-risk contaminants are present at elevated levels but are diluted within an aggregated index value. Reviews by Akhtar *et al.* (2021a) and Kachroud *et al.* (2019) genuinely recommend adapting WQI frameworks to make them more sensitive to high-risk contaminants and to supplement them with additional assessments, ensuring that critical health hazards are not overlooked. Uddin et al. (2021) stated that WQI calculations may fail to reflect the true condition of water quality, particularly when improper weighting or sub-indexing is applied. This can result in the masking of hazardous pollutants within the overall index score, potentially leading to an underestimation of the health risks associated with elevated contaminant levels. Boyacioglu (2007) argued that while WQI is a valuable screening tool, it should not replace detailed parameter-specific assessments, especially where public health or environmental risks are concerned.

In the South African context, WQI has been adopted as a useful metric for evaluating the condition of water resources, especially in rural and peri-urban communities. Studies such as those by Fatoki

© University of Venda

and Awofolu (2003) and Edokpayi *et al.* (2015) have highlighted the index's utility in identifying water bodies at risk of contamination from domestic, agricultural, and industrial sources. Given the increasing threats posed by groundwater contamination, the proliferation of informal settlements, and the expansion of rainwater harvesting systems, the WQI remains a critical tool for water quality monitoring and environmental risk assessment in both developed and developing regions.

2.9.1 Types of WQIs

- **National Sanitation Foundation Water Quality Index (NSF-WQI)**

The NSF-WQI, developed in the early 1970s, is one of the most widely used indices globally. It includes nine core parameters: dissolved oxygen, faecal coliforms, pH, biochemical oxygen demand (BOD), temperature, phosphate, nitrates, turbidity, and total solids (Brown et al., 1970).

The mathematical expression of NSFWQI is given by:

$$WQI = \sum_{i=1}^{n} Q_i W_i \quad \ldots\ldots\ldots\

applicability across different regions (Sutadian *et al.,* 2016). One of its key strengths is its simplicity, the results are presented in a way that is easy for policymakers, stakeholders, and the general public to understand, thereby enhancing communication and awareness around water quality issues. However, the NSFWQI also has several limitations. It is not well-suited for addressing local or emerging contaminants, such as pharmaceuticals or specific heavy metals, which are becoming increasingly relevant in water quality management. Moreover, its use of equal or fixed parameter weighting may overlook site-specific environmental risks and priorities (Boyacioglu, 2007).

- **Oregon Water Quality Index (OWQI)**

The OWQI was created in the 1970s by the Oregon Department of Environmental Quality, USA, to provide a concise summary and evaluation of water quality assessment reports (Abassi and Abbasi, 2012). While the OWQI was specifically designed by the Oregon Department of Environmental Quality to assess the water quality of Oregon's streams, caution is advised when applying it to other geographic regions or different types of water bodies (Poonam *et al.*, 2013). The index focuses on eight parameters: temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), pH, ammonia and nitrate nitrogen NO_3 total phosphorus (TP), total solids, and faecal coliform. It was developed as an improvement on the NSFWQI, using the Delphi method for selecting variables. The OWQI reflects the overall water quality status and trends in line with legislatively mandated water quality assessments. Unlike some other indices, it avoids subjective weighting of parameters by applying the concept of harmonic averaging. The mathematical formula for calculating the OWQI is as follows:

$$WQI = \sqrt{\frac{n}{\sum_{i=1}^{n} \frac{1}{SI_i^2}}} \qquad \text{.....(2.2)}$$

Where:

n = number of sub-indices

SI_i = sub-index of i^{th} parameter

The WQI is ranked by relating it to the categories in Table 2.2.

© University of Venda

Table 2.2: OWQI ratings of water quality

WQI Value	Rating of water quality
90-100	Excellent
85-89	Good
80-84	Fair
60-79	Poor
0-59	Very

The OWQI presents several important advantages, particularly for ecological and regulatory applications. One of its primary strengths is its strong emphasis on ecological relevance, making it particularly effective in evaluating stream health and aquatic ecosystem integrity (Cude, 2001). The index also accounts for seasonal and temporal variability in its scoring process, which improves its accuracy in reflecting water quality trends over time. This feature makes it a valuable tool for regulatory compliance and long-term water quality monitoring. Additionally, the OWQI was specifically designed to support legislative water quality assessments, enhancing its utility for environmental policy and management. Despite these benefits, the OWQI also has limitations. It is not ideal for evaluating all types of water uses, such as drinking water quality and due to its focus on ecological indicators. Moreover, some of the selected parameters may not be relevant in regions facing different environmental challenges or stressors, reducing its transferability. Lastly, its adoption outside the United States remains limited when compared to more globally recognized indices like the NSFWQI or Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) (Boyacioglu, 2007).

- **Weighted Arithmetic Water Quality Index (WAWQI)**

The WAWQI applies weights to each parameter based on its perceived importance and calculates a score through a weighted arithmetic mean (Ramakrishnaiah *et al.*, 2009). It assesses and categorizes water quality by quantifying the degree of purity through the integration of commonly measured physicochemical parameters, providing a comprehensive evaluation of overall water condition.

According to Akoteyon *et al.* (2011), the WAWQI offers several advantages, including its ability to integrate multiple water quality parameters into a single numerical value that reflects the overall

© University of Venda

health status of a water body. It requires fewer parameters for assessment compared to evaluating all individual parameters for a specific use, making it more efficient. Additionally, WAWQI serves as an effective tool for conveying comprehensive water quality information to stakeholders, such as the general public and policymakers. Furthermore, it captures the combined effects of various key parameters essential for effective water quality assessment and management, and is capable of determining the suitability of both surface and groundwater sources for human consumption.

The WAWQI may not fully reflect the true complexity of water quality since it compresses multiple water quality parameters into a single number, potentially oversimplifying or masking specific water quality issues (Yogendra and Puttaiah, 2008). Important parameters are sometimes omitted, leading to incomplete assessments (Yogendra and Puttaiah, 2008). Additionally, WAWQI scores can be disproportionately influenced by a single poor parameter, skewing the overall water quality interpretation (Tyagi *et al.*, 2013). The selection and weighting of parameters tend to be subjective, resulting in inconsistent outcomes between studies (Horton, 1965; Sahu and Sikdar, 2008). Furthermore, WAWQI does not provide insight into pollution sources or causative factors, limiting its application for targeted water quality management (Simeonov *et al.*, 2003). Lastly, it may lack sensitivity to detect small but ecologically significant changes in water quality over time (Brown *et al.*, 1970).

A typical WQIs methodology, which is founded on common key factors, is outlined by Tyagi *et al.* (2013) and involves the following steps:

- **Parameter selection**

  The evaluation is conducted through the expertise of professionals, organizations, or government bodies authorized within the legislative framework. Parameters are chosen according to five categories: oxygen content, eutrophication, health-related factors, physical properties, and dissolved substances, all of which significantly influence water quality

- **Determination of quality function (curve) for each parameter considered as a sub-index**

  Sub-indices are converted into dimensionless values from variables with varying units, based on the water quality standards specific to each country.

- **Sub-indices aggregation with mathematical expression**

  It is frequently utilized through arithmetic or geometric averages.

- **Calculation of sub-index of quality rating *(Q_n)***

Q_n is a number reflecting the relative value of the water quality parameter with respect to its standard permissible value. The value of Q_n is calculated using the following expression;

© University of Venda

$$Q_n = 100\ \left(\frac{V_n - V_{io}}{S_n - V_{io}}\right) \quad (2.3)$$

Where Q_n = is the quality rating for the n^{th} water quality parameters,

V_n = is the measured value of the n^{th} parameter at a given sampling station.

S_n = is the standard permissible value of the n^{th} parameter

V_{io} = is the ideal value of the n^{th} parameter. In most cases $V_{io} = 0$ except in certain parameters like pH which is 7 (Pathak *et al*., 2015).

- **Calculation of unit weight *(W_n)***

W_n for various water quality parameters is inversely proportional to the recommended standards for the corresponding parameters.

$$W_n = \frac{k}{S_n} \quad (2.4)$$

Where W_n= unit weight for the n^{th} parameters

k = proportional constant

Where $k = (1/(1/\sum_i^n si))$ (2.5)

S_n=standard permissible value for the n^{th} parameter.

- **Calculation of WQI**

Equation 2.9 is based to calculate WQI:

$$WQI = \frac{\sum_{n=1}^{n} q_n w_n}{\sum_{n=1}^{n} w_n} \quad (2.3)$$

The variables are as defined in Equations 2.3 and 2.4. The WQI is determined and be ranked by relating it to one of the categories in Table 2.3.

© University of Venda

Table 2.3: WAWQI for water quality

WQI value	Rating of water quality
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very poor
Above 100	Unsuitable

2.10 Health risk assessment

Risk assessment can be defined as determining the probability of potentially harmful effects over time (Bempah and Ewusi, 2016). Health risk assessment is conducted to assess the overall exposure of individuals in a specific area due to certain contaminants in water, air and soil. Humans can be exposed to harmful effect through various pathways including ingestion, inhalation and dermal exposure. Swallowing contaminated soil and water is a major exposure route for contaminants, especially for children and those residing or working in polluted areas. Contaminants that enter the body through the skin are known as dermal exposures. This exposure route is especially significant for individuals who have direct contact with contaminated soil, water, or surfaces.

Exposure to hazardous substances, particularly through drinking water, soil, food, and air, can result in long-term health complications. The health of human and also of the environment is threatened by heavy metals (Rai *et al*., 2019). Heavy metals are of particular concern due to their non-biodegradability, bioaccumulative nature, and potential toxicity, even at low concentrations (Devi and Kumar, 2020). Chronic exposure to heavy metals, such as As, Cd, Pb, and Hg, has been linked to severe health conditions, including neurological disorders, kidney damage, and cardiovascular diseases (Balali-Mood *et al.,* 2021). The health risk is determined by estimating the level of risk and it can be grouped into carcinogenic and non-carcinogenic (Dorne *et al.*, 2010; Mohammandi *et al.,* 2019). Carcinogenic risk assessment evaluates the probability of developing cancer due to exposure to hazardous substances over a lifetime. Non-carcinogenic risk assessment examines potential health impacts unrelated to cancer, including adverse effects on neurological function, kidney health, and cardiovascular system (Marufi *et al.,* 2024). There are two toxicity risk indices that are used to assess health risks. These are the cancer slope factor (CSF) and the oral reference dose (RfD) for non-cancer risk characterization (Adamu *et al.,* 2015;

© University of Venda

Kamuda *et al.*, 2016). The CSF is used to estimate the probability of an individual developing cancer over a lifetime due to exposure to a carcinogenic substance, while the RfD represents the estimated daily exposure level of a substance that is unlikely to pose significant health risks over a lifetime (USEPA, 2004).

The evaluation of health risks is a crucial method to evaluate possible health impacts in water due to various contaminants (Xiao *et al.*, 2017; Mohammandi *et al.*, 2019). To evaluate health risks, it is crucial to assess water quality as well. Understanding the potential human health impacts of contaminants present in drinking water is a key component of this assessment. This involves comparing the detected contaminant levels with established drinking water guidelines set by regulatory authorities such as the WHO, DWAF, SANS, and United States Environmental Protection Agency (USEPA) (Hashmi *et al.*, 2014).

2.11 Summary

This chapter provided a comprehensive review of the literature relevant to the study, focusing on essential aspects of physical, microbiological, and chemical water quality parameters. It also discussed the analytical instruments employed for water quality assessment, the current status of water quality in rural areas, potential contaminants, and the impact of water quality on human health. WQIs and its various types were examined in terms of their structure, purpose, advantages, and limitations. Furthermore, the chapter highlighted the evaluation of health risks linked to the presence of heavy metals in water. The following chapter will outline the research methodology.

© University of Venda

CHAPTER THREE: METHODS AND MATERIALS

3.1 Preamble

This chapter covers data collection water sampling procedures, sample analysis methods, and the health risk assessment procedures.

3.2 Water pollutants related to domestic water supply

Field survey was undertaken to identify potential pollutants located within the vicinity of water sources in the study area. The survey also included the identification of main sources of in the study area. Any activities that can potentially contaminate the water sources were identified and noted.

3.3 Water sampling

The samples of water from Matatani Village were collected from 5 different sources that the residents use for their domestic uses (Figure 3.1) and rainwater from 4 types of roofing was also collected because the residents also harvest water it for use (Figure 3.2). The sources are borehole 1 (BH1), borehole 2 (BH2), Mutale River (upstream and downstream), a spring and a municipal tap. Groundwater and river water samples were collected for a period of 6 months, 3 months during the wet season (December 2023 to February 2024) and 3 months during the dry season (March 2024 to May 2024) to establish the seasonal variations. The municipal tap was only sampled in February 2024 and March 2024 because in other months water was not available. Spring was only sampled in April 2024 because during the preliminary site visits it was not identified, in May it was not sampled because it was not accessible. The BH2 was not sampled in March 2024 because it was non-functional. A total of 12, 10, 12, 12, 4 and 2 samples were collected from BH1, BH2, upstream, downstream, municipal tap and spring, respectively. Rainwater from concrete tiles, grass roofing, corrugated sheets, and metal Harvey tile roof types was sampled during the wet season. A total of 24 samples were collected in December 2023, January 2024 and March 2024 for rainwater; each roof type had two samples collected every month. All samples were collected using sterile 250 ml water bottles. The physical, microbial and chemical water quality parameters were determined for all the samples. However, microbial parameters were not analyzed for rainwater as it was not possible to reach the laboratory within the recommended time of 6 hours after sample collection.Parameters that were analysed were selected based on that they are of concern for domestic water supply following the DWAF *et al.*, 1998.

© University of Venda

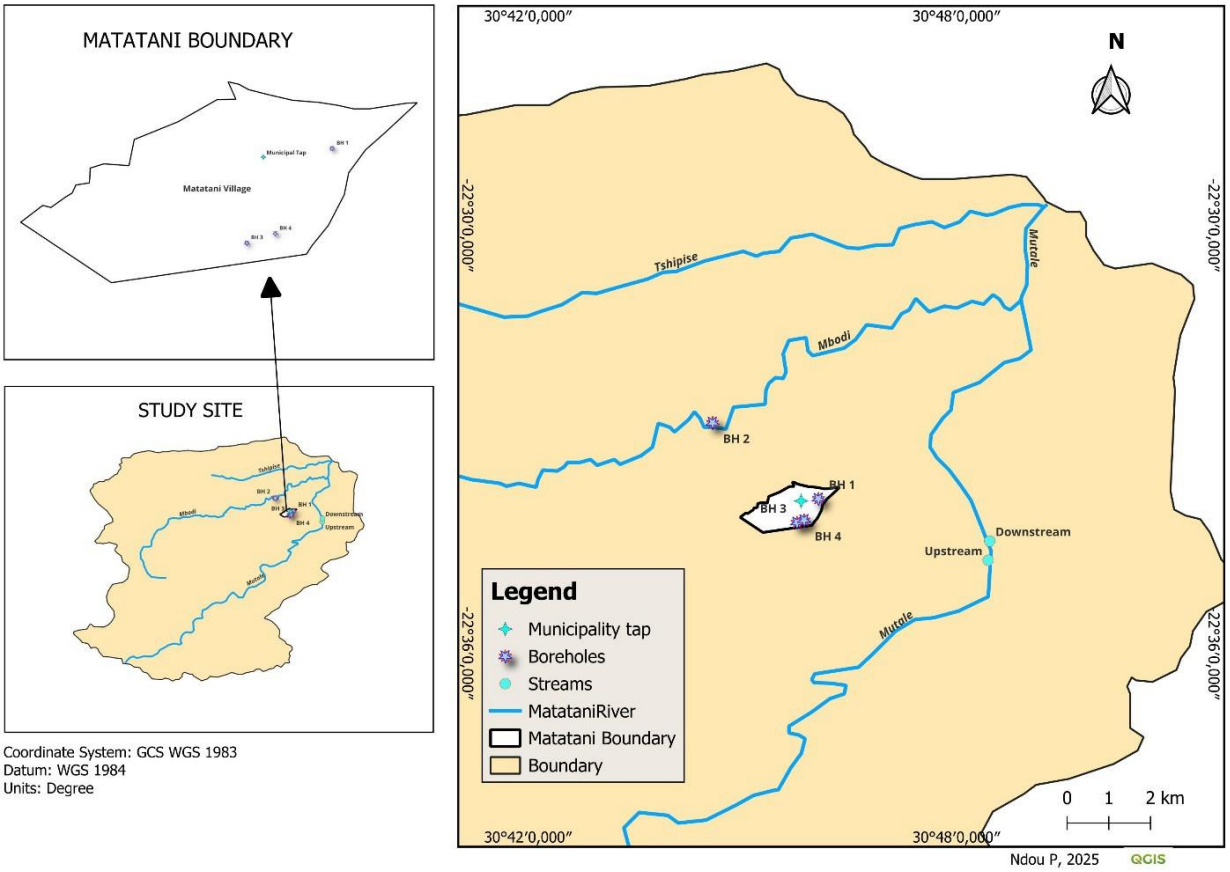


Figure 3.1: Map of the sources of the study area

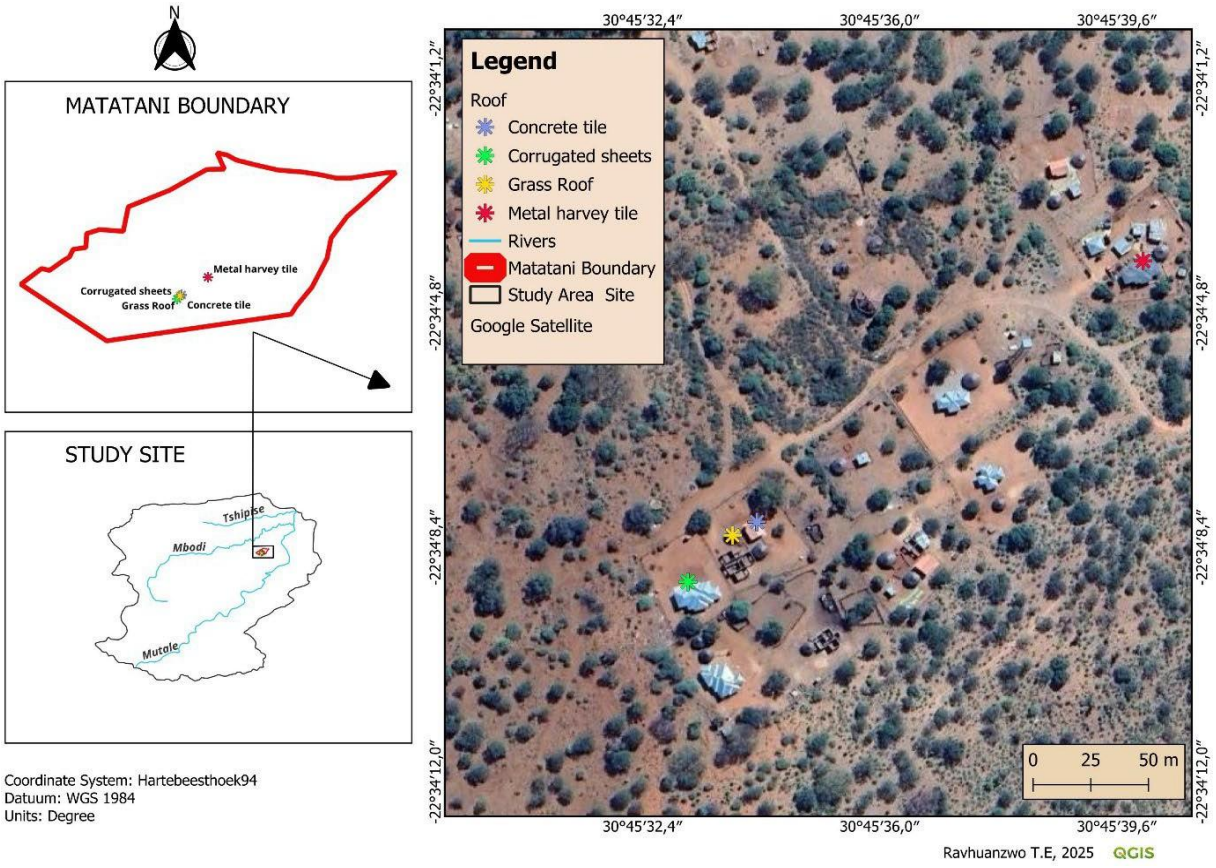


Figure 3.2: Roof types for rainwater harvesting

© University of Venda

3.3.1 Samples quality control

The samples were stored in a cooler box with ice and transported to the Hydrology and Water Resources Laboratory at the University of Venda, where they were kept at 4°C in a refrigerator prior to analysis. Microbial parameters were analyzed within six hours of collection, with one sample being analyzed twice to ensure reliability. To preserve the integrity of the trace metals, the samples were acidified with 3 ml of concentrated nitric acid (HNO_3) before analysis. All metal and non-metal analyses were conducted in triplicate to enhance the accuracy and reliability of the results.

3.4 Analysis of water quality parameters

3.4.1 Measurement of physical quality water parameters

The pH, EC, and TDS were measured on-site using a multi-parameter water quality probe (GPS Aquameter 200, Aquaread Ltd., Broadstairs, United Kingdom). Turbidity was measured on site using a turbidity meter (Model TB 400, Exstek Instruments, Taiwan). All equipment were calibrated according to the manufacturer's guidelines. On-site measurements of the physical water parameters are crucial, as these values can quickly change after sampling from the aquifer

3.4.2 Metals analysis

- **Samples pre-treatment**

The samples were pre-treated with concentrated nitric acid (HNO_3) in a fume hood, by the procedure outlined by Ogola *et al.* (2023). Following digestion, the solution was filtered and stored under refrigerated conditions, with analysis performed within a few weeks.

- **Analysis procedure**

The sample preparation involved digesting the samples using a Digestion Microwave Mars One (CEM) in order to transform complex samples into a form that allows for reliable, accurate quantification of metals or other elements. The collected water samples were prepared for trace metal analysis through microwave-assisted digestion using a Mars 6 Microwave Digestion System (CEM Corporation, Matthews, NC, USA). For each sample, 50 mL of water was placed into Teflon digestion vessels, followed by the addition of 5 mL of concentrated nitric acid (65% HNO_3) and 2 mL of hydrogen peroxide (30% H_2O_2). The vessels were securely sealed and subjected to a controlled digestion program consisting of a temperature ramp to 180 °C over 10 minutes, a hold time of 15 minutes at 180 °C, and a maximum pressure limit of 800 psi. Following

© University of Venda

digestion, samples were allowed to cool for 10 minutes before being filtered through a 0.45 µm membrane filter. The filtered digested sample was then diluted to a final volume of 50 mL using deionized water, preparing them for subsequent instrumental analysis. All apparatus were sterilized using sterile water. After digestion, the sample was removed from the centrifuge tube and transferred to a smaller vessel for ICP-OES analysis.

The ICP-OES (Model Optima 8000, PerkinElmer Inc., and Waltham, MA, USA) was used to analyze metals. The calibration of the instrument was performed using eight working standards from a multi-element calibration standard IV for ICP-OES, targeting Cu, Mn, Fe, Cd, As, Zn, and Pb. The ICP-OES system was calibrated by introducing the standards into the plasma, allowing the system to record the emission intensities at the specific wavelengths for each element. The calibration curves were generated by plotting the known concentrations of each standard against their corresponding emission intensities. The analytical procedure was validated through the regular analysis of both standards and blanks. A blank sample, typically deionized water, was used to zero the instrument and account for any potential baseline drift or interference. Furthermore, an ICP multi-standard solution (1000 ppm) for K, Ca, Mg, and Na was prepared using NH_4OAc to ensure the accuracy of the instrument's calibration and quantification.

3.4.3 Non-metal analysis

- **Sample preparation and measurement**

After sample collection, turbid samples were filtered through a 0.45 µm membrane filter to remove suspended solids. A 10 mL aliquot of each filtered sample was transferred into a clean cuvette, and the appropriate reagent for each non-metal parameter was added and thoroughly mixed. Each analyte was analyzed using specific reagent-based colorimetric methods, mercuric thiocyanate for Cl, sodium 2-(parasulfophenylazo)-1, 8-dihydroxy-3, 6-naphthalene disulfonate (SPADNS) for F, turbidimetric method for sulphate (SO_4), and ascorbic acid method for phosphate (PO_4). After reagent addition, the reaction was allowed to develop for the specified time to produce a measurable color change. The treated sample was then transferred into a clean cuvette, ensuring it was free of air bubbles and fingerprints. The cuvette was placed in the DR 3900 laboratory spectrophotometer (Model DR 3900, Hach Company), where absorbance was measured at the designated wavelength for each analyte.

Water quality parameters including PO_4, SO_4, and F were determined following standard Hach Method protocols. PO_4 at 890 nm using the ascorbic acid method, SO_4 at 450 nm using the

© University of Venda

turbidimetric method, and F at 570 nm using the SPADNS method. For each parameter, reagents were added to 10 mL of the filtered sample, mixed thoroughly, and incubated for the required reaction time before absorbance readings were taken to quantify the analytes.

- **Analysis procedure**

Non-metals, including F, Cl, SO4, and PO4, were analyzed using the laboratory spectrophotometer (Model DR 3900, Hach Company, Loveland, CO, USA). The instrument was calibrated using a certified standard solution to ensure accurate measurements. The calibration involved the preparation and analysis of a series of standard solutions at various concentrations. The calibration standard solutions s for each analyzed parameter are in Table 3.1. Before analysis, the instrument was standardized by measuring a blank sample of deionized water to establish the baseline reading. The standard was then analyzed at its respective wavelength and the calibration was generated by plotting the absorbance against concentration and placed in the spectrometer, and the zero button was pressed to establish the baseline. To maintain the measurement precision and instrument reliability, the periodic verification was performed using the intermediate standard solution.

Table 3.1: Calibration standard solutions for non -metals

Parameter	Calibration standard solution (mg/L)
Cl	10, 50 and 100 of sodium chloride (NaCl)
F	0.2,1.0 and 2.0 of sodium fluoride (NaF)
SO_4	10, 50 and 150 of sodium sulfate (Na_2SO_4)
PO_4	0.1, 0.5 and 1.5 potassium dihydrogen phosphate (KH_2PO_4)

3.5 Microbiological analysis

The membrane filtration technique was utilized to analyze *E. coli* and TCs in the water samples. During this process, the filtration cups were placed in a water bath with distilled water and they were boiled until 100°C. The beaker tongs were then used to remove the filtration cups, and they were placed in a filtration unit to cool them and avoid burning the filter paper. The filtration cups were then removed one by one and placed on filter papers having a diameter of 0.45 µm. These were then returned to the filtration unit. A filtration unit, combined with a vacuum pump, was utilized to filter 100 mL from each sample. For surface water only, 10 ml of the sample was used together with 90 ml of distilled water, and for groundwater 100 ml from the samples was used to

© University of Venda

together with 90 ml of distilled water, and for groundwater 100 ml from the samples was used. After filtering the filter papers, petri dishes were placed, and agar (m-ColiBlue24 Broth) was poured into the petri dishes then filter papers were arranged in the petri dishes with agar (m-ColiBlue24 Broth). The petri dishes were incubated 24 hours then they were removed to count the colonies that had grown and the colonies were estimated manually using the most probable number method.

3.6 Determination of WQIs

The water quality parameters outlined in Section 3.5 were utilized in the development of the WQIs. As discussed in that section, these parameters are significant for human health and reflect the general quality standards necessary for domestic water use. For the development of the Simplified Water Quality Index (SWQI), only metal and non-metal parameters with complete data from previous studies were included.

- **Calculation of the sub-index (Qn) for the nth water quality Parameter**

This step involved creating a rating curve, or sub-index, to standardize and compare each parameter by transforming them onto a common scale. The sub-indices were derived using analyzed data from various water sources referenced in both past and current studies. These values were then compared against the maximum allowable limits set by DWAF (1996) and SANS 241 (2015). The selected water quality parameters were converted into their respective sub-index values using Equation 2.1, which is detailed in Sub-section 2.9.1 of Chapter 2.

- **Calculation of unit weight (Wn)**

The Wn represents the relative importance of each water quality parameter in the overall assessment. It is determined by calculating the ratio between a constant of proportionality and the standard permissible value for the nth parameter. These weights were computed using Equation 2.2, as explained in section 2.9.1 of Chapter 2, and ensure that parameters with greater health significance have a higher influence on the final index score

- **Aggregation of sub-indices to obtain the final index score**

The overall WQI was obtained by linearly aggregating the sub-indices (quality ratings for individual parameters) with their corresponding unit weights, following the procedure outlined in Equation 2.3, as detailed in sub-section 2.9.1 of Chapter 2. This approach provides a single numerical value that reflects the overall status of water quality. The classification of water quality

© University of Venda

based on WQI values is presented in Table 2.3. The WQI was interpreted with respect to suitability for human consumption and domestic use, with a score of 100 representing the maximum permissible value for drinking water quality.

3.7 Health risk assessment procedures

There were no health effects associated with non-metals as they were all within recommended standards. As such it was not necessary to assess their health risks. Health effects of microbial parameters were inferred from water quality guidelines (DWAF, 1996; SANS 241, 2015).

3.7.1 Non-carcinogenic risk assessment procedures

The water quality parameters analyzed were compared to the DWAF (1996) and SANS 241 (2015) guidelines for domestic use to evaluate the suitability of the water and identify potential health risks. To assess the non-carcinogenic risks through ingestion of water, Mg, K, Ca, Zn, Fa, Ca, Na, Mn were considered. The ADDingestion, HQ and HI were calculated to assess the potential non-carcinogenic effects for adults and children following the procedures described in USEPA (1989), Edokpayi et al. (2018a) and Mohammadi et al. (2019). The risk assessment evaluates the potential carcinogenic and non-carcinogenic risk for adults and children by assimilating all collected data to get a quantitative estimate of cancerous risk and hazard indices (USEPA, 2004). The non-carcinogenic risk is determined using the USEPA methodology, where the hazard index (HI) is computed as the sum of the hazard quotients (HQs).This method is employed to evaluate the potential non-carcinogenic health effects of exposure to metals found in water. The guidelines for this assessment are outlined in the EPA's health risk assessment procedures (Huang *et al.*, 2008; Bamuwamye *et al.*, 2015; Mohammadi *et al.*, 2019). The HI is computed using Equation 3.1.

$$HI = \sum_{n=1}^{n} HQ \quad \text{..... (3.1)}$$

The calculated HI is then compared to standard values provided by the EPA to determine the potential for non-carcinogenic effects on the population. The HQ is computed using Equation 3.2

$$HQ = \frac{ADD_{ingestion}}{RfD} \text{..... (3.2)}$$

The RfD represents the highest daily intake of a metal from a particular exposure route that is considered safe for sensitive individuals over their lifetime without causing adverse health effects. (Qing *et al.*, 2015). The ADD is the average daily dose in mg/kg/day.

© University of Venda

The HQ assesses the likelihood of adverse health effects in humans (Jiang *et al.*, 2020). The HQ should be < 1 to be within acceptable limits of non-carcinogenic risks. The HQ > 1 indicates the risk of causing adverse health hazards on humans (USEPA, 2011). Equation 3.3 is used to estimate $ADD_{ingestion}$ adverse health hazards on humans (USEPA, 2011). Equation 3.3 is used to estimate $ADD_{ingestion}$ (USEPA, 1989; Dashtizadeh *et al.*, 2019; Madilonga *et al.*, 2021).

$$ADD_{ingestion} = \frac{cf \times DI \times EF \times ED}{BW \times AT} \quad \text{.....} \quad (3.3)$$

Where:

Cf is the average metal concentration (mg/kg) in water.

DI refers to the daily intake (kg/day).

EF is the exposure frequency in days/year

ED is the exposure duration in years

BW is the mean body weight of the person (kg).

AT is the average time in days.

For this study, values adopted in the calculations the DI, EF, ED, BW and AT were adopted from USEPA (1989), Edokpayi *et al*. (2018a) and Madilonga *et al.*, 2021) (Table 3.2). The HQ was calculated following USEPA (1989), Edokpayi *et al*. (2018), and Mohammadi *et al.* (2019). The HQ should be lower than 1, if it is higher, this indicates that there are possible health risks effects of non-carcinogenic health effects. Similarly, the H1 should be less than 1 so that people do not experience the adverse effects of non-carcinogenic substances. If it is greater than 1, people are at a risk of contracting non-cancerous health effects.

Table 3. 2 Adopted values for non-carcinogenic health risk assessment

Value	Adults	Children
DI (L/day)	2.2	1.8
BW (kg)	70	15
ED (years)	70	6
EF (days/year)	365	365
AT (days)	365×70	365×6

3.7.2 Carcinogenic risk ($CR_{ingestion}$)

The $CR_{ingestion}$ was calculated using the ADD and the CSF. The parameters As, Cd, and Pb were considered in the calculation of $CR_{ingestion}$. These metals are classified as priority elements and are

© University of Venda

recognized for their ability to cause organ damage, even at low concentrations. These metals are also regarded to be cancerous by Tchounwou *et al.* (2012). The CSF_s for As, Cd, and Pb of 1.51, 8.5 and 6.1, respectively were adopted from studies by Chen *et al.* (2021) and Mohammadi *et al.* (2019). According to Kumar *et al.* (2024), a $CR_{ingestion}$ of a value below 10^{-6} indicates no significant risk, while values ranging from 10^{-6} to 10^{-4} are considered within acceptable limits of carcinogenic risk. Conversely, values exceeding 10^{-4} suggest a potential risk of cancer.

The carcinogenic risk is calculated using Equation 3.4 which is to assess the carcinogenic risk (USEPA, 1989; Madilonga *et al.*, 2021)

$$CR_{ingestion} = \frac{ADD}{CSF} \quad \text{..... (3.4)}$$

Where:

$CR_{ingestion}$ is the cancer risk by ingestion in mg/kg/day

3.8 Summary

This chapter offers detailed description of the methodology used to conduct the study and achieve its objectives in Matatani Village. It provides details on where the samples were collected, handled after collection, prepared for analyses, the instrument used to analyze. It also outlines the procedures used for analyzing the collected data. The next chapter presents the results and discusses the findings.

© University of Venda

CHAPTER 4: RESULTS AND DISSCUSSION

4.1 Preamble

This chapter presents and discusses the results of identified water sources and their potential pollutants, assessed water quality status in comparison to drinking water quality standards established by organizations like SANS 241 (2015) and DWAF (1996). Health risk assessment results are also presented and discussed.

4.2 Water sources available and identified potential pollutants

The identified sources of water in Matatani Village include boreholes, springs, municipal taps, rainwater and Mutale River (Figure 4.1). BH1 (Figure 4.1) is the most preferred water source. BH2 (Figure 4.1) is in Mbodi Village and has a water supply line to Matatani Village. Residents of Mbodi and Matatani Villages were supposed to share this water source. Water is supplied to Matatani by gravity only after the Mbodi pipeline is fully fed. However, this process is challenging as it typically takes over five hours to fill the water supply tank, after which water is distributed to the Mbodi pipelines. As a result, residents of Matatani Village often face difficulties in accessing water from this source. Water from the municipal tap is from the Nwanedzi water supply scheme and it is mostly available once in every 6 months due to schemes difficulties.

There are two boreholes that are not functional which are BH3 and BH4 (Figure 4.2). BH3 was drilled in the 1980s and it is nonfunctional. BH4 was drilled in 2014 and operated until 2018, the pump just stopped working. It used to supply water to the Matatani residents through a reservoir. There is a spring in (Figure 4.2) which is inaccessible due to their cultural beliefs. In Matatani Village there are four types of roofing materials that are used. Residents harvest rainfall water from the grass roofing, corrugated sheets, concrete tile and metal Harvey tile (Figure 4.3).

© University of Venda



Municipal tap



Spring 1



BH1



BH2



Mutale River

Figure 4.1: Functional water sources of the study area

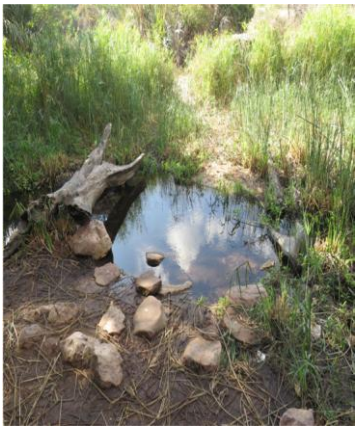
© University of Venda



BH3



BH4



Spring 2

Figure 4.2: Non-functional water sources of the study area



Grass roofing



Concrete tile roofing



Corrugated sheets roofing



Metal Harvey tile

Figure 4.3: Identified roof types of rainwater

Livestock (Figure 4.4) frequently drink from the river and excrete their waste (cow dung) and contaminate the water with potential to cause microbial contamination and increased nutrients levels. Figure 4.5 (a and b) indicate variations of the state of the river during the dry and wet seasons. Clearer water is observed during the dry seasons while river is seen to be turbid during

© University of Venda

the dry season. This is because water sediments from upstream are transported and deposited into the downstream point. The sediments likely carry contaminants from upstream area to downstream area. Residents also bath and wash clothes in the downstream point of the river thereby introducing pollutants such as soap scum. Figure 4.6 shows white soap scum which is evidence of washing clothes in the river. This potentially introduces chemical contaminants in water.



Figure 4.6: Washing and bathing area in the downstream point of Mutale

The area where the spring is located (Figure 4.7), is protected by a fence so there are no animals that can enter and contaminate the water. There is therefore no observed direct potential contamination of the spring. However runoff from the upstream may be drained into the open spring since it is located at a lower elevation with potential to contaminate it. In addition the geological rocks within the environment where the spring originates has potential to contaminate the spring water through rock-water interaction. BH2 is located near a potential pollution source which is the cattle dipping station (Figure 4.8a). Inside the dipping area, they use chemicals and cows also excrete their cow dung around the area. The chemicals used and the cow dung are likely to be transported by runoff to the lower elevation which may be the recharge point that can introduce potential contaminants into groundwater.

© University of Venda



Figure 4.7: Potential contaminants for the spring

Stagnant water as observed in (Figure 4.8b) is a potential source of pollution. The waste dump may attract diseases vectors and flies and rodents which may increase the risk for animals (Figure 4.8c). When rainwater infiltrates the waste dump it may dissolves harmful substances. BH1 is located at a lower elevated area than the residential areas. For example pit latrines from Matatani primary School are located at a higher elevated area than BH1 (Figure 4.9a). Most residents use pit latrines and contaminants can therefore be transported or recharged into groundwater especially during the wet season. An overview of the furthest households to BH1 (Figure 4.9b) shows that households are located at higher elevation compared to the location of BH1.



Figure 4.4: Potential water contaminants for the upstream point of Mutale River

© University of Venda



(a) Downstream area during the dry season



(b) Downstream area during the wet season

Figure 4.5: Potential contaminants for the downstream point of Mutale River

© University of Venda



(a) Fence around dipping station



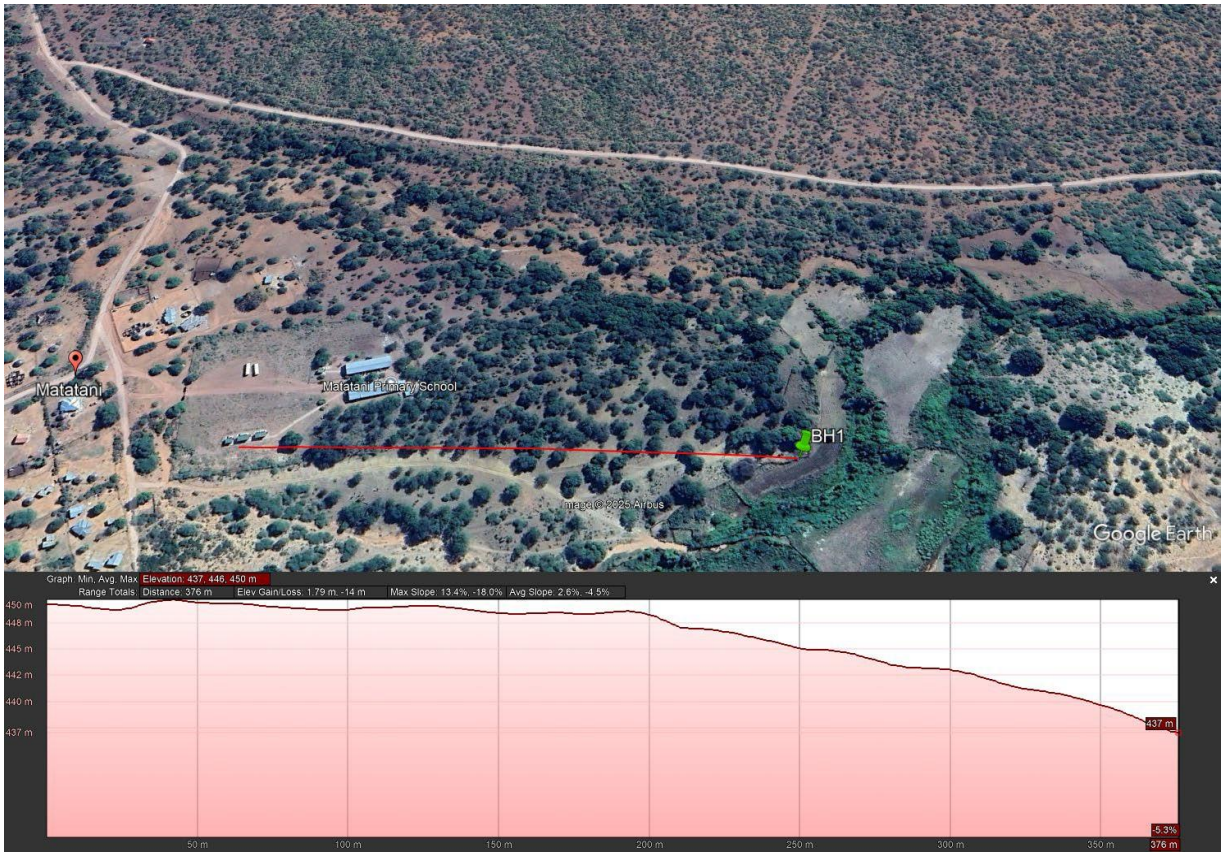
(b) Stagnant water in the dipping station



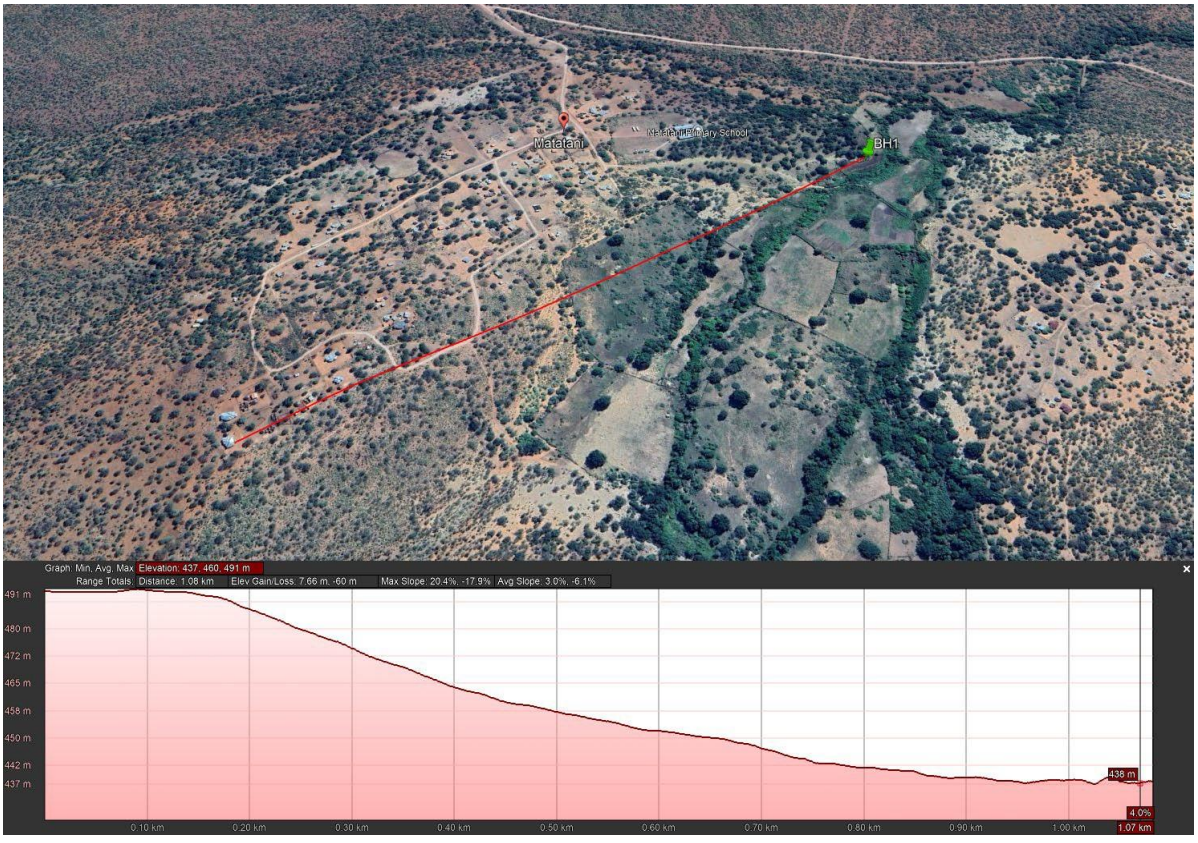
(c) Waste dump closer to the dipping station

Figure 4.4: Potential contaminats for BH2

© University of Venda



(a) Elevation from Matatani Primary school pit latrine toilets to BH1



(b) Overview of the elevation of the entire village to BH1

Figure 4.5: Elevation maps for BH1

© University of Venda

4.3 Water quality results for river water and groundwater

4.3.1 Physical water quality parameters

Appendices 1 and 2 present the physical water quality parameters for both the wet and dry seasons. The pH values of all water samples remained within the recommended guidelines of 6-8.0 (Figure 4.10). The pH values were between 6.31 and 8.53 from December 2023 to March 2024. In general, a lower pH value corresponds to a higher level of corrosion. An acidic pH promotes elevated concentrations of toxic and heavy metals in water (OB and Muchie, 2010). The pH of water does not directly impact human health. Mpenyana-Monyatsi and Momba (2012) recorded pH values were higher ranging from 6.5 to 9.1 in Northwest Province in South Africa. Elevated pH values can result in a bitter taste, promote scaling and encrustation in pipes and appliances, and reduce the efficiency of chlorine disinfection in water treatment. Water with a lower pH value corrodes and dissolves metals. For humans, a pH value of 7.0 is considered ideal, although a permissible range of 6 to 9 is acceptable (DWAF, 1996).

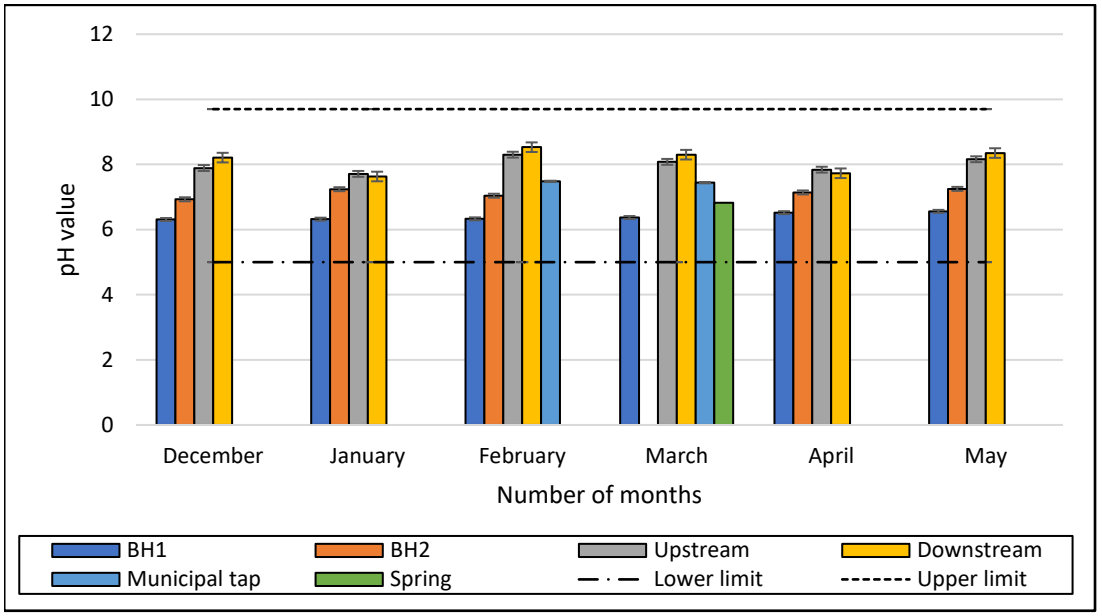


Figure 4.6: pH values for groundwater and river water

Turbidity (Figure 4.11) ranged from 0 NTU- 76.67 NTU during both the wet and dry seasons, it varied within a range of 0 NTU- 74.33 NTU. Water from upstream and downstream of Mutale River had the highest turbidity of 63 NTU in December. According to DWAF (1996), safe drinking water typically has a turbidity level below 1 NTU, as higher levels could suggest contamination. Oputu and Akharame (2022) stated elevated turbidity levels in surface water are

© University of Venda

typically a result of human activities, this makes the water inappropriate for drinking and domestic use. The highest turbidity was for water from BH1 (76.67 NTU) during the wet period. This may be seasonal factors like runoff affecting water in these months. The highest value during the dry period was also recorded in BH1 (74.33 NTU). The use of a hand pump can lead to water contamination due to corrosion, which may release metals or other harmful substances into the water (Palamuleni and Akoth, 2015). A plausible explanation for the high turbidity observed in water from BH1 could be the corrosion associated with the use of a hand pump, which may introduce particulates into the water.

According to Palamuleni and Akoth (2015), corrosion can weaken the hand pump, making it more permeable and enabling soil particles to enter the water, leading to elevated turbidity levels. Groundwater turbidity is mainly caused by colloidal particles, including bacteria, viruses, soil particles, and colour-producing substances derived from both organic and inorganic sources (Edokpayi *et al.* 2018a). Water from BH2 consistently had very low turbidity levels, mostly close to or below the guideline, indicating clear water making it a reliable source of water. Higher turbidity values were recorded at Dzindi River, Limpopo Province by Edokpayi *et al*. 2014. Edokpayi *et al*., (2018c) also recorded high values of turbidity at Nzhelele River, Limpopo South Africa while evaluating microbial and physiochemical parameters of alternative sources of drinking water, the values varied from 1.12-739.9 NTU. In a study conducted at Buffalo River in the Eastern Cape Province, South Africa, turbidity levels exceeded the maximum limit recommended by DWAF (Chigor *et al*., 2013). Chidrawar (2020) stated that high values of turbidity indicate that the water contains clay, silt, and fine organic matter and microscopic organisms.

© University of Venda

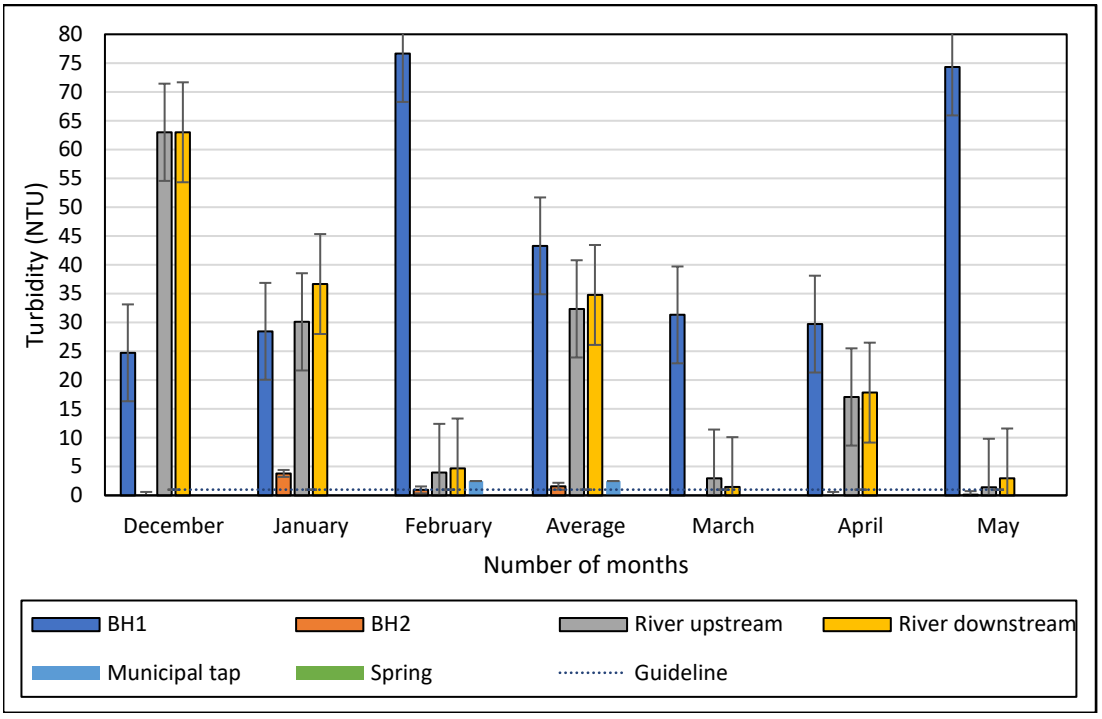


Figure 4.7: Turbidity values for groundwater and river water

In this study (Figure 4.12) all sources adhered to the regulatory guidelines for drinking water, with all measured samples ranging from 3.53 - to 1284.67µs/cm. The EC is regarded as a key parameter for evaluating drinking water quality (Islam *et al.*, 2020). According to SANS 241 (2015), the suitable EC for drinking water should be ≤ 1700 $\mu s/cm$. It acts as a dependable indicator of the total salinity or the overall concentration of dissolved solids in water. While it does not give specific details about the ionic composition, it is useful for assessing the water's suitability for drinking purposes.

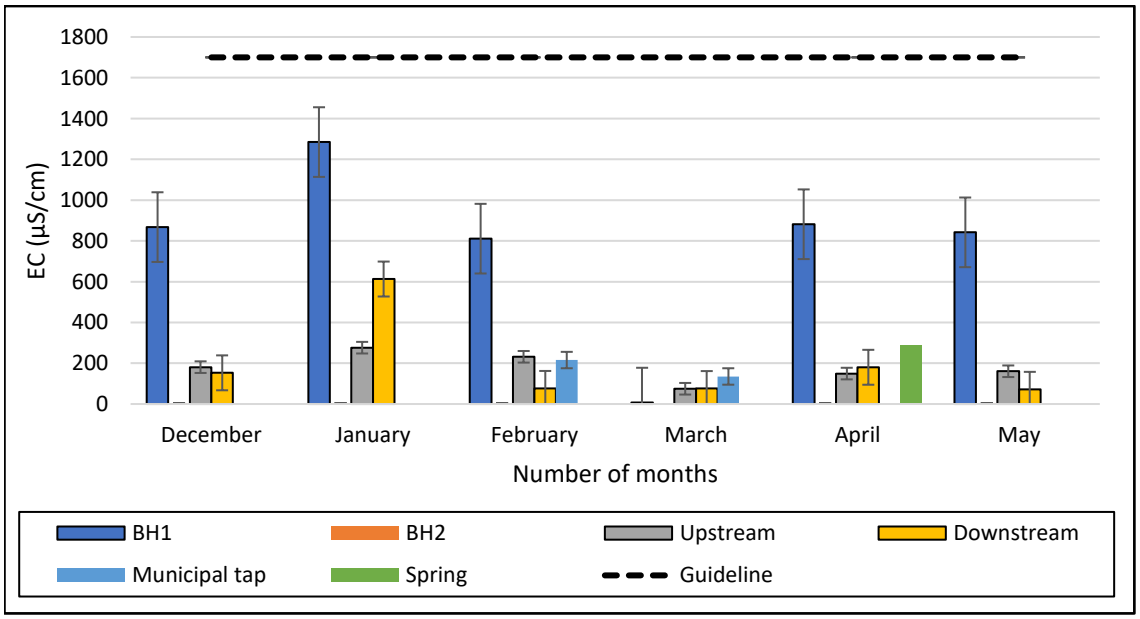


Figure 4.8: EC values for groundwater and river water

© University of Venda

The recorded TDS values (Figure 4.13) ranged from 2.71 to 988 mg/L during the wet season and from 2.54 to 624 mg/L during the dry season. The highest values exceeding the guideline in all the months recorded were recorded in water from BH1, with the highest value of 988 mg/L in February 2024 showing that the water is not good for consumption. DWAF (1996) recommends a TDS value of ≤ 450 mg/L for water to be considered suitable for drinking. Seth *et al.* (2016) stated that high TDS levels in water suggest that the water is rich in minerals, and they impact the water's taste, hardness, and corrosive nature, making it unsuitable for drinking. Elevated TDS levels decrease the palatability of water and can lead to gastrointestinal irritation in consumers and its long-term consumption of water in high content may also contribute to the formation of kidney stones (Abel, 2022).

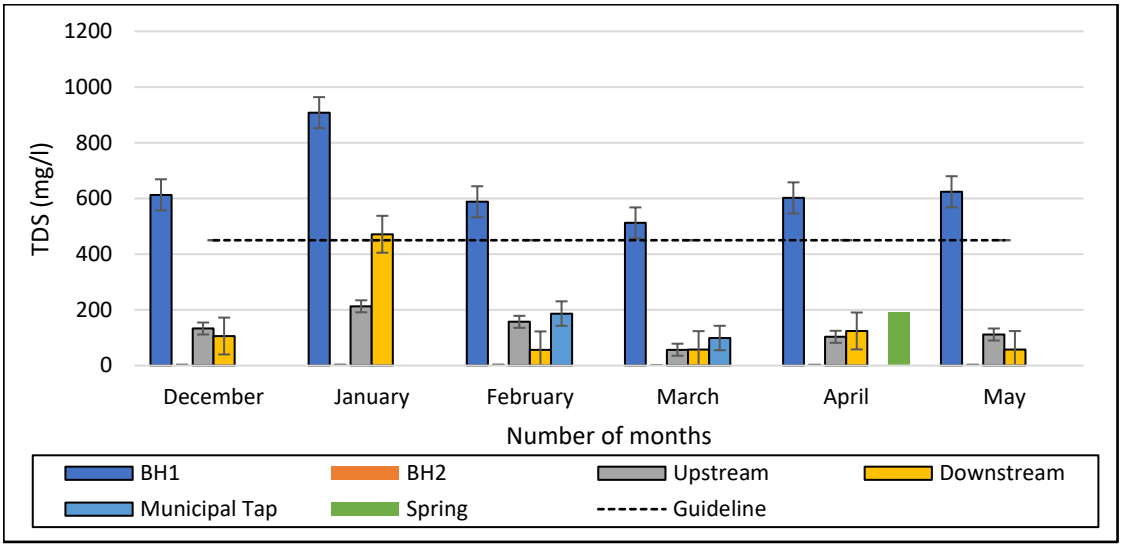


Figure 4.9: TDS values for groundwater and river water

4.3.2 Microbiological water quality parameters

Appendix 3 indicates the microbiological parameters for wet and dry season, respectively. *E.coli* counts in this study ranged from 0 to 100 cfu/100ml. In December 2023, January 2024, and February 2024, the levels of *E. coli* counts increased steadily in most sources exceeding the guideline (Figure 4.14). This indicates that there could be seasonal factors such as rainfall influencing the contamination. In May 2024 *E. coli* counts drop in all water sources, with counts close to the guideline of 0 cfu/100ml. This also supports the fact that increase in *E.coli* counts is due to seasonal factors. The water sources in the study area exhibited E. coli contamination during both the wet and dry seasons with counts exceeding the South African drinking water standard of less than 0 cfu/100 mL. Elevated *E. coli* counts may also be linked to the closeness of certain boreholes to pit latrines and inadequate sanitation precautions during borehole

© University of Venda

construction, leading to groundwater contamination (Back *et al.*, 2018). The sloping area from the households of Matatani Village to BH1 (Figure 4.9) may also contribute to the high contamination during the wet season.

Bessong *et al*. (2009) reported significant fecal contamination in groundwater sources around the Tshikuwi Community in the District of Vhembe South Africa. Also, Madilonga *et al*. 2021 higher counts of *E. coli* were detected in the Mutangwi River under Thulamela municipality in Limpopo Province. The counts exceeded the regulatory standards of drinking water leaving the river not suitable for use for any domestic purpose without any proper treatment of water. Edokpayi *et al*. (2018c) reported that *E. coli* levels, ranging from 1 x 102 to 8 x 104 cfu/100 mL, were found in the water, which could present a health risk to individuals utilizing this water source in Nzhelele River in Limpopo, South Africa. The detection of *E. coli* in a water sample indicates fecal pollution and the possible presence of harmful pathogens that can cause diseases (Cabral, 2010).

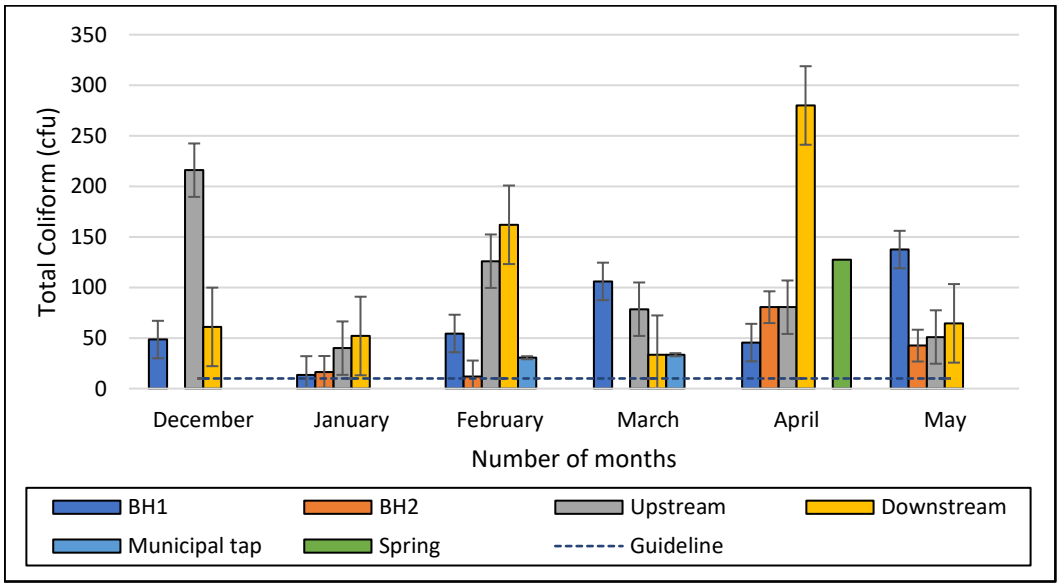


Figure 4.10: E.coli counts for groundwater and river water

Most of the rainfall samples had high TC counts ranging from 12– 216 cfu/100ml throughout the dry and wet seasons was between 33.5 cfu/100ml – 280 cfu/100ml (Figure 4.15). The highest total coliform counts were recorded downstream of Mutale River during the dry season while the upstream of Mutale River had the highest during the wet season. In April 2024, a significant increase in contamination occurred particularly in the downstream site. Niyoyitungiye and Ndayisenga (2020) indicated that detecting total coliform in a water sample strongly indicates recent faecal contamination. SANS 241(2015) stated that the acceptable counts of total coliform is ≤10. The counts observed in this study exceeded the SANS 241 guidelines for drinking water.

© University of Venda

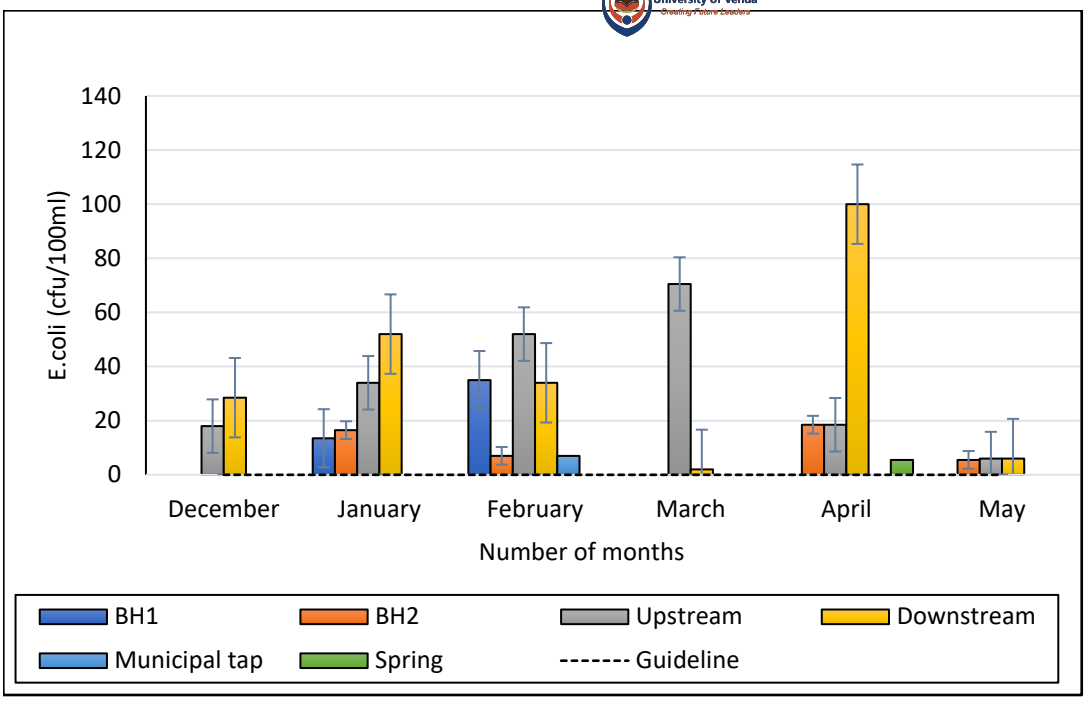


Figure 4.11: Total coliform counts for groundwater and river water

4.3.3 Chemical water quality parameters

Appendices 4, 5, 6, and 7 show the concentrations of non-metals and metals for both the wet and dry seasons. Appendix 12 presents the monthly concentrations of Fe, Cu, Zn, Pb, Al, Cd, Mn and As. The Cu concentrations in most samples exceeded the recommended guideline of 1 mg/L (Figure 4.16). Cu concentrations were only below the guideline during the dry season. The Cu concentrations ranged from 2.27 to 8.49 mg/L in the wet season and from 0.28 mg/L to 5.90 mg/L in the dry season. Cu is an important nutrient in the body of a human being and a drinking-water contaminant. The results show a significant increase in Cu concentration during the wet season, with the highest concentration of 8.49 mg/L recorded upstream in February 2024. The upstream source often has higher concentrations compared to the downstream, possibly due to contamination along the water flow. Cu adds a bitter, unpleasant taste to water, and at elevated levels, it can alter the water's color (DWAF, 1996). Consuming high levels of Cu can lead to digestive issues and may cause harm to the liver, kidneys, and red blood cells. However, due to the highly unpleasant taste of water at elevated copper concentrations, it is unlikely that people would choose to drink it (DWAF, 1996).

© University of Venda

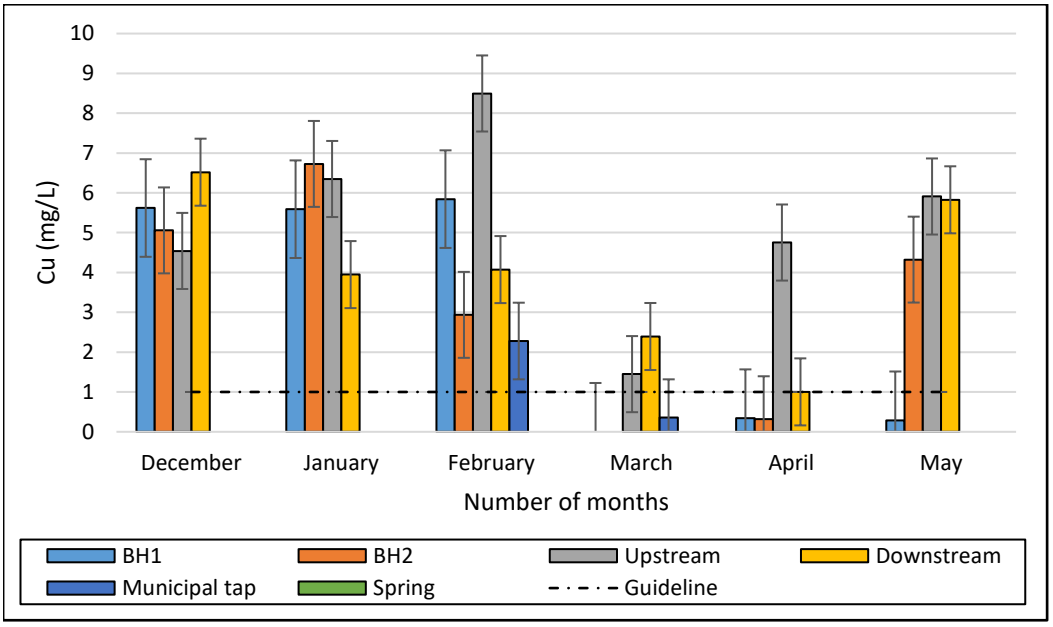


Figure 4.12: Cu concentration for groundwater and river water

All water samples (Figure 4.17) had higher As concentrations which exceeded a guideline of 0.01 mg/L (10µg / L) according to SANS 241 (2015). The As concentrations varied from 0.60 to 6. 88 mg/L in all months sampled. In the rainy season, the highest concentrations was 5.61mg/L in BH2 and BH1 5.46 mg/L and in the dry season, respectively. The maximum concentration was from downstream of the river of 6.88 mg/L. The As concentrations in water from BH1 and BH2 were always above the guideline. Elevated concentration of As from BH2 may be caused by the dipping station near BH2. DWAF (1996) sated that high of As concentrations can result from contamination associated with mining activities and cattle dipping. The pollution in the river could be due to industrial activities, agricultural runoff, or natural arsenic deposits in the geology. Elevated levels of As can result in arsenic-related health issues, such as skin conditions like pigmentation changes and keratosis (Mazumder, 2008). Additionally, prolonged exposure to arsenic toxicity can lead to lung, kidney, and bladder cancer, along with neurological damage and even death (Smith *et al*., 1992). Many research have shown a link between As concentration in drinking water and cancer development (Hopenhayn-Rich *et al.*, 1998; Celik *et al.*, 2008). A study conducted on As concentrations in drinking water and blood samples from residents living along the banks of the Ganges River in Patna, India, identified a significant correlation between elevated As levels in groundwater and a higher prevalence of breast cancer, liver cancer, and skin cancer. The findings suggest a strong association between increased As contamination in groundwater and rising cancer incidence rates in the affected population.

© University of Venda

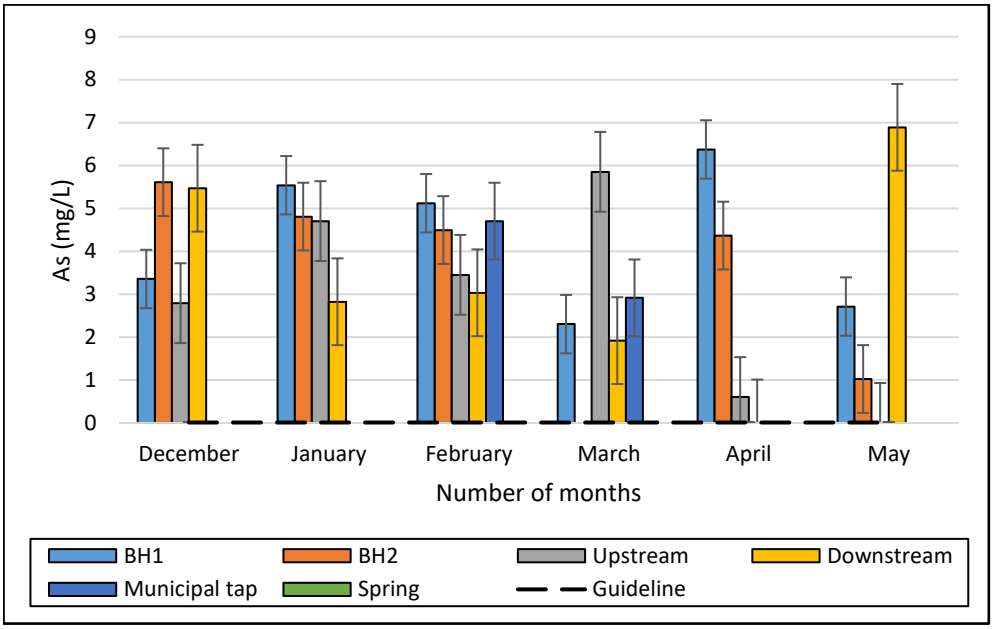


Figure 4.13: As concentrations for groundwater and river water

The K concentrations in water from BH1 and BH2 consistently exceeded the guideline of 50 mg/L (Figure 4.18) throughout the rainy and dry seasons. The K in the spring also was above the guideline in April, all other sources (downstream, upstream, and municipal tap) were below the guideline in all months sampled. In May 2024, K concentration in all sources decreased except for BH2 which increased to 69.01 mg/L and surpassed all other values from different months. The K concentrations ranged from 2.86-62.24 mg/L and 2.76-69.01 mg/L, in the rainy and dry seasons, respectively. The reason for the high concentrations of K in groundwater from BH1 and BH2 may be contamination from agricultural runoff or fertilizers. K is a vital element for human health and is rarely present in drinking water at concentrations that could pose a health risk (WHO, 2009). K is essential for protein synthesis and carbohydrate metabolism, playing a key role in proper growth and overall physiological development in humans (Zoroddu *et al.*, 2019). However, an excessive amount of K in the body which is called hyperkalemia can lead to symptoms such as irritability, reduced urine production, and even cardiac arrest (Pohl *et al.*, 2013).

© University of Venda

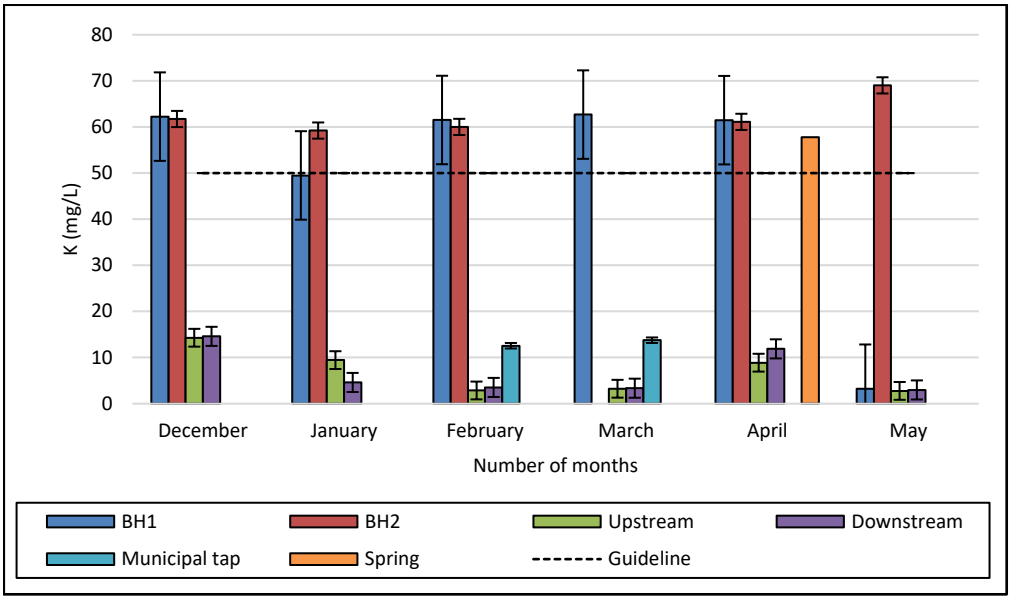


Figure 4. 14: K concentrations for groundwater and river water

Concentrations of Al at all sampling points consistently exceeded the SANS (2015) guideline of 0.3 mg/L throughout the dry and rainy seasons (Figure 4.19). Concentrations of Al varied between 4.22 and 5.74 mg/L. The concentrations of Al may be from soil materials within the aquifer where groundwater is stored. The high concentrations recorded in the river may be attributed to human activities, such as the use of fertilizers. The concentrations exceeding the guideline, can cause an unpleasant taste in water and affect its aesthetic properties (Shomar and Hawari, 2017). The consumption of Al at elevated concentrations from water impacts the nervous system and has been linked to kidney failure, Parkinson's, and Alzheimer's diseases (Inan-Eroglu and Ayaz, 2018).

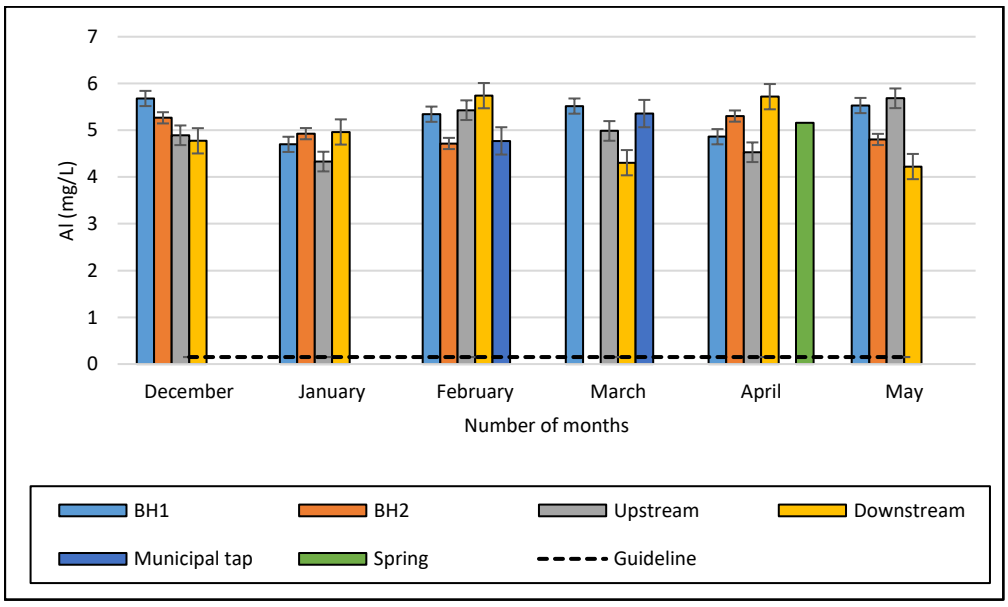


Figure 4.15: Al concentrations for groundwater and river water

© University of Venda

In all the samples collected, BH1 is the only source with high Mg concentrations exceeding the guideline from December 2023 to April 2024 (Figure 4.20). All sources were within the permissible guideline recommended by DWAF (1996) of 30 mg/L. The concentrations were between 1.30 - 95.94 mg/L in all seasons sampled (dry and wet). High concentrations of Mg in water from BH1 may be due to agricultural activities. DWAF (1996) stated that elevated Mg concentrations are linked to runoff from effluents and leaching caused by agricultural activities. BH1 is situated near a farm where there are applications of fertilizers. The Mg is essential for all living organisms, as it is required in various cells, body tissues, and organs to perform a range of functions (Luvhimbi *et al.*, 2022).

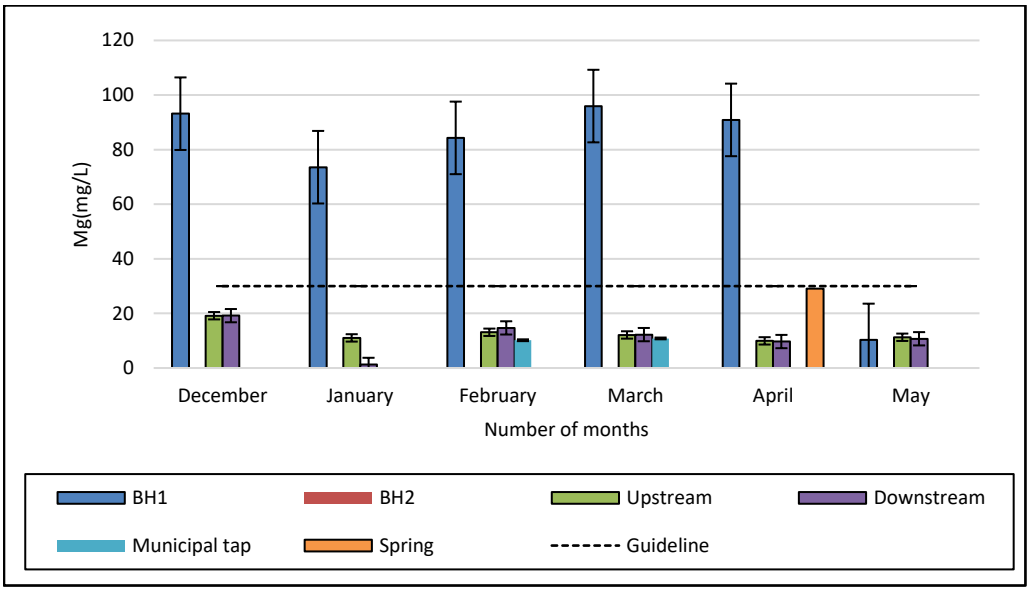


Figure 4.16: Mg concentrations for groundwater and river water

The Na concentrations at most sampling points remained within the guideline limits, except in December 2023, February 2024, and April 2024 (Figure 4.21). During these months, some sources, including upstream, downstream, and the spring, exceeded the guideline values. The Na concentrations ranged from 0- 274.97 mg/L. BH1 and BH2 Na was not detected in all months (Figure 4.20). In April 2024 the spring had more than double the concentration of the guideline with 274.97 mg/L. Na naturally occur in raw water, but its concentration can rise due to pollution sources like rock salt, runoff from precipitation, soapy solutions, and detergent (Pradeep *et al.*, 2012). Na is vital for regulating body fluids and electrolytes, as well as ensuring proper nerve and muscle function. However, excessive Na intake can elevate the risk of hypertension, cardiovascular conditions, and renal damage (Munteanu, and Iliuta, 2011).

© University of Venda

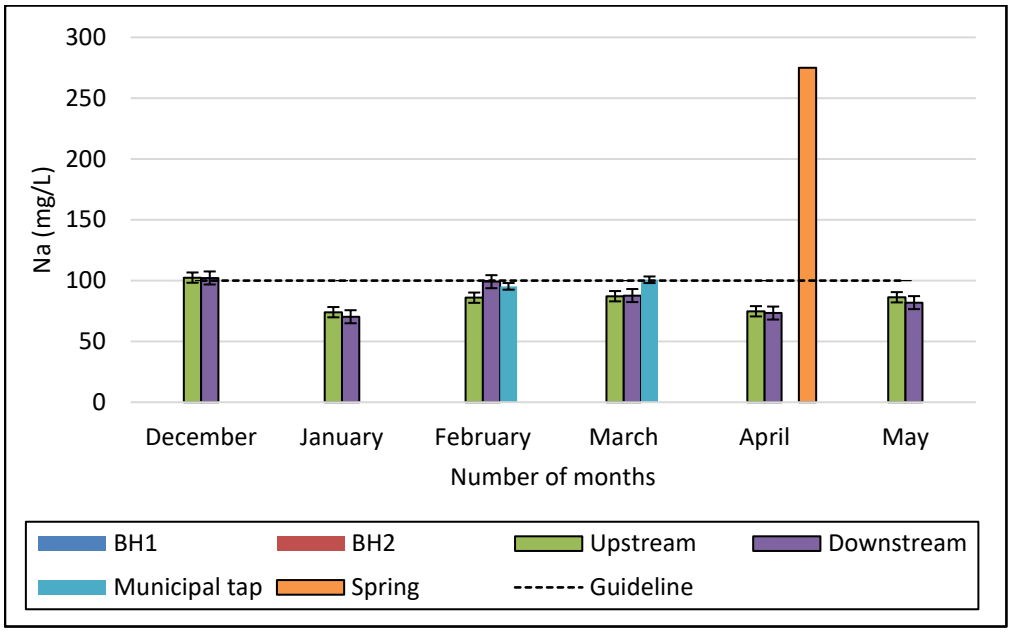


Figure 4. 17: Na concentrations for groundwater and river water

The Zn concentrations were high, especially in April 2024 where there is a maximum value of 7.63 mg/L but not all values were above the DWAF (1996) guideline of 3mg/L (Figure 4.22). The Zn concentrations ranged from 1.63-6.51 mg/L and 2.02- 7.63 mg/L for the wet and dry seasons, respectively. The downstream source shows consistently high Zn concentrations, particularly in February 2024 to April 2024 which could be from agricultural runoff. The spring showed the highest concentration, recorded at 7.63 mg/L. The cause of the high concentration of the spring in April could be the leaching of zinc from surrounding rocks and soils, particularly during seasonal changes. The Zn concentration of the municipal tap consistently remains around 5–6 mg/L which exceeds the drinking water standard. Increased rainfall during the wet season may cause surface runoff carrying Zn-rich sediments into water sources, resulting in elevated concentrations. Excessive Zn intake adversely affects the immune system by decreasing the lymphocyte stimulation response and interfering with cholesterol metabolism (Goldhaber, 2003). Insufficient zinc concentrations can result in a lack of appetite, a weakened sense of taste and smell, slower healing of wounds, and the appearance of skin sores (Bhowmik *et al.*, 2010)

© University of Venda

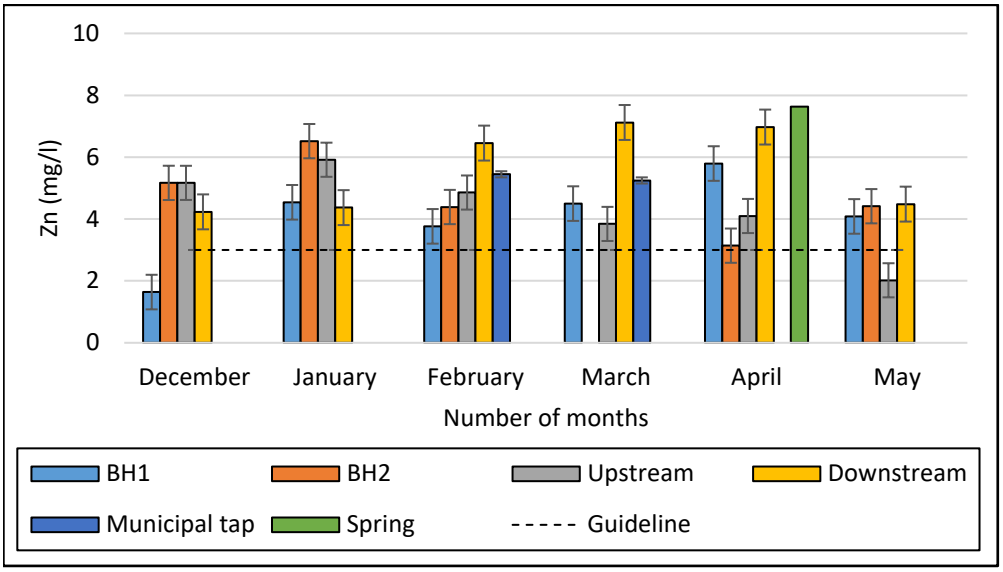


Figure 4.18: Zn concentrations for groundwater and river water

In this study, all water sources demonstrated elevated concentrations of Mn, exceeding the DWAF (1996) guideline of 0.05 mg/L (Figure 4.23). The concentrations ranged from 1.54 to 6.51 mg/L during both the dry and wet seasons, with higher levels observed in the dry season compared to the wet season. Agricultural runoff near borehole sources could also introduce Mn into groundwater. Upstream water remains consistently low Mn concentrations, indicating minimal human impact. Concentrations of Mn at downstream sampling point were slightly higher, possibly due to some contamination from upstream or natural leaching processes. Elevated Mn concentrations in drinking water can lead to a reduction in intelligence quotient (IQ) in children Khan *et al.*, 2013). Deficiencies in Mn can lead to anemia, growth problems, and skeletal abnormalities (DWAF, 1996).

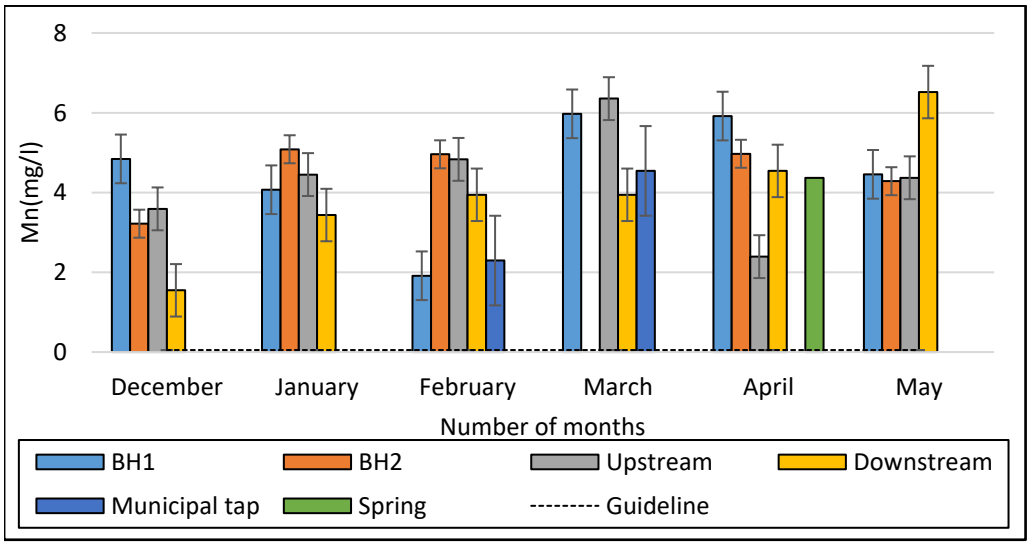


Figure 4.19: Mn concentrations for groundwater and river

© University of Venda

The Pb concentrations were above the SANS 241 (2015) standard guideline of 0.01 mg/L in all of the water sources in Matatani Village (Figure 4.24). Higher Pb concentrations occurred mostly in the rainy season than in the dry season. The downstream sampling point of the river had the highest concentration of 7.44 mg/L and BH1 had 7.30 mg/L, in the rainy and dry seasons respectively. High concentrations of Pb intake may lead to severe respiratory damage since Pb is stated to be a cumulative toxin and a potential human carcinogen (Ismael *et al.*, 2021). The source of the elevated Pb concentrations in all water sources within the study area remains unclear, though it is likely to be of geological origin. Odey *et al.* (2018) noted that the material used for borehole casing can impact the level of lead (Pb) in the borehole water, suggesting that borehole water could also be influenced by this factor. The presence of Pb in drinking water in high concentrations is concerning as it is a carcinogen and can have detrimental effects on children's growth (Cronin *et al.*, 2006).

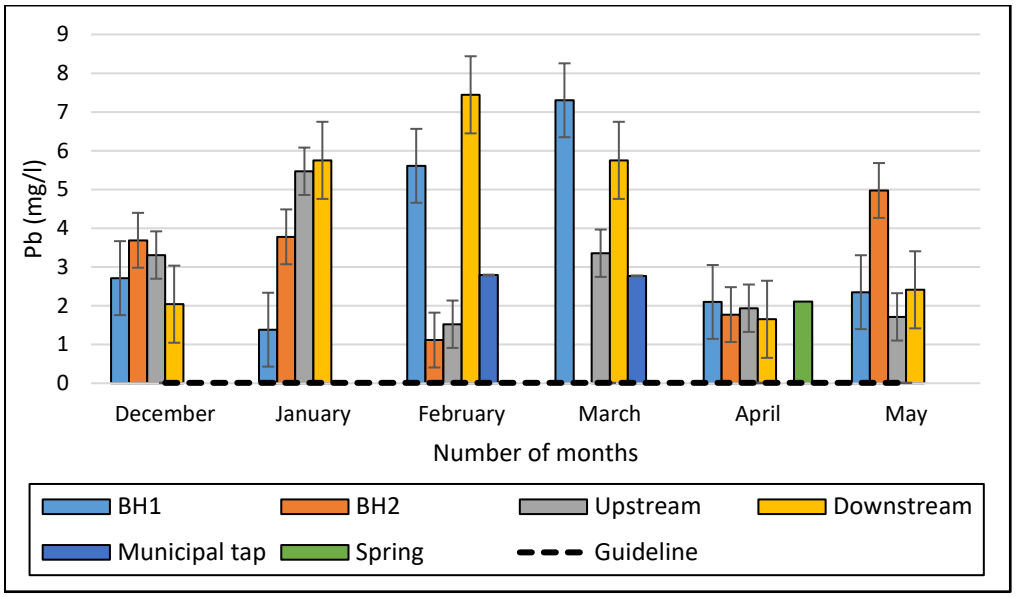


Figure 4. 20: Pb concentrations for groundwater and water

The Cd concentrations detected in most of the sources exceeded the guideline set DWAF (1996) guideline of 0.03 mg/L (4.25). Water samples of Cd ranged from 0 - 16.61 mg/L in the dry and the wet season, respectively. Cd is known as very toxic and very soluble in water (IARC, 2017). From the results, Cd concentrations were higher during the wet season than in the dry season, although during March 2024 is where there was a peak of 16.61 mg/L for municipal tap. Prolonged exposure to elevated Cd concentrations can result in kidney damage and increased blood pressure (Ismael *et al.*, 2021). Multiple studies have established a connection between Cd exposure and renal cancer in countries such as Thailand (Satarug *et al.*, 2018), China (Prince *et*

© University of Venda

al., 2015), and the USA (García-Esquinas *et al.*, 2014). High Cd concentrations have been linked to various diseases in humans and aquatic organisms, including memory loss, reproductive disorders, cancer, and damage to the lungs and kidneys (WHO, 2015). Even at low concentrations, cadmium ingestion through drinking water can result in severe inflammation of the stomach and intestines, renal tubular dysfunction, and a higher risk of kidney cancer (Song *et al.*, 2015). Individuals may experience histopathological changes (Wu *et al.*, 2016) and are particularly susceptible to the acute toxicity of Cd due to its prolonged biological half-life of 10–35 years (WHO, 2010).

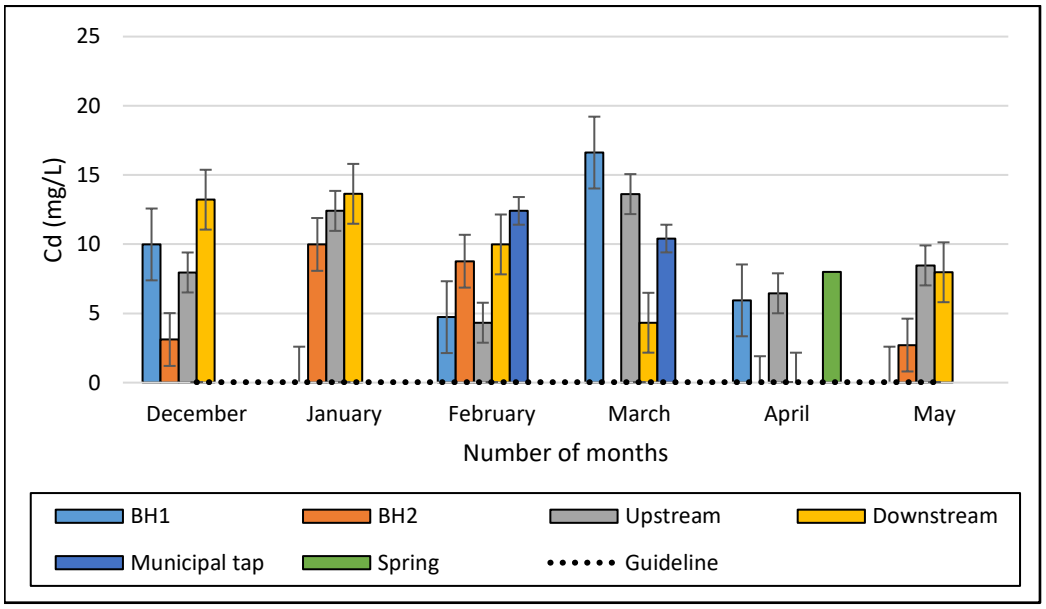


Figure 4.21: Cd concentrations for groundwater and river water

The Fe concentrations in the study area varied from 0.36 to 7.86 mg/L (Figure 4.26). All samples exceeded the DWAF (1996) recommended guideline of 0.1 mg/L. The municipal tap water exhibited the highest Fe concentration at 7.86 mg/L in February 2024, followed by BH1 with a concentration recorded in January 2024.and upstream in February 2024 with 7.18 mg/L and 7.06 mg/L. High Fe content in municipal tap samples is a concern. At high concentrations, Fe can negatively affect water supplies by discoloring the water, resulting in staining in stagnant water areas or change its taste (Kosaka *et al.*, 2007; Chung *et al.*, 2009). High concentrations of Fe in the downstream point may be due to the laundry washing. Madilonga *et al.* (2021) stated that elevated Fe concentrations have been associated with human activities like laundry and car washing in rivers. The Fe is an essential nutrient for human health, playing a crucial role in the production of hemoglobin, the protein that carries oxygen from the lungs to different parts of the body. (Gupta, 2014). Both low and high Fe concentrations can disrupt bodily functions. The Fe is commonly found in rocks and soil, in significant concentrations in different water sources,

© University of Venda

and its presence is typically linked to natural soil characteristics or the deterioration of old Fe pipes (Raimi *et al.*, 2022). However, this metal is not widely regarded as a health risk and is not considered toxic. (Thapa et al., 2015; Ismael *et al.*, 2021). The main concern about Fe in drinking water is its unpleasant taste and also that kidney stone-related problem may develop if Ca and Fe contents are high (Ezekwe *et al.*, 2017). Elevated concentrations of Fe in water can lead to in a metallic flavor, although the water typically remains safe to drink.

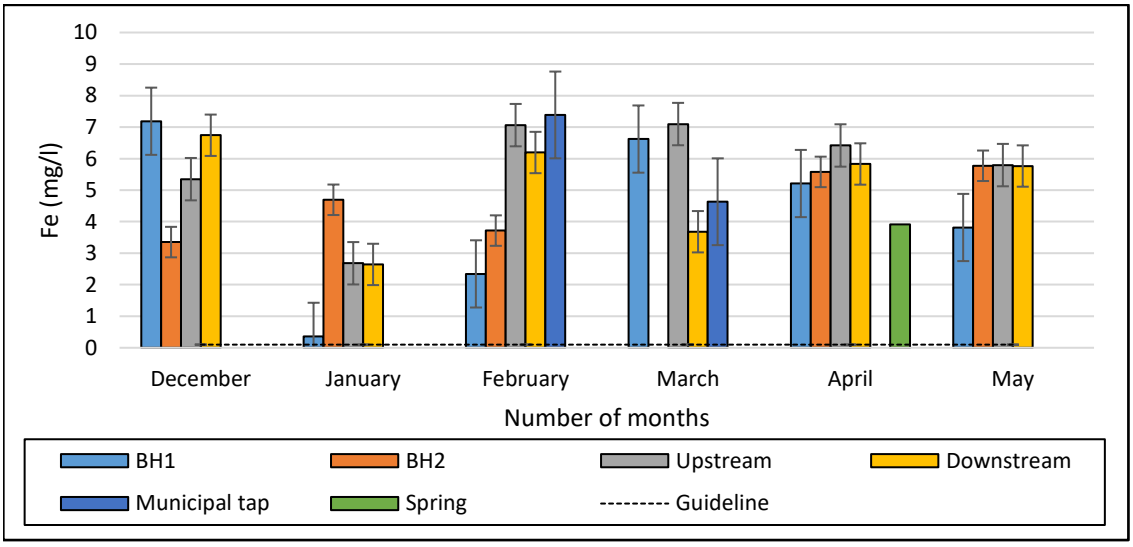


Figure 4. 22: Fe concentrations for groundwater and river water

The Ca concentration in the study varied from 10.59-47.27 mg/L (Figure 4.27). Not all sources met the 32 mg/L guideline established by DWAF (1996). BH1 was the only source that exceeded the guideline from December 2023 to April 2024, ranging from 34.02 to 47.27 mg/L. The explanation for the elevated concentration of BH1 may be due to what Saha *et al.* (2019) suggested lime from agricultural fertilizers can cause high Ca concentrations in groundwater. The downstream point of Mutale River exceeded the guideline only once in May 2024 with a concentration of 43.57 mg/L. Ca concentrations downstream are slightly higher than of the concentrations upstream suggesting that there is potential leaching or contamination of activities such as agricultural runoff and natural dissolution between the two points. Ca is an important nutrient for all living organisms, it helps in the bony skeleton of all mammals (DWAF, 1996). High concentrations of Ca result contribute to kidney stones (DWAF, 1998). In this study, Ca concentrations were generally higher during the wet season than in the dry season. Contrarily, a study conducted by Mutileni (2021) observed Ca higher in the dry season compared to the wet season.

© University of Venda

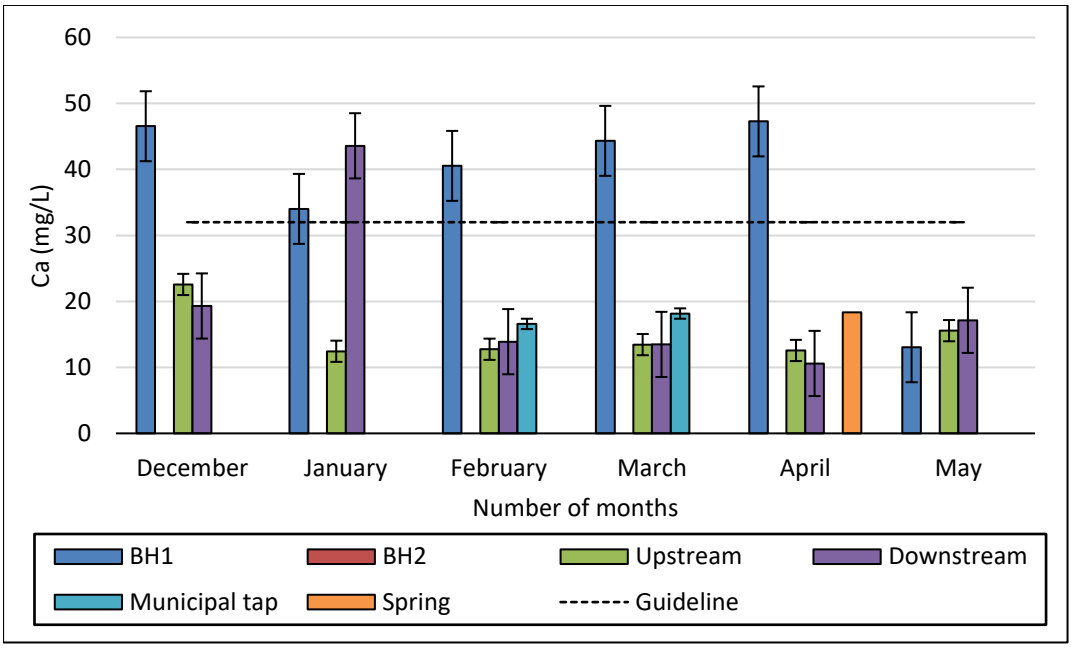


Figure 4. 23: Ca concentrations for groundwater and river water

The concentration of Cl varied between 0 - 468.2 mg/L (Figure 4.28). All samples met the recommended SANS 241 (2015) guideline of 300 mg/L except for BH1 in January 2024 which had a concentration of 468.2 mg/L. There are no health risks that are linked to consuming water between 200-600 mg/L, only children are affected by nausea at high Cl concentrations over 1200 mg/L. Cl is a concern in household water supplies because high concentrations can make the water taste salty and increase the corrosion rate of metals (DWAF, 1996). Rising Cl concentrations are believed to be caused by human activities such as sewage contamination from septic tanks and the use of water softeners (Hinga, 2016). The study is consistent with Ntshangase (2019) who observed low concentrations of Cl below the SANS 241 (2015) of drinking water.

© University of Venda

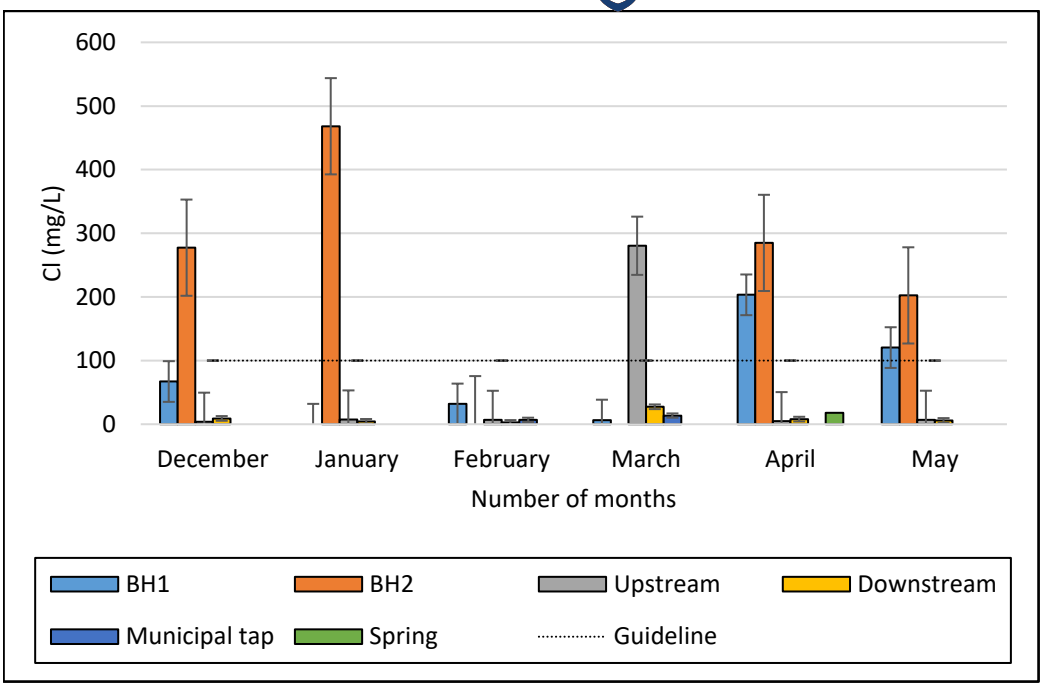


Figure 4. 24: Cl concentrations for groundwater and river water

The F concentration varied between 0.1-0.57 mg/L (Figure 4.29). All recorded F concentrations fell within the recommended water quality drinking guideline of 1.5 mg/L set by SANS 241 (2015). Concentrations of F in drinking water ranging from 0.7 to 1.2 mg/L are effective in preventing dental cavities. High concentrations over 1.5 mg/L of F can lead to tooth discoloration (Lewoyehu, 2021). Dental mineral discoloration and mottling occur at F concentrations between 1.5-20 mg/L in individuals whose teeth are still mineralizing, the children at the age of 7 and below are generally at risk (DWAF, 1996). High F concentration may cause skeletal damage and may cause bone diseases. This study is inconsistent with the high concentrations of F in Hawassa Lake, ranging from 2.31 to 17.29 mg/L, which exceeded the recommended drinking water guideline by SANS 241 (2015), were reported by Worako *et al.* (2015). Similarly, Odiyo and Makungo (2012) reported elevated F concentrations in groundwater sources around Siloam Village.

© University of Venda

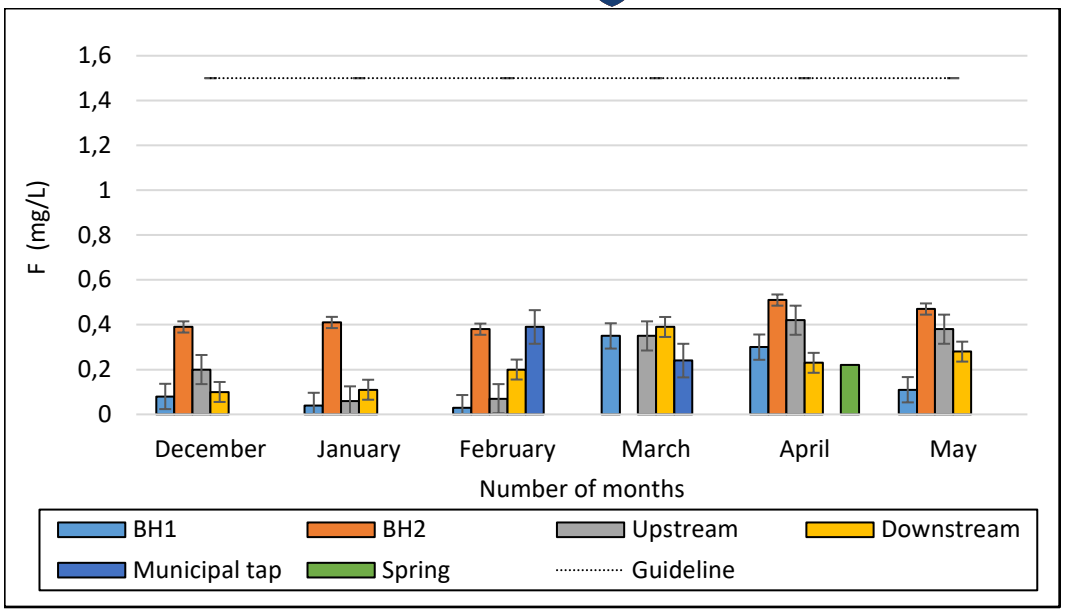


Figure 4. 25: F concentrations for groundwater and river water

The SO_4 concentrations in this study varied between 0- 89 mg/L (Figure 4.30). All concentrations were within the recommended guideline for both DWAF (1996) and SANS 241 (2015) for 200 mg/L and 500 mg /L, respectively. SO_4 is a naturally occurring component in drinking water. Elevated SO_4 concentrations can results in respiratory problems in the human body. Health issues including diarrhea can be caused by consuming water with high concentrations of SO_4 (Mutileni *et al.*, 2023). This study recorded low concentrations of SO_4. Similarly, Odiyo *et al.* (2020) and Mutileni (2021), both recorded SO_4 concentrations within the recommended guideline.

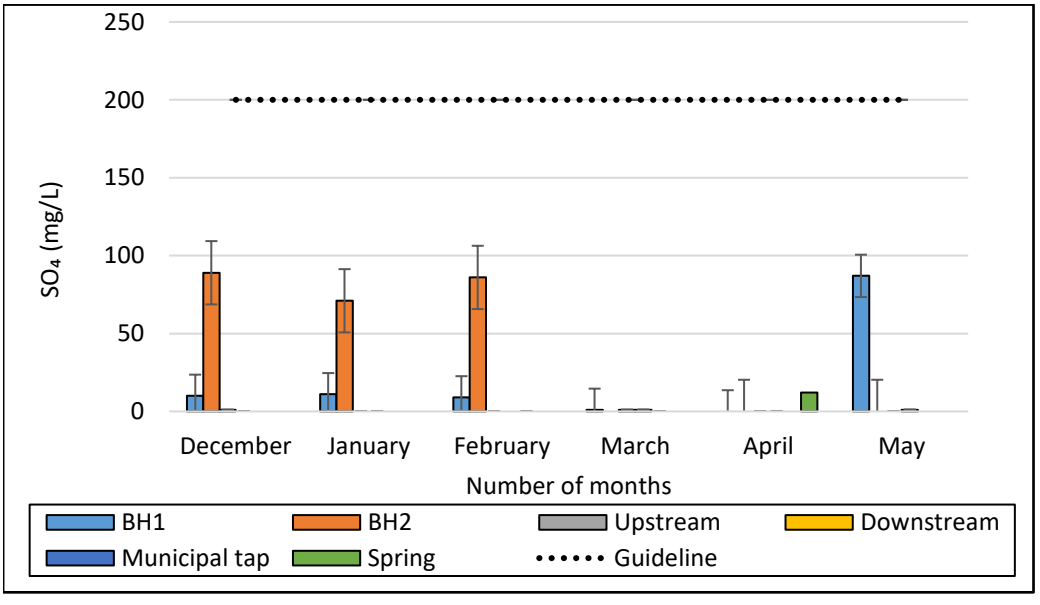


Figure 4. 26: SO_4 concentrations for groundwater and river water

All concentrations for PO_4 recorded were below 1 for all sources (Figure 4.31). PO_4 concentrations ranged from 0-0.9 mg/L. DWAF (1996) and SANS 241 (2015) have not set a guideline for PO_4 in consumable water. The presence of PO_4 in groundwater can present a risk, as

© University of Venda

it may serve as a pathway for the contamination of surface water, thereby contributing to the process of eutrophication (Odiyo *et al.*, 2020). According to Karunanithi *et al*. (2015), overusing of chemical fertilizers, sewage disposal and waste landfilling contribute to elevated PO_4 concentration. High PO_4 concentrations in water can lead to joint and knee pain, as well as increase the risk of kidney disease for those who consume it. This study has observed low concentrations in water. Similarly, Ntshangase (2019) recorded concentrations between 0, 03-0.39 mg/L in Chaneng Village, Rustenburg.

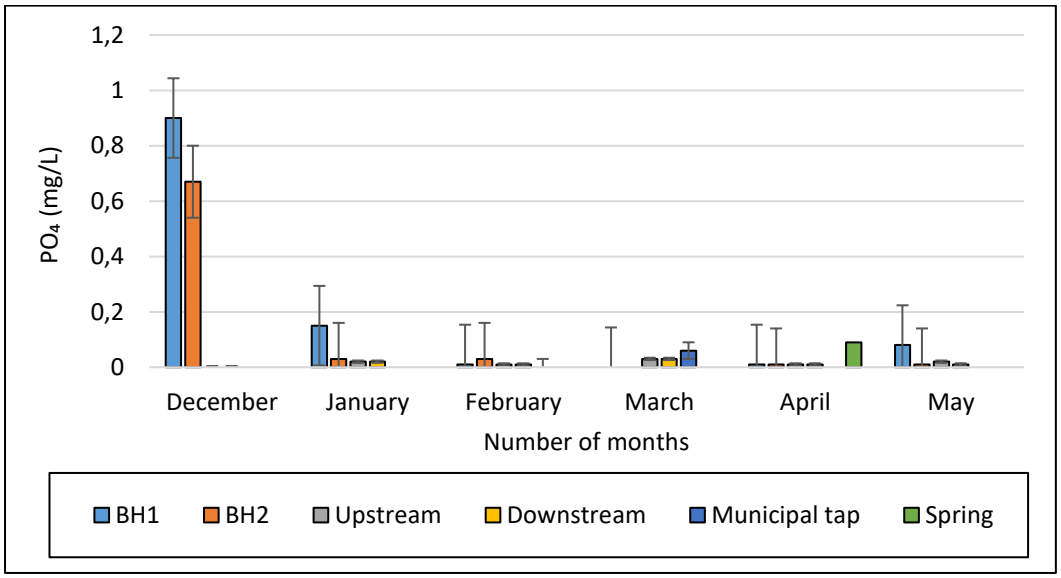


Figure 4. 27: PO_4 concentrations in groundwater and river water

4.4 Water quality results for rainwater

4.4.1 Physical water quality parameters

Appendix 1 indicates the physical water parameters for the wet season. The pH of rainwater samples of different roof types found in Matatani Village ranged from 5.61 to 7.76 in December 2023, January 2024, and March 2024 (Figure 4.32). Most of the samples that were collected were within the guideline of drinking water except one sample that fell below the the guideline of 6. In March 2024 the grass roofing had a value of 5.61. All roof types had pH values that were consistently within the guideline except for the grass roofing in March only. An acidic pH causes tooth to be weakened by tooth enamel and increases the likelihood of cavities (Schneider, 2013). According to Samie *et al.* (2013), pH influences the solubility and bioavailability of chemical components, including nutrients like phosphorus (P), nitrogen (N), and carbon (C), as well as heavy metals such as Pb, Cu, and Zn. Almost all rainwater samples were above the guideline (Figure 4.32), except for only one sample taken in March from corrugated sheets. Turbidity

© University of Venda

ranged from 0.16 NTU - 29.62 NTU in all the months.

Grass roofing and metal Harvey tile consistently show higher turbidity levels, likely due to their increased potential to accumulate debris and dust. In contrast, corrugated sheets and concrete tiles demonstrate much lower turbidity, suggesting they are more efficient at preserving water quality for rainwater harvesting. High turbidity of grass roofing may be due to the type of the grass that have been used, as the grass gets old it decomposes and result in suspended materials that can increase the turbidity. The turbidity recorded from the rainfall samples did not meet the standard of 1 NTU from DWAF (1996). Highly turbid water increases the risk of infectious diseases and can facilitate their spread on an epidemic scale (DWAF, 1996). Grass roofing in all months have the highest values of TDS ranging from 241.66– 284.67 mg/L in all months sampled (Figure 4.32). Concrete tile follows grass roofing with recorded values ranging from 122.93– 66.13 mg/L.

The TDS measured from rainwater samples complied with the recommended guideline of 450 mg/L. Metal Harvey tile and corrugated sheets have the lowest recorded values of TDS making them safer to harvest rainfall during the rainfall season. Grass roofing consistently records the highest EC values among all roofing types, with values well above 400 µS/cm in December 2023 and January 2024 and a value of 361 µS/cm in March 2024 (Figure 4.32). The EC values for corrugated sheets are the lowest across all the months, followed by metal heavy tile and concrete tiles suggesting limited contamination and better quality. All rainfall samples were within the SANS 241 guideline of 1700 µS/cm.

© University of Venda

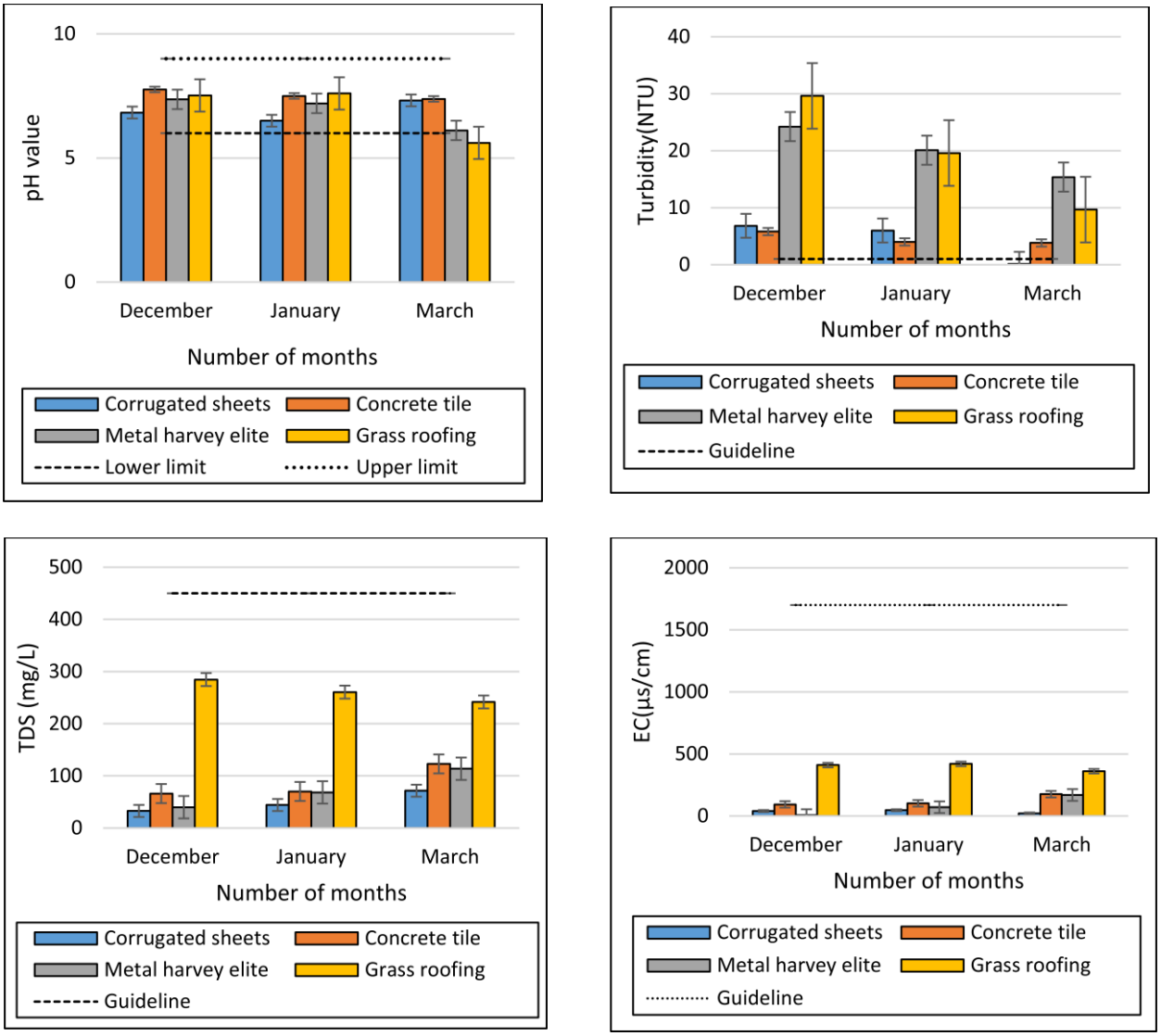


Figure 4.28: pH, TDS, EC and Turbidity values for rainwater

4.4.2 Chemical water quality parameters

Mg concentrations for rainwater were mostly in accordance with the recommended guideline of 30 mg/L set by DWAF (1996) (Figure 4.33).The concentrations ranged from 2.13 to 84.71 mg/L (Figure 4.33). Rainwater from only one roof type (corrugated sheets) was above the guideline. Rainwater from most roof types had K concentrations above the DWAF (1996) guideline of 50 mg/L. The K concentrations were between 5.07 to 1158.93 mg/L. Rainwater samples for grass roofing had a high K concentration of 1158.93 mg/L in December 2023. The grass roofing type did not exceed the recommended guideline in December 2023 only, but in all other months sampled for K concentrations. Followed by the corrugated sheets having a concentration of 53.26 mg/L in January 2024 and metal Harvey tile in March 2024 with a concentration of 238.84 mg/L.

© University of Venda

The Mg and K are both essential for all living things. Mg is responsible for various functions across cells and body tissues and organs, while K controls the fluid balance both inside and outside cells (Ciosek *et al.,* 2021). Higher concentrations of K water can have a bitter taste and consuming it can lead to a person vomiting or being nauseous and the excess intake of Mg concentration in water can lead to diarrhea (DWAF, 1996). Ca ranged from 2.23-101 mg/L (Figure 4.31). A higher number of values were within the recommended drinking water guideline of 32 mg/L set by DWAF (1996) than those exceeding this guideline. Rainwater from grass roofing was the one with the highest concentration. Ca is responsible for physiological and bone health (Ciosek *et al.,* 2021).

The Na ranged between 2.03 to 395.97 mg/L. Rainwater from grass roofing was higher than the DWAF (1996) guideline of 100 mg/L for drinking water in December 2023 and March 2024. Rainwater from grass roofing was above the DWAF (1996) guideline of 100 mg/L for drinking water in December 2023 and March 2024. The reason for high concentrations they may be due to the type of roof material. The grass may accumulate dust particles that contaminate water. The Na was the highest in December 2023 since this was the first rainfall month after a dry season where there was dust accumulation. The Na was also high in March 2024 since it didn't rain in February 2024.

© University of Venda

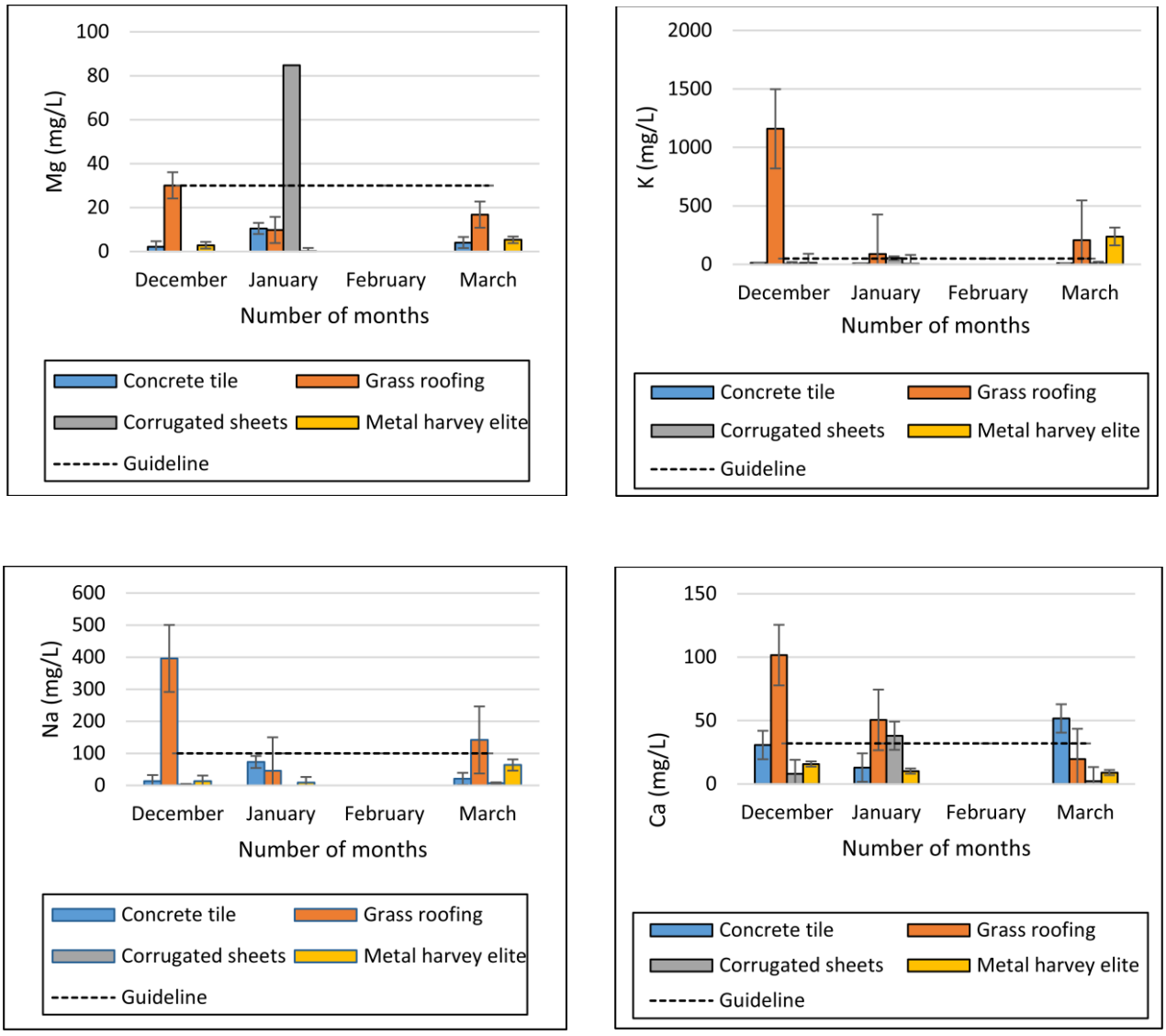


Figure 4.29: Mg, K, Ca, and Na concentrations for rainwater

Rainwater from all types of roofing had Zn, Cu, Al, and Fe concentrations which were above the guideline set by SANS 241(2015) and DWAF (1996). Rainwater collected from grass roofing and corrugated sheets exhibited elevated concentrations in January, the highest concentration recorded of 5.16 mg/L (Figure 4.34). The Zn concentrations varied between 3.76 to 5.16 mg/L and its recommended limit is 3 mg/L by DWAF (1996). Zn is known for its antioxidant properties, which contribute to the prevention of premature aging of muscles and skin, as well as aid in the healing process after an injury, when consumed in moderate and recommended amounts (Asare-Donkor *et al.*, 2016). The Cu concentrations range from 1.29 to 6.72 mg/L (Figure 4.34). The metal Harvey tile showed the highest concentration of Cu in this study. At elevated concentrations of Cu, the water colour is also affected (WHO, 2011). All Al concentrations were very high ranging from 4.28 to 5.55 mg/L throughout the study. The recommended guideline by SANS 241

© University of Venda

(2015) is 0, 15 mg/L. According to DWAF (1996), the consumption of water with elevated Al concentrations can lead to chronic neurological disorders, such as dialysis dementia. The Fe concentrations of ranged between 0.36 to 5.62 mg/L, while the guideline established by DWAF (1996) is 0.1 mg/L. When concentrations surpass this guideline, aluminum can impact the taste of the water and degrade its aesthetic qualities. Excessive Fe concentrations intake can cause cellular damage in the heart, liver, and other organs, potentially leading to severe consequences such as metabolic acidosis, shock, liver failure, coagulopathy, adult respiratory distress syndrome, long-term organ damage, and even death (Dina *et al.*, 2000; Asare-Donkor *et al.*, 2016).

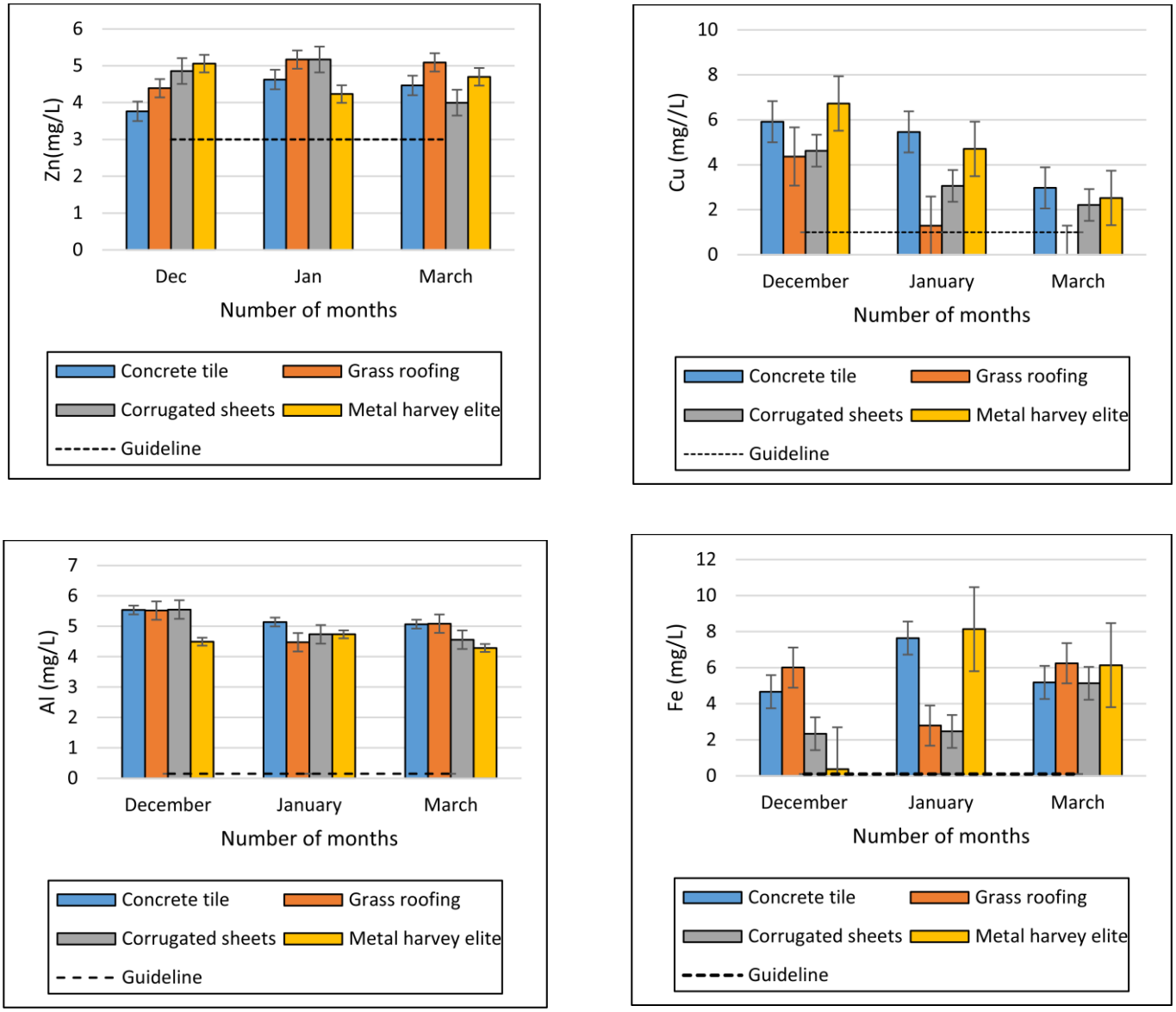


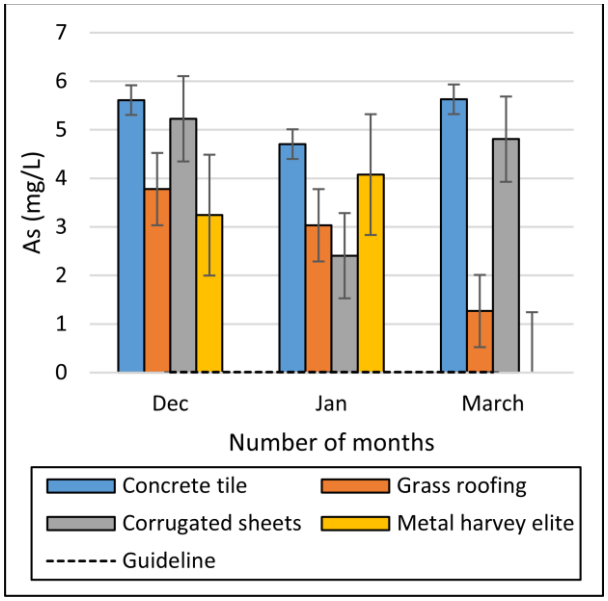
Figure 4.30: Zn, Cu, Al and Fe concentrations for rainwater

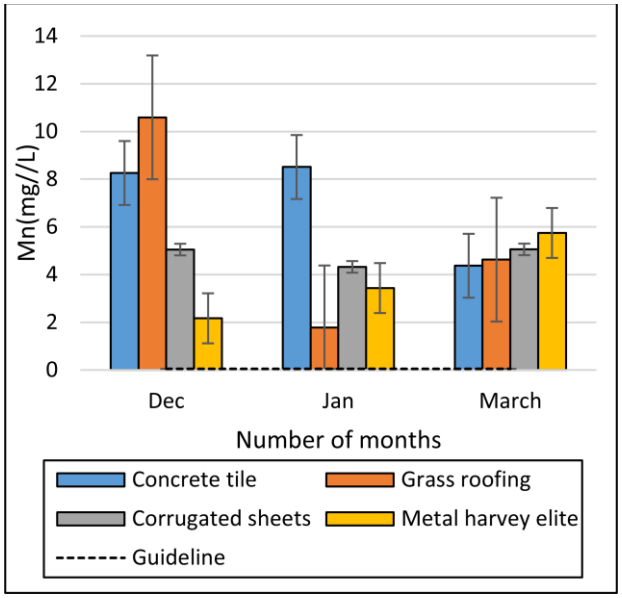
© University of Venda

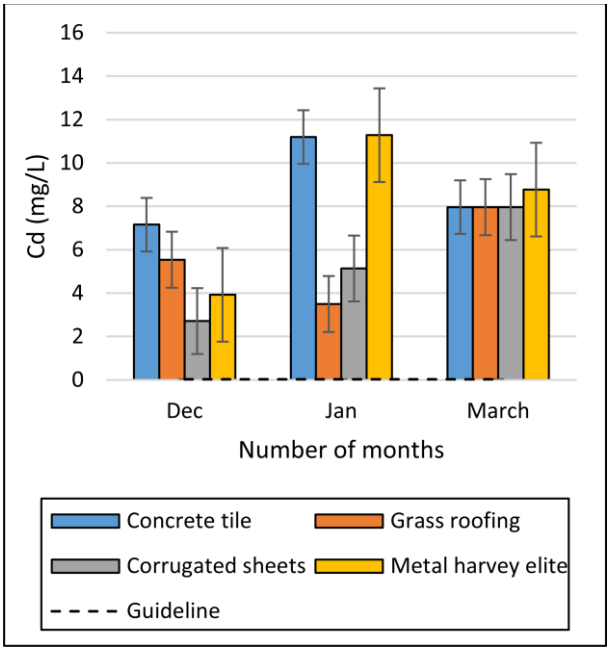
The As concentration range from 1.26 to 5.62 mg/L (Figure 4.35). The concrete tile consistently exhibited the highest concentration throughout the sampling period. The recommended drinking water guideline for As is 0.01 mg/L, as established by DWAF (1996), all concentrations were above the recommended guideline. Prolonged exposure to As can result in skin conditions like hyperpigmentation and may also cause cancer its acute poisoning can result in gastrointestinal and cardiovascular failure (DWAF, 1996). The concentrations of Mn were all above the guideline, they range between 1.78-10.59 mg/L. DWAF (1996) recommends that the concentration of Mn in drinking water should not exceed 0.05 mg/L. Aaccording to Malassa *et al.* 2014 Mn in rainwater can originate from wind-transported dust settling on residential rooftops. As one of the most abundant metals in the Earth's crust, typically occurring as hydroxides and oxides, Mn contamination in water sources is often associated with suspended particles produced by soil erosion, volcanic eruptions, combustion of organic and fossil fuels, and emissions from industrial activities (Hassan and Umer, 2022). High Mn cause an unpleasant taste to beverages (Mutileni *et al.*, 2023).

The Cd for drinking water should not exceeds 0.03 mg/L (SANS 241, 2015). All samples were above the guideline and ranged between 2.71-11.27 mg/L. High Cd concentrations causes severe renal damage by failure of the renal system (DWAF, 1996). According to Hassan (2023) Cd concentrations in the rainwater are likely influenced by emissions from fossil fuel combustion and agricultural activities. Additional potential sources include the use of Cd containing pesticides, vehicle exhaust emissions, leakage from engines, as well as ashes and dust particles enriched with Cd, which can be transported by wind and deposited onto residential rooftops (Hassan, 2023). The Pb concentration range from 1.89 to 10.12 mg/L in this study. All sources exhibited Pb concentrations exceeding the permissible limit set by SANS (2015). Pb contamination in harvested rainwater may originate from the corrosion or degradation of metallic roofing materials and storage tanks. Furthermore, emissions from municipal solid waste incinerators represent a significant source of Pb, largely due to the presence of metal oxide (Anabtawi *et al.*, 2022). Prolonged exposure to high levels of Pb can cause substantial damage to the brain and kidneys in males (Golub, 2005).

© University of Venda







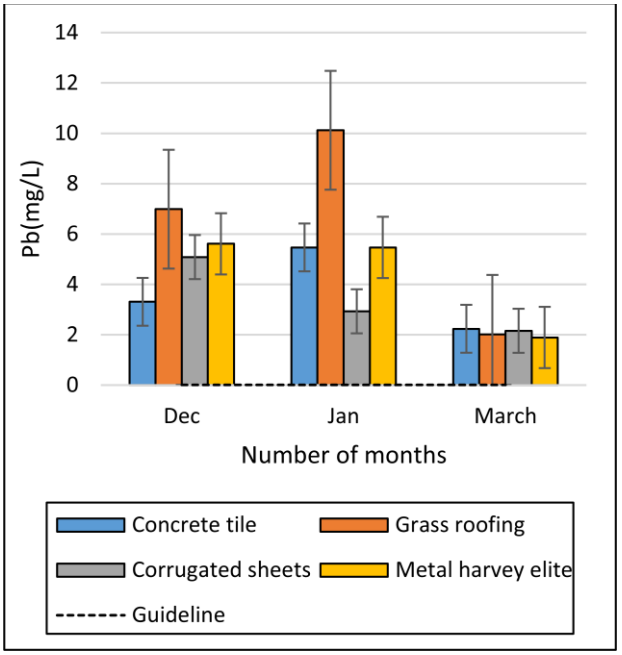


Figure 4.31: As, Mn, Cd and Pb concentrations for raınwater

© University of Venda

The F concentrations in rainwater varied between 0.12-0.41 mg/L (Figure 4.36). All concentrations. All recorded concentrations were within the SANS 241 (2015) recommended drinking water guideline of 1.5 mg/L. F is important in the human body in small concentrations as it reduces dental cavities in both adults and children. It is essential for proper strengthening of dental enamel and enhancing its resistance to bacterial acids (DWAF, 1996). F content plays a crucial role in the proper development of bones and teeth. Excessive F accumulation on teeth leads to dental fluorosis, while its deposition in bones can result in skeletal fluorosis and, in severe cases, crippling fluorosis (Srivastava, and Flora, 2020). The study observed low concentrations of F. Similarly Odiyo *et al*. (2020) reported concentrations that were within the guideline for Cl and F in Vhuronga 1, Limpopo Province, South Africa.

The Cl concentrations in rainfall water samples from different roof types varied between 0.4 to 27.9 mg/L. All values were within the recommended guidelines of 300 mg/L by SANS 241 (2015) and 100 mg/L by DWAF (1996). Excessive Cl concentration above 1200 mg/L can lead to notable effects on humans such as nausea and dehydration (DAWF, 1996). SO_4 concentrations for rainfall water ranged from 0-85 mg/L throughout the period (Figure 4.34). All sample concentrations did not exceed the recommended 200 mg/L set by DWAF (1996). SO_4 is a critical and essential nutrient that plays an important role in the development of tissues in both plants and animals. (Madilonga *et al.*, 2021). SO_4 contributes a salty or bitter taste to water, and the elevated SO_4 concentrations increase the corrosion of metal fittings in the distribution system (DWAF, 1996). Madilonga *et al.* (2021) reported SO_4 concentrations that were also below the recommended guideline of domestic water from 2.46-2.94 mg/L in the Mutangwi River in Vhembe district, Limpopo Province, South Africa. The PO_4 concentrations for rainfall water ranged from 0-1.19 mg/L (Figure 4.36). SANS 241 (2015) has not specified a guideline for PO_4. Phosphorus where PO_4 originates, is naturally abundant in plants, microorganisms, and animal waste. This study reported low concentrations of PO_4. Similarly, Gumbo *et al.* (2016) also recorded low values of PO_4 in Nandoni Dam in Limpopo Province, South Africa from 0.08-0.25 mg/L.

© University of Venda

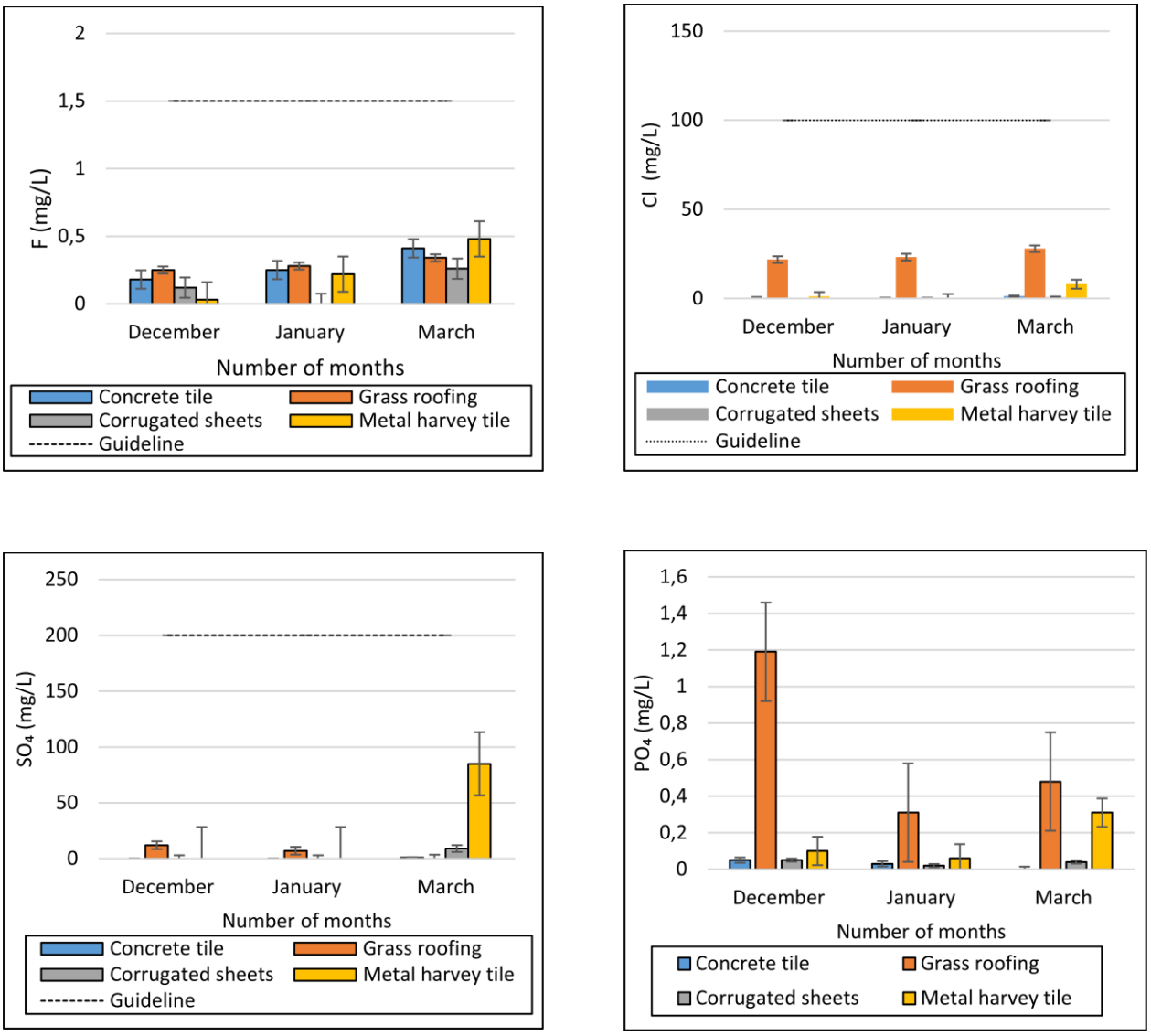


Figure 4.32: F, Cl, SO_4, PO_4 concentrations for rainwater

4.5 Results on WQIs

Appendix 8 presents the calculation of the WQIs for groundwater, river water, and rainwater**.** The WQIs of various water sources including boreholes (BH1 and BH2), Mutale river water (upstream and downstream), municipal tap water, and spring water are shown in Figure 4.37. The results show that all sources are above the poor category (WQI > 100). The highest WQI values were observed in municipal tap water and upstream river samples (above 4000) which suggest substantial contamination. High concentrations of Al and Fe contributed to poor water quality in all water sources. The concentrations were above the guidelines, they ranged from 4.95 to 5.27 mg/L, 4.25 to 6 mg/L for Al and Fe, respectively. BH1 had a high value of turbidity of 44.20 NTU, while BH2had high concentrations of K (62.21 mg/L) and Cl (308.22 mg/L). The spring had a high

© University of Venda

concentration of Na (274.97 mg/L), upstream and downstream had high values of turbidity (19.75 to 21.79 NTU) and municipal tap had a high Zn concentration of 5.34 mg/L that contributed poor water quality.

Groundwater sources, while often considered safer, can still accumulate contaminants through shallow recharge zones, especially in areas with poor sanitation. River water, especially downstream, often accumulates contaminants from domestic sewage, industrial effluents, and runoff containing agrochemicals and pathogens (Islam *et al.*, 2020; Tiwari and Mishra, 1985). The elevated WQI in the upstream section suggests that non-point source pollution may already be affecting the river at its entry point into the study area. Municipal tap water, which is expected to be treated, still shows extremely poor WQI values. This might be due to aging infrastructure, post-treatment contamination, or inefficient treatment processes.

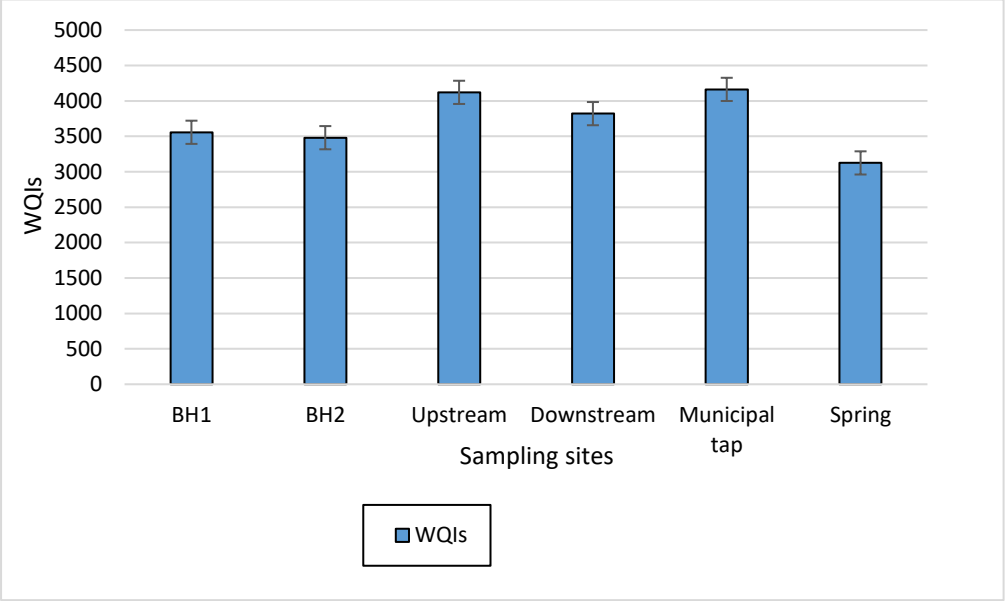


Figure 4.33: WQIs for groundwater and river water

Appendix 9 presents the calculations of WQIs for rainwater. The WQI for various roof types from ranged from 2889.25 to 4151.03 (Figure 4.38). All sampled rooftops produced WQIs values exceeded the upper limit of the very poor category (WQI > 100), indicating severely deteriorated water quality, making it unfit for domestic consumption or drinking purposes unless adequately treated. Among the sampled roof types, concrete tile roofs had the highest WQI value 4151.03**,** indicating the most deteriorated water quality, followed by grass roofing and metal Harvey tile**.** Although corrugated sheets had the lowest WQI of 2889.25 the values still reflects a level of pollution far above acceptable standards**.** The consistently elevated WQI values may be attributed to various contamination sources associated with roofing materials. High concentrations of Al and Fe contributed to poor water quality in all water sources. The concentrations were above the guidelines, they ranged from 4.50 to 5.24

© University of Venda

mg/L, 3.31 to 5.83 mg/L for Al and Fe, respectively. Concrete tile had a high Cu concentration of 4.78 mg/L, while grass roofing concentration of Na (194.35 mg/L) and K (485.07 mg/L) which were also above the guideline. Corrugated sheets had high concentration of Mg (84.72 mg/L) and metal Harvey tile had high K concentration of 86.06 mg/L which is contributing to poor water quality.

Atmospheric deposition of pollutants, accumulation of bird droppings, decaying organic matter, and the leaching of roofing components are known contributors to roof runoff contamination. Concrete tiles, due to their high surface roughness and porosity**,** may retain more debris and promote microbial growth, increasing organic and inorganic pollutant loads in collected rainwater (Sazakli *et al.*, 2007). Metal and corrugated roofs are often linked to heavy metal leaching, particularly Zn, and Fe, which can significantly elevate WQI values (Gwenzi and Nyamadzawo, 2014). Additionally, grass or thatched roofs have been shown to support microbial activity and harbour decomposing organic material, further contributing to biological contamination (Dobrowsky *et al.*, 2014). These findings are consistent with Gwenzi and Nyamadzawo (2014) who observed that metallic roofs in sub-Saharan Africa often contribute to heavy metal contamination, while organic roofs (thatch or grass) tend to increase microbial load. Sazakli *et al. (*2007**)** similarly reported that roof material type strongly influences the chemical and bacteriological characteristics of stored rainwater.

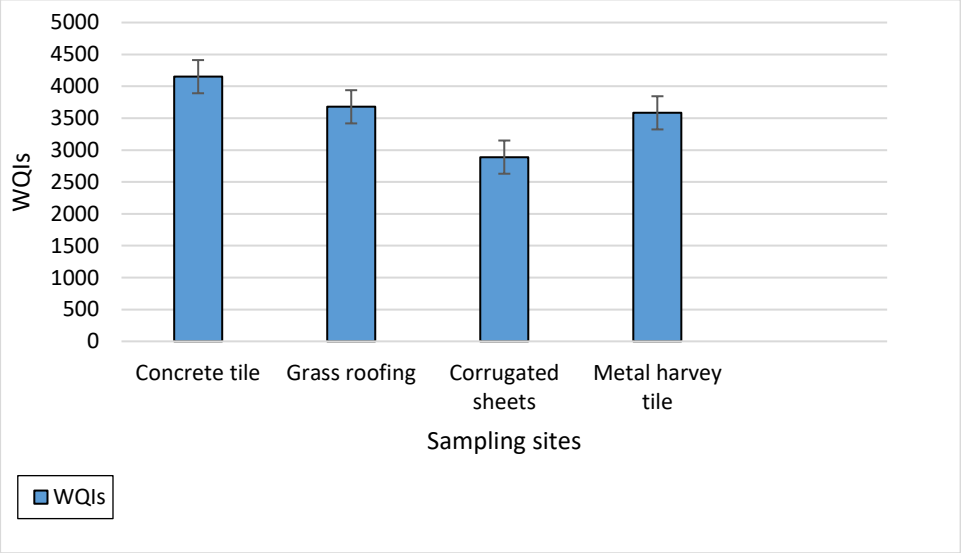


Figure 4.34: WQIs for rainwater

4.6 Health risk assessment results

4.6.1 Non carcinogenic and microbial health risks

Appendix 10 presents the estimation of non-carcinogenic risk for groundwater, river water, and rainwater. The health risk assessment was carried out based on the average concentrations of Mg,

© University of Venda

K, Ca, Zn, Fe, Cu, Na, and Mn. The results of the non-carcinogenic health risk assessment for the selected metals across all water sources for both adults and children are summarized in Tables 4.1 and 4.2, respectively. Table 4.1 is for indicators of health risk assessment for river and groundwater while Table 4.2 is for indicators of health risk assessment of rainwater. The HQ values for Table 4.1 ranged from 0.0304 to 2.85, 0.00827 to 2.15, and 0.00429 to 6.88 for groundwater, municipal tap, and river water for adults, while for children it varied from 0.07 to 5.55, 0.01 to 8.20, and 0.01 to 9.57 for groundwater, municipal tap, and river water. The HQ forTable 4.2 ranged from 0.01 to 4.43, 0.02 to 3.56, 0.01 to 3.02, and 0.01 to 2.83 for concrete tile, grass roofing, corrugated sheets and metal Harvey tile for adults, respectively. The HQ for children ranged from 0.02. to 7.00, 0.05 to 6.02, 0.01 to 3.97 and 0.04 to 9.08 for concrete tile, grass roofing, corrugated sheets and metal Harvey tile, respectively. The findings showed that HQ for all the metals were less than 1 except for Fe, Mn which were greater than 1. The HQ values were high for all sources for both children and adults. The parameters identified as the primary contributors to non-carcinogenic health risks for children and adults across all samples in the study were Fe and Mn, as all HI and HQ values exceeded 1.

The HI values from Table 4.1 ranged from 4.23 to 4.47, 4.37 to 4.79 and 4.02 for adults from groundwater, river water and municipal tap while for children they ranged from 16.1 to 17.3, 16.7 to 18.3 and 16.0 from groundwater, river water and municipal tap, respectively. Upstream of the Mutale River, BH2 and BH1 recorded the highest HI values, suggesting that these sites pose a greater potential health risk compared to the other sources. The H1 values for adults from Table 4.2 were 0.81, 0.70, 0.54 and 0.52 for concrete tile, grass roofing, corrugated sheets and metal Harvey tile, while for children was 3.11, 2.71, 2.03 and 2.00 for concrete tile, grass roofing, corrugated sheets and metal Harvey tile. Concrete tile and grass roofing poses a high potential health risk to those harvesting rainwater compared to other roof types. The HI values for all metals exceeded 1 for both children and adults, as shown in Table 4.1, while in Table 4.2, the HI was greater than 1 only for children.

This suggests a potential risk associated with non-carcinogenic metals. Children are at a higher risk of suffering from anaemia, headaches, kidney and brain damage, abdominal pain, and stomach cancer due to consuming contaminated water (Mutileni, 2021). The HQ for all elements was less than 1 except for K for grass roofing water for children and Fe and Mn for all roof types. The possible human health risks linked to non-carcinogenic metals in drinking water from Matatani Village were assessed using the USEPA model. Health risks are determined by factors such as age, body weight, the volume of water consumed, and the average concentration of a given

© University of Venda

metal. The exposure of a human to trace metals occurs through consumption, inhalation, the mouth and nose, and absorption occurs through the skin (Asare-Donkor *et al.,* 2016). The HQ represents the oral reference dose of a metal to which humans may be exposed to (Mahmud *et al.,* 2020; Luvhimbi *et al.,* 2022).

The HI values for various roof types, as presented in Table 4.2, indicate the presence of a non-carcinogenic risk associated with all roof types for children only. The results indicate that people at Matatani Village are at risk through water consumption. The HI for adults and children for in groundwater and river water was greater than 1 while rainwater, only children was greater 1. Similarly, A Hazard index exceeding 1 in children and adults was reported by Durowoju *et al.* (2020) in geothermal springs within Southpansberg in South Africa. Mutileni (2021) also reported that the overall non-carcinogenic risk assessment exceeded 1 for HQ and HI, except for the HQ of Hg (mecury) in groundwater from Collins Chabane and Makhado Municipality in the District of Vhembe. Children are at a higher risk of suffering from anaemia, headaches, kidney and brain damage, abdominal pain, and stomach cancer due to consuming contaminated water. A study by Sulaiman *et al.* (2024) evaluated the non-carcinogenic and carcinogenic risks of trace elements in rainwater near a cement factory in northeastern Nigeria, the results from the samples collected from rainwater indicated the presence of a potential non-carcinogenic risk. The HI was exceeded 1 for children and adults through ingestion exposure and children are more at a greater risk than adults.

This indicates that the drinking water in Matatani Village poses considerable health risks to both adults and children from surface and groundwater sources. However, for rainwater, children are at a higher risk compared to adults. This study was inconsistent with Alipour *et al.* (2024) who assessed non-carcinogenic risk in drinking water conducted in rural areas of West Azarbaijan Province, Iran. In City A, the HI values for both ingestion and dermal exposure pathways were found to be less than 1 for children and adults, respectively. Similarly, Dashtizadeh et al. (2019) evaluated the human health risks associated with trace metals in tap water in Zahedan, Iran. They determined that the HQ and HI values were below 1 for adults and children.

© University of Venda

Table 4.1: Indicators of non-carcinogenic health risk assessment for groundwater and river water

Source	Age group	HQ								HI
		Mg	K	Ca	Zn	Fe	Cu	Na	Mn	
BH1	Adult	0.08	0.03	0.04	0.04	1.34	0.09	N/A	2.85	4.47
	Child	0.3	0.12	0.14	0.16	5.11	0.35	N/A	10.9	17.1
BH2	Adult	N/A	0.04	N/A	0.05	1.45	0.12	0.03	2.83	4.52
	Child	N/A	0.15	N/A	0.19	5.55	0.47	0.1	10.8	17.3
Municipal tap	Adult	0.01	0.01	0.02	0.06	1.89	0.04	0.03	2.15	4.2
	Child	0.04	0.03	0.07	0.21	7.21	0.16	0.12	8.2	16
Upstream	Adult	0.01	0	0.01	0.05	1.8	0.17	0.03	2.72	4.79
	Child	0.05	0.02	0.06	0.17	6.88	0.63	0.1	10.4	18.3
Downstream	Adult	0.01	0	0.02	0.06	1.62	0.12	0.03	2.51	4.37
	Child	0.05	0.02	0.07	0.22	6.17	0.48	0.1	9.57	16.7
Spring	Adult	0.03	0.04	0.02	0.08	1.23	N/A	0.09	2.75	4.23
	Child	0.12	0.14	0.07	0.31	4.7	N/A	0.33	10.5	16.1

Table 4.2: Indicators of non-carcinogenic health risk assessment for rainwater

Roof type	Age group	HQ								HI
		Mg	K	Ca	Zn	Fe	Cu	Na	Mn	
Concrete tile	Adult	0.01	0.01	0.03	0.04	1.83	0.15	0.01	4.43	0.81
	Child	0.02	0.03	0.12	0.17	7.00	0.57	0.04	16.90	3.11
Grass	Adult	0.02	0.31	0.03	0.05	1.58	0.06	0.06	3.56	0.71
	Child	0.08	1.16	0.13	0.20	6.02	0.23	0.23	13.60	2.71
Corrugated sheets	Adult	0.09	0.01	0.02	0.05	1.04	0.10	0.00	3.02	0.54
	Child	0.01	0.05	0.08	0.19	3.97	0.40	0.01	11.50	2.03
Metal Harvey tile	Adult	0.00	0.05	0.01	0.05	1.53	0.15	0.01	2.38	0.52
	Child	0.01	0.21	0.04	0.19	5.86	0.56	0.03	9.08	2.00

4.6.2 The carcinogenic and microbial health risk

Appendix 11 presents the estimation of carcinogenic risk for groundwater, river water, and rainwater. The CRingestion assessments for river water, groundwater, and rainwater are displayed in Tables 4.3 and 4.4, respectively. The heavy metals considered in the assessment include Cd, Pb, and As, based on the availability of the cancer slope factor (CSF) for ingestion. In Table 4.3, the values are ranked as Pb > Cd >As. The CRingestion values ranged from 0.0943 to 0.119, 0.955 to 4.26, and 0.00 to 0.767 for Cd, Pb, and As for children and adults in all river and groundwater. BH2 had lower values than BH1 but still greater than 1×10-4.

© University of Venda

The As was not detected in the spring making it a safer source and also having the lowest values compared to other metals. The highest CRingestion value of 3.65 for Pb from BH1 was observed in children, showing that children are at a greater risk of contamination compared to adults and also suggesting that BH1 poses a higher potential risk compared to other sources. As was not detected in the spring making it a safer source. The CRingestion values for children were generally greater than those for adults in all metals indicating that they are more vulnerable to carcinogenic effects.

According to Peek *et al.* (2018), children's exposure during their early growth stages results in irreparable harm. CRingestion values ranged from 0.0981 to 0.116, 0.109 to 0.624, and 0.116 to 0.963 for Pb, Cd, and As for both adults and children in all roof types (Table 4.4). The As poses the greatest CR risk in all roofing materials. The highest CRingestion value of 0.963 for As from concrete tile was observed, suggesting that concrete tile poses a high potential health risk. Exposure to heavy metals can elevate the risk of cancer in humans (Cao *et al.*, 2014). Most CRingestion values in this study were greater than the recommended 1×10^{-4}, for rainwater, river water, and groundwater and there is a greater chance of them getting cancer.

Mohammadi *et al.* (2019) stated that prolonged exposure to toxic metals, even at low concentrations, can contribute to the development of various types of cancer. Ungureanu *et al.* (2022) evaluated of carcinogenic and non-carcinogenic risks in adults through ingestion in bottled drinking water and found that 72% of the analyzed samples exceeded the recommended limit for carcinogenic health risk, indicating a potential contribution to cancer development.

The findings of the current study are consistent with Moradnia *et al.* (2024) assessed the carcinogenic risk of metals in drinking water in Isfahan in Iran and As showed a notable cancer risk because it was greater than the guideline of $1\times10^{-4.}$ Mohammadi *et al.* (2019) evaluated the health risk of heavy metals along the water distribution network in Iran, Khorramabad city and the assessment revealed a potential carcinogenic risk to residents due to exposure to contaminants through ingestion. Similarly Aslani *et al.* (2024) assessed the presence of potentially toxic elements in bottled drinking water distributed in Tehran, Iran, and identified a cancer risk associated with Cr and Ni, which may pose a carcinogenic threat to both adults and children.

© University of Venda

It is important to note that the effects of exposure may accumulate long-term after continuous consumption of contaminated water. The formula used in calculating assumes constant BW_s of 15 kg and 70 kg, and consumption of 2.2 L/day and 1.8 L/day for adults and children, respectively. The intake of contaminated water is considered to be for 365 days for 6 years and 70 years for adults and children. The variations in actual BW, daily intake as well as use of multiple sources may result in actual health risks which are different from the estimated ones. Matatani residents also use a mix of multiple water sources which may also result in the variation of actual health risk. It is therefore crucial to take note of this in application of the findings in this study.

Table 4.3 Indicators of carcinogenic health risk assessment for groundwater and river water

Source	Age group	CRingestion		
		Cd	Pb	As
BH1	Adult	0.12	0.96	0.20
	Child	0.46	3.65	0.77
BH2	Adult	0.09	0.82	0.19
	Child	0.36	3.13	0.74
Municipal tap	Adult	0.22	0.74	0.18
	Child	0.84	2.84	0.69
Upstream	Adult	0.17	0.77	0.14
	Child	0.65	2.94	0.53
Downstream	Adult	0.16	1.12	0.16
	Child	0.6	4.26	0.61
Spring	Adult	0.15	0.56	0
	Child	0.59	2.15	0

Table 4.4: Indicators of carcinogenic health risk assessment for rainwater

Roof Type	Age Group	CRingestion		
		Pb	Cd	As
Concrete	Adult	0.0981	0.168	0.252
	Child	0.375	0.642	0.963
Grass	Adult	0.17	0.109	0.128
	Child	0.65	0.415	0.488
Corrugated	Adult	0.0906	0.101	0.197
	Child	0.346	0.386	0.751
Metal	Adult	0.116	0.153	0.116
	Child	0.441	0.585	0.442

© University of Venda

The microbial water quality analysis conducted in Matatani Village revealed that *E. coli* and TC counts in the assessed water sources exceeded the recommended guidelines with potential health risks. These findings indicate faecal contamination, posing potential health risks to the community. The associated health risks of these water quality parameters are summarized in Table 4.5. The potential health risks include gastroenteritis, nausea, vomiting, abdominal cramps, cholera, typhoid fever salmonellosis and dysentery. The findings of this study are consistent with Odiyo *et al.* (2020) who also identified potential health effects including gastroenteritis, nausea, fever, vomiting, headaches, abdominal cramps and chills in groundwater used by public schools in Vhuronga 1, Limpopo Province, South Africa.

Table 4.5: Potential health risk for microbiological parameters in water sources

Parameters	Sources	Health effects
E.coli	BH1, BH2, municipal tap, upstream, downstream and spring	gastroenteritis, nausea, vomiting, abdominal cramps, cholera and typhoid fever
Total coliform	BH1, BH2, municipal tap, upstream, downstream and spring	gastroenteritis, salmonellosis, dysentery, cholera and typhoid fever

4.7 Summary

All sources of groundwater and river water only complied with guidelines for pH and EC. The rainwater complied with guidelines for pH, TDS, and EC only. For all other parameters, some sources did not comply with the recommended guidelines. BH1 and surface water are the sources that mostly have poor water quality with the potential to endanger residents who consume this water. Rainwater collected for grass roofing generally does not adhere to the guidelines, suggesting poor water quality. The microbial parameters including E.coli and total coliform did meet with the recommended guideline for majority of the samples for river and ground water. The metals including As, Cd, Pb, Fe, and Zn did not meet the recommended standard. Non-metals including F and SO_4 complied with the recommended standard for rainwater, river water, and groundwater respectively.

The WQIs results showed that all sampled water sources had poor quality, with WQIs values greater than guideline of 100, which classifies water as very poor. Among the groundwater and surface water sources, the municipal tap and the upstream of the Mutale River had the highest WQI values. Similarly, for rainwater collected from different roofing materials, concrete tile and grass roofing showed the highest levels of contamination, as indicated by their elevated WQI values. The Hazard Index (HI) for both adults and children was greater than 1 for river water and

© University of Venda

groundwater, whereas for rainwater, only children were at an increased risk, as the HI exceeded 1 for children, not for adults. The $CR_{ingestion}$ also did not comply with the recommended standard, this indicates that the residents of Matatani Village face a high risk associated with the use of their water sources.

© University of Venda

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study evaluated the potential health risks to humans linked to domestic water sources in Matatani Village. The field survey was conducted to identify the water sources available and their potential contaminants. Five sources were identified (BH1, BH2, municipal tap, spring, upstream, and downstream of the Mutale River as well as rainwater collected from four different types of roofs for rainwater harvesting, and the most used source was found to be BH1. The potential sources of pollution include a dipping station, livestock drinking water from the river and pit latrines.

Only a few samples met the recommended guidelines for the physical, microbial, and chemical parameters. The EC and TDS in harvested rainwater, which was within acceptable limits. *E. coli* and TC exceeded the recommended guidelines for rainwater, groundwater, and river water. The Al, Fe, As, Mn, Zn, Cu, Cd, and Pb concentrations exceeded the guidelines in rainwater, river water, and groundwater. Additionally, the majority of rainwater samples had high concentrations of Mg, K, Na, and Ca above the recommended guideline. The non-metals including Cl, F were within the recommended guideline. The WQIs results shows that all water sources had WQIs values exceeding 100, indicating very poor water quality. Within the groundwater and river water, municipal tap water and the upstream of the Mutale River recorded the highest WQI values. For rainwater collected from various roof types the poorest quality was observed from concrete tile and grass roofing. Potential health risk of parameters exceeding guidelines include hypertension, kidney failure, Alzheimer's disease, dental fluorosis, liver and skin cancer, joint and knee pain and dehydration for metals and non-metals, respectively. For microbial water quality, the identified potential health risks include cholera, typhoid fever, abdominal cramps, dysentery, nausea and gastroenteritis.

The health risk assessment for cancerous and non-cancerous effects through ingestion was conducted using the methodologies established by USEPA. The estimated HI values from to 4.79 to 16.0 for groundwater, river water, and municipal tap for children and adults, respectively. The lifetime consumption risk analysis identified considerable potential for non- carcinogenic effects, particularly in children consuming harvested rainwater, as the HI for all roof types was greater than 1. Similarly, the HI for all water sources exceeded 1 for children and adults, indicating elevated potential health risks. The potential health risks for non-carcinogenic include headaches, anaemia,

© University of Venda

abdominal pain, kidney and brain damage.

5.2 Recommendations

The current study considered health risk due to the ingestion. It is therefore recommended that further research to be undertaken, focusing on the pathways of exposure, such as dermal absorption and inhalation. It is also recommended that the estimation of HI variables as BW, DI and number of years should be established use for all risk estimation within a local setting for improved accuracy USEPA may result in over estimation of variables. Water quality monitoring should be implemented wherein regular testing of all water sources to identify and manage various water contamination trends. Implementation of source protection for sources such as springs, and improvement to be a better water supply source. Implementation of water treatment methods and their systems suitable for rural areas for all sources, to reduce contaminants in drinking water. These methods include boiling, filtration and solar disinfection. Identification of old and corroded pipes and replace plumbing that may be leaching metals and heavy metals into boreholes and municipal systems. The resident should be encourage residents to use the sources of water such as municipal water which consistently showed lower levels of contamination. Residents should always boil the water before use to minimize the microbial risks of water. Community awareness and education on the risks of metals, physical and microbial parameters exposure and the importance of using treated water should be conducted. Minimizing pollution by implementing stricter regulations to minimize the release of various elements to the environment such as agricultural practices, or improper waste disposal is recommended. Consequently, effective control measures and interventions must be implemented to safeguard the health of the local community in the study area.

© University of Venda

REFERENCES

Abbassi, T. and Abbassi, S.A. (2012). Water quality indices. Elsevier, Amsterdam, the Netherlands, 353p.

Abdel-Shafy, H.I. and Mansour, M.S., 2018. Solid waste issue: sources, composition, disposal, recycling and valorization. Egyptian Journal of Petroleum, Vol.27 (4), pp.1275-1290.

Abel, A., 2022. Testing the quality of drinking water in Bahir Dar city generated from different sources (Doctoral dissertation).

Acharya, S., Sharma, S.K. and Khandegar, V., 2018. Assessment of groundwater quality by water quality indices for irrigation and drinking in South West Delhi, India. Data in Brief, Vol.18, pp.2019-2028.

Adamu, C., Nganje, T. and Edet, A., 2015. Heavy metal contamination and health risk assessment associated with abandoned barite mines in Cross River State, southeastern Nigeria. Environmental Nanotechnology, Monitoring and Management, Vol.3, pp.10-21.

Adimalla, N. and Qian, H., 2019. Groundwater quality evaluation using water quality index (WQI) for drinking purposes and human health risk (HHR) assessment in an agricultural region of Nanganur, south India. Ecotoxicology and Environmental Safety, Vol.176, pp.153-161.

Ahmed, M.F. and Mokhtar, M.B., 2020a. Assessing cadmium and chromium concentrations in drinking water to predict health risk in Malaysia. International Journal of Environmental Research and Public Health, Vol.17 (8), 2966p.

Ahmed, T., Pervez, A., Mehtab, M. and Sherwani, S.K., 2015. Assessment of drinking water quality and its potential health impacts in academic institutions of Abbottabad (Pakistan). Desalination and Water Treatment, Vol.54 (7), pp.1819–1828.

Ahmed, T., Zounemat-Kermani, M. and Scholz, M., 2020b. Climate change, water quality and water-related challenges: a review with focus on Pakistan. International Journal of Environmental Research and Public Health, Vol.17, 8518p.

Akhtar, N., Ishak, M.I.S., Ahmad, M.I., Umar, K., Md Yusuff, M.S., Anees, M.T., Qadir, A. and Ali Almanasir, Y.K., 2021a. Modification of the water quality index (WQI) process for

© University of Venda

simple calculation using the multi-criteria decision-making (MCDM) method: a review. *Water*, Vol. 13 (7), 905p.

Akhtar, N., Syakir Ishak, M.I., Bhawani, S.A. and Umar, K., 2021b. Various natural and anthropogenic factors responsible for water quality degradation: a review. Water, Vol.13 (19), 2660p.

Akoteyon, I.S., Omotayo, A.O., Soladoye, O. and Olaoye, H.O., 2011. Determination of water quality index and suitability of urban river for municipal water supply in Lagos-Nigeria. European Journal of Scientific Research, Vol.54 (2), pp.263-271.

Akyuz, D.E., 2020. Research frontiers in water, environment, and human health. In: R. Singh, B. Srinagesh and S. Anand, eds. Urban Health Risk and Resilience in Asian Cities. Advances in Geographical and Environmental Sciences, pp.165–177.

Alipour, E., Aghapour, A.A. and Bahrami Asl, F., 2024. Concentration, spatial distribution, and non-carcinogenic risk assessment of arsenic, cadmium, chromium, and lead in drinking water in rural areas of eight cities of West Azarbaijan province, Iran. Environmental Science and Pollution Research, Vol.31 (13), pp.20222-20233.

Allen, M.J., Edberg, S.C. and Reasoner, D.J., 2004. Heterotrophic plate count bacteria—what is their significance in drinking water? International Journal of Food Microbiology, Vol.92 (3), pp.265-274.

Al-Mussawi, W.H., 2014. Assessment of groundwater quality in Umm Er Radhuma aquifer (Iraqi Western Desert) by integration between irrigation water quality index and GIS. Journal of University of Babylon, Vol.22 (1), pp.201-217.

American Society for Microbiology, 2016. Bacteriological examination of waters: membrane filtration protocol. Available at: https://asm.org/ASM/media/Protocol-Images/Bacteriological-Examination-of-Waters-Membrane-Filtration-Protocol.pdf (Accessed: 4 February 2025).

Anabtawi, F., Mahmoud, N., Al-Khatib, I.A. and Hung, Y.T., 2022. Heavy metals in harvested rainwater used for domestic purposes in rural areas: Yatta Area, Palestine as a case study. International Journal of Environmental Research and Public Health, Vol.19 (5), 2683p.

© University of Venda

Andrews, P.C., Cook, K.H. and Vizy, E.K., 2024. Mesoscale convective systems in the Congo Basin: seasonality, regionality, and diurnal cycles. Climate Dynamics, Vol.62 (1), pp.609-630.

Arega, T., Demissie, B., Weldetinsae, A., Abera, D., Gizaw, M. and Assefa, T., 2019. Fluoride, total dissolved solid and electrical conductivity in drinking water supplies analyzed in EPHI from April 2017 to December 2018. Environmental Chemistry, Vol.3 (1), pp.43-52.

Asare, R., Sakyi, P.A., Fynn, O.F. and Osiakwa, G.M., 2016. Assessment of groundwater quality and its suitability for domestic and agricultural purposes in parts of the Central Region, Ghana. West African Journal of Applied Ecology, Vol.24 (2), pp.67-89.

Asare-Donkor, N.K., Boadu, T.A. and Adimado, A.A., 2016. Evaluation of groundwater and surface water quality and human risk assessment for trace metals in human settlements around the Bosomtwe Crater Lake in Ghana. SpringerPlus, Vol.5, pp.1-19.

Aslani, R., Esmaeili, S., Molaee-aghaee, E., Akbari, M.E., Sadighara, P. and Nazmara, S., 2024. Potentially toxic elements (PTEs) in bottled water (mineral and drinking) distributed in different seasons in Tehran, Iran: a health risk assessment study. International Journal of Environmental Research, Vol.18 (3), p.38.

Back, J.O., Rivett, M.O., Hinz, L.B., Mackay, N., Wanangwa, G.J., Phiri, O.L., Songola, C.E., Thomas, M.A., Kumwenda, S., Nhlema, M. and Miller, A.V., 2018. Risk assessment to groundwater of pit latrine rural sanitation policy in developing country settings. Science of the Total Environment, Vol.613, pp.592-610.

Bahetnur, Y. and Lee, W., 2023. Trace heavy metal contamination of urban water bodies in Central Asia: Its distribution, source detection, and probabilistic health risk assessment for recreational and household use of water. ACS ES&T Water, Vol.3 (8), pp.2765-2775.

Baker-Austin, C., Trinanes, J., Gonzalez-Escalona, N. and Martinez-Urtaza, J., 2017. Non-cholera vibrios: the microbial barometer of climate change. Trends in Microbiology, 25(1), pp.76-84.

Balali-Mood, M., Naseri, K., Tahergorabi, Z., Khazdair, M.R. and Sadeghi, M., 2021. Toxic mechanisms of five heavy metals: mercury, lead, chromium, cadmium, and arsenic. Frontiers in Pharmacology, Vol.12, 643972p.

© University of Venda

Bamuwamye, M., Ogwok, P. and Tumuhairwe, V., 2015. Cancer and non-cancer risks associated with heavy metal exposures from street foods: evaluation of roasted meats in an urban setting. Journal of Environment Pollution and Human Health, Vol.3 (2), pp.24-30.

Basu, P., Choudhury, S., Shridhar, V., Huilgol, P., Roychoudhury, S., Nandi, I., Chaudhuri, A. and Mitra, A., 2022. Surveillance of SARS-CoV-2 RNA in open-water sewage canals contaminated with untreated wastewater in resource-constrained regions. Access Microbiology, Vol.4 (1).

Belov, A.A., Vasilyev, A.N. and Musenko, A.A., 2019. Electrical conductivity of water treated by spark discharge. Indonesian Journal of Electrical Engineering and Informatics (IJEEI), Vol.7 (3), pp.422-431.

Bempah, C.K. and Ewusi, A., 2016. Heavy metals contamination and human health risk assessment around Obuasi gold mine in Ghana. Environmental Monitoring and Assessment, Vol.188, pp.1-13.

Bessong, P.O., Nyathi, E., Mahopo, T.C. and Netshandama, V., 2014. Development of the Dzimauli community in Vhembe District, Limpopo Province of South Africa, for the MAL-ED cohort study. Clinical Infectious Diseases, Vol.59 (4), pp.S317-S324.

Bessong, P.O., Odiyo, J.O., Musekene, J.N. and Tessema, A., 2009. Spatial distribution of diarrhoea and microbial quality of domestic water during an outbreak of diarrhoea in the Tshikuwi community in Venda, South Africa. Journal of Health, Population and Nutrition, Vol.27 (5), 652p.

Beyene, H.D., 2015. Quality analysis of potable water in Dowhan, Erop Wereda, Tigrai, Ethiopia. Chemistry and Materials Research, Vol.7 (3), pp.93-99.

Bharadwaj, K.K., 2018. Water pollution: a threatening alarm to the mankind. Innovative Research Thoughts, Vol.4, pp.204-209.

Bhowmik, D., Chiranjib, K. and Kumar, S., 2010. A potential medicinal importance of zinc in human health and chronic. International Journal of Pharmacy, Vol.1 (1), pp.5-11.

Bordalo, A.A., Nilsumranchit, W. and Chalermwat, K., 2001. Water quality and uses of the Bangpakong River (Eastern Thailand). Water Research, Vol.35 (15), pp.3635-3642.

Boyacioglu, H., 2007. Development of a water quality index based on a European

© University of Venda

classification scheme. Water Sa, Vol.33. (1), pp. 101-106.

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

Cabral, J.P., 2010. Water microbiology: bacterial pathogens and water. International Journal of Environmental Research and Public Health, Vol.7 (10), pp.3657-3703.

Cao, S., Duan, X., Zhao, X., Ma, J., Dong, T., Huang, N., Sun, C., He, B. and Wei, F., 2014. Health risks from the exposure of children to As, Se, Pb and other heavy metals near the largest coking plant in China. Science of the Total Environment, Vol.472, pp.1001-1009.

Carrard, N., Foster, T. and Willetts, J., 2019. Groundwater as a source of drinking water in Southeast Asia and the Pacific: a multi-country review of current reliance and resource concerns. Water, Vol.11 (8), 1605p.

Celik, I., Gallicchio, L., Boyd, K., Lam, T.K., Matanoski, G., Tao, X., Shiels, M., Hammond, E., Chen, L., Robinson, K.A., Caulfield, L.E., Herman, J.G., Guallar, E. and Alberg, A.J., 2008. Arsenic in drinking water and lung cancer: a systematic review. Environmental Research, Vol.108 (1), pp.48-55.

Chalchisa, D., Megersa, M. and Beyene, A., 2018. Assessment of the quality of drinking water in storage tanks and its implication on the safety of urban water supply in developing countries. Environmental Systems Research, Vol.6 (1), pp.1-6.

Chen, R., Jin, Z., Wang, Y. and Shi, J., 2021. Non-carcinogenic and carcinogenic health risks associated with heavy metals and polycyclic aromatic hydrocarbons in well-water samples from an automobile junk market in Ibadan, SW-Nigeria. Environmental Science and Pollution Research, Vol.28, pp.43208-43220.

Chen, S.S., Kimirei, I.A., Yu, C., Shen, Q. and Gao, Q., 2022. Assessment of urban river water pollution with urbanization in East Africa. Environmental Science and Pollution Research, Vol.29 (27), pp.40812-40825.

Chidrawar, A.B., 2020. Analysis of water quality in Kharadkhed dam water reservoir using physicochemical parameters. European Journal of Biomedical, Vol.7 (2), pp.269-272.

Chigor, V.N., Sibanda, T. and Okoh, A.I., 2013. Variations in the physicochemical characteristics of the Buffalo River in the Eastern Cape Province of South Africa.

© University of Venda

Environmental Monitoring and Assessment, Vol.185, pp.8733-8747.

Chouhan, S. and Flora, S.J.S., 2010. Arsenic and fluoride: two major ground water pollutants. CSIR Indian Journal of Experimental Biology, Vol.48, pp.666-678.

Chowdhary, P., Bharagava, R.N., Mishra, S. and Khan, N., 2020. Role of industries in water scarcity and its adverse effects on environment and human health. In: Environmental Concerns and Sustainable Development, Air, Water and Energy Resources, Vol.1, pp.235-256.

Chromatography Today, 2022. Ion chromatography advantages v disadvantages. Available at: https://www.chromatographytoday.com/news/ion-chromatography-ic/58/international-labmate-ltd/ion-chromatography-advantages-v-disadvantagesnbsp/61026 (Accessed: 14 January 2025).

Chung, K.T., Wong, T.Y., Wei, C.I., Huang, Y.W. and Lin, Y.T., 2009. Tannins and human health: a review. Critical Reviews in Food Science and Nutrition, Vol. 49 (5), pp.544-554.

Ciosek, Ż., Kot, K., Kosik-Bogacka, D., Łanocha-Arendarczyk, N. and Rotter, I., 2021. The effects of calcium, magnesium, phosphorus, fluoride, and lead on bone tissue. Biomolecules, Vol. 11(4), 506p.

Constitution of the Republic of South Africa, 1996. (1996). South African Government. Available at: https://www.gov.za/documents/constitution/constitution-republic-south-africa-1996-1 (Accessed: 12 February 2025).

Corwin, D.L. and Yemoto, K., 2020. Salinity: electrical conductivity and total dissolved solids. Soil Science Society of America Journal, Vol. 84(5), pp.1442-1461.

Cronin, A.A., Breslin, N., Gibson, J. and Pedley, S., 2006. Monitoring source and domestic water quality in parallel with sanitary risk identification in Northern Mozambique to prioritise protection interventions. Journal of Water and Health, Vol. 4(3), pp.333-345.

Cude, C.G., 2001. Oregon water quality index a tool for evaluating water quality management effectiveness 1. JAWRA Journal of the American Water Resources Association, Vol.37 (1), pp.125-137.

Currie, J., Graff Zivin, J., Meckel, K., Neidell, M. and Schlenker, W., 2013. Something in the water: contaminated drinking water and infant health. Canadian Journal of

© University of Venda

Economics/Revue canadienne d'économique, Vol. 46(3), pp.791-810.

Cutsail III, G.E. and DeBeer, S., 2022. Challenges and opportunities for applications of advanced X-ray spectroscopy in catalysis research. ACS Catalysis, Vol.12 (10), pp.5864-5886.

Dashtizadeh, M., Kamani, H., Ashrafi, S.D., Panahi, A.H., Mahvi, A.H., Balarak, D., Hoseini, M., Ansari, H., Bazrafshan, E. and Parsafar, F., 2019. Human health risk assessment of trace elements in drinking tap water in Zahedan city, Iran. Journal of Environmental Health Science and Engineering, Vol. 17, pp.1163-1169.

Daud, M.K., Nafees, M., Ali, S., Rizwan, M., Bajwa, R.A., Shakoor, M.B., Arshad, M.U., Chatha, S.A.S., Deeba, F., Murad, W. and Malook, I., 2017. Drinking water quality status and contamination in Pakistan. BioMed Research International, 2017, 7908183p.

Department of Water Affairs and Forestry (DWAF), 1996. South African Water Quality Guidelines (2nd ed.), Volume 1: Domestic Use. Pretoria: DWAF.

Department of Water Affairs and Forestry (DWAF), 1998. Quality of Domestic Water Supplies: Assessment Guide. WRC Report No. TT.101/98. Pretoria: DWAF.

Department of Water Affairs and Forestry, South Africa, 2004. Internal Strategic Perspective: Lower Orange Water Management Area. DWAF Report No. P WMA 14/000/00/0304. Available at: http://www.dwaf.gov.za/Documents/Other/WMA/14/Lower%20OrangeISPJul04Intro.pdf (Accessed: 22 July 2024).

Devi, P. and Kumar, P., 2020. Concept and application of phytoremediation in the fight of heavy metal toxicity. Journal of Pharmaceutical Sciences and Research, Vol.12 (6), pp.795-804.

Dharminder, R.K.S., Kumar, V., Devedee, A.K., Mruthyunjaya, M. and Bhardwaj, R., 2019. The clean water: the basic need of human and agriculture. International Journal of Current Science, Vol. 7(2), pp.1994-1998.

Dina, O.A., Adedapo, A.A., Oyinloye, O.P. and Saba, A.B., 2000. Effect of Telfaria occidentalis extract on experimentally induced anaemia in domestic rabbits. African Journal of Biomedical Research, Vol. 3(3), pp.181-183.

© University of Venda

Dirk, W., Georges-Ivo, E. and Antoinette, J., 2010. Halogen chemistry of borehole water used in drinking troughs on game ranches in the Musina area, Limpopo Province, South Africa. African Journal of Agricultural Research, Vol.5 (23), pp.3297-3309.

Dobrowsky, P.H., De Kwaadsteniet, M., Cloete, T.E. and Khan, W., 2014. Distribution of indigenous bacterial pathogens and potential pathogens associated with roof-harvested rainwater. Applied and Environmental Microbiology, Vol.80 (7), pp.2307-2316.

Dorne, J.L., Kass, G.E., Bordajandi, L.R., Amzal, B., Bertelsen, U., Castoldi, A.F., Heppner, C., Eskola, M., Fabiansson, S., Ferrari, P. and Scaravelli, E., 2010. Human risk assessment of heavy metals: principles and applications.

Dube, T., Mutanga, O., Seutloali, K., Adelabu, S. and Shoko, C., 2015. Water quality monitoring in sub-Saharan African lakes: a review of remote sensing applications. African Journal of Aquatic Science, Vol.40 (1), pp.1-7.

Duressa, G., Assefa, F. and Jida, M., 2019. Assessment of bacteriological and physicochemical quality of drinking water from source to household tap connection in Nekemte, Oromia, Ethiopia. Journal of environmental and public health, Vol.2019 (1), 2129792p.

Durowoju, O.S., Ekosse, G.-I.E. and Odiyo, J.O., 2020. Occurrence and health-risk assessment of trace metals in geothermal springs within Soutpansberg, Limpopo Province, South Africa. International Journal of Environmental Research and Public Health, Vol. 17 (12), 4438p.

Dutta, V., Dubey, D. and Kumar, S., 2020. Cleaning the River Ganga: impact of lockdown on water quality and future implications on river rejuvenation strategies. Science of the Total Environment, Vol. 743, 140756p.

Edokpayi, J.N., Enitan, A.M., Mutileni, N. and Odiyo, J.O., 2018a. Evaluation of water quality and human risk assessment due to heavy metals in groundwater around Muledane area of Vhembe District, Limpopo Province, South Africa. Chemistry Central Journal, Vol.12, pp.1-16.

Edokpayi, J.N., Enitan-Folami, A.M., Adeeyo, A.O., Durowoju, O.S., Jegede, A.O. and Odiyo, J.O., 2020. Recent trends and national policies for water provision and wastewater treatment in South Africa. In: Water conservation and wastewater treatment in BRICS

© University of Venda

nations, pp.187-211.

Edokpayi, J.N., Nkhumeleni, M., Enitan-Folami, A.M. and Olaniyi, F.C., 2022. Water quality assessment and potential ecological risk of trace metals in sediments of some selected rivers in Vhembe district, South Africa. Physics and Chemistry of the Earth, Parts A/B/C, Vol.126, 103111p.

Edokpayi, J.N., Odiyo, J.O. and Olasoji, S.O., 2014. Assessment of heavy metal contamination of Dzindi River, in Limpopo Province, South Africa. International Journal of Natural Science Research, Vol.2 (10), 185194p.

Edokpayi, J.N., Odiyo, J.O., Msagati, T.A. and Popoola, E.O., 2015. Removal efficiency of faecal indicator organisms, nutrients and heavy metals from a peri-urban wastewater treatment plant in Thohoyandou, Limpopo Province, South Africa. International Journal of Environmental Research and Public Health, Vol.12 (7), pp.7300-7320.

Edokpayi, J.N., Odiyo, J.O., Popoola, E.O. and Msagati, T.A., 2018c. Evaluation of microbiological and physicochemical parameters of alternative source of drinking water: a case study of Nzhelele River, South Africa. The Open Microbiology Journal, Vol.12, 18p.

Edokpayi, J.N., Odiyo, J.O., Popoola, O.E. and Msagati, T.A., 2021. Evaluation of contaminants removal by waste stabilization ponds: a case study of Siloam WSPs in Vhembe District, South Africa. Heliyon, Vol.7 (2), 06150p.

Edokpayi, J.N., Rogawski, E.T., Kahler, D.M., Hill, C.L., Reynolds, C., Nyathi, E., Smith, J.A., Odiyo, J.O., Samie, A., Bessong, P. and Dillingham, R., 2018b. Challenges to sustainable safe drinking water: a case study of water quality and use across seasons in rural communities in Limpopo province, South Africa. Water, Vol.10 (2), 159p.

Enitan-Folami, A.M., Mutileni, N., Odiyo, J.O., Swalaha, F.M. and Edokpayi, J.N., 2020. Hydrochemical, bacteriological assessment, and classification of groundwater quality in Thulamela Municipality, South Africa: potential health risk. Human and Ecological Risk Assessment: An International Journal, Vol.26 (8), pp.2044-2058.

Eyankware, M.O., Akakuru, O.C. and Eyankware, E.O., 2022. Interpretation of hydrochemical data using various geochemical models: a case study of Enyigba mining district of Abakaliki, Ebonyi State, SE Nigeria. Sustainable Water Resources Management, Vol.8 (1), 33p.

© University of Venda

Ezekwe, I.C., Arokoyu, S.B. and Amadi, M.D., 2017. Health implications of physico–chemical parameters in drinking water from parts of Gokana local government area of Rivers State, Nigeria. Port Harcourt Journal of Social Sciences, Vol.7 (1), pp.161-184.

Fatoki, O.S. and Awofolu, R.J.W.S., 2003. Levels of Cd, Hg and Zn in some surface waters from the Eastern Cape Province, South Africa. Water SA, Vol.29 (4), pp.375-380.

Fida, M., Li, P., Wang, Y., Alam, S.K. and Nsabimana, A., 2022. Water contamination and human health risks in Pakistan: a review. Exposure and Health, pp.1-21.

Fitri, A., Maulud, K.N.A., Pratiwi, D., Phelia, A., Rossi, F. and Zuhairi, N.Z., 2020. Trend of water quality status in Kelantan River downstream, Peninsular Malaysia. Jurnal Rekayasa Sipil, Vol.16 (3), pp.178-184.

Foster, S.S.D. and Chilton, P.J., 2003. Groundwater: the processes and global significance of aquifer degradation. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, Vol.358 (1440), pp.1957-1972.

García-Esquinas, E., Pollán, M., Téllez-Plaza, M., Francesconi, K.A., Goessler, W., Guallar, E., Umans, J.G., Yeh, J., Best, L.G. and Navas-Acien, A., 2014. Cadmium exposure and cancer mortality in a prospective cohort: the strong heart study. Environmental Health Perspectives, Vol.122 (4), pp.363-370.

Gerber, P. and Chen, B., 2011. Recognition of the human right to water: has the tide turned? Alternative Law Journal, Vol.36 (1), pp.21-26.

Ghoderao, S.B., Meshram, S.G. and Meshram, C., 2022. Development and evaluation of a water quality index for groundwater quality assessment in parts of Jabalpur District, Madhya Pradesh, India. Water Supply, Vol.22 (6), pp.6002-6012.

Goldhaber, S.B., 2003. Trace element risk assessment: essentiality vs. toxicity. Regulatory Toxicology and Pharmacology, Vol.38 (3), pp.232-242.

Golub, M.S. (ed.), 2005. Metals, fertility, and reproductive toxicity. CRC Press.

Grobbelaar, J.U., 2009. From laboratory to commercial production: a case study of a Spirulina (Arthrospira) facility in Musina, South Africa. Journal of Applied Phycology, Vol.21 (5), pp.523-527.

© University of Venda

Gumbo, J.R., Dzaga, R.A. and Nethengwe, N.S., 2016. Impact on water quality of Nandoni water reservoir downstream of municipal sewage plants in Vhembe District, South Africa. Sustainability, Vol.8 (7), 597p.

Guo, H. and Keppler, H., 2019. Electrical conductivity of NaCl-bearing aqueous fluids to 900°C and 5 GPa. Journal of Geophysical Research: Solid Earth, Vol.124 (2), pp.1397-1411.

Gupta, C.P., 2014. Role of iron (Fe) in body. IOSR Journal of Applied Chemistry, Vol.7 (11), pp.38-46.

Gwenzi, W. and Nyamadzawo, G., 2014. Hydrological impacts of urbanization and urban roof water harvesting in water-limited catchments: a review. Environmental Processes, Vol.1 (4), pp.573-593.

Haseena, M., Malik, M.F., Javed, A., Arshad, S., Asif, N., Zulfiqar, S. and Hanif, J., 2017. Water pollution and human health. Environmental Risk Assessment and Remediation, Vol.1 (3).

Hashmi, M.Z., Yu, C., Shen, H., Duan, D., Shen, C., Lou, L. and Chen, Y., 2014. Concentrations and human health risk assessment of selected heavy metals in surface water of the Siling Reservoir Watershed in Zhejiang Province, China. Polish Journal of Environmental Studies, Vol.23 (3), pp.455-456.

Hassan, N.E. & Umer, M.I., 2022. Improving physicochemical properties of municipal solid waste landfill leachate by aeration and filtration in Kwashe industrial area in Iraqi Kurdistan Region. AIP Conference Proceedings, Vol.2660 (1), 020111p.

Hassan, N.E., 2023. An investigation of heavy metals concentration in rainwater and their effects on human health in Kurdistan Region, Iraq. GSC Advanced Research and Reviews, Vol.17 (02), pp.229-239.

Hinga, M., 2016. The effect of septic tanks sewage disposal system distances on borehole water quality in Ongata Rongai, Kajiado County, Kenya. [Doctoral dissertation, University of Nairobi].

Hopenhayn-Rich, C., Biggs, M.L. and Smith, A.H., 1998. Lung and kidney cancer mortality associated with arsenic in drinking water in Córdoba, Argentina. International Journal of Epidemiology, Vol.27 (4), pp.561-569.

© University of Venda

Horton, R.K., 1965. An index number system for rating water quality. Journal of the Water Pollution Control Federation, Vol.37 (3), pp.300-306.

Hossain, M.R., Khan, M.S., Islam, M.A. and Hasan, M., 2022. Pond sand filter as an alternative system for purifying drinking water: climate change perspective in Mongla, Bangladesh. International Journal of Energy and Water Resources, Vol.6 (2), pp.243-252.

Howard, E.T., 2000. Inductively coupled plasma-mass spectrometry. In: Handbook of Instrumental Techniques for Analytical Chemistry, pp.16-30.

Huang, M., Zhou, S., Sun, B. and Zhao, Q., 2008. Heavy metals in wheat grain: assessment of potential health risk for inhabitants in Kunshan, China. Science of the Total Environment, Vol.405 (1–3), pp.54-61.

Hutton, G. and Chase, C., 2016. The knowledge base for achieving the sustainable development goal targets on water supply, sanitation and hygiene. International Journal of Environmental Research and Public Health, Vol.13 (6), 536p.

Hwang, J.Y., Park, S., Kim, H.K., Kim, M.S., Jo, H.J., Kim, J.I., Lee, G.M., Shin, I.K. and Kim, T.S., 2017. Hydrochemistry for the assessment of groundwater quality in Korea. Journal of Agricultural Chemistry and Environment, Vol.6 (01), 1p.

IARC, 2017. IARC Monographs on the Evaluation of the Carcinogenic Risks to Humans. Lyon, France: International Agency for Research on Cancer. Available at: http://monographs.iarc.fr/ENG/Classification/latest_classif.php (Accessed: 16 December 2024).

Ilori, B.A., Adewumi, J.R., Lasisi, K.H. and Ajibade, F.O., 2019. Qualitative assessment of some available water resources in Efon-Alaaye, Ekiti State Nigeria. Journal of Applied Sciences and Environmental Management, Vol.23 (1), pp.35-40.

Inan-Eroglu, E. and Ayaz, A., 2018. Is aluminum exposure a risk factor for neurological disorders? Journal of Research in Medical Sciences, Vol.23 (1), 51p.

Islam, A.R.M.T., Al Mamun, A., Rahman, M.M. and Zahid, A., 2020. Simultaneous comparison of modified-integrated water quality and entropy weighted indices: implication for safe drinking water in the coastal region of Bangladesh. Ecological Indicators, Vol.113, pp.106229.

© University of Venda

Islam, A.R.M.T., Al Mamun, A., Rahman, M.M. and Zahid, A., 2020. Simultaneous comparison of modified-integrated water quality and entropy weighted indices: implication for safe drinking water in the coastal region of Bangladesh. Ecological Indicators, Vol.113, 106229p.

Islam, R., Faysal, S.M., Amin, R., Juliana, F.M., Islam, M.J., Alam, J., Hossain, M.N. and Asaduzzaman, M., 2017. Assessment of pH and total dissolved substances (TDS) in the commercially available bottled drinking water. IOSR Journal of Nursing and Health Science, Vol.6 (5), pp.35-40.

Ismael, M., Al-Momani, I. and Al-Momani, M., 2021. Health risk assessment of heavy metals in drinking water from the Jordan Valley, Jordan. Environmental Monitoring and Assessment, Vol.193 (3), pp.1-11.

Ismael, M., Mokhtar, A., Farooq, M. and Lü, X., 2021. Assessing drinking water quality based on physical, chemical and microbial parameters in the Red Sea State, Sudan using a combination of water quality index and artificial neural network model. Groundwater for Sustainable Development, Vol.14, 100612p.

Ismail, A.A. and Ismail, N.A., 2016. Magnesium: a mineral essential for health yet generally underestimated or even ignored. Journal of Nutrition and Food Sciences, Vol.6 (2), pp.1-8.

Jiang, H.H., Cai, L.M., Wen, H.H., Hu, G.C., Chen, L.G. and Luo, J., 2020. An integrated approach to quantifying ecological and human health risks from different sources of soil heavy metals. Science of the Total Environment, Vol.701, 134466p.

Joshi, A. and Amadi, C., 2013. Impact of water, sanitation, and hygiene interventions on improving health outcomes among school children. Journal of Environmental and Public Health, 984626p.

Juwana, I., Muttil, N. and Perera, B.J.C., 2012. Indicator-based water sustainability assessment—A review. Science of the total environment, Vol.438, pp.357-371.

K'oreje, K.O., Vergeynst, L., Ombaka, D., De Wispelaere, P., Okoth, M., Van Langenhove, H. and Demeestere, K., 2016. Occurrence patterns of pharmaceutical residues in wastewater, surface water and groundwater of Nairobi and Kisumu city, Kenya. Chemosphere, Vol.149, pp.238-244.

© University of Venda

Kachroud, M., Trolard, F., Kefi, M., Jebari, S. and Bourrié, G., 2019. Water quality indices: Challenges and application limits in the literature. *Water*, Vol.11 (2), 361p.

Kamunda, C., Mathuthu, M. and Madhuku, M., 2016. Health risk assessment of heavy metals in soils from Witwatersrand gold mining basin, South Africa. International Journal of Environmental Research and Public Health, Vol.13, 663p.

Karunanithi, R., Szogi, A.A., Bolan, N., Naidu, R., Loganathan, P., Hunt, P.G., Vanotti, M.B., Saint, C.P., Ok, Y.S. and Krishnamoorthy, S., 2015. Phosphorus recovery and reuse from waste streams. Advances in Agronomy, Vol.131, pp.173-250.

Kashani, A., 2011. Aerosol characterization and analytical modeling of concentric pneumatic and flow focusing nebulizers for sample introduction. [Doctoral dissertation].

Kaur, K., 2020. The impact of water on key health and social outcomes: evidence from developed and developing countries. Indian Journal of Economics and Development, Vol.16 (2), pp.378-383.

Khabo-Mmekoa, C.M.N. and Momba, M.N.B., 2019. The impact of social disparities on microbiological quality of drinking water supply in Ugu District Municipality of KwaZulu-Natal Province, South Africa. International Journal of Environmental Research and Public Health, Vol.16 (16), 2972p.

Khan, M., Almazah, M.M., Elahi, A., Niaz, R., Al-Rezami, A.Y. and Zaman, B., 2023. Spatial interpolation of water quality index based on ordinary kriging and universal kriging. Geomatics, Natural Hazards and Risk, Vol.14 (1), 2190853p.

Khan, N., Hussain, S.T., Saboor, A., Jamila, N., Khan, S.N. and Kim, K.S., 2013. Chemical investigation of the drinking water sources from Mardan, Khyber Pakhtunkhwa, Pakistan. World Applied Sciences Journal, Vol.27 (1), pp.112-122.

Khan, S.R., Sharma, B., Chawla, P.A. and Bhatia, R., 2022. Inductively coupled plasma optical emission spectrometry (ICP-OES): a powerful analytical technique for elemental analysis. Food Analytical Methods, pp.1–23.

Khwaja, M.A. and Aslam, A., 2018. Comparative assessment of Pakistan national drinking water quality standards with selected Asian countries and World Health Organization.

Kmiecik, E., Tomaszewska, B., Wątor, K. and Bodzek, M., 2016. Selected problems with

© University of Venda

boron determination in water treatment processes. Part I: comparison of the reference methods for ICP-MS and ICP-OES determinations. Environmental Science and Pollution Research, Vol.23, pp.11658-11667.

Kosaka, T., Sato, T. and Sato, T., 2007. Brown hair and nail discoloration by water containing iron. Hautarzt, Vol.48 (8), pp.568-571.

Krishnan, R.R., Dharmaraj, K. and Kumari, B.R., 2007. A comparative study on the physicochemical and bacterial analysis of drinking, borewell and sewage water in three different places of Sivakasi. Journal of Environmental Biology, Vol.28 (1), pp.105-108.

Kristanti, R.A., Hadibarata, T., Syafrudin, M., Yılmaz, M. and Abdullah, S., 2022. Microbiological contaminants in drinking water: current status and challenges. Water, Air, & Soil Pollution, Vol.233 (8), 299p.

Kumar, P., Kothari, A., Yadav, S.R.M., Kumar, S., Mandal, A., Mamgain, G., Omar, B.J., Bhadoria, A.S., Singh, B., Kumar, A. and Mirza, A.A., 2024. Carcinogenic and non-carcinogenic health risk assessment of River Ganges in different climatic conditions and regions of Uttarakhand, India. The Nucleus, pp.1-18.

Lajçi, N., Sadiku, M., Lajçi, X., Baruti, B. and Nikshiq, S., 2017. Assessment of major and trace elements of fresh water springs in village Pepaj, Rugova region, Kosova. Journal of International Environmental Application and Science, Vol.12 (2), pp.112-120.

Leclerc, H.D.A.A., Mossel, D.A.A., Edberg, S.C. and Struijk, C.B., 2001. Advances in the bacteriology of the coliform group: their suitability as markers of microbial water safety. Annual Reviews in Microbiology, Vol.55 (1), pp.201-234.

Leeming, R., Ball, A., Ashbolt, N. and Nichols, P., 1996. Using faecal sterols from humans and animals to distinguish faecal pollution in receiving waters. Water Research, Vol.30 (12), pp.2893-2900.

Lei, Y., Xiao, W., Peng, H., Yu, P., Cai, X., Luan, Z., Deng, S. and Wang, S., 2021. An integrated epoxy rust conversion coating: Its anticorrosion properties and rust conversion mechanism. Journal of Alloys and Compounds,Vol. 853, 157005p.

Lewiński, A. and Skowrońska-Jóźwiak, E., 2014. Calcium and vitamin D supply in Polish population - facts and myths. Annals of Agricultural and Environmental Medicine, Vol.21

© University of Venda

(3).

Lewoyehu, M., 2021. Evaluation of drinking water quality in rural area of Amhara region, Ethiopia: the case of Mecha district. Journal of Chemistry, 2021, 9911838p.

Li, P., Karunanidhi, D., Subramani, T. and Srinivasamoorthy, K., 2021. Sources and consequences of groundwater contamination. Archives of Environmental Contamination and Toxicology, Vol.80 (1), pp.1-10.

Li, Z., Boyle, F. and Reynolds, A., 2010. Rainwater harvesting and greywater treatment systems for domestic application in Ireland. Desalination, Vol.260 (1-3), pp.1-8.

Liu, J.M., Liu, C.C., Fang, G.Z. and Wang, S., 2015. Advanced analytical methods and sample preparation for ion chromatography techniques. RSC Advances, Vol.5 (72), pp.58713-58726.

Luvhimbi, N., Tshitangano, T.G., Mabunda, J.T., Olaniyi, F.C. and Edokpayi, J.N., 2022. Water quality assessment and evaluation of human health risk of drinking water from source to point of use at Thulamela municipality, Limpopo Province. Scientific Reports, Vol.12 (1), 6059p.

Madigan, M.T., Bender, K.S., Buckley, D.H., Sattley, W.M. and Stahl, D.A., 2018. Brock Biology of Microorganisms. 15th edn. New York: Pearson.

Madilonga, R.T., Edokpayi, J.N., Volenzo, E.T., Durowoju, O.S. and Odiyo, J.O., 2021. Water quality assessment and evaluation of human health risk in Mutangwi River, Limpopo Province, South Africa. International Journal of Environmental Research and Public Health, Vol.18 (13), 6765p.

Madziga, M., Rahil, A. and Mansoor, R., 2018. Comparison between three off-grid hybrid systems (solar photovoltaic, diesel generator and battery storage system) for electrification for village, South Africa. Environments, Vol.5 (5), 57p.

Magonono, M., 2017. A comparative study of the origins of cyanobacteria at Musina Water Treatment Plant using DNA fingerprints. [Doctoral dissertation].

Mahmud, M.J., Sultana, M.S., Hossain, S., Sultana, S. and Rahman, M.M., 2020. Health risk assessment based on the trace elements in the fruits and vegetables grown in an industrial area in Dhaka City, Bangladesh. Journal of Human Environment and Health Promotion,

© University of Venda

Vol.6 (3), pp.106-114.

Makungo, R. and Odiyo, J.O., 2018. Groundwater quality and its distributions in Siloam Village, Limpopo Province, South Africa. WIT Transactions on Ecology and the Environment, Vol.228, pp.35-44.

Malassa, H., Al-Rimawi, F., Al-Khatib, M. and Al-Qutob, M., 2014. Determination of trace heavy metals in harvested rainwater used for drinking in Hebron (south West Bank, Palestine) by ICP-MS. Environmental monitoring and assessment, Vol.186 (10), pp.6985-6992.

Mandindi, W.Z., Nyaba, L., Mketo, N. and Nomngongo, P.N., 2022. Seasonal variation of drinking water quality and human health risk assessment: a case study in rural village of the Eastern Cape, South Africa. Water, Vol.14 (13), 2013p.

Markou, G., Wang, L., Ye, J. and Unc, A., 2018. Using agro-industrial wastes for the cultivation of microalgae and duckweeds: contamination risks and biomass safety concerns. Biotechnology Advances, Vol.36 (4), pp.1238-1254.

Marufi, N., Conti, G.O., Ahmadinejad, P., Ferrante, M. and Mohammadi, A.A., 2024. Carcinogenic and non-carcinogenic human health risk assessments of heavy metals contamination in drinking water supplies in Iran: a systematic review. Reviews on Environmental Health, Vol.39 (1), pp.91-100.

Matta, G. and Kumar, A., 2017. Health risk, water hygiene, science and communication. ESSENCE-International Journal for Environmental Rehabilitation and Conservation, Vol.1, pp.179-186.

Mazumder, D.N.G., 2008. Chronic arsenic toxicity & human health. Indian Journal of Medical Research, Vol.128 (4), pp.436-447.

Medema, G.J., Payment, P., Dufour, A., Robertson, W., Waite, M., Hunter, P., Kirby, R. and Andersson, Y., 2003. Safe drinking water: an ongoing challenge. In: Assessing Microbial Safety of Drinking Water, pp.1-11.

Meride, Y. and Ayenew, B., 2016. Drinking water quality assessment and its effects on resident's health in Wondo Genet campus, Ethiopia. Environmental Systems Research, Vol.5 (1), pp.1–7.

© University of Venda

Microbe Notes, 2021. Ion Exchange Chromatography: Principle, Parts, Steps, Uses. Available at: https://microbenotes.com/ion-exchange-chromatography/ (Accessed: 14 January 2025).

Mohammadi, A.A., Zarei, A., Majidi, S., Ghaderpoury, A., Hashempour, Y., Saghi, M.H., Alinejad, A., Yousefi, M., Hosseingholizadeh, N. and Ghaderpoori, M., 2019. Carcinogenic and non-carcinogenic health risk assessment of heavy metals in drinking water of Khorramabad, Iran. MethodsX, Vol.6, pp.1642-1651.

Mohsin, M., Safdar, S., Asghar, F. and Jamal, F., 2013. Assessment of drinking water quality and its impact on resident's health in Bahawalpur City. International Journal of Humanities and Social Science, Vol.3 (15), pp.114-128.

Molekoa, M.D., Avtar, R., Kumar, P., Thu Minh, H.V., Dasgupta, R., Johnson, B.A., Sahu, N., Verma, R.L. and Yunus, A.P., 2021. Spatio-temporal analysis of surface water quality in Mokopane area, Limpopo, South Africa. Water, Vol.13 (2), 220p.

Moradnia, M., Attar, H.M., Hajizadeh, Y., Lundh, T., Salari, M. and Darvishmotevalli, M., 2024. Assessing the carcinogenic and non-carcinogenic health risks of metals in the drinking water of Isfahan, Iran. Scientific Reports, Vol.14 (1), 5029p.

Motlagh, A.M. and Yang, Z., 2019. Detection and occurrence of indicator organisms and pathogens. Water Environment Research, Vol.91 (10), pp.1402-1408.

Mpenyana-Monyatsi, L. and Momba, M.N.B., 2012. Assessment of groundwater quality in the rural areas of the North West Province, South Africa. Scientific Research and Essays, Vol.7 (8), pp.903-914.

Muhammad, S., Shah, M.T. and Khan, S., 2011. Health risk assessment of heavy metals and their source apportionment in drinking water of Kohistan region, northern Pakistan. Microchemical Journal, Vol.98 (2), pp.334-343.

Mukonazwothe, M., Munyai, L.F. and Mutoti, M.I., 2022. Groundwater quality evaluation for domestic and irrigation purposes for the Nwanedi Agricultural Community, Limpopo Province, South Africa. Heliyon, Vol.8 (4), 09203p.

Munteanu, C. and Iliuta, A., 2011. The role of sodium in the body. Balneo Research Journal, Vol.2, pp.70-74.

© University of Venda

Munyai, R.B., Chikoore, H., Musyoki, A., Chakwizira, J., Muofhe, T.P., Xulu, N.G. and Manyanya, T.C., 2021. Vulnerability and adaptation to flood hazards in rural settlements of Limpopo Province, South Africa. Water, Vol.13 (24), 3490p.

Mutileni, N., 2021. Assessment of health risk association with groundwater from Collins Chabane and Makhado Municipality of Vhembe District. [Doctoral dissertation].

Mutileni, N., Mudau, M. and Edokpayi, J.N., 2023. Water quality, geochemistry and human health risk of groundwater in the Vyeboom region, Limpopo Province, South Africa. Scientific Reports, Vol.13 (1), 19071p.

Namugize, J.N., Jewitt, G. and Graham, M., 2018. Effects of land use and land cover changes on water quality in the uMngeni river catchment, South Africa. Physics and Chemistry of the Earth, Parts A/B/C, Vol.105, pp.247-264.

Nawaz, R., Nasim, I., Irfan, A., Islam, A., Naeem, A., Ghani, N., Irshad, M.A., Latif, M., Nisa, B.U. and Ullah, R., 2023. Water quality index and human health risk assessment of drinking water in selected urban areas of a Mega City. Toxics, Vol.11 (7), 577p.

Ndubuisi, C.C., Nwakanma, C. and Onyeizu, U.R., 2021. Assessment of water quality status and benthic fauna diversity of Amuzuta Stream, Umuahia, Southeast Nigeria. Nigeria Agricultural Journal, Vol.52 (3), pp.209-221.

Nekhvhambe, T.J., Van Ree, T. and Fatoki, O.S., 2014. Determination and distribution of polycyclic aromatic hydrocarbons in rivers, surface runoff, and sediments in and around Thohoyandou, Limpopo Province, South Africa. Water SA, Vol.40 (3), pp.415-424.

Niyoyitungiye, L., Giri, A. and Ndayisenga, M., 2020. Assessment of coliforms bacteria contamination in Lake Tanganyika as bioindicators of recreational and drinking water quality. Academic Leadership, Vol.6 (3), pp.9-16.

Njoku, K., Ude, E.O., Iheme, P.O., Onuaguluchi, P.N. and Osukoya, O.O., 2024. Health risk assessment of groundwater from selected areas of Ijebu North, Ogun State, Nigeria. Aswan University Journal of Environmental Studies, Vol.5 (1), pp.1-14.

Nthunya, L.N., Maifadi, S., Mamba, B.B., Verliefde, A.R. and Mhlanga, S.D., 2018. Spectroscopic determination of water salinity in brackish surface water in Nandoni Dam, at Vhembe District, Limpopo Province, South Africa. Water, Vol.10 (8), 990p.

© University of Venda

Ntshangase, S.N., 2019. Assessment of nitrate pollution in groundwater (Chaneng Village, Rustenburg). [Doctoral dissertation, North-West University (South Africa)].

OB, A. and Muchie, M., 2010. Remediation of heavy metals in drinking water and wastewater treatment systems: processes and applications. International Journal of Physical Sciences, Vol.5, pp.1807-1817.

Obiefuna, G.I. and Sheriff, A., 2011. Assessment of shallow groundwater quality of Pindiga Gombe Area, Yola Area, NE Nigeria for irrigation and domestic purposes. Research Journal of Environmental and Earth Sciences, Vol.3 (2), pp.131-141.

Odey, M.O., Ibor, O.R., Andem, A.B., Ettah, I. and Chukwuka, A.V., 2018. Drinking water quality and risk implications for community health: a case study of shallow water wells and boreholes in three major communities in Northern Cross-River, Southern Nigeria. Human and Ecological Risk Assessment: An International Journal, Vol.24 (2), pp.427-444.

Odiyo, J.O. and Makungo, R., 2012. Fluoride concentrations in groundwater and impact on human health in Siloam Village, Limpopo Province, South Africa. Water SA, Vol.38 (5), pp.731-736.

Odiyo, J.O., Mathoni, M.M. and Makungo, R., 2020. Health risks and potential sources of contamination of groundwater used by public schools in Vhuronga 1, Limpopo Province, South Africa. International Journal of Environmental Research and Public Health, Vol.17 (18), 6912p.

Ogola, J.B., Madzivhandila, V., Maseko, S.T. and Leboho, T.M., 2023. P-fertiliser and rhizobial inoculation increased the concentration of mineral nutrients in the rhizosphere of two chickpea genotypes. Acta Agriculturae Scandinavica, Section B—Soil & Plant Science, Vol.73 (1), pp.94–101.

Olasoji, S.O., Oyewole, N.O., Abiola, B. and Edokpayi, J.N., 2019. Water quality assessment of surface and groundwater sources using a water quality index method: a case study of a peri-urban town in Southwest Nigeria. Environments, Vol.6 (2), 23p.

Olowoyo, J.O., Mugivhisa, L.L. and Moganedi, K.L.M., 2022. Health risk assessment of trace metals in bottled water purchased from various retail stores in Pretoria, South Africa.

© University of Venda

International Journal of Environmental Research and Public Health, Vol.19 (22), 15131p.

Omer, N.H., 2019. Water quality parameters. In: Water Quality – Science, Assessments and Policy. Vol.18, pp.1-34.

Oputu, O.U. and Akharame, M.O., 2022. Assessment of surface water quality within Cape Town, South Africa using NSF water quality index. International Journal of Energy and Water Resources, pp.1-13.

Oyem, H.H., Oyem, I.M. and Ezeweali, D., 2014. Temperature, pH, electrical conductivity, total dissolved solids and chemical oxygen demand of groundwater in Boji-Boji Agbor/Owa area and immediate suburbs. Research Journal of Environmental Sciences, Vol.8 (8), 444p.

Pachepsky, Y., Shelton, D., Dorner, S. and Whelan, G., 2016. Can E. coli or thermotolerant coliform concentrations predict pathogen presence or prevalence in irrigation waters? Critical Reviews in Microbiology, Vol.42 (3), pp.384-393.

Pal, M., Ayele, Y., Hadush, M., Panigrahi, S. and Jadhav, V.J., 2018. Public health hazards due to unsafe drinking water. Air Water Borne Diseases, Vol.7 (1000138), 2p.

Palamuleni, L. and Akoth, M., 2015. Physico-chemical and microbial analysis of selected borehole water in Mahikeng, South Africa. International Journal of Environmental Research and Public Health, Vol.12 (8), pp.8619-8630.

Pathak, S.K., Prasad, S. and Pathak, T. (2015). Determination of water quality index River Bhagirathi in Uttarkashi, Uttarakhad, India, International Journal of Research-Granthaalayah, Vol. 3(9), 7p.

Peek, L., Abramson, D.M., Cox, R.S., Fothergill, A. and Tobin, J., 2018. Children and disasters. In: Handbook of Disaster Research, pp.243–262.

Pesce, S.F. and Wunderlin, D.A., 2000. Use of water quality indices to verify the impact of Córdoba City (Argentina) on Suquía River. Water research, Vol.34 (11), pp.2915-2926.

Petersen, R.B. and Melchers, R.E., 2012. Long-term corrosion of cast iron cement lined pipes. Corrosion and Prevention, Vol.23 (10).

Pinto, A.J., Xi, C. and Raskin, L., 2012. Bacterial community structure in the drinking water microbiome is governed by filtration processes. Environmental Science & Technology,

© University of Venda

Vol.46 (16), pp.8851-8859.

Pohl, H.R., Wheeler, J.S. and Murray, H.E., 2013. Sodium and potassium in health and disease. In: Interrelations between Essential Metal Ions and Human Diseases, pp.29–47.

Poonam, T., Tanushree, B. and Sukalyan, C., 2013. Water quality indices-important tools for water quality assessment: a review. International Journal of Advances in chemistry, Vol.1 (1), pp.15-28.

Potgieter, N., Karambwe, S., Mudau, L.S., Barnard, T. and Traore, A., 2020. Human enteric pathogens in eight rivers used as rural household drinking water sources in the northern region of South Africa. International Journal of Environmental Research and Public Health, Vol.17 (6), 2079p.

Poursaeid, M., Mastouri, R., Shabanlou, S. and Najarchi, M., 2020. Estimation of total dissolved solids, electrical conductivity, salinity and groundwater levels using novel learning machines. Environmental Earth Sciences, Vol.79, pp.1-25.

Pradeep, V., Deepika, C., Urvi, G. and Hitesh, S., 2012. Water quality analysis of an organically polluted lake by investigating different physical and chemical parameters. International Journal of Research in Chemistry and Environment, Vol.2 (1), pp.105-111.

Prince, M., Wimo, A., Guerchet, M., Ali, G.C., Wu, Y.T. and Prina, M., 2015. World Alzheimer Report 2015: The Global Impact of Dementia: An analysis of prevalence, incidence, cost and trends. [Doctoral dissertation, Alzheimer's disease International].

PubMed Central, 2025. ICP-MS in environmental analysis. Available at: https://pmc.ncbi.nlm.nih.gov/articles/PMC6719745/ (Accessed: 14 January 2025).

Pye, H.O., Nenes, A., Alexander, B., Ault, A.P., Barth, M.C., Clegg, S.L., Collett Jr, J.L., Fahey, K.M., Hennigan, C.J., Herrmann, H., and Kanakidou, M., 2020. The acidity of atmospheric particles and clouds. Atmospheric Chemistry and Physics, Vol.20 (8), pp.4809-4888.

Qing, X., Yutong, Z. and Shenggao, L., 2015. Assessment of heavy metal pollution and human health risk in urban soils of steel industrial city (Anshan), Liaoning, Northeast China. Ecotoxicology and Environmental Safety, Vol.120, pp.377-385.

Rahman, A. and Rahaman, H., 2018. Contamination of arsenic, manganese and coliform

© University of Venda

bacteria in groundwater at Kushtia District, Bangladesh: human health vulnerabilities. Journal of Water and Health, Vol.16 (5), pp.782-795.

Rai, P.K., Lee, S.S., Zhang, M., Tsang, Y.F. and Kim, K.H., 2019. Heavy metals in food crops: health risks, fate, mechanisms, and management. Environment International, Vol.125, pp.365-385.

Raimi, M.O., Ayibatonbira, A.A., Anu, B., Odipe, O.E. and Deinkuro, N.S., 2019. 'Digging Deeper' evidence on water crisis and its solution in Nigeria for Bayelsa State: a study of current scenario. International Journal of Hydrology, Vol.3 (4), pp.244-257.

Raimi, M.O., Ezekwe, C.I., Bowale, A. and Samson, T.K., 2022. Hydrogeochemical and multivariate statistical techniques to trace the sources of groundwater contaminants and affecting factors of groundwater pollution in an oil and gas producing wetland in Rivers State, Nigeria. Open Journal of Yangtze Gas and Oil, Vol.7, pp.166-202.

Ramaano, A.I., 2022. Tourism implications and challenges in Musina Municipality: a case of the Big Tree Nature Reserve and adjacent tourism ventures; Limpopo. Rajagiri Management Journal, Vol.16 (3), pp.239–259.

Ramakrishnaiah, C.R., Sadashivaiah, C. and Ranganna, G., 2009. Assessment of water quality index for the groundwater in Tumkur Taluk, Karnataka State, India. Journal of Chemistry, Vol.6 (2), pp.523-530.

ResearchGate, 2025. Atomic absorption, emission, and ICP-MS: advantages and disadvantages. Available at: https://www.researchgate.net/publication/318147631_Atomic_Absorption_Spectroscopy_Atomic_Emission_Spectroscopy_and_Inductively_Coupled_Plasma-Mass_Spectrometry (Accessed: 11 January 2025).

Rompré, A., Servais, P., Baudart, J., De-Roubin, M.R. and Laurent, P., 2002. Detection and enumeration of coliforms in drinking water: current methods and emerging approaches. Journal of Microbiological Methods, Vol.49 (1), pp.31–54.

Runa, R.A., Maksud, S., Rahman, M.S., Hasan, M. and Alam, M.R., 2022. Impact of drinking of saline water on hemato-biochemical parameters of Black Bengali goats in the selected areas of Bangladesh. Saudi Journal of Biological Sciences, Vol.29 (10), 103397p.

© University of Venda

Saha, S., Reza, A.H. and Roy, M.K., 2019. Hydrochemical evaluation of groundwater quality of the Tista floodplain, Rangpur, Bangladesh. Applied Water Science, Vol.9.

Sahu, P. and Sikdar, P.K., 2008. Hydrochemical framework of the aquifer in and around East Kolkata Wetlands, West Bengal, India. Environmental geology, Vol.55 (4), pp.823-835.

Samie, A., Makonto, O.T., Mojapelo, P., Bessong, P.O., Odiyo, J.O. and Uaboi-Egbenni, P.O., 2013. Physico-chemical assessment of borehole water used by schools in Greater Giyani Municipality, Mopani District, South Africa. African Journal of Biotechnology, Vol.12 (30), pp. 4858-4865.

Sánchez, E., Colmenarejo, M.F., Vicente, J., Rubio, A., García, M.G., Travieso, L. and Borja, R., 2007. Use of the water quality index and dissolved oxygen deficit as simple indicators of watersheds pollution. Ecological indicators, Vol.7 (2), pp.315-328.

Satarug, S., Nishijo, M., Ujjin, P. and Moore, M.R., 2018. Chronic exposure to low-level cadmium induced zinc-copper dysregulation. Journal of Trace Elements in Medicine and Biology, Vol.46, pp.32-38.

Sazakli, E., Alexopoulos, A. and Leotsinidis, M., 2007. Rainwater harvesting, quality assessment and utilization in Kefalonia Island, Greece. Water research, Vol.41 (9), pp.2039-2047.

Schneider, S., 2023. The onset of dental erosions caused by acidic foods and drinks and its prevention. [Doctoral dissertation, Vilniaus Universitetas].

Seth, R., Mohan, M., Singh, P., Singh, R., Dobhal, R., Singh, K.P. and Gupta, S., 2016. Water quality evaluation of Himalayan Rivers of Kumaun region, Uttarakhand, India. Applied Water Science, Vol.6, pp.137-147.

Shammi, M., Rahman, M.M., Bondad, S.E. and Bodrud-Doza, M., 2019. Impacts of salinity intrusion in community health: a review of experiences on drinking water sodium from coastal areas of Bangladesh. Healthcare, Vol.7 (1), 50p.

Sharma, D. and Kansal, A., 2011. Water quality analysis of River Yamuna using water quality index in the national capital territory, India (2000–2009). Applied water science, Vol.1 (3), pp.147-157.

© University of Venda

Sharma, M., Verma, M.L., Tewatia, M., Kumar, S., Singh, B.P. and Kumar, P., 2016. Physico-chemical assessment of Ganga Canal (Gaziabad). International Journal of Advanced Engineering Sciences, 4(5), pp.405–412.

Shomar, B. and Hawari, J., 2017. Desalinated drinking water in the GCC countries – the need to address consumer perceptions. Environmental Research, Vol.158, pp.203-211.

Sibanda, T., Selvarajan, R. and Tekere, M., 2015. Urban effluent discharges as causes of public and environmental health concerns in South Africa's aquatic milieu. Environmental Science and Pollution Research, Vol.22 (23), pp.18301-18317.

Simeonov, V., Stratis, J.A., Samara, C., Zachariadis, G., Voutsa, D., Anthemidis, A., Sofoniou, M. and Kouimtzis, T., 2003. Assessment of the surface water quality in Northern Greece. Water research, Vol.37 (17), pp.4119-4124.

Sindane, T.J. and Modley, S.L.A., 2023. The impacts of poor water quality on the residential areas of Emfuleni Local Municipality: a case study of perceptions in the Rietspruit River catchment in South Africa. Urban Water Journal, Vol.20 (10), pp.1568–1578.

Singo, N.K. and Kramers, J.D., 2020. Retreatability analysis of the Musina copper mine tailings in South Africa: an exploratory study. SN Applied Sciences, Vol.2 (10), 1707p.

Singo, N.K., 2013. An assessment of heavy metal pollution near an old copper mine dump in Musina, South Africa. University of South Africa (South Africa).

Smith, A.H., Hopenhayn-Rich, C., Bates, M.N., Goeden, H.M., Hertz-Picciotto, I., Duggan, H.M., Wood, R., Kosnett, M.J. and Smith, M.T., 1992. Cancer risks from arsenic in drinking water. British Journal of Cancer, Vol.66 (5), pp.888-892.

Sobsey, M.D., Stauber, C.E., Casanova, L.M., Brown, J.M. and Elliott, M.A., 2008. Point of use household drinking water filtration: a practical, effective solution for providing sustained access to safe drinking water in the developing world. Environmental Science & Technology, Vol.42 (12), pp.4261-4267.

Soetan, K.O., Olaiya, C.O. and Oyewole, O.E., 2010. The importance of mineral elements for humans, domestic animals and plants: a review. African Journal of Food Science, Vol.4 (5), pp.200-222.

Solomon, S., Qin, D., Manning, M., Averyt, K. and Marquis, M. (eds), 2007. Climate Change

© University of Venda

2007 – The Physical Science Basis: Working Group I Contribution to the Fourth Assessment Report of the IPCC, Vol.4. Cambridge University Press.

Song, J.K., Luo, H., Yin, X.H., Huang, G.L., Luo, S.Y., Lin, D.R., Yuan, D.B., Zhang, W. and Zhu, J.G., 2015. Association between cadmium exposure and renal cancer risk: a meta-analysis of observational studies. Scientific Reports, Vol.5 (1), 17976p.

Sorensen, J.P.R., Lapworth, D.J., Marchant, B.P., Nkhuwa, D.C.W., Pedley, S., Stuart, M.E., Bell, R.A., Chirwa, M., Kabika, J., Liemisa, M. and Chibesa, M., 2015. In-situ tryptophan-like fluorescence: a real-time indicator of faecal contamination in drinking water supplies. Water Research, Vol.81, pp.38-46.

South African National Standards (SANS), 2015. Drinking Water. Part 1: Microbiological, Physical, Chemical, Aesthetic and Chemical Determinants. Pretoria: South African Bureau of Standards.

Srivastava, S. and Flora, S.J.S., 2020. Fluoride in drinking water and skeletal fluorosis: a review of the global impact. Current Environmental Health Reports, 7, pp.140-146.

Stamatas, G.N. and Tierney, N.K., 2014. Diaper dermatitis: etiology, manifestations, prevention, and management. Pediatric Dermatology, Vol.31 (1), pp.1-7.

Strehmel, A., Schmalz, B. and Fohrer, N., 2016. Evaluation of land use, land management and soil conservation strategies to reduce non-point source pollution loads in the Three Gorges region, China. Environmental Management, Vol.58, pp.906-921.

Sulaiman, M.B., Asegbeloyin, J.N. and Okoye, C.O., 2024. Occurrence, non-carcinogenic and carcinogenic risk assessment of trace elements in rainwater in the vicinity of a cement factory in northeastern Nigeria. Discover Public Health, Vol.21 (1), 156p.

Sutadian, A.D., Muttil, N., Yilmaz, A.G. and Perera, B.J.C., 2016. Development of river water quality indices—a review. Environmental monitoring and assessment, Vol.188 (1), p.58.

Sutton, S., 2011. Accuracy of plate counts. Journal of Validation Technology, Vol.17 (3), pp.42-46.

Tchounwou, P.B., Yedjou, C.G., Patlolla, A.K. and Sutton, D.J., 2012. Heavy metal toxicity and the environment. In: Molecular, Clinical and Environmental Toxicology, Vol. 3, pp.133-

© University of Venda

164.

Thapa, A., Tamrakar, A.S. and Subedi, I.P., 2015. Pesticide use practices among tomato growers in Kavre District, Nepal. Nepalese Journal of Zoology, Vol.3 (1), pp.17-23.

Tiwari, T.N. and Mishra, M.A., 1985. A preliminary assignment of water quality index of major Indian rivers. Indian Journal of Environmental Protection, Vol.5 (4), pp.276-279.

Traoré, A.N., Mulaudzi, K., Chari, G.J., Foord, S.H., Mudau, L.S., Barnard, T.G. and Potgieter, N., 2016. The impact of human activities on microbial quality of rivers in the Vhembe District, South Africa. International Journal of Environmental Research and Public Health, Vol.13 (8), 817p.

Tyagi, S., Sharma, B., Singh, P. and Dobhal, R., 2013. Water quality assessment in terms of water quality index. American Journal of water resources, Vol.1 (3), pp.34-38.

Uddin, M.G., Nash, S. and Olbert, A.I., 2021. A review of water quality index models and their use for assessing surface water quality. *Ecological Indicators*, Vol.122, 107218p.

Ugboko, H.U., Nwinyi, O.C., Oranusi, S.U. and Oyewale, J.O., 2020. Childhood diarrhoeal diseases in developing countries. Heliyon, Vol.6 (4), e03690p.

UNEP, 2016. A snapshot of the world's water quality: towards a global assessment. Nairobi: United Nations Environment Programme.

Ungureanu, E.L., Soare, A.D., Mocanu, A.L., Iorga, S.C., Mustatea, G. and Popa, M.E., 2022. Occurrence of potentially toxic elements in bottled drinking water – carcinogenic and non-carcinogenic risks assessment in adults via ingestion. Foods, Vol.11 (10), 140.

United States Environmental Protection Agency (USEPA), 1989. Risk assessment guidance for Superfund, human health evaluation manual (Part A), Report EPA/540/1-89/002 (Vol.1). Washington, DC: USEPA.

United States Environmental Protection Agency (USEPA), 2004. Guidelines for water reuse. EPA/625/R-04/108. Available at: https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=30006MKD.txt (Accessed: 25 January 2025).

Vanhaecke, F. and Degryse, P. (eds), 2012. Isotopic analysis: fundamentals and applications

© University of Venda

using ICP-MS. John Wiley & Sons.

Wang, Q. and Yang, Z., 2016. Industrial water pollution, water environment treatment, and health risks in China. Environmental Pollution, Vol.218, pp.358-365.

Wątor, K., Rusiniak, P., Martyna, A., Kmiecik, E. and Postawa, A., 2021. Human health risk assessment of trace elements in tap water and the factors influencing its value. Minerals, Vol.11 (11), 1291p.

Weber-Scannell, P.K. and Duffy, L.K., 2007. Effects of total dissolved solids on aquatic organisms: a review of literature and recommendation for salmonid species.

Wen, X., Chen, F., Lin, Y., Zhu, H., Yuan, F., Kuang, D., Jia, Z. and Yuan, Z., 2020. Microbial indicators and their use for monitoring drinking water quality – a review. Sustainability, Vol.12 (6), 2249p.

Westcott, C., 2012. pH measurements. Elsevier.

Wolfrum, S., Marcus, J., Touraud, D. and Kunz, W., 2016. A renaissance of soaps?—how to make clear and stable solutions at neutral pH and room temperature. Advances in Colloid and Interface Science, Vol.236, pp.28-42.

Worako, A.W., 2015. Physicochemical and biological water quality assessment of Lake Hawassa for multiple designated water uses. Journal of Urban and Environmental Engineering, Vol.9 (2), pp.146-157.

World Health Organization and WHO, 2004. Guidelines for drinking-water quality, Vol. 1. Geneva: WHO.

World Health Organization, 2009. Potassium in drinking-water: background document for development of WHO guidelines for drinking-water quality (No. WHO/HSE/WSH/09.01/7). Geneva: WHO.

World Health Organization, 2010. Preventing disease through healthy environments: exposure to cadmium, a major public health concern. Geneva: WHO. Available at: http://www.who.int/ipcs/features/cadmium.pdf (Accessed: 16 December 2024).

World Health Organization (WHO), 2011. Guidelines for drinking-water quality. 4th edn. Geneva: WHO. Available at: https://apps.who.int/iris/handle/10665/44584 (Accessed: 5

© University of Venda

November 2024).

World Health Organization, 2015. WHO/UNICEF joint water supply and sanitation monitoring programme: progress on sanitation and drinking water: 2010 update. Geneva: WHO.

World Health Organization, 2017. Guidelines for drinking-water quality: first addendum to the 4th edition. Geneva: WHO.

World Health Organization (WHO), 2019. Guidelines on sanitation and health. Geneva: WHO. Available at: https://apps.who.int/iris/handle/10665/275673 (Accessed: 1 February 2025).

World Health Organization, 2021. A global overview of national regulations and standards for drinking-water quality. Geneva: WHO.

World Health Organization, 2022. Guidelines for drinking-water quality: incorporating the first and second addenda. Geneva: WHO.

Wu, H., Liao, Q., Chillrud, S.N., Yang, Q., Huang, L., Bi, J. and Yan, B., 2016. Environmental exposure to cadmium: health risk assessment and its associations with hypertension and impaired kidney function. Scientific Reports, 6(1), p.29989.

Xiao, M.S., Li, F., Zhang, J.D., Lin, S.Y., Zhuang, Z.Y. and Wu, Z.X., 2017. Investigation and health risk assessment of heavy metals in soils from partial areas of Daye City, China. In: IOP Conference Series: Earth and Environmental Science, Vol.64 (1), 012066p.

Yashin, A.Y. and Yashin, Y.I., 2004. High-performance liquid chromatography with amperometric detection in the analysis of food products and beverages. Journal of Analytical Chemistry, Vol.59 (10), pp.927-936.

Yasir, M., Farman, M., Shah, M.W., Jiman-Fatani, A.A., Othman, N.A., Almasaudi, S.B., Alawi, M., Shakil, S., Al-Abdullah, N., Ismaeel, N.A. and Azhar, E.I., 2020. Genomic and antimicrobial resistance genes diversity in multidrug-resistant CTX-M-positive isolates of Escherichia coli at a health care facility in Jeddah. Journal of Infection and Public Health, Vol.13 (1), pp.94-100.

Yogendra, K. and Puttaiah, E.T., 2008. Determination of water quality index and suitability of an urban waterbody in Shimoga Town, Karnataka. In: Proceedings of Taal2007: The 12th

© University of Venda

World Lake Conference, Vol 342, pp. 346.

Yohannes, H. and Elias, E., 2017. Contamination of rivers and water reservoirs in and around Addis Ababa City and actions to combat it. Environmental Pollution and Climate Change, Vol.1 (116), 8p.

Zavitsanou, A. and Drigas, A., 2021. Nutrition in mental and physical health. Technium Social Sciences Journal, Vol.23, 67p.

Zoroddu, M.A., Aaseth, J., Crisponi, G., Medici, S., Peana, M. and Nurchi, V.M., 2019. The essential metals for humans: a brief overview. Journal of Inorganic Biochemistry, Vol.195, pp.120-129.

© University of Venda

LIST OF APPENDICES

Appendix 1: Physical water quality parameters for the wet season

(a) Groundwater and river water

Month	Source	pH	Turbidity (NTU)	TDS (mg/L)	EC (µS/cm)
Dec 2023	BH1	6.31	24.74	613	867.67
	BH2	6.93	0.00	2.67	3.81
	Upstream	7.89	63.00	133	180.9
	Downstream	8.21	63.00	105.97	152.97
Jan 2024	BH1	6.32	28.47	908	1284.67
	BH2	7.24	3.81	2.69	3.87
	Upstream	7.71	30.11	212.67	276.33
	Downstream	7.63	36.67	471.33	613
Feb 2024	BH1	6.33	76.67	588	811
	BH2	7.04	0.95	2.71	3.79
	Upstream	8.3	3.98	157	231.67
	Downstream	8.53	4.67	56.37	76.60
	Municipal Tap	7.48	2.49	186.67	215.67

(b) Rainwater

Month	Roof type	pH	Turbidity (NTU)	EC (µS/cm)	TDS (mg/L)
Dec 2023	Corrugated sheets	6.83	6.83	40.03	32.8
	Concrete tile	7.76	5.81	93.83	66.13
	Metal harvey tile	7.36	24.24	7.36	40.06
	Grass roofing	7.52	29.62	410	284.67
Jan 2024	Corrugated sheets	6.5	6.00	46.6	44.2
	Concrete tile	7.5	4.00	102.6	70.2
	Metal harvey tile	7.2	20.1	70.8	68.4
	Grass roofing	7.6	19.6	420	260.6
Mar 2024	Corrugated sheets	7.32	0.16	19.76	71.63
	Concrete tile	7.38	3.82	175.73	122.93
	Metal harvey tile	6.11	15.38	169.5	113.73
	Grass roofing	5.61	9.67	361	241.66

© University of Venda

Appendix 2: Physical water quality parameters for the dry season

Month	Source	pH	Turbidity (NTU)	TDS (mg/L)	EC (µS/cm)
Mar 2024	BH1	6.37	31.32	512	6.97
	Upstream	8.08	2.99	56.83	74.9
	Downstream	8.3	1.44	57.4	75.9
	Municipal tap	7.44	0.00	98.9	135.12
Apr 2024	BH1	6.52	29.72	602	881.67
	BH2	7.14	0.00	2.54	3.53
	Upstream	7.84	17.08	103.2	149.3
	Downstream	7.73	17.83	124.27	180.2
	Spring	6.82	0.03	191.67	284.67
May 2024	BH1	6.56	74.33	624	842
	BH2	7.25	0.13	2.63	3.75
	Upstream	8.16	1.39	111.53	160.73
	Downstream	8.35	2.94	57.7	72.2

Appendix 3: Microbiological parameters for wet and dry season in cfu/100ml

Month	Source	E.coli	Total c
Dec 2023	BH1	0	49
	BH2	0	0
	Upstream	18	216
	Downstream	29	61
Jan 2024	BH1	14	14
	BH2	17	17
	Upstream	34	40
	Downstream	52	52
Feb 2024	BH1	35	55
	BH2	7	12
	Upstream	52	126
	Downstream	34	162
	Municipal tap	7	31

Month	Source	E.coli	Total c
Mar 2024	BH1	0	106
		71	79
	Downstream	2	34
	Municipal tap	0	34
Apr 2024	BH1	0	46
	BH2	19	81
	Upstream	19	81
	Downstream	100	280
	Spring	6	128
May 2024	BH1	0	138
	BH2	6	43
	Upstream	6	51
	Downstream	6	65

© University of Venda

Appendix 4: Non -metals concentrations for dry and wet seasons in mg/L

(a) Groundwater and river water

Month	Source	Cl	F	SO_4^{2}	PO_4^{3}
Dec 2023	BH1	67.1	0.08	10.0	0.9
	BH2	277.4	0.39	89.0	0.67
	Upstream	3.8	0.2	1.0	0.0
	Downstream	9.1	0.1	0.0	0.0
Jan 2024	BH1	0.0	0.04	11.0	0.15
	BH2	468.2	0.41	71.0	0.03
	Upstream	7.4	0.06	0.0	0.02
	Downstream	4.5	0.11	0.0	0.02
Feb 2024	BH1	31.8	0.03	9.0	0.01
	BH2	0.0	0.38	86.0	0.03
	Upstream	6.8	0.07	0.0	0.01
	Downstream	2.8	0.2	0.0	0.01
	Municipal tap	6.9	0.39	0.0	0.0

Month	Source	Cl	F	SO_4^{2}	PO_4^{3}
Mar 2024	BH1	6.5	0.35	1.0	0.0
	Upstream	280.4	0.35	1.0	0.03
	Downstream	27.4	0.39	1.0	0.03
	Municipal tap	13.6	0.24	0.0	0.06
Apr 2024	BH1	203.3	0.3	0.0	0.01
	BH2	284.9	0.51	0.0	0.01
	Upstream	4.7	0.42	0.0	0.01
	Downstream	8.0	0.23	0.0	0.01
	Spring	18.1	0.22	12	0.09
May 2024	BH1	120.4	0.11	87	0.08
	BH2	202.4	0.47	0.0	0.01
	Upstream	6.9	0.38	0.0	0.02
	Downstream	5.9	0.28	1.0	0.01

(b) Rainwater

Month	Roof type	F	Cl	SO_4^{2}	PO_4^{3}
Dec 2024	Concrete tile	0.18	0.40	0.00	0.05
	Grass roofing	0.25	21.80	12.00	1.19
	Corrugated sheets	0.12	0.00	0.00	0.05
	Metal harvey tile	0.03	1.10	0.00	0.10
Jan 2024	Concrete tile	0.25	0.00	0.00	0.03
	Grass roofing	0.28	23.20	7.00	0.31
	Corrugated sheets	0.00	0.00	0.00	0.02
	Metal harvey tile	0.22	0.00	0.00	0.06
Feb 2024	Concrete tile	0.41	1.30	1.00	0.00
	Grass roofing	0.34	27.90	0.00	0.48
	Corrugated sheets	0.26	0.70	9.00	0.04
	Metal harvey tile	0.48	8.00	85.00	0.31

© University of Venda

Appendix 5: Metals concentrations for wet season in mg/L

(a) Groundwater and river water

Month	Source	As	Fe	Zn	Al	Mn	Ca	Cd	Pb	Cu	Na	Mg	K
Dec 2023	BH1	3.36	7.19	1.64	5.68	4.84	46.55	9.98	2.71	5.62		93.15	62.24
	BH2	5.61	3.35	5.17	5.27	3.22		3.11	3.69	5.06			61.73
	Upstream	2.79	5.35	5.17	4.89	3.59	22.57	7.96	3.31	4.54	102.47	19.16	14.30
	Downstream	5.47	6.74	4.23	4.77	1.55	19.31	13.22	2.04	6.52	102.17	19.18	14.59
Jan 2024	BH1	5.54	0.36	4.54	4.70	4.07	34.02	0.00	1.38	5.59		73.56	49.49
	BH2	4.81	4.69	6.52	4.93	5.08		9.98	3.78	6.73			59.22
	Upstream	4.70	2.68	5.92	4.33	4.45	12.45	12.41	5.47	6.35	74.03	11.03	9.45
	Downstream	2.82	2.64	4.37	4.96	3.44	43.58	13.64	5.75	3.95		1.31	4.60
Feb 2024	BH1	5.12	2.34	3.76	5.34	1.91	40.54	4.73	5.61	5.84		84.30	61.51
	BH2	4.50	3.72	4.39	4.72	4.96		8.77	1.11	2.94			60.01
	Upstream	3.45	7.06	4.86	5.43	4.83	12.75	4.33	1.52	8.50	85.95	13.09	2.86
	Downstream	3.03	6.19	6.46	5.74	3.94	13.90	9.98	7.44	4.07	99.12	14.69	3.52
	Municipal tap	4.70	7.39	5.45	4.77	2.29	16.59	12.41	2.79	2.28	95.26	10.17	12.56

© University of Venda

(b) Rainwater

Month	Roof type	As	Fe	Mn	Al	Cu	Pb	Zn	Cd	K	Ca
Dec 2023	Concrete tile	5.61	4.67	8.26	5.54	5.92	3.31	3.76	7.16	13.76	30.73
	Grass roofing	3.78	6.01	10.59	5.52	4.37	6.99	4.39	5.54	1158.94	101.62
	Corrugated sheets	5.23	2.34	5.05	5.55	4.63	5.08	4.86	2.71	5.41	7.94
	Metal harvey tile	3.24	0.37	2.17	4.50	6.73	5.61	5.06	3.92	14.26	15.76
Jan 2024	Concrete tile	4.70	7.64	8.51	5.14	5.46	5.47	4.63	11.20	9.37	12.95
	Grass roofing	3.03	2.79	1.79	4.48	1.29	10.12	5.17	3.50	88.11	50.53
	Corrugated sheets	2.41	2.47	4.32	4.74	3.06	2.93	5.17	5.13	53.27	38.07
	Metal harvey tile	4.08	8.14	3.44	4.74	4.71	5.47	4.23	11.28	5.07	10.21
Mar 2024	Concrete tile	5.63	5.18	4.37	5.07	2.97	2.24	4.47	4.47	9.95	51.67
	Grass roofing	1.27	6.25	4.63	5.09	0.00	2.02	5.09	5.09	208.19	19.58
	Corrugated sheets	4.81	5.13	5.06	4.56	2.21	2.16	4.00	4.00	7.94	2.24
	Metal harvey tile	0.00	6.14	5.75	4.29	2.53	1.89	4.70	4.70	238.85	9.03

Appendix 6: Metals concentration for dry season in mg/L

Month	Source	As	Fe	Zn	Al	Mn	Ca	Cd	Pb	Cu	Na	Mg	K
Mar 2024	BH1	2.30	6.62	4.50	5.52	5.97	44.33	16.62	7.30	0.00		95.95	62.68
	Upstream	5.85	7.10	3.84	4.99	6.35	13.45	13.62	3.36	1.45	87.18	12.11	3.24
	Downstream	1.92	3.68	7.12	4.31	3.94	13.48	4.33	5.75	2.39	87.71	12.24	3.35
	Municipal tap	2.92	4.63	5.25	5.36	4.54	18.16	10.41	2.77	0.36	100.69	10.83	13.76
Apr 2024	BH1	6.37	5.21	5.79	4.86	5.92	47.28	5.94	2.10	0.34		90.88	61.47
	BH2	4.37	5.58	3.14	5.30	4.97		0.00	1.77	0.32			61.10
	Upstream	0.60	6.42	4.10	4.53	2.39	12.57	6.45	1.94	4.75	74.78	9.94	8.89
	Downstream	0.00	5.83	6.97	5.72	4.54	10.59	0.00	1.65	1.00	73.31	9.69	11.88
	Spring		3.92	7.64	5.16	4.37	18.36	7.99	2.10	0.00	274.98	29.03	57.80
May 2024	BH1	2.71	3.82	4.08	5.53	4.46	13.05	0.00	2.35	0.29		10.28	3.24
	BH2	1.02	5.77	4.41	4.80	4.28		2.71	4.97	4.32			69.02
	Upstream	0.00	5.79	2.02	5.68	4.37	15.57	8.47	1.71	5.91	86.30	11.26	2.77
	Downstream	6.89	5.77	4.48	4.22	6.52	17.13	7.97	2.41	5.83	81.89	10.71	2.98

© University of Venda

(c) Rainwater

Month	Roof type	As	Fe	Mn	Al	Cu	Pb	Zn	Cd	K	Ca
Dec 2023	Concrete tile	5.61	4.67	8.26	5.54	5.92	3.31	3.76	7.16	13.76	30.73
	Grass roofing	3.78	6.01	10.59	5.52	4.37	6.99	4.39	5.54	1158.94	101.62
	Corrugated sheets	5.23	2.34	5.05	5.55	4.63	5.08	4.86	2.71	5.41	7.94
	Metal harvey tile	3.24	0.37	2.17	4.50	6.73	5.61	5.06	3.92	14.26	15.76
Jan 2024	Concrete tile	4.70	7.64	8.51	5.14	5.46	5.47	4.63	11.20	9.37	12.95
	Grass roofing	3.03	2.79	1.79	4.48	1.29	10.12	5.17	3.50	88.11	50.53
	Corrugated sheets	2.41	2.47	4.32	4.74	3.06	2.93	5.17	5.13	53.27	38.07
	Metal harvey tile	4.08	8.14	3.44	4.74	4.71	5.47	4.23	11.28	5.07	10.21
Mar 2024	Concrete tile	5.63	5.18	4.37	5.07	2.97	2.24	4.47	4.47	9.95	51.67
	Grass roofing	1.27	6.25	4.63	5.09	0.00	2.02	5.09	5.09	208.19	19.58
	Corrugated sheets	4.81	5.13	5.06	4.56	2.21	2.16	4.00	4.00	7.94	2.24
	Metal harvey tile	0.00	6.14	5.75	4.29	2.53	1.89	4.70	4.70	238.85	9.03

© University of Venda

Appendix 7: Metals concentration for dry season in mg/L

Month	Source	As	Fe	Zn	Al	Mn	Ca	Cd	Pb	Cu	Na	Mg	K
Mar 2024	BH1	2.30	6.62	4.50	5.52	5.97	44.33	16.62	7.30	0.00		95.95	62.68
	Upstream	5.85	7.10	3.84	4.99	6.35	13.45	13.62	3.36	1.45	87.18	12.11	3.24
	Downstream	1.92	3.68	7.12	4.31	3.94	13.48	4.33	5.75	2.39	87.71	12.24	3.35
	Municipal tap	2.92	4.63	5.25	5.36	4.54	18.16	10.41	2.77	0.36	100.69	10.83	13.76
Apr 2024	BH1	6.37	5.21	5.79	4.86	5.92	47.28	5.94	2.10	0.34		90.88	61.47
	BH2	4.37	5.58	3.14	5.30	4.97		0.00	1.77	0.32			61.10
	Upstream	0.60	6.42	4.10	4.53	2.39	12.57	6.45	1.94	4.75	74.78	9.94	8.89
	Downstream	0.00	5.83	6.97	5.72	4.54	10.59	0.00	1.65	1.00	73.31	9.69	11.88
	Spring		3.92	7.64	5.16	4.37	18.36	7.99	2.10	0.00	274.98	29.03	57.80
May 2024	BH1	2.71	3.82	4.08	5.53	4.46	13.05	0.00	2.35	0.29		10.28	3.24
	BH2	1.02	5.77	4.41	4.80	4.28		2.71	4.97	4.32			69.02
	Upstream	0.00	5.79	2.02	5.68	4.37	15.57	8.47	1.71	5.91	86.30	11.26	2.77
	Downstream	6.89	5.77	4.48	4.22	6.52	17.13	7.97	2.41	5.83	81.89	10.71	2.98

© University of Venda

Appendix 8: Water quality index for river water and groundwatwer

(a) BH1

Parameters	Average measured	S_n	$1/S_n$	Ideal value	Unit Weights	Quality Rating	Weighted value
					$(W_n)= K/S_n$	$(Q_n)=100((V_n-V_{io})/(S_n-V_{io}))$	(Q_n*W_n)
pH	6.4017	8.0000	0.1250	7.0000	0.0063	-59.8333	-0.3759
EC	782.3300	1700.0000	0.0006	0.0000	0.0000	46.0194	0.0014
TDS	641.1667	450.0000	0.0022	0.0000	0.0001	142.4815	0.0159
Turbidity	44.2083	1.0000	1.0000	0.0000	0.0503	4420.8333	222.2188
Ca	37.6270	32.0000	0.0313	0.0000	0.0016	117.5845	0.1847
K	50.1058	50.0000	0.0200	0.0000	0.0010	100.2117	0.1007
Mg	74.6858	30.0000	0.0333	0.0000	0.0017	248.9527	0.4171
Al	5.2716	0.1500	6.6667	0.0000	0.3351	3514.3778	1177.6975
Zn	4.0537	3.0000	0.3333	0.0000	0.0168	135.1239	2.2641
Fe	4.2560	0.1000	10.0000	0.0000	0.5027	4256.0167	2139.3404
Cu	2.9470	1.0000	1.0000	0.0000	0.0503	294.7000	14.8135
Cl	85.8200	100.0000	0.0100	0.0000	0.0005	85.8200	0.0431
F	0.1517	1.5000	0.6667	0.0000	0.0335	10.1111	0.3388
SO4	19.6667	200.0000	0.0050	0.0000	0.0003	9.8333	0.0025
		$\sum(1/S_n)= 19.8941$		$\sum W_n= 1.0000$		$\sum Q_n.W_n= 3557.0625$	
	$K=1/\sum(1/S_n)= 0.0503$		Overall water quality index= WQI= $\sum Q_n.W_n/ \sum W_n= 3557.0625$				

(b) BH2

Parameters	Average measured	S_n	$1/S_n$	Ideal value	Unit Weights	Quality Rating	Weighted value
					$(W_n)= K/S_n$	$(Q_n)=100((V_n-V_{io})/(S_n-V_{io}))$	(Q_n*W_n)
pH	7.1200	8.0000	0.1250	7.0000	0.0063	12.0000	0.0756
EC	3.7500	1700.0000	0.0006	0.0000	0.0000	0.2206	0.0000
TDS	2.2067	450.0000	0.0022	0.0000	0.0001	0.4904	0.0001
Turbidity	0.8150	1.0000	1.0000	0.0000	0.0504	81.5000	4.1100
K	62.2156	50.0000	0.0200	0.0000	0.0010	124.4312	0.1255
Al	5.0035	0.1500	6.6667	0.0000	0.3362	3335.6933	1121.4595
Zn	4.7259	3.0000	0.3333	0.0000	0.0168	157.5307	2.6481
Fe	4.6230	0.1000	10.0000	0.0000	0.5043	4623.0000	2331.3777
Cu	3.8719	1.0000	1.0000	0.0000	0.0504	387.1900	19.5260
Cl	308.2250	100.0000	0.0100	0.0000	0.0005	308.2250	0.1554
F	0.4320	1.5000	0.6667	0.0000	0.0336	28.8000	0.9683
SO4	49.2000	200.0000	0.0050	0.0000	0.0003	24.6000	0.0062
	$\sum(1/S_n)= 19.8295$			$\sum W_n= 1.0000$		$\sum Q_n.W_n= 3480.4524$	
	$K=1/\sum(1/S_n)= 0.0504$		Overall water quality index= WQI= $\sum Q_n.W_n/ \sum W_n= 3480.4524$				

© University of Venda

(c) Upstream of Mutale River

Parameters	Average measured	S_n	$1/S_n$	Ideal value	Unit Weights	Quality Rating	Weighted value
					$(W_n)= K/S_n$	$(Q_n)=100((V_n-V_{io})/(S_n-V_{io}))$	(Q_n*W_n)
pH	7.9967	8.0000	0.1250	7.0000	0.0063	99.6667	0.6259
EC	178.9717	1700.0000	0.0006	0.0000	0.0000	10.5277	0.0003
TDS	129.0383	450.0000	0.0022	0.0000	0.0001	28.6752	0.0032
Turbidity	19.7583	1.0000	1.0000	0.0000	0.0502	1975.8333	99.2679
Ca	14.8920	32.0000	0.0313	0.0000	0.0016	46.5376	0.0731
Na	85.1193	100.0000	0.0100	0.0000	0.0005	85.1193	0.0428
K	6.9152	50.0000	0.0200	0.0000	0.0010	13.8304	0.0139
Mg	12.7621	30.0000	0.0333	0.0000	0.0017	42.5404	0.0712
Al	4.9754	0.1500	6.6667	0.0000	0.3349	3316.9111	1110.9663
Zn	4.3173	3.0000	0.3333	0.0000	0.0167	143.9089	2.4100
Fe	5.7331	0.1000	10.0000	0.0000	0.5024	5733.0667	2880.3503
Cu	5.2488	1.0000	1.0000	0.0000	0.0502	524.8833	26.3707
Cl	51.6667	100.0000	0.0100	0.0000	0.0005	51.6667	0.0260
F	0.2467	1.5000	0.6667	0.0000	0.0335	16.4444	0.5508
SO4	0.3333	200.0000	0.0050	0.0000	0.0003	0.1667	0.0000
		$\sum(1/S_n)= 19.9041$		$\sum W_n= 1.0000$		$\sum Q_n.W_n = 4120.7724$	
		$K=1/\sum(1/S_n)= 0.0502$		Overall water quality index= $WQI= \sum Q_n.W_n/\sum W_n= 4120.7724$			

(d) Downstream of Mutale River

Parameters	Average measured	S_n	$1/S_n$	Ideal value	Unit Weights	Quality Rating	Weighted value
					$(W_n)= K/S_n$	$(Q_n)=100((V_n-V_{io})/(S_n-V_{io}))$	(Q_n*W_n)
pH	8.1250	8.0000	0.1250	7.0000	0.0063	112.5000	0.7065
EC	195.1450	1700.0000	0.0006	0.0000	0.0000	11.4791	0.0003
TDS	145.5067	450.0000	0.0022	0.0000	0.0001	32.3348	0.0036
Turbidity	21.0917	1.0000	1.0000	0.0000	0.0502	2109.1667	105.9667
Ca	19.6656	32.0000	0.0313	0.0000	0.0016	61.4549	0.0965
Na	85.7494	100.0000	0.0100	0.0000	0.0005	85.7494	0.0431
K	6.8211	50.0000	0.0200	0.0000	0.0010	13.6423	0.0137
Mg	11.3029	30.0000	0.0333	0.0000	0.0017	37.6763	0.0631
Al	4.9545	0.1500	6.6667	0.0000	0.3349	3302.9667	1106.2958
Zn	5.6055	3.0000	0.3333	0.0000	0.0167	186.8500	3.1292
Fe	5.1424	0.1000	10.0000	0.0000	0.5024	5142.4000	2583.5934
Cu	3.9599	1.0000	1.0000	0.0000	0.0502	395.9917	19.8950
Cl	9.6167	100.0000	0.0100	0.0000	0.0005	9.6167	0.0048
F	0.2183	1.5000	0.6667	0.0000	0.0335	14.5556	0.4875
SO4	0.4000	200.0000	0.0050	0.0000	0.0003	0.2000	0.0001
		$\sum(1/S_n)= 19.9041$		$\sum W_n= 1.0000$		$\sum Q_n.W_n= 3820.2993$	
		$K=1/\sum(1/S_n) =0.0502$		Overall water quality index= $WQI=\sum Q_n.W_n/ \sum W_n=$ 3820.2993			

© University of Venda

(e) Municipal tap

Parameters	Average measured	S_n	$1/S_n$	Ideal value	Unit Weights	Quality Rating	Weighted value
					$(W_n)= K/S_n$	$(Q_n)=100((V_n-V_{io})/(S_n-V_{io}))$	(Q_n*W_n)
pH	7.4600	8.0000	0.1250	7.0000	0.0063	46.0000	0.2889
EC	175.3950	1700.0000	0.0006	0.0000	0.0000	10.3174	0.0003
TDS	142.7850	450.0000	0.0022	0.0000	0.0001	31.7300	0.0035
Turbidity	0.4150	1.0000	1.0000	0.0000	0.0502	41.5000	2.0850
Ca	17.3737	32.0000	0.0313	0.0000	0.0016	54.2928	0.0852
Na	97.9773	100.0000	0.0100	0.0000	0.0005	97.9773	0.0492
K	13.1583	50.0000	0.0200	0.0000	0.0010	26.3167	0.0264
Mg	10.5029	30.0000	0.0333	0.0000	0.0017	35.0097	0.0586
Al	5.0648	0.1500	6.6667	0.0000	0.3349	3376.5333	1130.9362
Zn	5.3466	3.0000	0.3333	0.0000	0.0167	178.2183	2.9846
Fe	6.0086	0.1000	10.0000	0.0000	0.5024	6008.6000	3018.7810
Cu	1.3175	1.0000	1.0000	0.0000	0.0502	131.7500	6.6193
Cl	10.2500	100.0000	0.0100	0.0000	0.0005	10.2500	0.0051
F	0.3150	1.5000	0.6667	0.0000	0.0335	21.0000	0.7034
		$\sum(1/S_n)= 19.9041$		$\sum W_n = 1.0000$		$\sum Q_n.W_n = 4162.6269$	
		$K=1/\sum(1/S_n)= 0.0502$		Overall water quality index= WQI= $\sum Q_n.W_n/\sum W_n= 4162.6269$			

(f) Spring

Parameters	Average measured	S_n	$1/S_n$	Ideal value	Unit Weights	Quality Rating	Weighted value
					$(W_n)= K/S_n$	$(Q_n)=100((V_n-V_{io})/(S_n-V_{io}))$	(Q_n*W_n)
pH	6.8200	8.0000	0.1250	7.0000	0.0063	-18.0000	-0.1130
EC	284.6700	1700.0000	0.0006	0.0000	0.0000	16.7453	0.0005
TDS	191.6700	450.0000	0.0022	0.0000	0.0001	42.5933	0.0048
Turbidity	0.0300	1.0000	1.0000	0.0000	0.0502	3.0000	0.1507
Ca	18.3622	32.0000	0.0313	0.0000	0.0016	57.3820	0.0901
Na	274.9791	100.0000	0.0100	0.0000	0.0005	274.9791	0.1382
K	57.7967	50.0000	0.0200	0.0000	0.0010	115.5935	0.1162
Mg	29.0313	30.0000	0.0333	0.0000	0.0017	96.7709	0.1621
Al	5.1576	0.1500	6.6667	0.0000	0.3349	3438.4000	1151.6578
Zn	7.6352	3.0000	0.3333	0.0000	0.0167	254.5067	4.2622
Fe	3.9163	0.1000	10.0000	0.0000	0.5024	3916.3000	1967.5885
Cl	18.1000	100.0000	0.0100	0.0000	0.0005	18.1000	0.0091
F	0.2200	1.5000	0.6667	0.0000	0.0335	14.6667	0.4912
SO4	12.0000	200.0000	0.0050	0.0000	0.0003	6.0000	0.0015
		$\sum(1/S_n)= 19.9041$		$\sum W_n= 1.0000$		$\sum Q_n.W_n= 3124.5597$	
		$K= 1/\sum(1/S_n)= 0.0502$		Overall water quality index= WQI= $\sum Q_n.W_n/\sum W_n =$ 3124.5597			

© University of Venda

Appendix 9: Water quality index for rainwater

(a) Concrete tile

Parameters	Average measured	S_n	$1/S_n$	Ideal value	Unit Weights	Quality Rating	Weighted value
					$(W_n)= K/S_n$	$(Q_n)=100((V_n-V_{io})/(S_n-V_{io}))$	(Q_n*W_n)
pH	6.8833	8.0000	0.1250	7.0000	0.0063	-11.6667	-0.0733
EC	35.4633	1700.0000	0.0006	0.0000	0.0000	2.0861	0.0001
TDS	49.5433	450.0000	0.0022	0.0000	0.0001	11.0096	0.0012
Turbidity	4.3300	1.0000	1.0000	0.0000	0.0502	433.0000	21.7544
Ca	32.3072	32.0000	0.0313	0.0000	0.0016	100.9599	0.1585
Na	35.6252	100.0000	0.0100	0.0000	0.0005	35.6252	0.0179
K	11.0260	50.0000	0.0200	0.0000	0.0010	22.0521	0.0222
Mg	5.5643	30.0000	0.0333	0.0000	0.0017	18.5478	0.0311
Al	5.2499	0.1500	6.6667	0.0000	0.3349	3499.9111	1172.2603
Zn	4.2859	3.0000	0.3333	0.0000	0.0167	142.8644	2.3926
Fe	5.8315	0.1000	10.0000	0.0000	0.5024	5831.5000	2929.8042
Cu	4.7842	1.0000	1.0000	0.0000	0.0502	478.4167	24.0361
Cl	0.5667	100.0000	0.0100	0.0000	0.0005	0.5667	0.0003
F	0.2800	1.5000	0.6667	0.0000	0.0335	18.6667	0.6252
SO4	0.3333	200.0000	0.0050	0.0000	0.0003	0.1667	0.0000
		$\sum(1/S_n)= 19.9041$		$\sum W_n= 1.0000$		$\sum Q_n.W_n= 4151.0308$	
		$K=1/\sum(1/S_n)= 0.0502$		Overall water quality index= $WQI=\sum Q_n.W_n/\sum W_n=$ 4151.0308			

(b) Grass roofing

Parameters	Average measured	S_n	$1/S_n$	Ideal value	Unit Weights	Quality Rating	Weighted value
					$(W_n)= K/S_n$	$(Q_n)=100((V_n-V_{io})/(S_n-V_{io}))$	(Q_n*W_n)
pH	7.5467	8.0000	0.1250	7.0000	0.0063	54.6667	0.3433
EC	124.0533	1700.0000	0.0006	0.0000	0.0000	7.2973	0.0002
TDS	86.4200	450.0000	0.0022	0.0000	0.0001	19.2044	0.0021
Turbidity	4.5433	1.0000	1.0000	0.0000	0.0502	454.3333	22.8262
Ca	35.0519	32.0000	0.0313	0.0000	0.0016	109.5373	0.1720
Na	194.3506	100.0000	0.0100	0.0000	0.0005	194.3506	0.0976
K	485.0785	50.0000	0.0200	0.0000	0.0010	970.1570	0.9748
Mg	18.8931	30.0000	0.0333	0.0000	0.0017	62.9770	0.1055
Al	5.0265	0.1500	6.6667	0.0000	0.3349	3351.0222	1122.3915
Zn	4.8829	3.0000	0.3333	0.0000	0.0167	162.7633	2.7258
Fe	5.0135	0.1000	10.0000	0.0000	0.5024	5013.5000	2518.8328
Cu	1.8877	1.0000	1.0000	0.0000	0.0502	188.7667	9.4838
Cl	24.3000	100.0000	0.0100	0.0000	0.0005	24.3000	0.0122
F	0.2900	1.5000	0.6667	0.0000	0.0335	19.3333	0.6476
SO4	6.3333	200.0000	0.0050	0.0000	0.0003	3.1667	0.0008
		$\sum(1/S_n)= 19.9041$		$\sum W_n= 1.0000$		$\sum Q_n.W_n= 3678.6162$	
		$K=1/\sum(1/S_n) =0.0502$		Overall water quality index= $WQI= \sum Q_n.W_n/\sum W_n=$ 3678.6162			

© University of Venda

(c) Corrugated sheets

Parameters	Average measured	S_n	$1/S_n$	Ideal value	Unit Weights	Quality Rating	Weighted value
					$(W_n)= K/S_n$	$(Q_n)=100((V_n-V_{io})/(S_n-V_{io}))$	(Q_n*W_n)
pH	6.8900	8.0000	0.1250	7.0000	0.0063	-11.0000	-0.0691
EC	82.5533	1700.0000	0.0006	0.0000	0.0000	4.8561	0.0001
TDS	74.0633	450.0000	0.0022	0.0000	0.0001	16.4585	0.0018
Turbidity	19.9067	1.0000	1.0000	0.0000	0.0502	1990.6667	100.0131
Ca	20.1517	32.0000	0.0313	0.0000	0.0016	62.9740	0.0989
Na	4.5274	100.0000	0.0100	0.0000	0.0005	4.5274	0.0023
K	22.2073	50.0000	0.0200	0.0000	0.0010	44.4147	0.0446
Mg	84.7145	30.0000	0.0333	0.0000	0.0017	282.3816	0.4729
Al	4.9491	0.1500	6.6667	0.0000	0.3349	3299.4222	1105.1086
Zn	4.6747	3.0000	0.3333	0.0000	0.0167	155.8233	2.6096
Fe	3.3122	0.1000	10.0000	0.0000	0.5024	3312.2333	1664.0993
Cu	3.3011	1.0000	1.0000	0.0000	0.0502	330.1067	16.5849
Cl	0.3500	100.0000	0.0100	0.0000	0.0005	0.3500	0.0002
F	0.1267	1.5000	0.6667	0.0000	0.0335	8.4444	0.2828
SO4	3.0000	200.0000	0.0050	0.0000	0.0003	1.5000	0.0004
		$\sum(1/S_n)= 19.9041$		$\sum W_n= 1.0000$		$\sum Q_n.W_n= 2889.2504$	
		$K=1/\sum(1/S_n)= 0.0502$		Overall water quality index= WQI= $\sum Q_n.W_n/ \sum W_n=$ 2889.2504			

(d) Metal Harvey tile

Parameters	Average measured	S_n	$1/S_n$	Ideal value	Unit Weights	Quality Rating	Weighted value
					$(W_n)= K/S_n$	$(Q_n)=100((V_n-V_{io})/(S_n-V_{io}))$	(Q_n*W_n)
pH	6.9100	8.0000	0.1250	7.0000	0.0063	-9.0000	-0.0565
EC	397.0000	1700.0000	0.0006	0.0000	0.0000	23.3529	0.0007
TDS	262.3100	450.0000	0.0022	0.0000	0.0001	58.2911	0.0065
Turbidity	19.6300	1.0000	1.0000	0.0000	0.0502	1963.0000	98.6231
Ca	9.6185	32.0000	0.0313	0.0000	0.0016	30.0578	0.0472
Na	28.4854	100.0000	0.0100	0.0000	0.0005	28.4854	0.0143
K	86.0601	50.0000	0.0200	0.0000	0.0010	172.1201	0.1729
Mg	2.7518	30.0000	0.0333	0.0000	0.0017	9.1726	0.0154
Al	4.5065	0.1500	6.6667	0.0000	0.3349	3004.3556	1006.2789
Zn	4.6634	3.0000	0.3333	0.0000	0.0167	155.4467	2.6033
Fe	4.8808	0.1000	10.0000	0.0000	0.5024	4880.8000	2452.1630
Cu	4.6527	1.0000	1.0000	0.0000	0.0502	465.2667	23.3755
Cl	3.0333	100.0000	0.0100	0.0000	0.0005	3.0333	0.0015
F	0.2433	1.5000	0.6667	0.0000	0.0335	16.2222	0.5433
SO4	28.3333	200.0000	0.0050	0.0000	0.0003	14.1667	0.0036
		$\sum(1/S_n)= 19.9041$		$\sum W_n= 1.0000$		$\sum Q_n.W_n= 3583.7927$	
		$K=1/\sum(1/S_n)= 0.0502$		Overall water quality index= WQI= $\sum Q_n.W_n/ \sum Wn=$ 3583.7927			

© University of Venda

Appendix 10: Non-carcinogenic risk estimations for groundwater, river water and rainwater

(a) Groundwater and river water

Source	Metal	CF	DI	EF	ED	BW	AT	ADD	RFD	HQ		Source	Metal	CF	DI	EF	ED	BW	AT	ADD	RFD	HQ
BH1-A	Mg	74.69	2.2	365	70	70	25550	2.35E+00	30	7.82E-02		BH2-A	Mg	0.00	2.2	365	70	70	25550	0.00E+00	30	0.00E+00
BH1-C		74.69	1.8	365	6	15	2190	8.96E+00	30	2.99E-01		BH2-C		0.00	1.8	355	6	15	2 190	0.00E+00	30	0.00E+00
BH1-A	K	50.11	2.2	365	70	70	25550	1.57E+00	50	3.15E-02		BH2-A	K	62.22	2.2	365	70	70	25550	1.96E+00	50	3.91E-02
BH1-C		50.11	1.8	365	6	15	2 190	6.01E+00	50	1.20E-01		BH2-C		62.22	1.8	355	6	15	2190	7.47E+00	50	1.49E-01
BH1-A	Ca	37.63	2.2	365	70	70	25550	1.18E+00	32	3.70E-02		BH2-A	Ca	0.00	2.2	365	70	70	25550	0.00E+00	32	0.00E+00
BH1-C		37.63	1.8	365	6	15	2190	4.52E+00	32	1.41E-01		BH2-C		0.00	1.8	355	6	15	2190	0.00E+00	32	0.00E+00
BH1-A	Zn	4.05	2.2	365	70	70	25550	1.27E-01	3	4.25E-02		BH2-A	Zn	4.73	2.2	365	70	70	25550	1.49E-01	3	4.95E-02
BH1-C		4.05	1.8	365	6	15	2190	4.86E-01	3	1.62E-01		BH2-C		4.73	1.8	355	6	15	2190	5.67E-01	3	1.89E-01
BH1-A	Fe	4.26	2.2	365	70	70	25550	1.34E-01	0.1	1.34E+00		BH2-A	Fe	4.62	2.2	365	70	70	25550	1.45E-01	0.1	1.45E+00
BH1-C		4.26	1.8	365	6	15	2190	5.11E-01	0.1	5.11E+00		BH2-C		4.62	1.8	355	6	15	2190	5.55E-01	0.1	5.55E+00
BH1-A	Cu	2.95	2.2	365	70	70	25550	9.26E-02	1	9.26E-02		BH2-A	Cu	3.87	2.2	365	70	70	25550	1.22E-01	1	1.22E-01
BH1-C		2.95	1.8	365	6	15	2190	3.54E-01	1	3.54E-01		BH2-C		3.87	1.8	355	6	15	2190	4.65E-01	1	4.65E-01
BH1-A	Na	0.00	2.2	365	70	70	25550	0.00E+00	100	0.00E+00		BH2-A	Na	85.75	2.2	365	70	70	25550	2.69E+00	100	2.69E-02
BH1-C		0.00	1.8	365	6	15	2190	0.00E+00	100	0.00E+00		BH2-C		85.75	1.8	355	6	15	2190	1.03E+01	100	1.03E-01
BH1-A	Mn	4.53	2.2	365	70	70	25550	1.42E-01	0.05	2.85E+00		BH2-A	Mn	4.50	2.2	365	70	70	25550	1.42E-01	0.05	2.83E+00
BH1-C		4.53	1.8	365	6	15	2190	5.43E-01	0.05	1.09E+01		BH2-C		4.50	1.8	355	6	15	2190	5.40E-01	0.05	1.08E+01
Up- A	Mg	12.76	2.2	365	70	70	25550	4.01E-01	30	1.34E-02		Dwn-A	Mg	11.30	2.2	365	70	70	25550	3.55E-01	30	1.18E-02
Up-C		12.76	1.8	365	6	15	2190	1.53E+00	30	5.10E-02		Dwn-C		11.30	1.8	355	6	15	2190	1.36E+00	30	4.52E-02
Up- A	K	6.92	2.2	365	70	70	25550	2.17E-01	50	4.35E-03		Dwn-A	K	6.82	2.2	365	70	70	25550	2.14E-01	50	4.29E-03
Up-C		6.92	1.8	365	6	15	2190	8.30E-01	50	1.66E-02		Dwn-C		6.82	1.8	355	6	15	2190	8.19E-01	50	1.64E-02
Up- A	Ca	14.89	2.2	365	70	70	25550	4.68E-01	32	1.46E-02		Dwn-A	Ca	19.67	2.2	365	70	70	25550	6.18E-01	32	1.93E-02
Up-C		14.89	1.8	365	6	15	2190	1.79E+00	32	5.58E-02		Dwn-C		19.67	1.8	355	6	15	2190	2.36E+00	32	7.37E-02
Up- A	Zn	4.32	2.2	365	70	70	25550	1.36E-01	3	4.52E-02		Dwn-A	Zn	5.61	2.2	365	70	70	25550	1.76E-01	3	5.87E-02
Up-C		4.32	1.8	365	6	15	2190	5.18E-01	3	1.73E-01		Dwn-C		5.61	1.8	355	6	15	2190	6.73E-01	3	2.24E-01
Up- A	Fe	5.73	2.2	365	70	70	25550	1.80E-01	0.1	1.80E+00		Dwn-A	Fe	5.14	2.2	365	70	70	25550	1.62E-01	0.1	1.62E+00
Up-C		5.73	1.8	365	6	15	2190	6.88E-01	0.1	6.88E+00		Dwn-C		5.14	1.8	355	6	15	2190	6.17E-01	0.1	6.17E+00
Up- A	Cu	5.25	2.2	365	70	70	25550	1.65E-01	1	1.65E-01		Dwn-A	Cu	3.96	2.2	365	70	70	25550	1.24E-01	1	1.24E-01

© University of Venda

(a) Continued

Source	Metal	CF	DI	EF	ED	BW	AT	ADD	RFD	HQ		Source	Metal	CF	DI	EF	ED	BW	AT	ADD	RFD	HQ
Up-C		5.25	1.8	365	6	15	2190	6.30E-01	1	6.30E-01		Dwn-C		3.96	1.8	355	6	15	2190	4.75E-01	1	4.75E-01
Up- A	Na	85.12	2.2	365	70	70	25550	2.68E+00	100	2.68E-02		Dwn-A	Na	85.75	2.2	365	70	70	25550	2.69E+00	100	2.69E-02
Up-C		85.12	1.8	365	6	15	2190	1.02E+01	100	1.02E-01		Dwn-C		85.75	1.8	355	6	15	2190	1.03E+01	100	1.03E-01
Up- A	Mn	4.33	2.2	365	70	70	25550	1.36E-01	0.05	2.72E+00		Dwn-A	Mn	3.99	2.2	365	70	70	25550	1.25E-01	0.05	2.51E+00
Up-C		4.33	1.8	365	6	15	2190	5.20E-01	0.05	1.04E+01		Dwn-C		3.99	1.8	355	6	15	2190	4.79E-01	0.05	9.57E+00
MT- A	Mg	10.50	2.2	365	70	70	25550	3.30E-01	30	1.10E-02		SP-A	Mg	29.03	2.2	355	70	70	25550	9.12E-01	30	3.04E-02
MT- C		10.50	1.8	365	6	15	2190	1.26E+00	30	4.20E-02		SP-C		29.03	1.8	365	6	15	2190	3.48E+00	30	1.16E-01
MT- A	K	13.16	2.2	355	70	70	25550	4.14E-01	50	8.27E-03		SP-A	K	57.80	2.2	355	70	70	25550	1.82E+00	50	3.63E-02
MT- C		13.16	1.8	365	6	15	2190	1.58E+00	50	3.16E-02		SP-C		57.80	1.8	365	6	15	2190	6.94E+00	50	1.39E-01
MT- A	Ca	17.37	2.2	355	70	70	25550	5.46E-01	32	1.71E-02		SP-A	Ca	18.36	2.2	355	70	70	25550	5.77E-01	32	1.80E-02
MT- C		17.37	1.8	365	6	15	2190	2.08E+00	32	6.52E-02		SP-C		18.36	1.8	365	6	15	2190	2.20E+00	32	6.89E-02
MT- A	Zn	5.35	2.2	355	70	70	25550	1.68E-01	3	5.60E-02		SP-A	Zn	7.64	2.2	355	70	70	25550	2.40E-01	3	8.00E-02
MT- C		5.35	1.8	365	6	15	2190	6.42E-01	3	2.14E-01		SP-C		7.64	1.8	365	6	15	2190	9.16E-01	3	3.05E-01
MT- A	Fe	6.01	2.2	365	70	70	25550	1.89E-01	0.1	1.89E+00		SP-A	Fe	3.92	2.2	355		70	25550	1.23E-01	0.1	1.23E+00
MT- C		6.01	1.8	365	6	15	2190	7.21E-01	0.1	7.21E+00		SP-C		3.92	1.8	365		15	2190	4.70E-01	0.1	4.70E+00
MT- A	Cu	1.32	2.2	365	70	70	25550	4.14E-02	1	4.14E-02		SP-A	Cu	0.00	2.2	355		70	25550	0.00E+00	1	0.00E+00
MT- C		1.32	1.8	365	6	15	2190	1.58E-01	1	1.58E-01		SP-C		0.00	1.8	365		15	2190	0.00E+00	1	0.00E+00
MT- A	Na	97.98	2.2	365	70	70	25550	3.08E+00	100	3.08E-02		SP-A	Na	274.98	2.2	355		70	25550	8.64E+00	100	8.64E-02
MT- C		97.98	1.8	365	6	15	2190	1.18E+01	100	1.18E-01		SP-C		274.98	1.8	365		15	2190	3.30E+01	100	3.30E-01
MT- A	Mn	3.42	2.2	355	70	70	25550	1.07E-01	0.05	2.15E+00		SP-A	Mn	4.37	2.2	355		70	25550	1.37E-01	0.05	2.75E+00
MT- C		3.42	1.8	365	6	15	2190	4.10E-01	0.05	8.20E+00		SP-C		4.37	1.8			15	2190	5.24E-01	0.05	1.05E+01

Legend:

BH1-A: Borehole 1 adult
BH1-C: Borehole 1 adult
UP-A: Upstream adult
UP-C: Upstream child
MT-A: Municipal tap adult
MT-C: Municipal tap child
BH2-A: Borehole 2 adult
BH2-C: Borehole 2 child
Dwn-A: Downstream adult
Dwn C: Downstream child
SP-A: Spring adult
SP-C: Spring child

© University of Venda

(b) Rainwater

Roof type	Metal	CF	DI	EF	ED	BW	AT	ADD	RFD	HQ		Roof type	Metal	CF	DI	EF	ED	BW	AT	ADD	RFD	HQ
Concrete-Adult	Mg	5.56	2.2	365	70	70	25550	1.75E-01	30	5.83E-03		Grass-Adult	Mg	18.89	2.2	365	70	70	25550	5.94E-01	30	1.98E-02
Concrete-Child		5.56	1.8	365	6	15	2 190	6.68E-01	30	2.23E-02		Grass-Child		18.89	1.8	365	6	15	2 190	2.27E+00	30	7.56E-02
Concrete-Adult	K	11.03	2.2	365	70	70	25550	3.47E-01	50	6.93E-03		Grass-Adult	K	485.08	2.2	365	70	70	25550	1.52E+01	50	3.05E-01
Concrete-Child		11.03	1.8	365	6	15	2190	1.32E+00	50	2.65E-02		Grass-Child		485.08	1.8	365	6	15	2190	5.82E+01	50	1.16E+00
Concrete-Adult	Ca	32.31	2.2	365	70	70	25550	1.02E+00	32	3.17E-02		Grass-Adult	Ca	35.05	2.2	365	70	70	25550	1.10E+00	32	3.44E-02
Concrete-Child		32.31	1.8	365	6	15	2190	3.88E+00	32	1.21E-01		Grass-Child		35.05	1.8	365	6	15	2190	4.21E+00	32	1.31E-01
Concrete-Adult	Na	35.63	2.2	365	70	70	25550	1.12E+00	100	1.12E-02		Grass-Adult	Na	194.35	2.2	365	70	70	25550	6.11E+00	100	6.11E-02
Concrete-Child		35.63	1.8	365	6	15	2190	4.28E+00	100	4.28E-02		Grass-Child		194.35	1.8	365	6	15	2190	2.33E+01	100	2.33E-01
Concrete Adult	Zn	4.29	2.2	365	70	70	25550	1.35E-01	3	4.49E-02		Grass-Adult	Zn	4.88	2.2	365	70	70	25550	1.53E-01	3	5.12E-02
Concrete-Child		4.29	1.8	365	6	15	2190	5.14E-01	3	1.71E-01		Grass-Child		4.88	1.8	365	6	15	2190	5.86E-01	3	1.95E-01
Concrete-Adult	Fe	5.83	2.2	365	70	70	25550	1.83E-01	0.1	1.83E+00		Grass-Adult	Fe	5.01	2.2	365	70	70	25550	1.58E-01	0.1	1.58E+00
Concrete-Child		5.83	1.8	365	6	15	2190	7.00E-01	0.1	7.00E+00		Grass-Child		5.01	1.8	365	6	15	2190	6.02E-01	0.1	6.02E+00
Concrete Adult	Mn	7.05	2.2	365	70	70	25550	2.21E-01	0.05	4.43E+00		Grass-Adult		5.67	2.2	365	70	70	25550	1.78E-01	0.05	3.56E+00
Concrete-Child		7.05	1.8	365	6	15	2190	8.45E-01	0.05	1.69E+01		Grass-Child		5.67	1.8	365	6	15	2190	6.80E-01	0.05	1.36E+01
Concrete-Adult	Cu	4.78	2.2	365	70	70	25550	1.50E-01	1	1.50E-01		Grass-Adult	Cu	1.89	2.2	365	70	70	25550	5.93E-02	1	5.93E-02
Concrete-Child		4.78	1.8	365	6	15	2190	5.74E-01	1	5.74E-01		Grass-Child		1.89	1.8	365	6	15	2190	2.27E-01	1	2.27E-01
Corrugated-Adult	Mg	84.71	2.2	365	70	70	25550	2.66E+00	30	8.87E-02		Metal-Adult	Mg	2.75	2.2	365	70	70	25550	8.65E-02	30	2.88E-03
Corrugated-Child		2.75	1.8	365	6	15	2190	3.30E-01	30	1.10E-02		Metal-Child		2.75	1.8	365	6	15	2190	3.30E-01	30	1.10E-02
Corrugated-Adult	K	22.21	2.2	365	70	70	25550	6.98E-01	50	1.40E-02		Metal-Adult	K	86.06	2.2	365	70	70	25550	2.70E+00	50	5.41E-02
Corrugated-Child		22.21	1.8	365	6	15	2190	2.66E+00	50	5.33E-02		Metal-Child		86.06	1.8	365	6	15	2190	1.03E+01	50	2.07E-01

© University of Venda

(b) Continued

Roof type	Metal	CF	DI	EF	ED	BW	AT	ADD	RFD	HQ		Roof type	Metal	CF	DI	EF	ED	BW	AT	ADD	RFD	HQ
Corrugated-Adult	Ca	20.15	2.2	365	70	70	25550	6.33E-01	32	1.98E-02		Metal-Adult	Ca	9.62	2.2	365	70	70	25550	3.02E-01	32	9.45E-03
Corrugated-Child		20.15	1.8	365	6	15	2190	2.42E+00	32	7.56E-02		Metal-Child		9.62	1.8	365	6	15	2190	1.15E+00	32	3.61E-02
Corrugated-Adult	Na	4.53	2.2	365	70	70	25550	1.42E-01	100	1.42E-03		Metal-Adult	Na	28.49	2.2	365	70	70	25550	8.95E-01	100	8.95E-03
Corrugated-Child		4.53	1.8	365	6	15	2190	5.43E-01	100	5.43E-03		Metal-Child		28.49	1.8	365	6	15	2190	3.42E+00	100	3.42E-02
Corrugated-Adult	Zn	4.67	2.2	365	70	70	25550	1.47E-01	3	4.90E-02		Metal-Adult	Zn	4.66	2.2	365	70	70	25550	1.47E-01	3	4.89E-02
Corrugated-Child		4.67	1.8	365	6	15	2190	5.61E-01	3	1.87E-01		Metal-Child		4.66	1.8	365	6	15	2190	5.60E-01	3	1.87E-01
Corrugated-Adult	Fe	3.31	2.2	365	70	70	25550	1.04E-01	0.1	1.04E+00		Metal-Adult	Fe	4.88	2.2	365	70	70	25550	1.53E-01	0.1	1.53E+00
Corrugated-Child		3.31	1.8	365	6	15	2190	3.97E-01	0.1	3.97E+00		Metal-Child		4.88	1.8	365	6	15	2190	5.86E-01	0.1	5.86E+00
Corrugated-Adult	Mn	4.81	2.2	365	70	70	25550	1.51E-01	0.05	3.02E+00		Metal-Adult	Mn	3.78	2.2	365	70	70	25550	1.19E-01	0.05	2.38E+00
Corrugated-Child		4.81	1.8	365	6	15	2190	5.77E-01	0.05	1.15E+01		Metal-Child		3.78	1.8	365	6	15	2190	4.54E-01	0.05	9.08E+00
Corrugated-Adult	Cu	3.30	2.2	365	70	70	25550	1.04E-01	1	1.04E-01		Metal-Adult	Cu	4.65	2.2	365	70	70	25550	1.46E-01	1	1.46E-01
Corrugated-Child		3.30	1.8	365	6	15	2190	3.96E-01	1	3.96E-01		Metal-Child		4.65	1.8	365	6	15	2190	5.58E-01	1	5.58E-01

© University of Venda

Appendix 11: Carcinogenic risk estimations for groundwater, river water and rainwater

(a) Groundwater and river water

Source	Age group	Metal	CF	DI	EF	ED	BW	AT	ADD	CSF	CR
BH1	Adult	Pb	3.58	2.2	365	70	70	25550	1.12E-01	8.5	9.55E-01
	Child		3.58	1.8	365	6	15	2 190	4.29E-01	8.5	3.65E+00
BH2	Adult	Pb	3.07	2.2	365	70	70	25550	9.63E-02	8.5	8.19E-01
	Child		3.07	1.8	365	6	15	2190	3.68E-01	8.5	3.13E+00
Municipal tap	Adult	Pb	2.78	2.2	365	70	70	25550	8.74E-02	8.5	7.43E-01
	Child		2.78	1.8	365	6	15	2190	3.34E-01	8.5	2.84E+00
Upstream	Adult	Pb	2.88	2.2	365	70	70	25550	9.06E-02	8.5	7.70E-01
	Child		2.88	1.8	365	6	15	2190	3.46E-01	8.5	2.94E+00
Downstream	Adult	Pb	4.17	2.2	365	70	70	25550	1.31E-01	8.5	1.12E+00
	Child		4.17	1.8	365	6	15	2190	5.01E-01	8.5	4.26E+00
Spring	Adult	Pb	2.10	2.2	365	70	70	25550	6.61E-02	8.5	5.62E-01
	Child		2.10	1.8	365	6	15	2 190	2.52E-01	8.5	2.15E+00
BH1	Adult	Cd	6.21	2.2	365	70	70	25550	1.95E-01	0.61	1.19E-01
	Child		6.21	1.8	365	6	15	2190	7.46E-01	0.61	4.55E-01
BH2	Adult	Cd	4.92	2.2	365	70	70	25550	1.55E-01	0.61	9.43E-02
	Child		4.92	1.8	365	6	15	2190	5.90E-01	0.61	3.60E-01
Municipal tap	Adult	Cd	11.41	2.2	365	70	70	25550	3.59E-01	0.61	2.19E-01
	Child		11.41	1.8	365	6	15	2190	1.37E+00	0.61	8.35E-01
Upstream	Adult	Cd	8.87	2.2	365	70	70	25550	2.79E-01	0.61	1.70E-01
	Child		8.87	1.8	365	6	15	2190	1.06E+00	0.61	6.49E-01
Downstream	Adult	Cd	8.19	2.2	365	70	70	25550	2.57E-01	0.61	1.57E-01
	Child		8.19	1.8	365	6	15	2 190	9.83E-01	0.61	5.99E-01
Spring	Adult	Cd	7.99	2.2	365	70	70	25550	2.51E-01	0.61	1.53E-01
	Child		7.99	1.8	365	6	15	2190	9.59E-01	0.61	5.85E-01
BH1	Adult	As	4.23	2.2	365	70	70	25550	1.33E-01	1.51	2.01E-01
	Child		4.23	1.8	365	6	15	2190	5.08E-01	1.51	7.67E-01
BH2	Adult	As	4.06	2.2	365	70	70	25550	1.28E-01	1.51	1.93E-01
	Child		4.06	1.8	365	6	15	2190	4.87E-01	1.51	7.36E-01
Municipal tap	Adult	As	3.81	2.2	365	70	70	25550	1.20E-01	1.51	1.81E-01
	Child		3.81	1.8	365	6	15	2190	4.57E-01	1.51	6.90E-01
Upstream	Adult	As	2.90	2.2	365	70	70	25550	9.12E-02	1.51	1.38E-01
	Child		2.90	1.8	365	6	15	2190	3.48E-01	1.51	5.26E-01
Downstream	Adult	As	3.36	2.2	365	70	70	25550	1.05E-01	1.51	1.59E-01
	Child		3.36	1.8	365	6	15	2190	4.03E-01	1.51	6.08E-01
Spring	Adult	As	0.00	2.2	365	70	70	25550	0.00E+00	1.51	0.00E+00
	Child		0.00	1.8	365	6	15	2190	0.00E+00	1.51	0.00E+00

© University of Venda

(b) Rainwater

Roof type	Age group	Metal	CF	DI	EF	ED	BW	AT	ADD	CSF	CR
Concrete tile	Adult	As	5.31	2.2	365	70	70	25550	1.67E-01	1.51	2.52E-01
	Child		5.31	1.8	365	6	15	2 190	6.38E-01	1.51	9.63E-01
Grass	Adult	As	2.69	2.2	365	70	70	25550	8.46E-02	1.51	1.28E-01
	Child		2.69	1.8	365	6	15	2190	3.23E-01	1.51	4.88E-01
Corrugated sheets	Adult	As	4.15	2.2	365	70	70	25550	1.30E-01	1.51	1.97E-01
	Child		4.15	1.8	365	6	15	2190	4.98E-01	1.51	7.51E-01
Metal Harvey tile	Adult	As	2.44	2.2	365	70	70	25550	7.67E-02	1.51	1.16E-01
	Child		2.44	1.8	365	6	15	2190	2.93E-01	1.51	4.42E-01
Concrete tile	Adult	Cd	8.77	2.2	365	70	70	25550	2.76E-01	0.61	1.68E-01
	Child		8.77	1.8	365	6	15	2190	1.05E+00	0.61	6.42E-01
Grass	Adult	Cd	5.67	2.2	365	70	70	25550	1.78E-01	0.61	1.09E-01
	Child		5.67	1.8	365	6	15	2 190	6.80E-01	0.61	4.15E-01
Corrugated sheets	Adult	Cd	5.27	2.2	365	70	70	25550	1.66E-01	0.61	1.01E-01
	Child		5.27	1.8	365	6	15	2190	6.32E-01	0.61	3.86E-01
Metal Harvey tile	Adult	Cd	7.99	2.2	365	70	70	25550	2.51E-01	0.61	1.53E-01
	Child		7.99	1.8	365	6	15	2190	9.59E-01	0.61	5.85E-01
Concrete tile	Adult	Pb	3.67	2.2	365	70	70	25550	1.15E-01	0.85	9.81E-02
	Child		3.67	1.8	365	6	15	2190	4.41E-01	0.85	3.75E-01
Grass	Adult	Pb	6.38	2.2	365	70	70	25550	2.00E-01	0.85	1.70E-01
	Child		6.38	1.8	365	6	15	2190	7.65E-01	0.85	6.50E-01
Corrugated sheets	Adult	Pb	3.39	2.2	365	70	70	25550	1.07E-01	0.85	9.06E-02
	Child		3.39	1.8	365	6	15	2 190	4.07E-01	0.85	3.46E-01
Metal Harvey tile	Adult	Pb	4.32	2.2	365	70	70	25550	1.36E-01	0.85	1.16E-01
	Child		4.32	1.8	365	6	15	2190	5.19E-01	0.85	4.41E-01

© University of Venda

Appendix 12: Concentrations of Fe, Cu, Zn, Pb, Al, Cd, Mn, As for all sources in both dry and wet seasons.

LIMPOPO
PROVINCIAL GOVERNMENT
REPUBLIC OF SOUTH AFRICA

DEPARTMENT OF
AGRICULTURE AND RURAL DEVELOPMENT

MADZIVHANDILA COLLEGE OF AGRICULTURE ANALYTICAL SERVICES

Private Bag X5024, Thohoyandou, 0950

Client	Pfunzo Ndou
Address	P/B x 5050, Univen, Thohoyandou, 0950
Telephone	083 522 2146/ 967 997 7893
Fax number	
e-mail address	Ndoupg5@gmail.com

WATER ANALYTICAL RESULTS

Sample#	Fe	Cu	Zn	Pb	Al	Cd	Mn	As
	mg/L	mg/L	Mg/L	mg/L	Mg/L	Mg/L	mg/L	mg/L
Wavelength	239.563	324.754	206.149	220.353	396.152	214.441	257.610	189.042
1 (BH1 Dec 2023)	7.1855	5.6191	1.6392	2.7131	5.6797	9.9834	4.8430	3.3554
2 (BH2 Dec 2023)	3.3526	5.0573	5.1692	3.6891	5.2659	3.1144	3.2181	5.6109
3 (Upstream Dec 2023)	5.3483	4.5415	5.1692	3.3085	4.8928	7.9574	3.5899	2.7915
4 (Downstream Dec 2023)	6.7415	6.5186	4.2322	2.0399	4.7742	13.2158	1.5476	5.4699
5 (Concrete tile Dec 2023)	4.6674	5.9169	3.7638	3.3085	5.5359	7.1550	8.2579	5.6109
6 (Grass roofing Dec 2023)	6.0057	4.3693	4.3884	6.9875	5.5175	5.5387	10.5920	3.7783
7 (Corrugated sheets Dec 2023)	2.3383	4.6275	4.8569	5.0846	5.5517	2.7103	5.0486	5.2262
8 (Metal Harvey tile Dec 2023)	0.3659	6.7268	5.0573	5.6109	4.4956	3.9225	2.1668	3.2423
9 (BH1 Jan 2024)	0.3622	5.5896	4.5415	1.3819	4.6985	0.0000	4.0697	5.5395
10 (BH2 Jan 2024)	4.6939	6.7268	6.5186	3.7783	4.9272	9.9834	5.0846	4.8086
11 (Upstream Jan 2024)	2.6807	6.3478	5.9169	5.4699	4.3307	12.4077	4.4503	4.7042
12 (Downstream Jan 2024)	2.6439	3.9471	4.3693	5.7518	4.9633	13.6402	3.4354	2.8247
13 (Concrete tile Jan 2024)	7.6433	5.4633	4.6275	5.4699	5.1421	11.1956	8.5094	4.7042
14 (Grass roofing Jan 2024)	2.7885	1.2937	5.1692	10.1218	4.4750	3.4982	1.7862	3.0335
15 (Corrugated sheets Jan 2024)	2.4658	3.0626	5.1692	2.9325	4.7364	5.1347	4.3234	2.4070
16 (Metal Harvey tile Jan 2024)	8.1358	4.7052	4.2322	5.4699	4.7364	11.2768	3.4354	4.0777

© University of Venda

Sample#	Fe	Cu	Zn	Pb	Al	Cd	Mn	As
	mg/L	mg/L	Mg/L	mg/L	Mg/L	Mg/L	mg/L	mg/L
Wavelength	239.563	324.754	206.149	220.353	396.152	214.441	257.610	189.042
17 (BH1 Feb 2024)	2.3433	5.8423	3.7638	5.6109	5.3433	4.7306	1.9131	5.1218
18 (BH2 Feb 2024)	3.7174	2.9362	4.3884	1.1138	4.7174	8.7712	4.9577	4.4953
19 (Upstream Feb 2024)	7.0622	8.4957	4.8569	1.5228	5.4293	4.3266	4.8309	3.4512
20 (Downstream Feb 2024)	6.1935	4.0734	6.4552	7.4434	5.7405	9.9834	3.9428	3.0335
21 (Municipal tap Feb 2024)	7.3850	2.2796	5.4459	2.7915	4.7725	12.4077	2.2937	4.7042
22 (BH1 March 2024)	6.6198	0.000	4.4993	7.3024	5.5170	16.6199	5.9726	2.3026
23 (Upstream March 2024)	7.0963	1.4474	3.8419	3.3554	4.9857	13.6199	6.3532	5.8527
24 (Downstream March 2024)	3.6809	2.3928	7.1211	5.7518	4.3065	4.3266	3.9428	1.9186
25 (Municipal tap March 2024)	4.6322	0.3554	5.2472	2.7706	5.3571	10.4077	4.5415	2.9155
26 (Concrete tile March 2024)	5.1838	2.9723	4.4665	2.2380	5.0716	7.9631	4.3696	5.6280
27 (Grass roofing March 2024)	6.2463	0.000	5.0911	2.0166	5.0871	7.9631	4.6275	1.2676
28 (Corrugated sheets March 2024)	5.1326	2.2131	3.9980	2.1591	4.5593	7.9633	5.0573	4.8075
29 (Metal Harvey tile March 2024)	6.1407	2.5260	4.7007	1.8921	4.2876	8.7712	5.7450	0.000
30 (BH1 April 2024)	5.2096	0.3421	5.7938	2.0975	4.8619	5.9428	5.9169	6.3740
31 (BH2 April 2024)	5.5781	0.3155	3.1392	1.7717	5.3038	0.0000	4.9713	4.3667
32 (Upstream April 2024)	6.4165	4.7523	4.0984	1.9364	4.5300	6.4532	2.3926	0.6030
33 (Downstream April 2024)	5.8296	1.0023	6.9732	1.6500	5.7182	0.0000	4.5415	0.000
34 (Spring April 2024)	3.9163	0.000	7.6352	2.1038	5.1576	7.9876	4.3696	0.000
35 (BH1 May 2024)	3.8157	0.2889	4.0847	2.3500	5.5290	0.0000	4.4556	2.7120
36 (BH2 May 2024)	5.7730	4.3237	4.4142	4.9742	4.8034	2.7134	4.2837	1.0235
37 (Upstream May 2024)	5.7944	5.9083	2.0203	1.7123	5.6837	8.4686	4.3696	0.000
38 (Downstream May 2024)	5.7650	5.8253	4.4820	2.4109	4.2240	7.9722	6.5186	6.8894

© University of Venda