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A quantity-quality tradeoff: Water quality and poverty assessment of drinking water sources in Southern Tanzania

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A QUANTITY-QUALITY TRADEOFF: WATER QUALITY AND POVERTY ASSESSMENT OF DRINKING WATER SOURCES IN SOUTHERN TANZANIA

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A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree Masters in Environmental Science and Engineering of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

Regardless of being essential for human survival, access to potable water is still a problem in many rural African communities with increasing exposure to waterborne illnesses. This study aimed at establishing accessible quality water sources in 5 drinking water sources in rural southern Tanzania. The water quality index (WQI) and water poverty index (WPI) were utilized to grade and measure the water quality and water stress respectively. The 26 households participated in a socioeconomic survey to gauge the water accessibility in relation to four WPI factors viz., preference, accessibility (distance), quality, and seasonal availability. Results from the WPI computed data revealed that all the investigated water sources possessed poor quality with 222.5 and 112 for surface water and shallow wells (>50 excellent, <300 unsuitable). The WPI scores for shallow wells were safer than surface water at 45.7 as contrasted to 33.8 for surface water (0-poorest levels, 100-best levels). This study concluded that, in this area, shallow wells have more secure water in terms of quality and accessibility. Health data from Milola ward showed high occurrences of water borne diseases. This study recommends urgent water treatment intervention by the responsible stakeholders to avail clean, reliable, and accessible drinking water for vulnerable communities.

DECLARATION

I, Nancy Indeche Maungu do hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that this dissertation is my original work and it has neither been submitted nor being concurrently submitted for a degree award in any other institution.

21/07/2023

Nancy Indeche Maungu — Date

The above declaration is confirmed by

24.08.2023

Prof. Revocatus Machunda — Date

24.8.2023

Dr. Tula M. Ngasala — Date

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Nelson Mandela African Institution of Science and Technology a Dissertation titled: *"A Quantity-Quality Tradeoff: Water Quality and Poverty Assessment of Drinking Water Sources in Southern Tanzania"*, in Partial fulfilment of the requirements for the degree of Master's in Environmental Science at Nelson Mandela African Institution of Science and Technology.

24.8.2023

Prof. Revocatus Machunda　　Date

24.8.2023

Dr. Tula M. Ngasala　　Date

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DEDICATION

I dedicate this dissertations to my parents.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABREVIATIONS AND SYMBOLS

EC	Electric Conductivity
IUCEA	Inter University Council of East Africa
MDGs	Millennium Development Goals
NRWSSP	National Rural Water Supply and Sanitation Plan
POC	Point of Collection
POU	Point of Use
TBS	Tanzania Bureau of Standards
TDS	Total Dissolved Solids
TDV	Tanzania Development Vision 2025
TP	Total Phosphorus
TPP	Tanzania Partnership Program
WHO	World Health Organization
WPI	Water Poverty Index
WQI	Water Quality Index

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

Water is vital for sustaining life. In sub-Saharan Africa, there is limited access to potable water, and rural areas are highly affected as a high of the population do not have the infrastructure for water supply (Ngasala *et al.*, 2018). Research shows that 10% of the rural population in sub-Saharan Africa consumes untreated surface water (World Water Assessment Programme, 2016).

It has become imperative to mitigate the water problems in rural areas over the last decade (Marobhe, 2008). Thus, sustainable rural water supply services (RWSS) has become a global endeavour especially in numerous developing countries such as Mali (Gleitsmann *et al.*, 2007), Ethiopia (Tadesse *et al.*, 2013), Tanzania (Jiménez & Pérez-Foguet, 2010), Nigeria (Nwankwoala, 2011), Ghana (Atipoka, 2009), India (Ince *et al.*, 2018; Kouro *et al.*, 2010; Mali & Dwibedi, 2013; Nayar & James, 2010), Nepal (Haapala & White, 2018) and Mali (Gleitsmann *et al.*, 2007), and Uganda (Chaudhuri, 2020). An improved rural water supply is important for the improvement of life and better health.

The UN SDG 6 (the 'water goal') aspires to ensure everyone has access to water and that it is managed sustainably (Priyadarshini & Abhilash, 2018). Different countries in the developed world have been able to achieve the water goal, however, many developing nations are yet to experience this (Grey & Sadoff., 2007). One of the top priorities for Tanzania's Vision 2025, which aims to give its population a High-quality Livelihood, is the attainment of 'Universal access to safer water' for all human beings (Tandari, 2004).

Tanzania is endowed with immense and valuable natural resources, water being one of them. The country lies in the African Great Lakes Region and out of the world's top ten largest freshwater lakes in terms of size and depth, three of them are in Tanzania (Lake Nyasa, Lake Tanganyika & Lake Victoria). Apart from these, there are other numerous lakes and important rivers found within its borders. Despite its abundant water resources, the rural population in Tanzania is no exception to this water scarcity issue. According to Connor (2015), just around 50% among rural human population has avenue to a trustworthy water supply provider. Additionally, it was observed that inadequate operating and maintenance practices were the main cause of more than 30% of the accessible rural water schemes' malfunctions. To combat this, the Tanzanian government established an expansive National Rural Water Supply and Sanitation Plan (NRWSSP) for the duration commencing the year 2006 – 2025 with support from several development partners. The

NRWSSPs' target is to escalate the avenue to safe drinking water in rural to 65% or at least 74% by 2010 and mid-2015, respectively (MDGs). Additionally, it also set a goal of increasing to 90% by 2025 the proportion of rural residents who have reliable access to water (URT, 2002), a target that has yet to be met.

The study was carried in Milola ward situated in Lindi district, southern Tanzania, one of the rural areas with human populations associated with severe waterborne diseases caused by water scarcity problems. In this area, almost all the residents rely on locally available water sources such as rivers wells, hand pumps etc., which are frequently contaminated. Uptake of contaminated drinking water poses serious threat to humans' health as it may trigger dangerous waterborne disease outbreaks viz., dysentery, cholera and typhoid (Ngasala *et al.*, 2018; Saria & Thomas, 2012). Tanzanian Partnership Program (TPP) is a collaborative alliance of local and international organizations and is dedicated to improving the livelihoods of the locals. The partnership is working to fix the water quality problems and scarcity in the rural areas. The TPP aims to co-create a model of sustainable community development and water security is one of the major sectors. Thus, water quality assessment and poverty of the available water sources were the main focus of this research in the selected stud area with the aim of giving recommendations to TPP for possible solutions partaining community's water issues.

1.2 Statement of the Problem

Milola ward in Lindi district has limited access to water resources and is one of the poorest villages in Milola ward with an average household living under 1 US Dollar a day. In most cases residents depend on shallow wells and seasonal streams that are untreated and of poor quality leading to water-borne diseases. To the best of our knowledge, we have found no prior study done in Milola ward on water quality of the existing water sources for households' usage. This study aimed to conduct an assessment on the quality of the existing water sources while also looking into the community practices with regards to water usage and household storage practices. This study also aimed to establish the community's water stress level by assessing its water poverty. Finally, the study will give a framework on feasible solutions to be offered to the residents in terms of safe water access and supply.

1.3 Rationale of the Study

Milola ward is among the two site areas for Tanzania Partnership Program. The study was performed in one of the Milola villages located in Lindi district in southern Tanzania. The study community in Ngwenya village has limited access to water resources and is one of the poorest villages in Milola ward with an average household living under 1 US Dollar a day. In most cases residents travel long distances to access water. They depend on shallow wells and seasonal streams that are untreated and of poor quality leading to water-borne diseases. They also collect rain water during the rainy seasons. Therefore, this is the reason the present work focused on assessing the water quality and poverty of available water sources in the area with the aim of giving recommendations to TPP for possible solutions to the community's water issues.

1.4 Research Objectives

1.4.1 Main Objective

The study's main objective was to evaluate the water quality and poverty among the existing sources in the study area and to pinpoint the most dependable water source according to accessibility and quality.

1.4.1 Specific Objectives

(i) To evaluate the quality of existing water sources while also looking into the community practices with regard to water usage and household storage practices.

(ii) To establish the community's water stress level by assessing its water poverty.

1.5 Research Questions

(i) What is the water quality of water sources in the study area?

(ii) What are the main factors limiting access of clean and quality water in the community in the study area?

1.6 Significance of the Research

This community in Milola ward was chosen as the study area because of the challenges facing its residents with regards to water quality and availability. The area does not have a designated water point to cater for their needs; the residents rely completely on seasonal streams and hand dug wells. They sometimes also track long distances to access water especially in the dry seasons. The residents also suffer from water related diseases and according to the health workers in Milola dispensary the most common diseases in the area were bilharzia, hookworm, and diarrhea. The results from this study will determine the most reliable water source in the area and will be used by TPP to provide a permanent water source to the community.

1.7 Delineation of the Study

This dissertation looks into a rural community in southern Tanzania and the water access challenges faced by its residents. An overview of the study area is given in the introduction and the available water sources. The methodology section describes the study area in more detail and gives baseline data of its residents and also covers the methods used in data collection i.e., obtaining water samples and surveys. This section also describes the analytical instruments that were utilized to interpret the data collected. Water quality index and water poverty index tools are used to give a clear and easy interpretation of the data. Results and discussion section follows the methodology chapter and this looks into the information derived from the data analysis. It discusses the results obtained in detail and the effects on the residents of Milola area. The dissertation concludes by giving recommendations to mitigate the water challenges being faced by the study area residents and also gives plausible suggestions to the decision-makers and other key players in the water provider sector.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In majority rural areas, the quantity of water in provided water sources is given more attention as compared to the quality (Awuah *et al.,* 2009). This, therefore, means a high number of residents are exposed to potential pollution in their water. When there is water scarcity, people have no alternative but to use other unimproved water sources which in most cases are contaminated resulting in insect and waterborne diseases (Satterthwaite, 2003). Children below five years are especially vulnerable to these diseases like severe diarrhea resulting in high mortality rates (Timgren *et al.,* 2011). It was approximated that 1 in 3 humans worldwide has no access to safe water for drinking (UNICEF, 2018). The WHO further estimated in 2014 that up to 1.8 million people die yearly from drinking polluted water (WHO/UNICEF, 2015).

Many third world rural communities face issues of poor water quality and scarcity because of unreliable rainfall, drought and unreliable water supply. Poor water resource management practices such as farming techniques, poor waste management of both animals and people with open defecation are the main contributors of surface water contamination in rural areas (Bohnert, Guy & Losby, 2018).

The use of water from untreated sources is widely reported in various literature. Globally, millions of people, especially those in rural areas setup in developing countries, still experience challenges in accessing clean and sustainable water owing to limited availability of potable water and poor water supply infrastructure (Edokpayi *et al.,* 2018). People in these areas are thus limited to unimproved water sources, like hand dug or shallow wells and rivers or other groundwater sources because of the lack of sustainable water access.

In developing nations, female populations that fetch water are disproportionately impacted by water scarcities (Sorenson *et al.*, 2011). According to Pereira *et al.* (2009), females can spend up to six hours gathering water in rural areas. Women and children could make an income, look after their families, or go to school instead of sacrificing their time to gather water. Research by Demie *et al.* (2016) which shown a relationship between waster scarcity and education, has validated this. The children’s education, health, and safety are all badly impacted by having to travel considerable distances to get this scarce resource (Cherutich *et al.,* 2015). Research done in rural Tanzania established lack of physical access to clean groundwater caused low yields, unreliable infrastructure and poor water quality (Mseli *et al.,* 2019).

An abundance of studies surface and groundwater quality do not simplify the results to the relevant authorities and policymakers which would help in better control of water resources (Rodriguez *et al.,* 2015). The use of WQI bridges that gap as it gives results in a simplified manner.

2.2 Water Quality

Water pollution is the degradation of water quality by the presence of harmful substances making the water toxic to humans, the environment and unable to be used for its intended purpose. Pollutants include chemicals from agriculture, industries and households. Consumption of contaminated drinking water poses a major danger to humans' health and may cause epidemics such as cholera, typhoid, and other water-borne diseases (Ngasala *et al.,* 2018; Saria & Thomas, 2012).

Water quality assessment is a process which ascertains the safety of water by evaluating the chemical, physical, and biological characteristics that are associated with its natural quality, human influence and desired applications that can pose negative impact on humans' health and the marine ecosystem (UNICEF, 2010). Assessment of water quality is important before policies on resource protection and allocation are made.

2.2.1 Water Quality Index

The present study determined the overall water quality by calculating the WQI of each water source in the researched area. The WQI is highly important for assessing surface water quality since it can collate huge amount of water quality data into a unit value by using aggregation techniques. It has been deployed internationally to study water quality for both surface and groundwaters grounded on bounded water quality criteria. The WQI was developed in the 1960s and has since gained popularity because of its ability to be tailored to a local level and it's also easy to use. The WQI tool has been used in various studies around the world to calculate water quality data. Due to its ability to be tailored to suit local needs, more than 35 WQI models have been established by different stakeholders worldwide (Abbasi & Abbasi, 2012; Dadolahi-Sohrab *et al.,* 2012; Kannel *et al.,* 2007; Stoner, 1978).

The WQI classifies water standards with respect to an index number that expresses the overall water suitability for any given purpose (Etim *et al.,* 2013). The WQI characterizes water quality by comparing data obtained through analysis of physio-chemical and biological water parameters according to stipulated standards (Karunanidhi *et al.,* 2020). These parameters are then aggregated in a mathematical equation and the result is a single value, relaying complex data into easily understood information by even those who are not water specialists (Singaraja, 2017) and giving the quality status of a water body (Reza & Singh, 2010).

While WQI is limited because most times microbial parameters are not included (Rabeiy, 2018; Su *et al.,* 2018), it still offers a reliable way to convey the quality of potable water using physicochemical parameters. The *E. coli* has been incorporated in some studies cater for the microbiological parameters (Sutadian *et al.*, 2018). This study incorporates bacteria, specifically total coliforms among its water quality parameters in the measurement of WQI.

Advantages of WQI (Akoteyon *et al.*, 2011; Yogendra & Puttaiah, 2008):

(i) Calculates a single number as the outcome of integrating data from several water quality metrics into an equation to rate the state of a water body.

(ii) One requires only a minimum number of parameters for measuring water for a particular use as compared to measuring all water quality parameters.

(iii) Clearly shows the various effects of different parameters on a water body which is critical for assessing and managing water quality.

(iv) It allows for easy presentation to the general population and decision makers the overall water quality results.

(v) It indicates how suitable various water sources are for human consumption.

The study calculated WQI by using potable water quality standards as per the World Health Organization (WHO) and the Tanzania Bureau of Standards (TBS) recommendations.

Therefore, this investigation was conducted to evaluate and assess the quality of several water sources utilized by people of Ngwenya village, Milola ward, Lindi district, Tanzania. The quality of the water sources in this area was unknown hence the study was carried out to assess them and the findings were reported using WQI.

2.3 Water Poverty

Water poverty is a set of circumstances that contribute to a nation or region not being able to sufficiently provide clean and sustainable water to its population. Water poverty index (WPI) compares the population’s capacity to obtain water with the actual availability and access to water. People are described to be ‘water poor’ when they lack access to adequate water to sufficiently meet their fundamental requirements due to its scarcity. Long distances to access water might be the cause of this or even when it is nearby, the quantity is limited for various reasons. The population may also be said to be 'water poor' because of financial reasons where the water may be available, but they cannot afford it.

Water scarcity is best described as the available quantity of water against the number of people requiring it (Feitelson & Chenoweth, 2002). It's important to also consider other causes of water scarcity apart from physical availability. Majority of stakeholders focus on the physical availability and do not consider other causes e.g., social and economic factors (Savenije, 2000). A strong link exists between poverty and water scarcity with inadequate water supply infrastructures further contributing towards physical water poverty (Pietrucha-Urbanik, 2016; Pietrucha-Urbanik & Żelazko, 2017). Salameh (2000), characterized water poverty as a direct proportion of an individual's water needs for both food production and domestic uses in a year to the corresponding renewable water available to them under the prevailing climate condition. A community's limited financial resources and the limited physical availability of water both contribute to water paucity (Lawrence *et al.*, 2002).

2.3.1 Water Poverty Index

The WPI was established to evaluate the water scarcity at the local society level. An important advantage of WPI is its ability to use the household perspective to assess the severity of water scarcity (Feitelson & Chenoweth, 2002). However, the index can be adapted to suit different levels and many studies have been done on wider scales such as city and national levels. The WPI methodology was first used in pilot projects in South Africa, Tanzania and Sri Lanka. It incorporated contributions and in-depth consultations from all the affected participants and collaborators such as the water sector experts, water users, policy makers and others (Sullivan *et al.*, 2003). This community consultation is important in finding lasting solutions to the myriad water problems facing the developing world, especially in poor rural communities as research has shown the inter-connectedness of 'water poverty', and 'income poverty' (Sullivan & Meigh, 2003).

The WPI is an all-inclusive tool developed to meticulously analyze water stress at both personal and levels. It was intended to assist the appropriate authority, at community and national levels, including interested donors, to correctly prioritize needs in the water provider's sector. In order to create a single unit, WPI combines data from several factors that both directly and indirectly contribute to water stress (Sullivan *et al.*, 2003). The WPI comprise metric sub-components such as environmental aspects, water access, water quantity and quality, water variability water usage (for household, productive applications) and water management ability.

The WPI has become an effective water management tool and has been hugely beneficial to policy-makers, particularly in prioritization and resources allocation processes (Pérez-Foguet *et al.*, 2011; Sullivan & Meigh, 2007). This research deployed WPI instrument to determine the severity of water shortage in this community in Lindi district, southern Tanzania and can be mirrored in other water-scarce areas of the nation and world.

2.4 Water Storage Practices

A source/location from where people collect water for their daily use is referred to as Point of collection (POC) while usage at household level is Point of Use (POU) and incorporates cooking, drinking, bathing etc.

The quality of each water source is different depending on the location and water management practices around it. Similarly, the quality of water in different households will vary based on their collection, usage and storage. Several studies have shown there is a direct link between drinking water contamination in households and their storage practices (Brick *et al.,* 2004; Ngasala *et al.*, 2019; Steele *et al.,* 2008).

2.5 Knowledge Gap and Objectives

Limited water access, poor water quality and management are major issues that villages in rural Lindi District, southern Tanzania face every day which affect families especially women and children. No prior study has been done on the available water sources in the studied area. This investigation fills that gap by utilizing the WQI tool to evaluate water sources quality. We also recognize that few studies have been done combining WQI and WPI tools, and by applying the two in this study, we were able comprehend the water situation in this community and offer viable solutions and recommendations for further studies to be duplicated in other water stressed areas in the rural developing world. The study's objective was to identify the reliable water source in the study area by targeting quality and access. Specifically, to identify the main sources of contamination, analyze possible contaminants and recommend sustainable solutions to advance the health and the residents' wellbeing. The second objective was to pinpoint the aspects that contribute towards the water stress in the area and quantify them using the water poverty index tool.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Site

The study was excecuted in April 2021 in Ngwenya, Milola Ward, Lindi district in the south-eastern corner of Tanzania (Fig. 1). The study area lies between latitude 9°55’12” & 10°0’0” South and longitude 39°12’0” & 39°16’48” east.

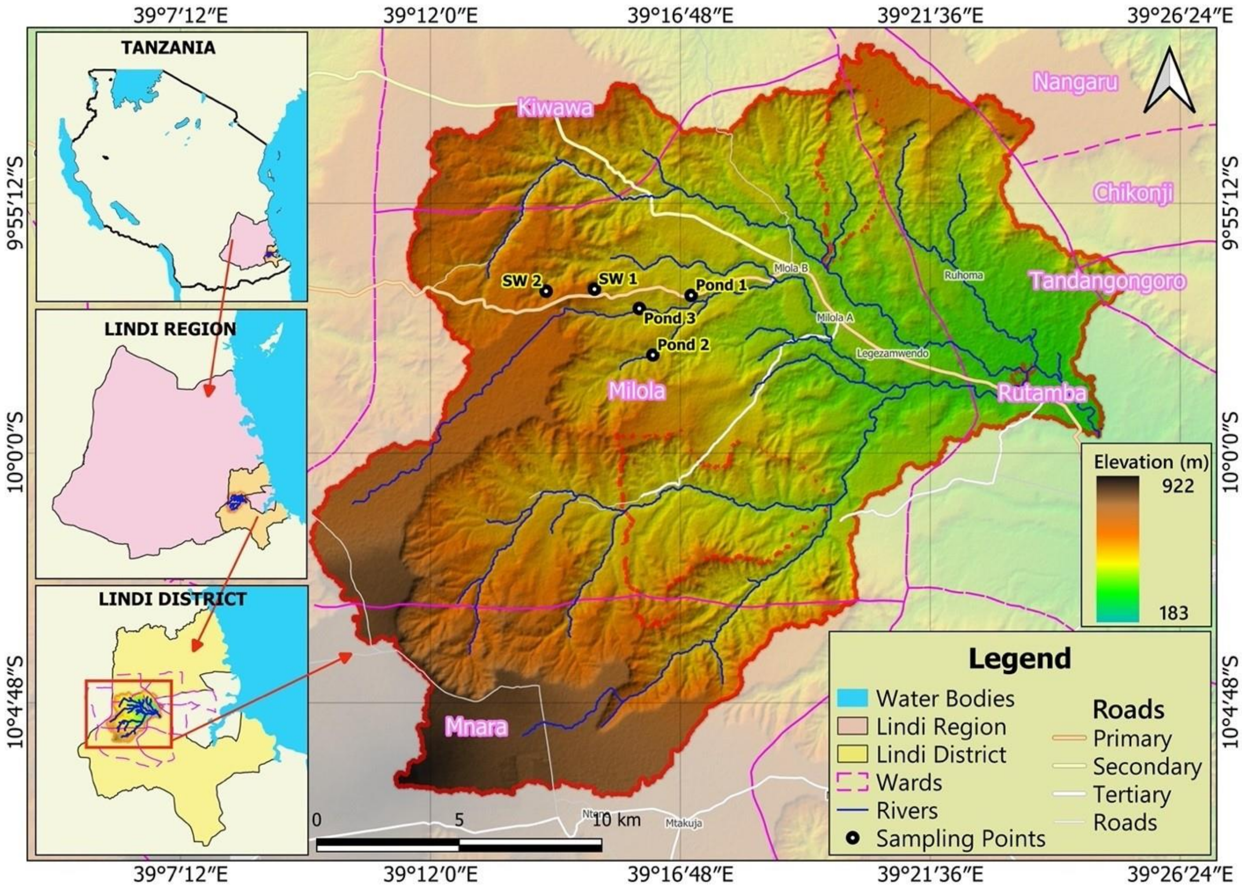

Figure 1: Study map area showing water source locations analyzed

There are two rainy seasons in the area; from November through December and March through May, with yearly precipitation average ranging between 800-1200 mm and temperatures ranging averagely between 24-27°C throughout the year. Lindi region has a total of 864 652 inhabitants living in approximately 67 000 sq (Wenban-Smith, 2014). Administratively, it is divided into 6 districts (Lindi Urban, Lindi Rural, Nachingwea, Ruangwa, Kilwa & Liwale). Lindi is ranked the third poorest region in Tanzania. Approximately 50% of the populace is classified as living beneath the poverty line (Ngana, 2009). Lindi Rural District is located 1 kilometre south of the Lindi town – the headquarters of the Lindi region. It borders with Lindi town in the East, Masasi and Mtwara Rural Districts in the South, Ruangwa District in the West and Kilwa District in the North. Lindi district is divided into 10 division, 28 Wards, 125 villages and 807 hamlets (Ngana, 2009). The district is located in the tropical zones with heavy forestry especially in Rondo plateau, Milola, Nyangamara and Mpingo Divisions. About 80% of the population in Lindi Rural District depends on agricultural production and livestock keeping. The main crops grown include cassava, paddy, sorghum, maize, coconut, cashew nut, sesame and legumes. Animals kept include cattle, goat, sheep donkey, poultry and ducks (Ngana, 2009). Population and Water Access in Milola Ward.

Milola, is one of the Lindi divisions. It consists of three wards which are, Milola, Rutamba and Kiwawa. As of 2019, Milola ward had a total population of 10 493 living in seven villages namely Milola East, Milola B, Rucheni, Namtamba, Mkangaulani, Milola West and Legeza Mwendo. The Ward is located just at the middle of the Lindi rural district with a distance of approximately 62 kilometres from Lindi town. The study area community has a population of around 400 people who depend on unimproved water sources due to lack of identifiable and reliable water source.

Table 1: The Current Milola Ward Population

Village Name	Number of Wards	Number of Households	Total Population
Milola A (Milola East)	8	419	1876
Milola B	9	1050	3347
Namtamba	8	342	1514
Legezamwendo	5	247	729
Ruchemi	3	177	602
Mkangaulani	6	416	1647
Milola West	5	358	878
TOTAL	**44**	**3009**	**10493**
Ngwenya (Milola B Sub-village)	-	88	404

3.2 Water Source Description

The study area is served by five water sources (Fig. 1) and rain water during the rainy seasons. Water samples were collected from these sources following recommended standard methods for water analysis (APHA, 2017). The water sources are further described below and summarized in Table 2.

3.3.1 Dug Wells (shallow wells) and Surface Water (Seasonal Streams)

Ngwenya is the only village in Milola that uses dug wells also known as shallow wells and seasonal streams because water supply system doesn’t cover this village. These sources are typically far, with average walking distances of 30 minutes to 1 hour (one way). During the rainy season, people collect water right from the streams or dug wells. When the rainy season starts to end, and the seasonal streams dry up, people dig up the wells by hand (~3-5ft deep) and wait for water to recharge before collecting it. Families in the study area spend between 1.5 - 2 hours (two way) to collect water without including the waiting times at the sources.

Figure 2: Sampled water sources from which water was collected in the study area

3.3.2 Rainwater Harvesting

More than 50% of families surveyed use rainwater as their alternative source of water during the rainy seasons. Most of the houses have grass thatched roofs which poses a problem in rainwater harvesting and also risk of contamination. Residents believe rainwater is the cleanest source compared to others. For some, when they have more than water source available, they separate rainwater just for drinking and use other sources for other purposes. However, they do not treat rainwater before drinking. None of the households have any kind of a rainwater harvesting structure to store water long term, and most of them only collect when it is raining as in Fig. 3.

Figure 3: Rain water harvesting in the study area

Table 2: Description of existing water sources in the study area

Water source name	Water source category	Water source type	Description	Size
Mnkule	Pond 1	Surface water	Rainfed. Available 6-8 months annually	Surface area ~6 m^2
Ng'ukule	Pond 2	Surface water	Rainfed. Available 8-10 months annually	Surface area ~20 m^2
Wimbwi Bondeni	Pond 3	Surface water	Rainfed. Available 6-8 months	Surface area ~2 m^2
Ngapa	SW 1	Shallow well	Underground spring. Available throughout the year.	Diameter ~1 m
Mwai	SW 2	Shallow well	Underground spring. Available throughout the year.	Diameter ~3 m
Rainwater Harvesting	-	Rainwater	During rainy seasons (Nov-Dec & March-May)	

3.3 Data Collection

This study was approved by the local administrative authority of Lindi District. Data collection process was a combination of household surveys, key informant interviews, and field observations. A household survey was performed using 26 households who were administered with base line questionnaires to assess the community's water sources satisfaction on its accessibility, quality and quantity. Due to the reliable water shortages that is presently experienced in the study area, the inhabitants have been forced to shift to other neighboring locations in search for better and improved water supplies. Milola ward has an estimated population 400 people and 88 households. Questions from the household and key informants' surveys are provided in Appendices 1-4. The questionnaire sought to know from the target population where they collect or sources of drinking water they fetch from, what reasons inform them to choose a specified water source, duration they use to fetch water, household water purification and storage techniques, discerned quality and the frequency of waterborne illnesses. The participants were given information consent prior to participating in the study. Key informants interviewed were selected from the community's water committee and health care workers at the local dispensary.

3.4.1 Site Visits

Site visits were conducted to all five water sources in the study area. All site visits were accompanied by the village government leadership. The water sources and the surroundings were observed, pictures were taken and GPS coordinate points were recorded for every site visited.

3.4.2 Water Sampling and Testing

Simultaneous water collection and interviews were carried out during the visits to water sources and household. Three (3) replicates of water samples were sampled from 5 water sources (POC) i.e., two shallow wells (SW 1 and 2) and 3 seasonal surface waters (Pond 1, 2 and 3) totaling to 15 samples. In-situ testing was done for some of the parameters (pH, EC, & turbidity). Furthermore, 33 water samples were sampled from 26 selected house for bacterial analysis. The 33 samples were obtained because some homes had stored water that was collected from one than one source. Membrane filtration method was utilized for bacteria testing which was done within 6 hours of water collection as the recommended holding time by APHA 2017. The remaining sampled water was stored in previously sterilized polyethylene plastic bottles and then added concentrated nitric acid to reduce the pH (<2) and stored in cooler boxes and taken for further analysis to the NM-AIST laboratory. A potable GPS was deployed to capture and record the coordinates of sampled locations during the water sampling sessions.

3.4 Data Analysis

3.5.1 Water Quality Analysis

All parameters were examined based on the accepted techniques for examination of water analysis (APHA, 2017) summarized in Table 3. Eight water quality parameters were tested from water samples collected from original water sources. Samples of water that were only collected from the households were tested for bacteria. Hanna Instrument Multiparameter (HI-9829) was deployed on site to measure various water quality parameters namely pH, turbidity, temperature, and electric conductivity (EC). The EDTA Titrimetric method was used for hardness analysis and nitrate (NO_3^-) was analyzed before preservation with nitric acid on the HACH DR 2800 spectrophotometer using cadmium reduction method. Iron was analyzed in the NM-AIST laboratory using DR 2800 by Method 8008. Calorimetry technique was followed for this purpose as per the provided procedures manual (APHA, 2017). As for the bacterial analysis, membrane filtration method was deployed with six hours of the water sample collection.

Table 3: Water quality analysis methods

Parameter	Methods of Analysis	Measurement units
pH	Multi-parameter kit	N/A
Electrical Conductivity (EC)	Multi-parameter kit	µS/cm
Turbidity	Multi-parameter kit	NTU
Total Hardness	Titration with EDTA	mg/L
Nitrate	DR2800 spectrophotometer	mg/L
Fluoride	Ion selective electrode	mg/L
Iron	DR2800 spectrophotometer	mg/L
Bacteria	Bacteria growth check (membrane filtration technique)	colony forming units (cfu)/100 mL

The WQI instrument was deployed to evaluate the quality of water samples that were collected from the existing water by comparing the physico-chemical and bacterial water parameters against the corresponding standards by WHO (Karunanidhi *et al.*, 2021). The WQI tool incorporates many quality parameters into a mathematical formula that scores a water source's quality and determines if it is suitable for drinking water (Ochuko *et al.*, 2014). The WQI technique makes the assumption that the weights for the various quality criteria were inversely proportional to the recognized norms for the corresponding parameters (Mishra & Patel, 2001).

The WQI follows three steps (Tyagi *et al.*, 2013):

(i) Choose which aspects of the water parameters to be assessed

(ii) Assess the quality functions of each parameter

(iii) Apply mathematical functions to combine the parameters.

Given the importance of the drinking water quality, each parameter has been given a weight (w_i) between 1 and 5 (Vasanthavigar *et al.*, 2010). The weights assigned to the greatest and the least significant characteristics are 5 and 1, correspondently. As per WHO, factors that pose greatest impact on human health such as microbiological parameters, should be given the most weight, as they are the most frequently found in drinking water at substantial quantities. To obtain the relative weight (Wi), the given in Equation 1 was used.

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad (1)$$

Where W_i-stands for relative weight; n- is the total number of parameters (for this study, n = 8 in this study) and w_i-u is the unit weight for each parameter.

The parameters relating to the water quality were scaled to standard units and dimensions. As shown in Equation 2, the rating scale (Q_i) was achieved by dividing each parameter's concentration by the corresponding WHO standard and multiplying the result by 100.

$$\boldsymbol{Q_i} = (\frac{C_i - I_i}{S_i - I_i}) \times \mathbf{100} \quad (2)$$

Where $\boldsymbol{Q_i}$ represents the rating scale, $\boldsymbol{C_i}$ indicates the concentration for i^{th} parameter in *mg/L* at the location of the sample, $\boldsymbol{S_i}$- indicates the WHO standard for i^{th} parameter in *mg/L* and I_i stands for the ideal value of i^{th} parameter in pure water (i.e., pH = 7, and 0 for all other parameters).

The water quality sub-index value (SI_i) is computed by multiplying each parameter's relative weight (W_i) by its rating scale (Q_i), as indicated in Equation 3.

$$\boldsymbol{SI_i} = \boldsymbol{W_i} \times \boldsymbol{Q_i} \quad (3)$$

Where: SI_i stands for the sub-index value for i^{th} parameter.

The application of additive aggregation produced the WQI as the summation of sub-indices of all selected parameters as given in Equation 4.

$$\boldsymbol{WQI} = \sum_{i=1}^{n} \boldsymbol{SI_i} \quad (4)$$

The calculated WQI values are classified into five categories (Table 4):

Table 4: Water Quality Index classification (Mophin-Kani & Murugesan, 2011)

Classification	Range	Description
Excellent	<50	Indicate that the water quality is safeguarded with no contamination and all the recommended guidelines are met.
Good	50–100	Water quality is protected, but slight impairment may be reported
Poor	100–200	Water quality is protected with only a minor degree of impairment; conditions rarely depart from recommended guidelines.
Very Poor	200–300	Water quality is often protected, however, once in a while is impaired where conditions at times deviate from the recommended guidelines.
Unsuitable	>300	Water quality is almost always poor; parameters usually deviate from recommended standards.

3.5.2 Water Poverty Analysis

The WPI instrument was deployed to analyze water poverty of the most reliable water source based on the components that were decided upon in the present study. The WPI combines information from several factors that both directly or indirectly add to water stress including water access, water quantity and quality, water variability, environmental factors water uses (domestic), and the capacity of water management into a single value (Sullivan *et al.,* 2003). To shun bias and subjectivity and as well as increasing comparability and transparency of the resultant indices, the chosen components are assigned similar weights (Pandey *et al.,* 2012) since each component influences the general community wellbeing (Komnenic *et al.,* 2009). Table 5 captures the measured components in the current study.

Table 5: Components of Water Poverty Index

WPI component	Indicator used (factor)	Description
Resources	Seasonal availability (*S*)	Number of months annually that existing water sources are available
Access	Distance (*D*)	Average distance measured in kilometres walking to and from a water source
Use	Preferences (*P*)	Overall preference of the households on water source accessed
Environment	Quality (*Q*)	Water quality for each source established from the Water Quality Index results

Jemmali and Sullivan (2014)

Equation 5 illustrates the formula that was employed to calculate the WPI.

$$\boldsymbol{WPI = \frac{\sum_{i=1}^{n} W_i X_i}{\sum_{i=1}^{n} W_i}} \quad (5)$$

Where: $\boldsymbol{X_i}$ represents the WPI component for a particular site, $\boldsymbol{W_i}$ stands for the component weight, and $\boldsymbol{n}$ is the total number of WPI components (n=4 for the current study).

The next subsections explore the four WPI components' description, computation, and normalization. The minimum–maximum approach was employed in the normalization stage to convert the indicators into a standard contrastable scale ranging from 0 to 100 (Jemmali & Matoussi, 2013).

(i) Seasonal availability (S)

This parameter implies the physical availability of water sources throughout the year. Since Ngwenya village lacks improved water sources, this infers that the villagers rely on water that's obtained from contaminated sources such as shallow wells and surface waters. The Village's available surface water sources are rain-fed and during the dry season, they mostly dry up entirely.

Equation 6 was applied to compute each of the source's seasonal availability based on the research questionnaires. This was determined using equation 6.

$$\mathbf{S} = \frac{\textbf{Months in a year water is available in a source}}{\mathbf{12}} \times \mathbf{100} \qquad (6)$$

(ii) Distance (D)

The distance (kilometers) that was covered by the households to and from a water source was retrieved from the documented household survey's data and GPS coordinates. The distance that was covered by a member of a household to a source (d_i) is and the maximum distance traveled from any household to a source (d_{max}) can be calculated from Equation 7.

$$\mathbf{D} = \frac{d_{max} - d_i}{d_{max}} \times \mathbf{100} \qquad (7)$$

(iii) Preference (P)

This component evaluated the households' preferences for a certain water source based on a variety of factors. This was computed based on the number of households that picked a specific water source, as stated in equation 8.

$$\mathbf{P} = \frac{N_i - N_{min}}{N_{max} - N_{min}} \times \mathbf{100} \qquad (8)$$

Where N_i is the number of households that selected a source, N_{min} represents the minimum number of households that selected a certain water source whereas N_{max} refers to the maximum number of households that chose a certain water source.

(iv) Water quality (Q)

This component is used to determine the quality of the water source based on the WQI scores that had previously been collected. The maximum–minimum equation was applied independently for individual water source as shown in equation 9.

$$\mathbf{Q} = \frac{q_i - q_{min}}{q_{max} - q_{min}} \times \mathbf{100} \qquad (9)$$

Where q_i represents the WQI of the water source, q_{min} and q_{max} represent the respective lowest and highest WQIs for all analyzed water sources.

The WPI was then calculated by combining each of the water source's parameters by applying Equation 10 (Lawrence, 2002).

$$\boldsymbol{WPI} = \frac{W_S S + W_D D + W_P P + W_Q Q}{W_S + W_D + W_P + W_Q} \quad (10)$$

Where *Wi* is the weight of each of the four components, *S* represents seasonal availability, *Q* is water quality, D is the distance covered during water collection, and *P* indicate the preference of a specific water source. The outcome will reveal the weighted average of each component and WPI value ratings are between 0 (poorest levels) and 100 (best levels).

3.5.3 Water Storage Practices

At the POUs, water samples were collected from various storage vessels. Different households had different storage containers though majority used 20L plastic containers (Fig. 4). Some of the stored water had been collected 2-3 days prior but majority had been collected the same day of sampling. Since it was the rainy season, around 70% of the households had harvested rain water for drinking. 40% of the households had preserved water for more than one POC. Water quality tested from the households were compared with those tested from two main common water sources reported (rainwater harvesting and Wimbwi Bondeni) at the household during collection in order to determine the extent of contamination.

Figure 4: Storage containers observed during household survey

During water sample collection, 33 samples were collected from the 26 households surveyed. identified based on the survey responses: 19 from rain water harvesting, 2 from Ngapa, 5 from Wimbwi Bondeni, 3 from Mnkule, 1 from Ng'ukule and 3 from Mwai. Samples collected from the households were tested for bacteria concentrations using membrane filtration technique.

Interview questions covered household's water sources, usage and storage practices. Households reported varying lengths of water storage according to number of people in the house and distance from water source. Most households reported covering their storage containers.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Water Quality Parameters and Index Scores

Water samples collected from the 5 water sources and tested for quality showed that majority of the parameters in the water fell within the set guidelines given by both WHO (2011) and TBS (2003). Bacteria in all sources showed higher concentrations than the 0 cfu/100 mL recommended. Table 6 shows the results for the sources for each water quality parameter analyzed against the recommended limits set by WHO and TBS.

Table 6: The average concentration of parameters at each water source against WHO (2011) and TBS (2003) drinking water quality standards

Parameters	Pond 1	SW 1	Pond 2	Pond 3	SW 2	WHO	TBS
pH	7.03 ± 0.08	6.80 ± 0.20	6.54 ± 0.24	6.72 ± 0.32	6.63 ± 0.14	6.5-8.5	5.5-9.5
E.C. (μS/cm)	199.27 ± 1.99	118.03 ± 2.01	159.73 ± 6.40	579.67 ± 18.49	149.83 ± 1.87	1400	2500
Turbidity (NTU)	5.67 ± 0.53	6.33 ± 0.53	6.33 ± 1.07	5.67 ± 0.53	6.00 ± 0.92	5	5-25
Nitrate-N (mg/L)	4.80 ± 0.28	3.84 ± 0.32	1.98 ± 0.12	2.17 ± 0.14	1.70 ± 0.05	10	45
Total Hardness (mg/L)	38.73 ± 0.23	14.17 ± 0.68	0.03 ± 0.05	54.20 ± 0.42	BDL	500	600
Fluoride (mg/L)	0.29 ± 0.04	0.21 ± 0.02	0.28 ± 0.02	0.29 ± 0.02	0.52 ± 0.03	1.5	1.5
Iron (mg/L)	0.58 ± 0.03	0.64 ± 0.05	0.81 ± 0.02	0.55 ± 0.02	0.22 ± 0.02	0.3	0.3
Bacteria (cfu/100mL)	983.33 ± 5.33	700.00 ± 18.48	408.33 ± 7.06	70.00 ± 4.62	663.33± 14.11	0	0

The pH is one of the most significant water quality parameters that impacts the suitability of its for different purposes including drinking. Additionally, water pH influences the formation of metal ion complexes as well as the amounts of carbonate and bicarbonates in water. All the water samples that were collected in the present student reported pH levels that was within the WHO and TBS recommended standards. The WHO guideline for pH in potable water is between 6.5 and 8.0 (WHO, 2011). The water that contains low pH (<6.5) may ascribe to the presents of some levels of toxic metals (Saria, 2011) that can quality related issues like metallic or sour taste. Water that exhibits pH > 8.5 ascribes basic nature of the water that results in scale build-up in the piping systems or give the water a slippery feeling along with an alkalic taste. Additionally, it’s is also typical for plates, utensils, and washing basins to develop scales or deposits (Nordstrom *et al.*, 2000).

The recorded water electrical conductivity ranged between 118.03 to 579.67 µS/cm as highlighted in Table 5, indicating that the water samples were within the approved WHO and TBS guidelines of <1400 and 2500 µS/cm, correspondingly. Elevated conductivity is a sign of salty state which often cause irritation of human eyes.

The measured turbidity level in the sampled water was between 5 - 7 NTU which indicated that it did not meet the WHO standards for drinking water <5 NTU but on contrast, it abided the TBS guidelines that recommends water to have 5-25 NTU. Elevated turbidity tends to affect the efficiency of water disinfection process since the existence of colloids in water introduces adsorptive characteristics and consequently, it may protect organisms from being effectively disinfected (WHO, 2006). While there exist no health-based recommendations for turbidity, its recommended that it should preferably fall below 0.1 NTU for successful disinfection to take place and to fulfill the accepted <5 NTU level.

The wasters samples were test for the contamination levels of fluoride and the results revealed that the water contained fluoride levels ranging from 0.21 to 0.52 which was below the recommended standard of 1.5 mg/L by WHO and TBS. This inferred that the sampled water was safe for human consumption. Water with fluoride levels exceeding 1.5 mg/L is typified to cause dental and skeletal fluorosis (Ayele *et al.*, 2019).

Iron was also analyzed to determine its concentration in the sampled water and it was found to be ranging from 0.22 and 0.81 mg/L. The measured levels were above the 0.3 mg/L limit recommended by the WHO and TBS. Iron impairs the quality of water by altering its colour and taste and if its pollution is elevated, it may lead to hypertension, increased respiration rates congestion of blood vessels, and increased respiration rates in humans (Islam *et al.,* 2018).

Total hardness of all the water samples was determined to be between 0 to 54.3 mg/L and hence fell under the WHO accept limit of 500 mg/L. Hardness is a health concern in water, and a nuisance. Myriad of studies have suggested a link the between ischemic heart disease (IHD) or stroke-related mortality and water hardness or minerals that contribute to water hardness (Miyake & Iki, 2003; Saria & Thomas, 2012). Hard water can cause poor performance of soaps and detergents (USGS, 2016). However, soft water with a typified water hardness below 100 mg^{-} $CaCO_3$/l has a drawback of causing mineral build-up on plumbing fixtures (WHO, 2006).

Nitrates (NO_3^-) were also analyzed in the collected water samples and its concentration was found to be low (2.2 – 4.5 mg/L), and within the permitted limit by the WHO and TBS (WHO, 2011; TBS, 2003) of 10 and 45 mg/L, respectively. Nitrate is byproduct of the biological breakdown of organic nitrogen via oxidation of ammonia in water. Nitrates are considered as one of the health threatening pollutants if present in elevated levels in drinking water. It is known to cause fatal blood disorder known as methemoglobinemia or "blue-baby" syndrome in infants aged below six months (Sproat *et al.*, 1989). The low concentrations of the recorded NO_3^- in the study area can be concluded by linking with community's low use fertilizers for farming which may be the reason for these low levels of nitrate.

Bacteria was analyzed in the collected water samples and bacterial counts was found to range from 70 to 980 CFU/100 mL which revealed that the water sources were contaminated. Moreover, the sampled water from the households exhibited high level of bacterial contamination range of 10 to 2000 CFU/100 mL. According to WHO and TBS, drinking water is recommended to contain of 0 CFU/100 mL zero bacteria (WHO, 2011; TBS, 2003). Bacterial contamination water renders it unsuitable for drinking since its known to cause health concerns and epidemics of water-borne illnesses such as cholera, dysentery, and typhoid (Saria & Thomas, 2012). The water contamination in the study site was caused mostly likely by defacation, bathing, and laundry among others nearby the water sources. Additionally, poor water handling and storage are the main potential causes of its contamination that was observed, particularly in homes with small children (Ngasala *et al.,* 2019).

4.1.1 Water Quality Index

The WQI was utilized to evaluate the water sources' overall quality. Parameters that were used to compute the WQI have been described in the previous section of this study whereas the WHO standards (WHO, 2001) that are applied for drinking water quality are shown in Table 7.

Table 7: Physicochemical parameters used for WQI determination

Parameters	WHO Standards (S_i)	Assigned Weight (w_i)	Relative Weight (W_i)	WQI Pond 1	WQI SW 1	WQI Pond 2	WQI Pond 3	WQI SW 2
pH	8.5	4	0.13	7.01	6.87	6.31	6.6	6.5
EC (µS/cm)	1400	3	0.10	199.5	117.2	153.7	579	152
Turbidity (NTU)	5	4	0.13	6	7	7	5	6
Nitrate-N (mg/L)	50	5	0.16	4.5	3.52	1.98	2.2	1.76
Total Hardness (mg/L)	500	3	0.10	38.7	13.9	0	54.3	0
Fluoride (mg/L)	1.5	5	0.16	0.25	0.23	0.30	0.27	0.55
Iron (mg/L)	0.3	2	0.06	0.58	0.59	0.84	0.55	0.24
Bacteria (cfu/100 mL)	0	5	0.16	980	700	400	70	650
		∑31	∑1	**34.4**	**186.8**	**28**	**605.2**	**37.3**

The WQI for Ponds 1 and 2 were 34.4 and 28, respectively, while Pond 3 was 605.2, meaning Ponds 1 and 2 were of better quality than Pond 3. The WQI for SW 1and 2 were relatively low at 186.8 and 37.3. By referring to the WQI categorization shown in Table 4, the above results reveal that the water quality of the water sources in the study area was poor, however, the shallow wells showed significantly better quality as compared to the sampled surface water. Although other water quality parameters abided to the WHO and TBS guidelines (WHO, 2011 & TBS, 2003), the bacterial counts in the sampled water exceeded the recommended standards hence posed a very critical water quality concern human health. Figure 5 illustrates that the WQI scores ranged between 28 and 605.2 ascribing that some of the water sources' quality was better and can be used to provide an improved water source for the residents.

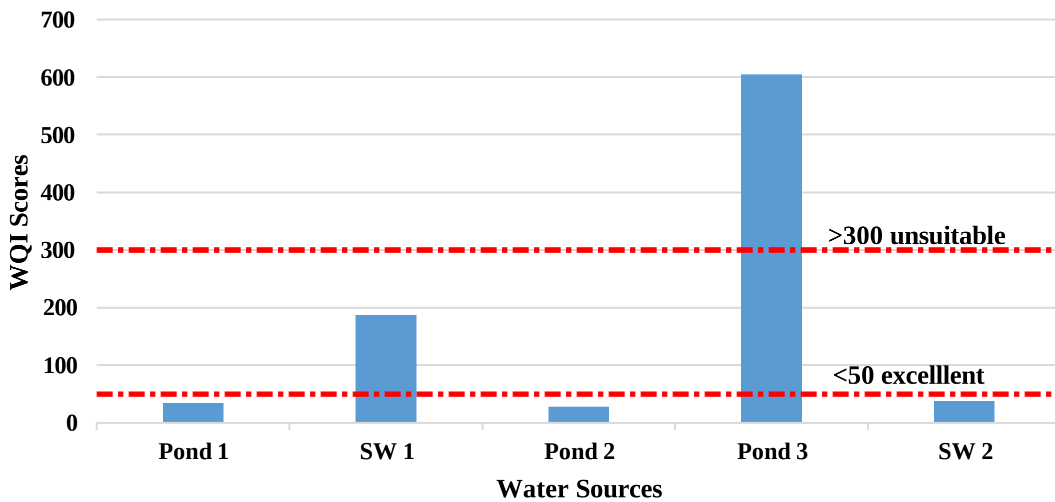

Figure 5: The WQI scores for all five water sources against WQI classification

4.2 Water Poverty

4.2.1 Water Usage and Management

The study area does not have any improved water source and rely solely on rain during the rainy season and seasonal streams and hand dug wells the rest of the year. Water usage is on availability and distance to a water source. While the residents appreciate quality water, this preference is mostly overlooked with regards to source availability and closeness to them. No formal resource management is in place as residents access water from whatever source is convenient to them. The village headman is part of the local water committee that includes the wider Milola ward

4.2.2 Village Community Responses

According to the household survey conducted (Appendix 1), the average household size in Milola is 5 people. All of families interviewed reported that they use multiple water sources depending on the availability. The water sources are seasonal and available during the rainy season. Only Mwai and Ngapa are available through most of the year, and since they are very far from most households they are only accessed when there is no other option. When water from the water supply is not available, they use rain water, underground tanks, or streams. For Ngwenya village, their only sources are streams and dug wells. Although these water sources are free, but they are seasonal and distant therefore they are not very reliable. Results from our water testing shows that they are all contaminated. While families agreed that the water quality is very vital for their health, however, when asked about treating drinking water at home, more than 90% drink water without any treatment. The residents believe that the water is good enough without drinking. Many rural dwellers don't purify drinking water owing to presumed 'cleanliness' of the water (Tamene, 2021) From the household survey responses, 58% of families reported that their children had stomach ache or diarrhoea in the last two months.

4.2.3 Water Poverty Index

WPI is an all-inclusive instrument that thoroughly examines water stress at both personal and societal levels (Sullivan *et al.*, 2003), and it may also be employed to portray and evaluate water poverty as a measure of availability. The index measures the actual availability of water vis-a-vis population's capability to access it by converting data from numerous components viz., water quality and variability, accessibility and amount, water usage, environmental aspects, and water management into a unit (Sullivan *et al.*, 2003). Table 8 presents the WPI results obtained from survey responses in the present study.

Table 8: Summary of survey responses (N=26) and field investigation before sub-index calculation

Water source name	Seasonal Availability (S)	Distance (D)	Preference (P)	Water Quality (Q)
	Water availability in months per year	Average two-way walking distance (km)	Number of households with water source preference	Water Quality Index calculated from 8 parameters
Shallow wells				
SW 1	12	7.5	11	186.8
SW 2	9	12.3	4	37.3
Surface water				
Pond 1	7	8.5	5	34.4
Pond 2	4	4.9	4	605.2
Pond 3	5	9.2	2	28

In some cases, a population can be 'water-poor' even though water is available when limited in terms of its affordability, and on the flipside, people can be 'water-poor' when they can't access it to sufficiently fulfil their basic necessities owing to unavailability (Lawrence *et al.*, 2002). This may be owed to long coverage to reach the water or its restricted availability for variety of reasons. The World Water Assessment Program under the United Nations Educational, Scientific and Cultural Organization's (UNESCO) reported in 2015 that women in water-scarce areas track a mean of 6 kilometers per day in search of water (Connor, 2015). In the present study, the distance walked to fetch water was the average return trip distance in km. Table 8 indicated that the furthest water source from the village was SW 2 whereas SW 1 which availed water throughout the year was quite far (7.5 km). As for the ponds, Pond 2 was the closest water to the residents, however, it was the most seasonal source which provide water to the villages for only 4 months annually. The distances of ponds 1 and 3 from the households averaged to 8.5 and 9.2 kilometers, respectively.

Household's choice of water sources may be influence by seasonal rainfall fluctuations and water accessibility. The community residents were forced to excavate around SW 1, which was shallow and availed little water, in order to enable water to seep from above so that they could reach it.

Preference refers to the proportions of households who choose a certain water source over the others. The most and least favoured water sources in the present research were SW 1 and Pond 3, correspondingly. Accessibility, quality, quantity and distance are the main influencing reasons the selection of water source. The WQI values from the 8 parameters examined in this study were utilized to determine the water quality. Pond 2 was the least suited for human consumption, having the greatest WQI of 605.2, whereas Pond 3 had the lowest WQI of 28 as illustrated in Fig 6. Additionally, SW 1 demonstrated the highest WPI (66.6) inferring that it's the most credible water source as contrasted to Pond 2 which had the least score for WPI at 16.6 and hence making it the least reliable source in terms of access.

Table 9: Sub-WPI values for surface water and shallow wells

Water sources	Sub-WPI Values				
	Seasonal availability (S)	Distance (D)	Preference (P)	Water quality (Q)	Total WPI score
Pond 1	14.58	7.8	8.3	0.28	30.96
Pond 2	10.42	6.22	0	0	16.64
Pond 3	8.33	15	5.6	25	53.93
Average WPI for surface water					**33.84**
SW 1	25	9.67	25	6.88	66.55
SW 2	18.75	0	5.6	0.4	24.75
Average WPI for shallow wells					**45.65**

The shallow wells and the surface waters yielded mean WPI scores of 45.7 and 33.8 and 45.7, correspondingly. The WPI ratings ranged from 0 for the poorest levels to 100 for the best levels. The shallow wells were, therefore, the most secure water sources in the study area compared to surface waters. The WPI was determined by combining the sub-indices that make up the WPI. Table 9 shows the results from the computation of the sub-index values for each water source and the WPI.

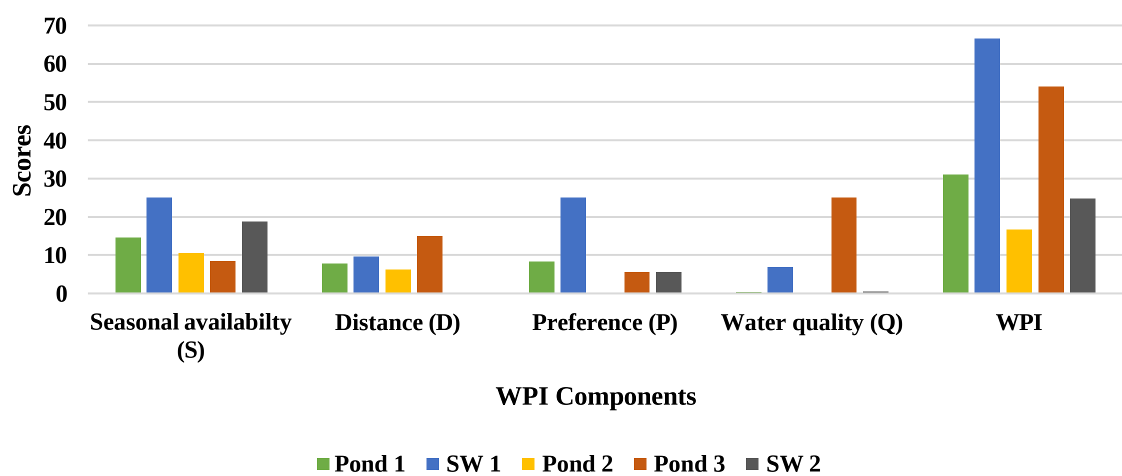

Figure 6: WPI component scores for the five available water sources in the study area

This finding of this study showed how unreliable surface water was since they were all highly seasonal, of poor quality and far away from the study area. Ngasala *et al.* (2018) did a study in northern Tanzania that used WPI and the components used were able to establish the shallow wells in the area as the least reliable compared to the deep wells.

The total sub-indices for each WPI component obtained from the grouped water sources are summarized in Fig. 7.

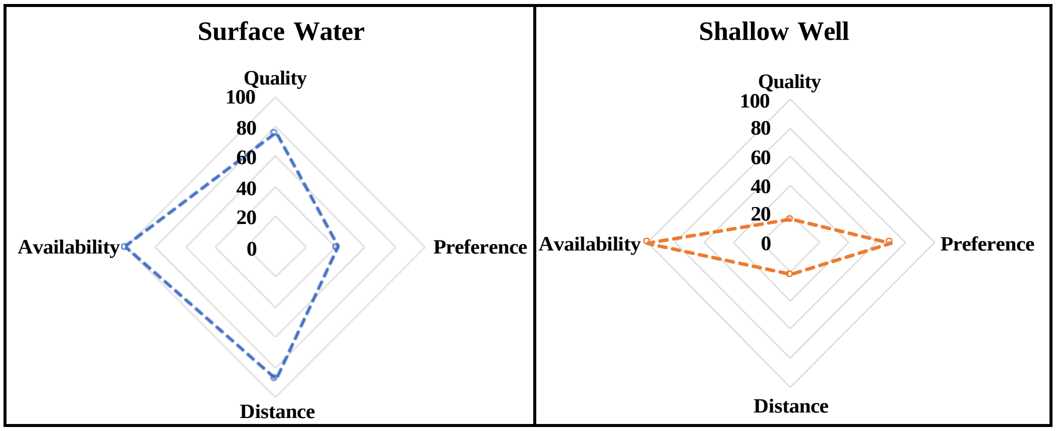

Figure 7: Water poverty mapping of four WPI components for two water sources

4.3 Pearson's Correlation Coefficients

The relationship between two variables, and their degree of association is determined by Pearson's correlation coefficient (r) analysis (Seo *et al.*, 2019). A positive correlation coefficient infers that an increase in the first variable would correspond to an increase in the second variable, indicating a direct relationship between the two variables. A negative correlation implies an inverse relationship in which, if one variable increases, the other variable decreases. In the current study, the seasonal availability of water sources was highly and positively correlated (r=0.83), showing that respondents preferred water sources that were accessible for a long duration of time throughout the year as reflected in Table 10.

Table 10: Pearson correlation matrix for water poverty components

	Seasonal availability (S)	Distance (D)	Preference (P)	Water quality (Q)
Seasonal availability (S)	1			
Distance (D)	-0.35	1		
Preference (P)	**0.83**	0.22	1	
Water quality (Q)	-0.38	**0.82**	0.07	1

Bold indicates positive correlation (r>0.5)

Strong and positive correlation (r=82) between the distance covered to the water sources and water quality demonstrated that residents had to cover long distances to collect good quality water. Least correlation (r = 0.07), between preference and water quality was found between the two-variable indicating that individuals may utilize any water source irrespective of its quality.

4.4 Household Water Storage Contamination

From the sampling at POUs, results showed that all household stored water for drinking were contaminated with bacteria. Both WHO (2011) and TBS (2003) guidelines recommend absence of bacteria in potable water. The water in POCs is likely contaminated from animals drinking directly at the sources and the open defecation near the sources as observed during visits to the study area. Figure 8 shows comparison between the water source quality and that of the stored water from two of the main common water sources reported (rainwater and Wimbwi Bondeni). Although the water from the source was not ideal as it also had high bacteria levels, there was a significant difference between that POC and that at the POU. The red line indicates the recommended guideline by TBS and WHO. Ngasala *et al.* (2019) study in Dar es Salaam established that the storage practices of the community contributed to increase in spread of waterborne diseases.

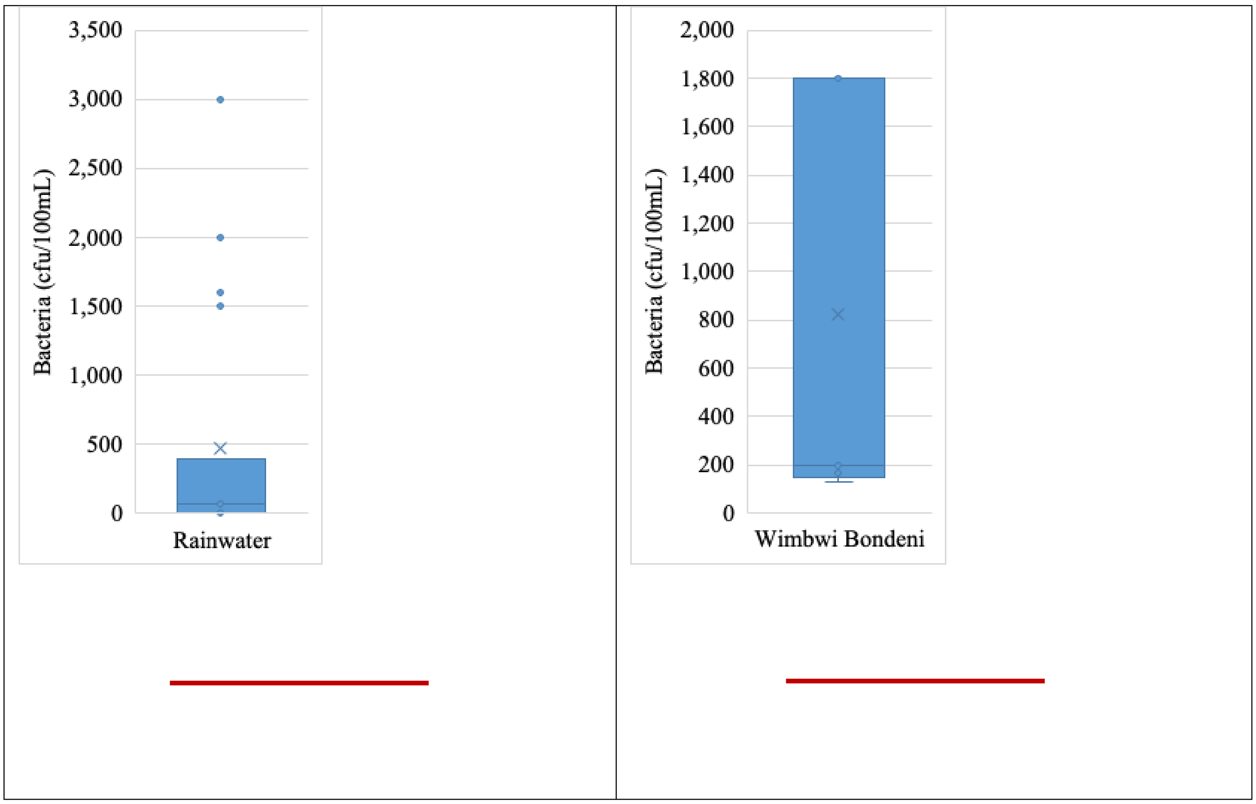

Figure 8: Bacteria levels in POCs (rainwater & Wimbwi Bondeni) compared to POU

Every 3 in 5 homes out of the 26 households surveyed did not have pit latrines but instead, the residents used the nearby bushes to relieve themselves and consequently may end up in the water sources as run-off. Bacteria levels increased in POU compared to POC, indicating that there is increased contamination in the households. The storage practices of the residents were poor with most not cleaning the storage containers. The households with small children were observed to have more contamination, which can be explained by the children being allowed to access the water without adult supervision. Ninety-two percent (92%) of the household reported not treating water before drinking, attributing this to the water being clean as it is from the source. Apart from the lack of good water practices knowledge by the community, poverty and lack of time was what prevented the households from safe water storage practices.

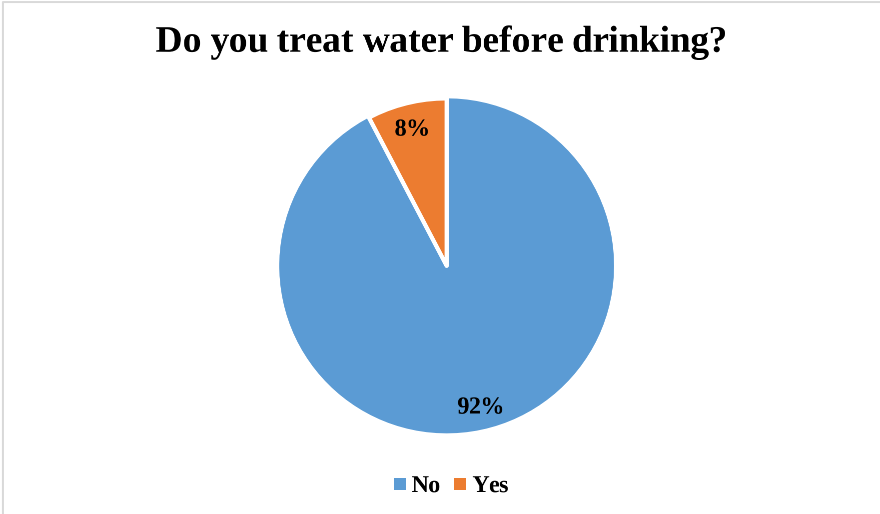

Figure 9: Water treatment practices within the study community

Studies globally have shown similar findings. Results for a study in Bagamoyo, Tanzania reported that children ingested 0.1 mg of fecal matter from preserved water and about 0.9 mg from hand-to-mouth contact (Mattioli *et al.*, 2015). A study in Sierra Leone in the Kailahun District analyzed 20 and 100 water samples from household storages and from unimproved sources, respectively. The results from the sources indicated 93% of the water exhibited bacterial contamination by fecal (Clasen & Bastable, 2003). Ngasala *et al.* (2019) established that there is significant increase in contamination from the water sampling point to the point of consumption (stored water) in households. The study analyzed 123 water samples to ascertain how water collection methods and storage practices affected its quality through contamination.

4.4.1 Health Impact

The data collection was concluded at the Milola dispensary where information on cases of water-borne illnesses that had been recorded were gathered. The collected data was from the years between 2018 – 2020 that included children aged under 5 years, above 5 years, and adults above 60 years. The common waterborne diseases we found are diarrhoea, UTI and schistosomiasis. The study revealed that diarrhea is the second leading disease that is blamed for deaths of children under the age of 5 years in Milola. It has been reported that about 525 000 children who are under 5 years die of diarrhea outbreak each year (WHO, 2017). However, through drinking water purification, sufficient sanitation, and good hygiene practices, diarrhea can be treated and avoided and mitigated with ease. According to Milola clinic data (Appendix 2), the main victims were children under five especially during the wet season (Fig. 10). When families were asked about their health status and the common diseases they experience (Appendix 1), the responses were similar to clinic data about waterborne diseases.

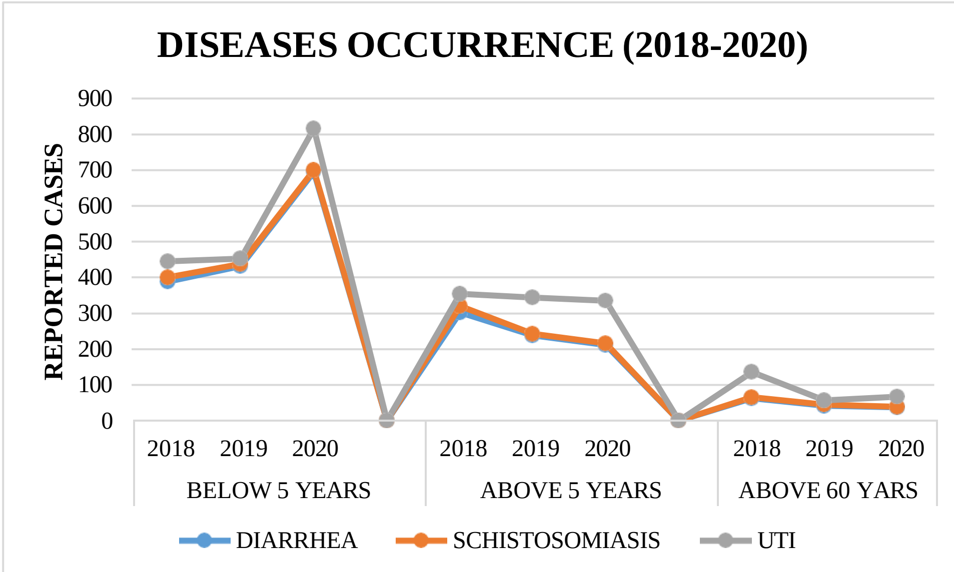

Figure 10: Waterborne disease occurrence within the study community from 2018-2020

Schistosomiasis (or bilharzia) is caused by parasitic worms. The parasites for instance, snails, live in particular type of freshwater. An individual's skin can be infected when it comes into conduct with contaminated water (CDC, 2018b). Data collected show that schistosomiasis is a serious problem in Milola especially for children. One of the reasons for high number of reported cases for this disease is water scarcity. Studies done indicate that schistosomiasis is prevalent in rural areas where safe and clean drinking water is poorly managed (Senghor *et al.*, 2014; Gryseels *et al.*, 2006).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study's objective was to identify community of Ngwenya's most reliable water source pertaining its quality and accessibility. Baseline information on the water quality of the existing and accessible water sources were evaluated using the WQI too. From the WQI results, it was revealed that the water quality of the water sources in the study area water sources was of poor quality although it was found out that other physiochemical parameters complied with WHO and TBS standards. It was found that shallow wells exhibited an overall better quality as contrasted with the sampled surface waters. All the investigated water sources reported very high levels of bacteria due to poor hygiene practices. It was also observed that most households in the community did not have access to latrines which can contribute to the high bacteria presence in the water sources from surface run-off. The analyzed households' water samples recorded from the households recorded increased bacterial contamination levels which can be attributed to poor storage practices. Due to its seasonality and poor water quality as compared to nearby shallow wells, surface water sources were discovered to be less dependable. Water access is a challenge with locals particularly women having to track for far distances to fetch water that's unfortunately of poor quality. It's worth noting that the application of WPI has helped rural communities throughout the world that are 'water poor' find long-term solutions. It can also be used in this study area to influence and inform decisions to help alleviate the water situation. This research work offers an illustration of how responsible leaders may evaluate the safety and quality in their communities. The employed water quality tools are simple, affordable, and accessible to use.

The study's successful application of the combined WQI and WPI tools may provide stakeholders with useful information they may need to make critical choices about water monitoring and management in other rural regions with poor water access. The study findings find it necessary for the community to be educated on the appropriate and safe water management practices including water preservation and affordable purification and treatment methods. This study recommends further studies to be done to demonstrate the connection between inadequate drinking water storage and the widespread water-borne diseases, particularly in households in unresearched communities in order to prevent mortalities of unsuspecting and vulnerable young children.

5.2 Recommendations

This study makes the following recommendations:

(i) Based on the study findings find, it is necessary for the community to be educated specifically on the improved water management practices including water storage and treatment techniques.

(ii) Further in-depth studies is encouraged to demonstrate the connection between poor storage of drinking water and widespread of waterborne outbreaks, particular in households with young children.

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APPENDICES

Appendix 1: Household Surveys

1. Interviewee

   Male/Female (head of household/other adult present)

   Age:18-35; 35-60; Above 60

2. How many people live in your home?

   Between 1-3; 3-5; 5-7; More than 7

   Any children below 5 years

3. Where do you obtain your water?
4. How often do you get water from the sources mentioned above?
5. How long does it take you to reach the water sources mentioned above?
6. What water source do you prefer the most? Only select one. In answer to above, why?
7. What is the seasonal availability of water from the source you use most often?
8. Do you ever pay for water?
9. If YES, how much is a 20L bucket?
10. Would you be willing to pay for water if it is brought closer to you?
11. What water do you usually use for drinking?
12. Do you treat the water before drinking?
13. If NO, explain why you don't treat the water?
14. If YES, how do you treat the water?
15. Do you think the quality of water is important for your family's health?
16. Have you or anyone in your family (children) had stomachache in the last 2 months?
17. Have you been diagnosed with any of the water borne diseases listed?
18. Malaria, UTI, Diarrhea, Schistosomiasis, Any other waterborne disease
19. What other water challenges do you face?
20. Can we test the quality of your drinking water?

Appendix 2: Focus Group (Women Baraza)

1. Occupation
2. Average length of stay in the area
3. How often do you go for water?
4. Where do you get your water from?
5. What challenges do you face in getting the water from the sources?
6. Why do you go there and not another place?
7. What options would you like to have?
8. Are you OK with paying a small fee to get clean water?
9. Any other comment?

Appendix 3: Key Informants

Health officials

1. Do you get cases of these water related diseases?

   Malaria; UTI; Diarrhea; Schistosomiasis; Other

2. When do you see such cases most (which period)?
3. What in your opinion causes these cases to occur?
4. What would be the ideal solution for such?

Appendix 4: Key Informants

Water Committee Members

1. Current Position
2. Where Do Ngwenya Residents Get Their Water Supply From?
3. In Your Opinion, What Are The Most Important Factors That Make Residents Opt For The Water Source?
4. In Your Opinion, What Are The Available/Recommended Solutions?
5. From Previous Response, What Will Be The Challenges Especially Cost-Wise & Maintenance?
6. In Your Opinion, Who Should Bear The Costs Of Water Provision & Maintenance?
7. Any Other Comment?

RESEARCH OUTPUTS

(i) Publications

Nancy, I. M., Tula, M. N., & Revocatus, L. M. (2022). A quantity-quality tradeoff: Water quality and poverty assessment of drinking water sources in Southern Tanzania. *Journal of Biodiversity and Environmental Sciences*, 21, 4, 48-56.

(ii) Poster Presentations