ASSESSMENT OF GROUNDWATER POLLUTION IN SINGIDA URBAN AND MANYONI DISTRICTS

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

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ABSTRACT

The quality of groundwater in Tanzania has over the years remained poorly understood, hence posing risks to human health and the environment. In this study, the quality of groundwater sources used for drinking purpose in Singida Urban and Manyoni districts were investigated with a view to explore how the end users could be safeguarded from water borne diseases. Water samples from 30 boreholes and 28 shallow wells were randomly collected during dry and wet seasons. Water quality assessments were conducted following recommended guidelines by Tanzania Bureau of Standards (TBS) and international standards (WHO) for drinking water. Twelve physicochemical parameters were assessed using standard methods for water and wastewater from American Public and Health Association (APHA). Microbial water quality (TC, FC, and *E.coli*) were examined using membrane filtration technique while toxic metals were determined using Inductively Coupled Plasma Optical Emission Spectrometer. Nitrate source identifications were done using Elemental Analyzer/ isotope ratio mass spectrometry techniques. Results showed that shallow wells recorded significant higher turbidity ($p<0.0001$) compared to boreholes. The water samples collected during wet season had significantly higher microbial contamination compared to those collected during dry season. Additionally, the wells were buckets are used to draw water had significantly higher TC, FC and *E.coli* ($n=11$, $p\leq 0.01$), also wells without covers ($n=15$, $p\leq 0.01$) had significantly higher feacal coliform bacteria than those which motor or hand pump were used in both seasons. Concentration of toxic metals was significantly higher ($p<0.05$) during the dry season than in the wet season and 40- 66% of all samples had an elevated level of Mn, Cr, Pb, and Al above the recommended standards by World Health Organization (WHO) and Tanzania Bureau of Standards (TBS), hence unsafe for drinking. Nitrate sources identification revealed that, most nitrate contamination were originated from sewage effluents and/or organic wastes such as manure. The study recommends that water from shallow wells should be treated either by boiling, chlorination, or use of low cost technologies such as sand filter before consumption. In addition, the proper sitting of the wells based on the recommended standards by TBS has to be enforced in order to prevent further contamination from human activities.

DECLARATION

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

Rita Alex 6/8/2021

Name and Signature of Candidate **Date**

The above declaration is confirmed

Prof. Karoli N. Njau 9/08/2021

Name and Signature of Supervisor **Date**

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CERTIFICATION

The undersigned certifies that, he has read and hereby recommend dissertation entitled; "*Assessment of Groundwater Pollution in Singida Urban and Manyoni Districts*" to be accepted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in Environmental Sciences and Engineering of the Nelson Mandela African Institution of Science and Technology.

Prof. Karoli N. Njau 9/08/2021

Name and Signature of Supervisor **Date**

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DEDICATION

This work is dedicated to the late, Mom Paulina and Dad Eliezer, **HEROES** of my life for seeing the **BEST** out of me **ALWAYS**

……Your love and encouragement have left an indelible expression in my life ……

AND

To the Lanerissa's for motivating me.

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LIST OF ABBREVIATIONS AND SYMBOLS

APHA	American Public Health Association
ATSDR	Agency for Toxic Substances and Disease Registry
BH	Borehole
BDL	Below Detection Limit
CAWST	Centre for Affordable Water and Sanitation Technology,
CFU	Coliform Forming Unity
DO	Dissolved Oxygen
EC	Electrical Conductivity
FC	Feacal coliforms
FT	Fertilizer
GPS	Geographical positioning system
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometer
NM-AIST	Nelson Mandela African Institution of Science and Technology
NBS	National Bureau of Statistics
NTU	Nephorometric Turbidity Unit
MN	Manure
MoW	Ministry of Water
SDG	Sustainable Development Goals
SEAMIC	Southern and Eastern African Mineral Centre
SE	Sewage Effluent
SUWASA	Singida Urban Water and Sanitation Authority
SW	Shallow well

TA	Total Alkalinity
TH	Total Hardness
TBS	Tanzania Bureau of Standards
TDS	Total Dissolved Salts
TC	Total Coliform
TURB.	Turbidity
Temp.	Temperature
URT	United Republic of Tanzania
UNEP	United Nations Environmental Protection
UNESCO	United Nations Educational, Scientific and Cultural Organization
US	United States
US EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UNICEF	United Nations Children's Fund
V-SMOW	Vienna-Standard Mean Oceanic Water
WHO	World Health Organization
δ	Delta
‰	Permill

CHAPTER ONE

General Introduction

1.1 Background of the problem

Water is essential not only for living, but also for development. Based on that premise, it has been designated as the sixth goal in the Sustainable Development Goals (SDG) with the primary aim of ensuring its availability and sustainable management for all people (UN-Water, 2015). Despite the efforts made to meet the sixth SDG, access to clean and safe drinking water remains a serious global concern. More than 2 billion people, half of them live in Sub-Saharan Africa, still lack access to safe and clean water (WHO/UNICEF, 2015). In Tanzania, access to clean and safe water has only increased by 12% from 2004/2005 to 2012, with only 33.1 % of the population having access to piped, treated water (Mahali and Kessy, 2017). A large section of the population relies on unprotected drinking sources such as springs, rivers, streams, canals, dam, lakes, and groundwater sources, which are susceptible to contamination.

Groundwater has been used as an alternative source of water in urban and rural areas in many parts of the world. Groundwater requires little or no treatment compared to surface water, inexpensive to exploit and it is relatively more reliable during drought (Baumann et al., 2005; Kashaigili, 2010a; MoW, 2016, 2019). Additionally, groundwater tends to be conveniently available to the needed areas and can be developed at a relatively lower cost thus many people have opted for domestic purposes (Kulabako *et al.,* 2007). Theoretically, groundwater is regarded as a safe, cost-effective, clean alternative water source that requires minimal or no prior treatment (Lapworth *et al.,* 2012; Prakash & Somashekar, 2006a). In reality, however, the quality of groundwater is increasingly deteriorating because of the natural and anthropogenic contamination from various sources such as leaking septic tanks, domestic sewage (Bain *et al.,* 2015; Joseph & David, 2011; Mcquillan, 2004), agricultural runoff (Lockhart *et al.,* 2013), mining and industrial waste (Annapoorna & Janardhana, 2015; Degnan *et al.,* 2015; Li *et al.,* 2014).

Anthropogenic contamination occurs from specific sources (point source such as leaking underground storage tanks, spills, landfills or industrial facilities (Fig.1), or from non-point sources such as runoff from agricultural fertilizer or pesticide applications which may enter the groundwater source through hydrological cycle (Avanish, 2012; Council *et al.*, 2015;

Elisante & Muzuka, 2016a; Kulabako *et al.,* 2007; Mukherjee & Nelliyat, 2007; Pastén-zapata *et al.,* 2014). Natural contamination depends on quality of the recharge water and nature of the geologic material through which the groundwater migrates (Robles-Camacho & Armienta, 2000). For example, leaching of heavy metals from ore deposit in concentrations above the recommended value makes water unsuitable for consumption (Akers *et al.,* 2015; Frisbie *et al.,* 2002; Geen *et al.,* 2011; Wu *et al.,* 2015). Toxic metals such as Arsenic, Cadmium, and Chromium may find their way into groundwater sources from both natural and anthropogenic sources such as pesticide, agricultural fertilizers, or industrial waste. The potential for a contaminant to affect groundwater quality is dependent upon the ability to migrate through the overlying soils as soil act as a protective filter or barrier that immobilize the downward migration of pollutants released on the land surface to the underlying groundwater resources (Frisbie *et al.,* 2002). Therefore, analysis of metals/ toxic chemicals levels in groundwater sources that are used for drinking purposes is crucial for understanding their impact on the human beings.

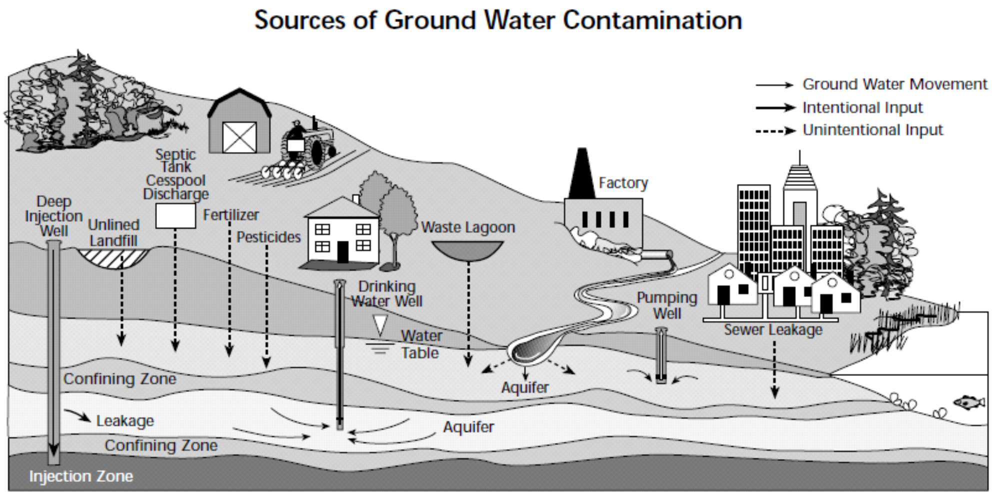


Figure 1: Sources of Groundwater contamination (www.epa.gov/safewater)

Other contamination routes may result from poor physical design of the wells (Elisante & Muzuka, 2016b). These include poor positioning and construction of the groundwater sources, lack of proper well head elevation, lack of lids/covers, use of poor water withdrawing mechanism (Kihupi, *et al.,* 2016; Pritchard *et al.,* 2008; Ugwuzor & Ifeanyi, 2015), and presence of poor hygiene surrounding the groundwater source (Graham & Polizzotto, 2013; Kiptum & Nbambuki, 2012). These together increase the chance of contamination, by favoring easy entrance of contaminants from external environment and further expose the population to a possibility of water-related health problem.

WHO/UNICEF, data from 2015 estimated that at least 2 billion people use drinking water sources contaminated with feces globally. Consumption of contaminated water has caused millions of death throughout the World (Hu, 2002; Knobeloch *et al.*, 2000; Macle & Merkle, 2000; Momba & Kaleni, 2002). Globally, 842 000 people die each year from diarrhoea as a result of unsafe drinking water and hygiene (Kessy & Mahali, 2017). Tanzania mainland and Zanzibar reported about 33 421 cholera cases and 542 deaths since 2015 to 2018. Furthermore, 18 500 children under the age of 5 die annually from diarrhoea with an estimated 90 % of these death attributed to poor water, sanitation, and hygiene conditions (URT, 2014a). Coliform bacteria mainly from the digestive tracks of warm-blooded animals, including humans, excreted in the feces are the most common microbiological contaminants of groundwater sources. Their detection in drinking water indicates the presence of pathogenic organisms that are the sources of waterborne diseases. Control of the microbial quality from drinking water should be given the higher priority due to the consequences of waterborne diseases, which can be prevented through proper understanding of the factors facilitating their growth and their possible route sources of contamination.

In Tanzania, more than 25 % of the domestic water is supplied by groundwater sources, especially in the semi-arid regions such as Singida, Dodoma, Simiyu, and Shinyanga (Kashaigili, 2012). However, there is no adequate groundwater quality monitoring and protection mechanism set up, hence most groundwater sources in the country remain poorly understood. For instance, the demand for water in Singida Urban District stood at 294 000 m^3/per month in the year 2014, while the quantity produced from major boreholes were 256 322 m^3/per month. The deficiency, (about 38 000 m^3 per month) is mostly supplied by other public and private owned groundwater sources (SUWASA, 2014). Most of the private owned groundwater sources, supply water of unknown quality, a situation that threatens human health (Elisante & Muzuka, 2016b). Likewise, a pilot study done by Internal Drainage Basin in boreholes showed higher level of uranium and sulphate of up to 73 mg/L and 85.7 mg/L respectively in existing groundwater sources in Singida region. The same report also indicated abnormally levels of nitrate up to 322 mg/L which is above the recommended level of 50 mg/L. The health effects of such higher levels are well documented including methemoglobinemia (blue baby syndrome) in infant (Fan & Steinberg, 1996; Gatseva 2008; Knobeloch *et al.,* 2000; Mahler *et al.,* 2007; Manassaram *et al.,* 2006; Squiliancem *et al.,* 2002). However, in Singida there is no documentation on the sources of such higher nitrate levels in groundwater which are used for drinking purpose. Despite the existing threats on the groundwater sources in Singida Region, majority of the population use them without prior treatment (field observation), posing health risks due to waterborne diseases. Deducing from the afore-mentioned problems, there was a need for conducting a proper analysis of the quality of groundwater in terms of microbial quality, physical-chemical parameters, metals, and nutrients contamination so as to safeguard end users.

This study, therefore focused on assessing the biogeochemical composition of the selected boreholes and shallow wells of Singida Urban and Manyoni District in Singida region so as to lay a foundation for proper intervention and effective improvement of water quality.

1.2 Statement of the problem

A pilot study conducted by Internal Drainage Basin office in selected groundwater sources in Singida Urban and Manyoni Districts showed existence of high concentrations of nitrate, uranium, and sulphate which exceeds WHO standards and can seriously affect human health through consumption (Internal Drainage Basin- Report). In these Districts, people rely completely on groundwater sources for domestic purposes due to limited supply of safe and clean water. About 38 000 m^3 per month of the water consumed in the area is obtained from privately owned shallow wells and boreholes. Most of the wells are poorly constructed, characterized by poor hygiene environment, and are supplying water of unknown quality, a condition that could result in health risks. Furthermore, water borne diseases (such as diarrhoea) were among the leading diseases reported to have occurred in the years 2014, 2015, and 2016 during the rainy season (http://dhis.moh.go.tz). The outbreak of these diseases might be linked to the consumption of contaminated water. Human activities and natural processes may release a significant amount of pollutants to the groundwater and therefore changing the biogeochemical composition and its usefulness for drinking purposes. However, there was limited information on the sources of this pollution and the extent of contamination in the groundwater sources of the study area. This is highly contributed to the prevalence of inadequate number of researches on groundwater characteristics. Therefore, the present study extended a pilot study initiated by Internal Drainage Basin office since it assessed the water quality of the study area with an underlined motive of safeguarding public health. The study also assessed the levels and sources of selected heavy metals and nitrate in the groundwater of the study areas.

1.3 Rationale of the study

The knowledge for water quality in groundwater sources that supply water for domestic purposes is a key in lessening water borne diseases since natural processes and man-made activities have direct impact on water quality. Currently, there are limited water quality data in private owned boreholes and shallow wells that are supplying drinking water in Singida Urban and Manyoni Districts. Available data are based only on limited water quality parameters on few boreholes that are monitored by Singida Urban Water and Sanitation Authority (SUWASA) and Internal Drainage Basin Office.

1.4 Research objectives

1.4.1 General objective

The general objective of the study was to assess the natural and anthropogenic pollutants in selected groundwater sources in Singida and Manyoni Districts, Tanzania.

1.4.2 Specific objectives

The specific objectives of this study are:

(i) Evaluate the suitability of groundwater for drinking purposes based on the major physical-chemical parameters and identify their possible contamination sources.

(ii) Establish the levels of coliform concentrations in the groundwater sources that are used for domestic purposes and to identify their sources and factors that contribute to their existence.

(iii) Assess the levels of concentrations of uranium, chromium, arsenic, lead, manganese, and Aluminium in the groundwater sources of the study area and,

(iv) Delineate the concentrations levels of nitrate, nitrite and ammonium in the selected groundwater sources.

1.5 Research questions

The research questions investigated in this study are:

(i) What are the major biogeochemical composition and levels in the boreholes and shallow wells?

(ii) What are the impact of anthropogenic activities on the microbial concentrations in the groundwater sources that are used for domestic purposes?

(iii) What is the effect of seasonal changes on the concentration’s levels of uranium, chromium, arsenic, lead, manganese, and aluminium in the groundwater of the study area?

(iv) What are the levels and sources contributing to nitrate contamination in the selected groundwater sources?

1.6 Significance of the study

Maintaining groundwater quality requires a general understanding of the existing condition of the source, identification of the possible factors facilitating source contamination and identification of contamination sources. Therefore, results of this study provide the baseline information about the groundwater quality of Singida Urban and Manyoni Districts. Also, the results from this study provides useful information to stakeholders about the existing levels of contamination, factors and sources contributing to high contamination hence help in reducing and preventing spreading of water borne diseases especially during rainy season. In addition, results of this study may be useful in strategies and guidelines formulation regarding future drilling of boreholes and shallow wells in other semi-arid regions of Tanzania.

1.7 Delineation of the study

Assessment of the quality of groundwater for domestic purposes basically depends on its physical-chemical composition and biological qualities. In this study, several water quality parameters were studied. These include pH, Dissolved Oxygen (DO), Total Dissolved Solids (TDS), Electrical Conductivity (EC), Turbidity, coliform bacteria, and the levels of heavy metals. Together with that, the nitrate sources were identified.

CHAPTER TWO

Physico-chemical Characteristics of Selected Groundwater Sources and its Suitability for Drinking Purposes in Singida Districts

Abstract

Evaluation of physico-chemical parameters of 58 groundwater sources was done during dry and wet seasons to assess their suitability for drinking purposes. The parameters investigated include pH, TDS, EC, DO, and turbidity which were measured on site while total alkalinity, total hardness, cations (Ca^{2+}, Mg^{2+}), anions (Cl^{-}, SO_4^{2-}) were analyzed in laboratory using the standard methods recommended by APHA (2005). The majority of the samples showed wide variations in the concentrations of the parameters from different locations, the pH value ranged from slightly acidic to neutral with a mean value of 6.8. Most shallow wells recorded low DO and significant higher turbidity (*n= 58; p= 0.0001*) than boreholes due to been poorly constructed hence allow easy entrance of contaminants from the external environment. Generally, the high levels of TDS, EC, were in the sample taken during dry season due to concentration effect which was contributed by the lack of dilution from rainwater. According to drinking water standards, 27% and 38% of all samples had Mg^{2+} and Ca^{+} concentrations above WHO recommended standards. While 10% of all boreholes and 57% of all shallow wells had pH below WHO and TBS standards thus indicate unfit for human consumption. Results suggest regular check-up and monitoring of the sources to prevent further contamination. Proper sitting of wells must also be reinforced to mitigate the contamination. The study recommends the use of low cost technique such as sand filter or biosand filter to treat contaminated water especially in reducing turbidity, clays, silts and sand particles.

Key Words: Physical-chemical parameters, groundwater, drinking standards, contamination

2.1 Introduction

Groundwater is considered as an important water supply for domestic, agricultural, industrial sectors, and recreational activities worldwide (Lapworth *et al.,* 2017; MacDonald *et al.*, 2012). In Tanzania, groundwaters are mostly dependent in arid and semi-arid due to low rainfall (550 -600 mm annually) and limited surface water supply (Kashaigili, 2010b).The rapid population increase and advance in scientific and technical knowledge in water drilling in both urban and rural areas of Tanzania has also increased the use of groundwater sources (Baumann *et al.,* 2005; Futakamba, 2009). However, deterioration of groundwater quality in urban and rural areas is increasing due to increasing population (Chowdhury *et al.*, 2016; Nana-Gyawu, 2012; Nolan & Weber, 2015; Picado *et al.*, 2010), urbanization (Ahaneku & Adeoye, 2014; Graham & Polizzotto, 2013; Kiptum & Nbambuki, 2012), and industrialization (Kiptala *et al.*, 2013; Kulabako *et al.*, 2007; Li *et al.;* Shen *et al.*, 2011).

The quality of groundwater is basically characterized by the physical, chemical composition and biological qualities that measure their suitability and usefulness for consumption, irrigation and/or industrial purposes (CAWST, 2013). Generally, most of the physical-chemical parameters, reflect the inputs from atmosphere, soil, water-rock interaction and various anthropogenic sources, and the change in physical-chemical quality leads to change in their suitability for the intended use (Krishna *et al.*, 2012; Nirmala *et al.*, 2012; Redwan *et al.*, 2016). Therefore, it is essential to monitor the physicochemical aspects of water quality to determine if the water is polluted or not.

The physical characteristics of water involve parameters like, temperature, colour, taste, and odor, while the chemical properties of water involve parameters such as dissolved oxygen (DO), pH, turbidity, Total Dissolved Solids (TDS), Electrical Conductivity (EC), hardness and alkalinity both determine the characteristics and suitability of the groundwater for consumption (Aremu *et al.*, 2014; Khan *et al.*, 2012; Palamuleni & Akoth, 2015; Srivastava & Pandey, 2012; Vasanthavigar & Srinivasamoorthy, 2012). Monitoring these characteristics helps to determine if the water meets the government regulations and is safe for human consumption. However, high levels of these parameters above international (WHO) or local (TBS) standards in drinking water may result in health risks. For example, the use of water with fluoride concentrations of below 0.5 mg/L may result in tooth decay while the concentrations above 1.5 mg/L may cause dental fluorosis (Hellens, 2013). Therefore, assessing the physicochemical parameters is significant in determining the suitability of the water for human consumption.

Most groundwater sources in Tanzania are contaminated with various, organic and inorganic compounds due to increased exploitation of water resources, agricultural, industrial activities, and urban development hence alter their physicochemical quality and usefulness for drinking and irrigation purposes (And & Buchweishaija, 2014; Chacha *et al.*, 2018; Chaki, 2015; Hellar-kihampa, 2017; Kihupi *et al.*, 2016; Mwegoha & Kihampa, 2010). Though studies have been conducted by various scholars on the aspect of ground water, it is evident that more sources of drinking water in Tanzania need to be assessed especially focusing on their physico-chemical quality so as to determine their suitability before use.

In so far as Singida Region is concerned, water used for domestic purposes is often coming from groundwater sources mostly of unknown quality (SUWASA, 2014). Apart from that, the majority of the population in Singida use pit latrines, which are poorly positioned, hence increasing the chances of chemicals such as chloride or nitrate to contaminate the source (Frisbie *et al.*, 2002) Regardless of the groundwater dependency and threats that exist, still, the physico-chemical composition of most sources in Singida, remained unknown except the little documentation of high levels of uranium, sulphate, and nitrate (Kaishwa *et al.*, 2018; Nyanda, 2014). There was limited information revealing the chemical composition of drinking water of the study area. Inferring from these formulations, the aspect of groundwater based on its physico-chemical quality warranted a need to be assessed with a view to addressing adequately possible adverse effects to human life and how they could be mitigated.

Therefore, this study aimed to analyze the physico-chemical parameters of the selected groundwater sources of Manyoni and Singida Urban Districts and determine their suitability for drinking purposes, through comparing its quality with respect to standard values recommended by WHO and TBS guidelines for drinking water.

2.2 Materials and methods

2.2.1 Description of the study area

The study was conducted in Manyoni and Singida Urban Districts which are located in the Central zone of Tanzania (Fig. 2). The region covers a total area of 49 438 km^2. According to Tanzania National Census of 2012, the population of Singida Region was 370 637 with a population growth of 2.3 per year (National Bureau of Statistics, 2013). Singida Urban and Manyoni Districts had a population of 150 379 and 296 763 respectively. The main source of livelihood in this Region includes livestock keeping and crop farming. It is estimated that 10.1% households lack toilet facility (URT, 2014a). This amount is higher than the national average level of 7.8% (URT, 2014a). Lack of enough toilet facility favours open defecation which might increase a threat to groundwater sources through run-off and leaching especially during the wet season. The area experiences a unimodal type of rainfall from December to April (Davies, 2005). The Region lacks enough piped water supply and most individuals rely entirely on earth dams, boreholes, and shallow wells. However, shallow wells are commonly available because they are relatively cheaper to construct compared to boreholes.

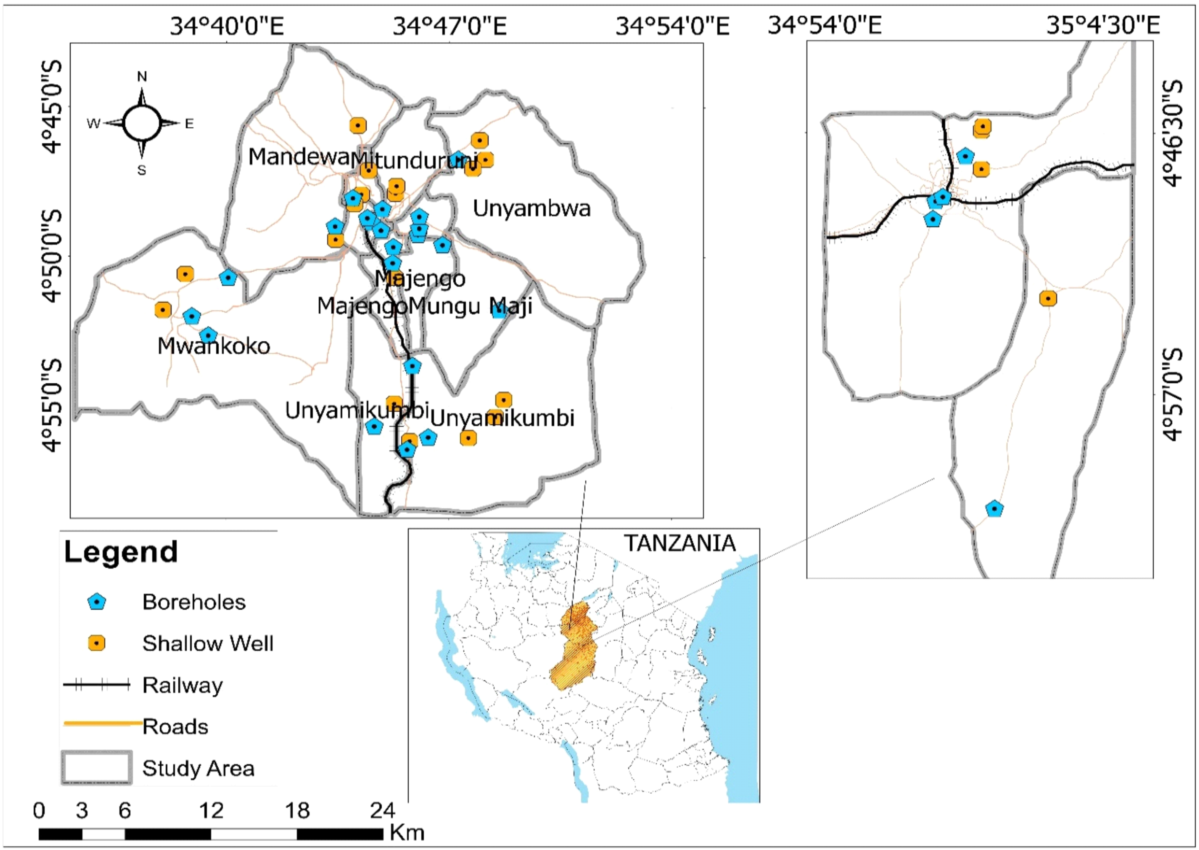


Figure 2: Map of United republic of Tanzania (below panel) showing sampling stations in Singida Urban (right panel) and Manyoni Districts (left panel)

2.2.2 Sample collection and preparation

Groundwater samples from random selected boreholes and shallow wells were collected during dry and wet seasons using sterile high-density polyethylene (HDPE) of 500 ml. Prior to collection, bottles were washed then rinsed with dilute nitric acid and finally with distilled water. Water samples were collected after pumping in source for sufficient time to ensure that the stagnant water in the source was replaced by fresh water from aquifer. During collection, bottles were rinsed thoroughly with source water to minimize any risk of external contamination before sampling. Samples for cation analyses were preserved by acidification with 2 ml of concentrated Sulphuric acid (Merck Ultra-pure) to a pH < 2 and samples for anion analysis, samples were acidified with pure nitric acid to pH < 2 then refrigerated at 4°C prior to analysis at NM-AIST laboratory respectively. All collected water samples were transported to Water Quality laboratory in the Internal Drainage Office-Singida for storage at 4°C and thereafter transported in ice-packed coolers up to NM-AIST where further chemical analysis was performed. Moreover, Sample location points were fixed using Etrex Geographical Positioning System (GPS) with an accuracy of ± 3 meters.

2.2.3 Onsite measurement and analysis

Parameters, such as temperature, pH, Total Dissolved Solids (TDS), Dissolved Oxygen (DO), Electrical Conductivity (EC) were measured using HANNA Multiparameter Model HI9829. The pH was calibrated at three points, i.e., pH 4, 7, and 10 using standard buffer solution. The pH probe was immersed in the selected buffer and stirred gently until the reading of the current measured became stable and close to the reading on the selected buffer solution. The value was then confirmed. The same procedure was done for the second and third buffer solution. Turbidity (TURB) was measured using portable turbid meter Model 2100Q01 HACH. Sulphate (SO_4^{2-}) was determined calorimetrically using HACH 2800^{TM} spectrophotometers (Model DR/ 2400). Chloride, total alkalinity (TA), total hardness (TH), and calcium hardness were determined using the standard methods suggested by the American Public Health Association (APHA, 2005). Magnesium concentrations were calculated from total hardness and calcium hardness.

2.2.4 Statistical data analysis

Descriptive statistics and correlation were calculated using SIGMA plot 11.0 software. Suitability of groundwater for drinking was assessed by comparing physicochemical parameters with the World Health Organization (WHO) guidelines for drinking water (WHO, 2008) and (TBS, 2005b). The relationships between the physico-chemical were established using the Pearson correlation coefficient (r) at 5% level of significance. Pie chart and combo histogram were drawn using Microsoft Excel 2013.

2.3 Results

2.3.1 Physico-chemical characteristics

The descriptive statistics summary (minimum, maximum, median, mean and standard deviation values) of various physico-chemical parameters i.e., temperature, pH, DO, Electrical conductivity (EC), Total Dissolved Solid (TDS), Turbidity, total alkalinity (TA), total hardness (TH), calcium (Ca^{2+}), Magnesium (Mg^{2+}), Chloride (Cl^-) and Sulphate (SO_4^{2-}) analyzed during dry and wet seasons are shown in Table 1 and 2.

Table 1: The statistical summary of the physico-chemical parameters in the study area during dry season

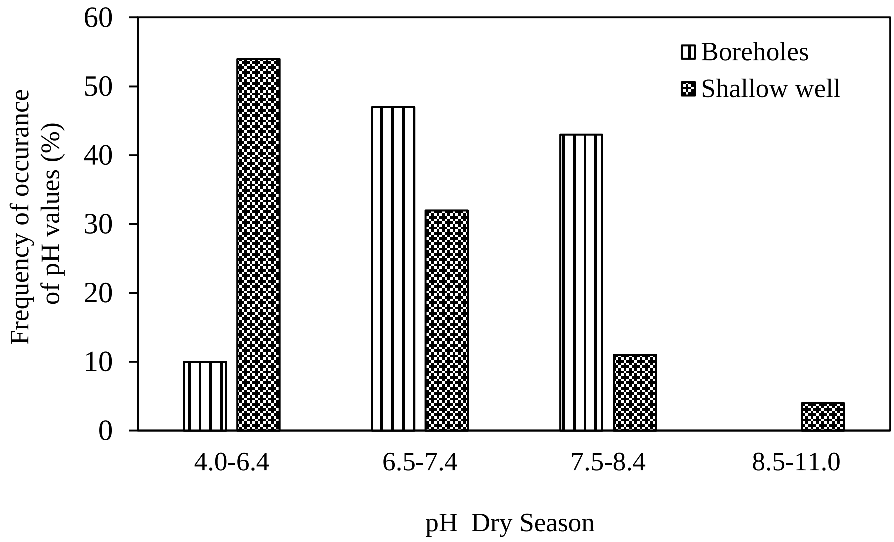
Parameters	WELLS				BOREHOLES			SD
	Min -Max	Median	Mean	SD	Min -Max	Median	Mean	
Temp (°C)	21.1- 28.1	25.2	24.7	1.9	24.7 -30.9	26	26.5	1.4
pH	4.4- 8.7	6.4	6.4	0.9	6.1 -8.12	7.2	7.2	0.6
DO (mg/L)	2.1- 5.8	3.3	3.3	0.9	2.0 -4.7	4	3.8	0.8
EC(µS/cm)	17.8-4547.0	972.5	1020.8	1002.1	428 -1768	959.5	1116	424.2
TDS (mg/L)	62.0- 2273.0	486	532.6	498.9	82.9- 883	883	533.9	219.7
Turb. (NTU)	0- 1865.0	48.7	258.6	457.3	0.0 -194	194	18.2	43.7
TA (mg/L)	8.0- 460.0	50	82.6	90.7	32 .0-196	82	95.6	38.4
TH (mg/L)	12.0 -786.0	110	183.7	219.7	64.0 -496	187	194.3	94.7
Ca^2+ (mg/L)	2.0 -718.0	37	91.3	143.6	34.0 -340	94	112.1	64
Mg^{2+} (mg/L)	4.0- 558.0	31	92.4	139.9	4 .0-184	72.9	82.7	61.7
Cl^- (mg/L)	9.9 -343.8	104.9	114.3	88.8	40.8 -675.7	135.9	175.8	115.9
SO_4^{2-} (mg/L)	0- 74.0	11.5	20.7	20.3	1.0 - 58.0	22.5	26.5	16.6

Table 2: The statistical summary of the physico-chemical parameters in study area during wet season

	WELLS				BOREHOLES			
Parameters	**Min.-Max**	**Median**	**Mean**	**SD**	**Min - Max**	**Median**	**Mean**	**SD**
Temper. (°C)	22.7- 28.5	25.1	25	1.3	22.7-28.8	26.2	26.3	1.2
pH	5.4 -8.7	6.8	6.8	0.7	5.8 -7.9	7.1	7	0.6
DO (mg/L)	3.2 -5.4	4.3	4.3	0.5	3.3-5.9	4.6	4.6	0.6
EC (µS/cm)	123.2 - 4790.0	960	1065.1	1049	70.2-2742.0	743	979.6	635.3
TDS (mg/L)	60.0 -2347.0	475	561	519.6	103.0 -1344.0	364	503.6	283.3
Turb. (NTU)	0.0- 280.0	4	28.8	60.2	0.0- 59.0	2	6.8	13
TA (mg/L)	4.0 -120.8	22.8	41.5	36.8	8.0 - 118.2	36.4	40.7	26.1
TH (mg/L)	13.8 -690.0	98.9	164.8	180.7	27.6 - 423.2	124.2	144.5	100.3
Ca^{2+} (mg/L)	9.2- 644.0	55.2	127.5	164.4	9.2- 322.0	73.6	106.2	83
$Mg^{2+($mg/L)	4.6- 147.2	23	37.6	38.2	4.6 -138.0	27.6	41	34.7
Cl^-(mg/L)	3.9-893.7	161.2	173	172.9	6.2 -375.5	137.9	183.7	124.4
SO_4^{2-} (mg/L)	4.0 -540.0	33	67.6	106.4	3.0 -110.0	38	41.3	28.6

Min: minimum, *Max*: maximum, *SD*: standard deviation (pH has no unit), Temper: temperature, Turb: Turbidity.

The water temperature values ranged from 21.1°C to- 30.9 °C in dry and from 22.7°C to 28.8 °C in the wet seasons with an average of 25.15 ± 1.65 °C and 25.65 ± 1.25 °C during dry and wet seasons respectively (Tables 1 and 2).



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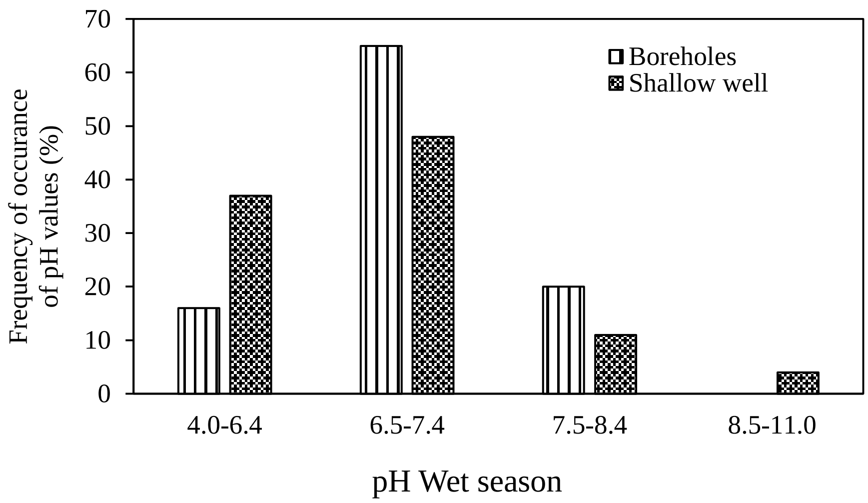

(b)

Figure 3: The range of pH distribution in boreholes and shallow wells during (a) dry season and (b) wet season

The pH values were in the ranges of 4.4 - 8.7 and 5.4-8.7 with an average of 6.8 ± 0.75 and 6.9 ± 0.65 in dry and wet seasons respectively. The extremely lowest pH of 4.4 was from SW 33 during dry season. This well lacked a cover, and the well mouth was covered with algae growth, and dried upon climax of the dry season. The overall highest pH during dry and wet season was 8.7 from SW 11 (Appendix 2 and 3). Classifications of pH were based on three categories, which are: slightly acidic (4.0-6.4), nearly neutral (6.5-7.4), slightly alkaline (7.5-8.4), and alkaline (8.5-11). Results indicated that 48 % and 32 % of shallow wells were slightly acidic and 65% and 47 % of boreholes were nearly neutral during wet and dry seasons respectively. During the wet and dry seasons, only 4% of shallow wells recorded an alkaline (8.5 -11) (Fig. 3). There was no water sample with pH value above the recommended standard by TBS and WHO (i.e. 9.2).However, during dry season 10% of boreholes and 54% of shallow wells, and 16% of boreholes and 37% of wells during wet season recorded pH values below recommended standard by TBS and WHO i.e. 6.5.

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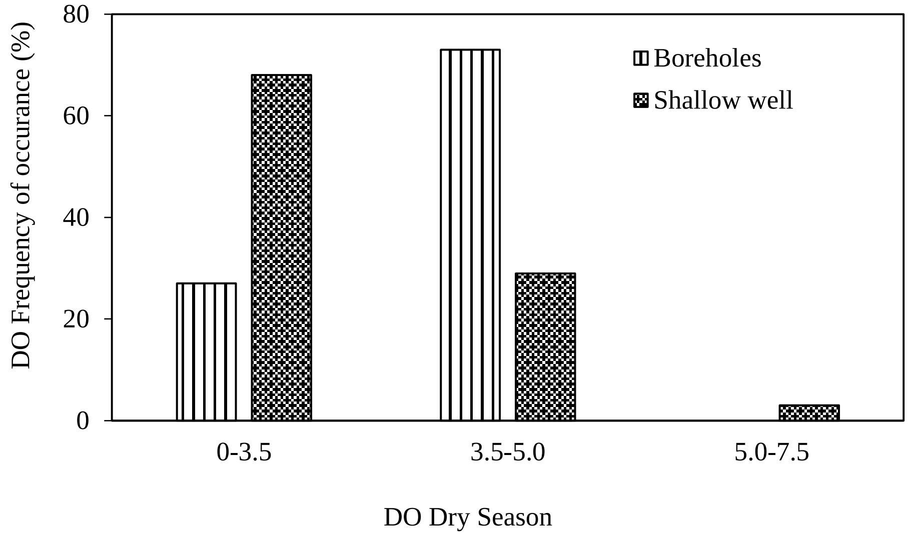
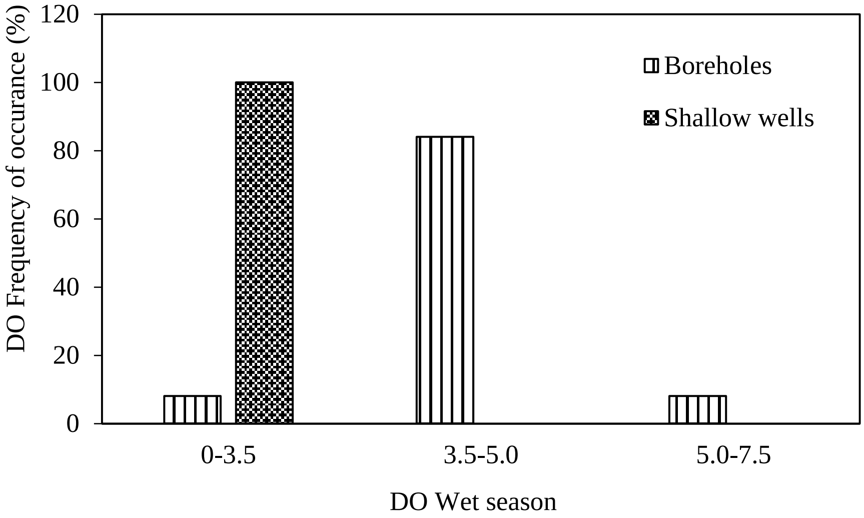


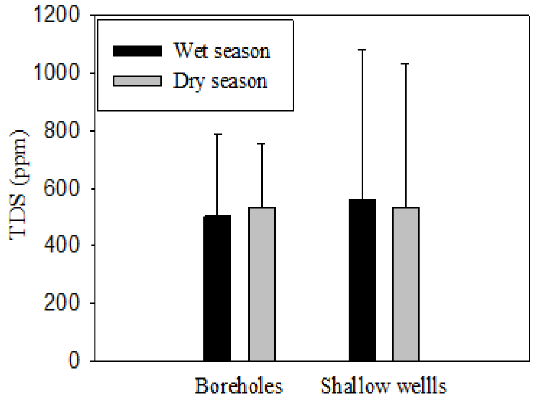
(a)



(b)

Figure 4: The range of DO distribution in boreholes and shallow wells during (a) dry season and (b) wet season

Results from Table 2.1 and 2.2 show that during the wet season, DO ranged from 3.2 -5.4 mg/L with the mean values of 4.3 ± 0.5 mg//L in wells and 4.6 ± 0.6 mg/L in boreholes respectively. During the dry season, the DO values ranged from 2.1 -5.8 mg/L. The mean values were 3.3 ± 0.9 mg/L in wells and 3.8 ± 0.8 in boreholes. The highest Dissolved Oxygen (DO) measured was 5.8 mg/L and 5.9 mg/L from two boreholes during wet season. In both seasons, majority of the boreholes had DO values in the category of 3.5-5.0. Generally, the mean DO value was significantly lower ($n=58$, $p \leq 0.0001$) in shallow wells than in boreholes during wet seasons (Fig. 4).



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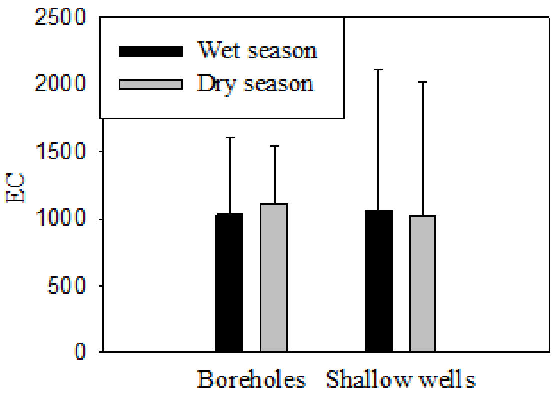
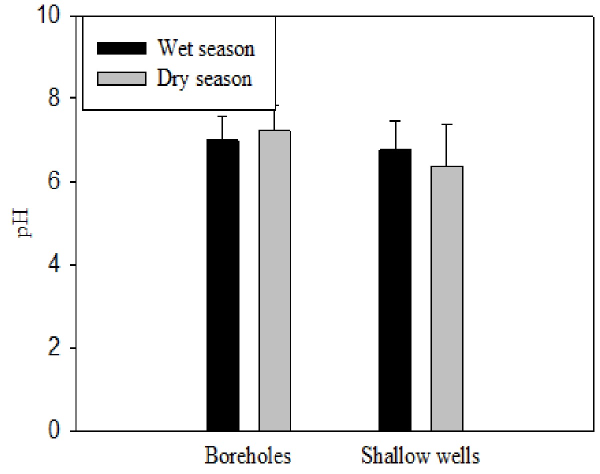


(a)

Figure 5: Mean values for (a) TDS (mg/L) and (b) EC (µS/cm) in boreholes and shallow wells during dry and wet seasons

The minimum and maximum values of Total Dissolve Solids (TDS), in dry season ranged from 62 to 2273 mg/L and in wet season from 60 to 2347 mg/L (Tables 1 and 2). There was no significant difference in TDS value of wells and boreholes in both seasons. However, according to David and De Wiest (1989) classification, majority of the water sample had TDS that is desirable (34% and 15%) and permissible (21% and 9%) for drinking during dry and wet seasons. The Electrical Conductivity (EC), values ranged from 17.8 to 4547 µS/cm and from 70 to 4790 µS/cm during dry and wet season respectively (Tables 1 and 2). There was no significant difference between the EC value in shallow wells and boreholes in both seasons (Fig. 5). However, based on the Wilcox (1995) classification, majority of samples had permissible EC value (i.e. 62% and 49% µS/cm of boreholes and shallow wells during dry and wet seasons). The samples with doubtful EC value were below 6% in both seasons and no sample recorded unsuitable EC value.



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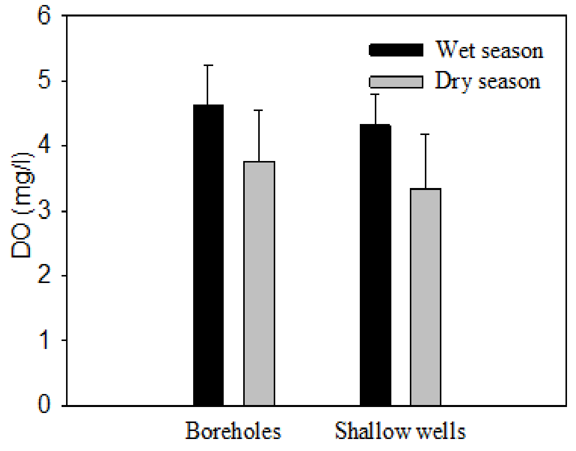

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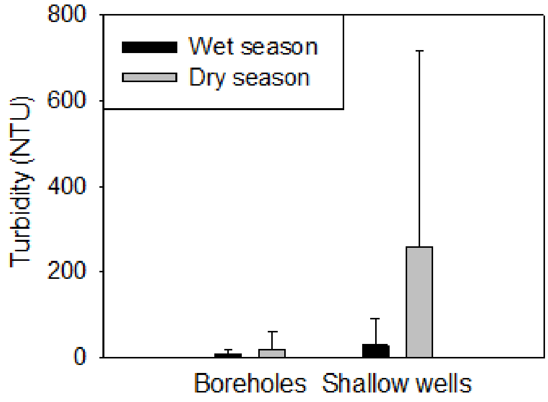


(c)

Figure 6: Mean values for various physicochemical parameters (a) pH (b) DO (mg/L) (c) Turbidity (NTU)

The mean turbidity values during the dry and wet seasons were 138.4 ± 138.4 NTU and 17.82 ± 36.6 NTU (Table 1 and 2). There was no significant difference in the means during dry and wet seasons (Fig. 6). However, during dry season, the turbidity of wells was higher and considered extremely significant ($p < 0.0001$) compared to boreholes Most boreholes 93% and 64% of all shallow wells recorded a value of 0-100 NTU. However, during dry season, 18% of all shallow wells recorded a value ranging from 500 - 1500 NTU. The percentages of wells samples exceeded TBS standard were 36 and 38 during dry and wet season respectively.

Table 3: Classification of groundwater sources in ranges based on hardness, TDS, chloride, and EC and number of samples (%) in each category

Classification Parameters	Ranges	Category	% of Samples	
			Dry Season	Wet Season
TDS (David and De Wiest, 1989)	< 500	Desirable for drinking	34	15
	500 - 1000	Permissible for drinking	21	9
	1000 -3000	Useful for agriculture	3	1
	> 3000	Unfit for drinking and irrigation	0	0
Chloride (Stuyfzand, 1989)	<0.141	Extremely fresh	0	0
	0.141 - 0.846	Very fresh	0	0
	0.846 - 4.23	Fresh	0	1
	4.231 - 8.462	Fresh Brackish	0	2
	8.462 - 28.206	Brackish	4	3
	28.206 - 282.064	Brackish salt	51	35
	282.064 - 564.127	Salt	2	10
	> 564.127	Hyperaline	1	1
EC (Wilcox, 1995)	< 250	Excellent	12	20
	250 -750	Good	22	26

	750 - 2250	Permissible	62	49
	2250 - 5000	Doubtful	3	6
	> 5000	Unsuitable	0	0
Hardness (Sawyer and Mc Cartly, 1967)	< 75	Soft	26	46
	75 -150	Slightly hard	22	27
	150 -300	Moderately hard	38	12
	> 300	Very hard	14	15

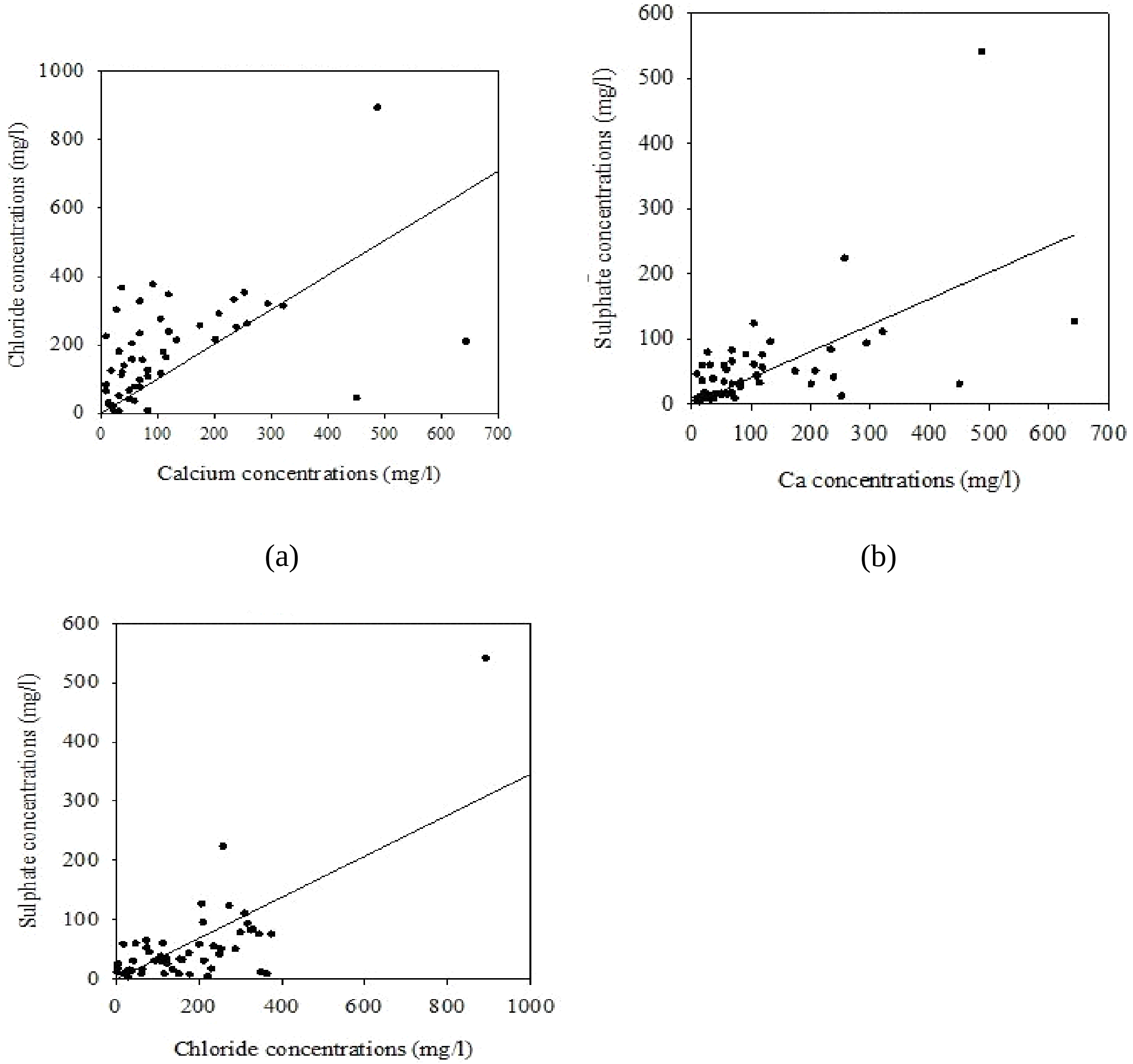
2.3.2 Correlation Analysis

The strong positive correlation between boreholes and shallow wells was observed between EC and TDS (*n=58), (p*≤ 0.001, *r= 0.9*), TH and Ca^{2+} in (*p≤ 0.001*, *r= 0.8*), TH and Mg^{2+} (*p≤ 0.001*, *r= 0.8*), TDS and Ca^{2+} (*p≤ 0.001*, *r= 0.8*), EC and Ca^{2+} (*p≤ 0.001*, *r= 0.8*), EC and TH (*p≤ 0.001*, *r= 0.8*), Cl^- and SO_4^{2-} (*p≤ 0.001*, *r= 0.8*) during dry season. Moderate positive correlation were between, TDS and SO_4^{2-} (*p≤ 0.05*, *r= 0.5*), EC and Mg^{2+} (*p≤ 0.05*, *r=0.5), EC* and SO_4^{2+} (*p≤ 0.0 5*, *r= 0.5)* during dry season. During wet season moderate correlation was between, Cl^- and Ca^{2+} (*p≤ 0.05*, *r= 0.5*), Ca2$^+$ and SO_4^{2-} (*p≤ 0.05*, *r= 0.6*) (Fig. 7, Table 4 and 5).

Table 4: Pearson correlation coefficient matrix of various physico-chemical parameters of groundwater samples collected during dry season

	Depth	Temp	pH	DO	EC	TDS	Turb.	TA	TH	Ca^{2+}	Mg^{2+}	$\bar{Cl}$	SO_4^{2-}
Depth	1.0												
Temp	0.3	1.0											
pH	**0.6**	0.1	1.0										
DO	0.3	-0.3	0.3	1.0									
EC	0.1	0.0	0.3	0.0	1.0								
TDS	0.1	0.0	0.4	-0.2	**0.9**	1.0							
Turb.	-0.4	0.0	**-0.5**	0.1	-0.4	-0.4	1.0						
TA	0.2	0.0	**0.6**	-0.1	0.1	0.3	-0.3	1.0					
TH	0.1	0.0	0.2	-0.2	**0.8**	**0.8**	-0.4	0.1	1.0				
Ca^{2+}	0.1	0.1	0.3	-0.1	**0.8**	**0.8**	-0.3	0.2	**0.8**	1.0			
Mg^{2+}	0.1	-0.1	0.1	-0.1	**0.5**	0.4	-0.2	0.0	**0.8**	0.2	1.0		
Cl^-	0.4	0.1	0.3	0.0	0.3	0.3	-0.3	0.3	0.3	0.2	0.3	1.0	
SO_4^{2-}	0.3	0.1	0.4	-0.1	0.5	0.5	-0.2	0.1	0.4	0.5	0.0	0.2	1.0

Depth (m), Temp (°C), pH = no unit, DO (mg/L), EC (µS/cm), TDS mg/L), Turb (NTU), TA (mg//l), TH (mg/L), Ca^{2+} (mg/L), Mg^{2+} (mg/L), Cl^-(mg/L), SO_4^{2-} (mg/L), bolded values showed significance difference (*p*≤0.05), n= 58



(a) (b)

(c)

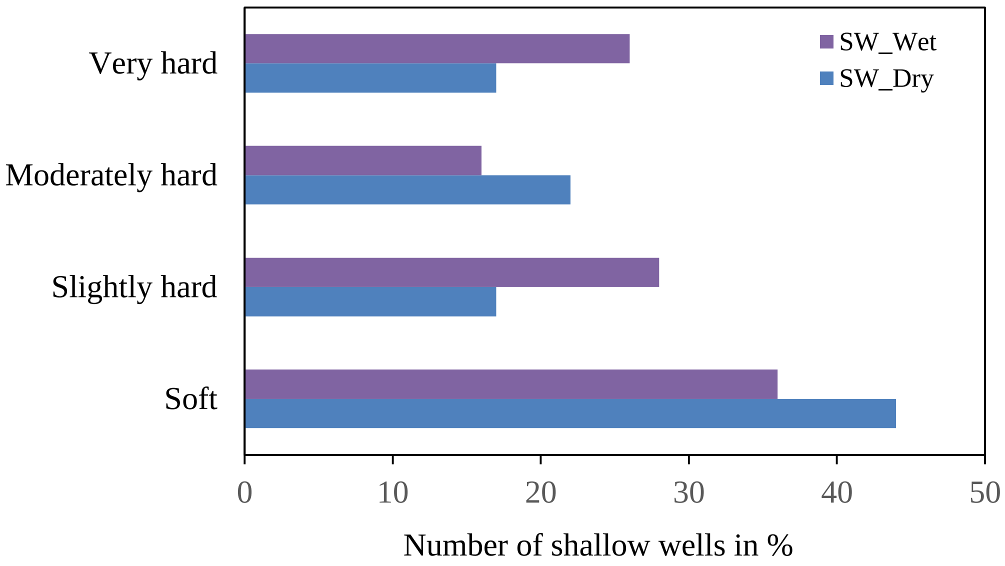
Figure 7: Scatter plot for (a) calcium and chloride (mg/L) (b) calcium and sulphate (mg/L) and (c) sulphate and chloride (mg/L) in groundwater samples collected during dry season

Table 5: Pearson correlation coefficient matrix of various physico-chemical parameters of groundwater samples collected during wet season

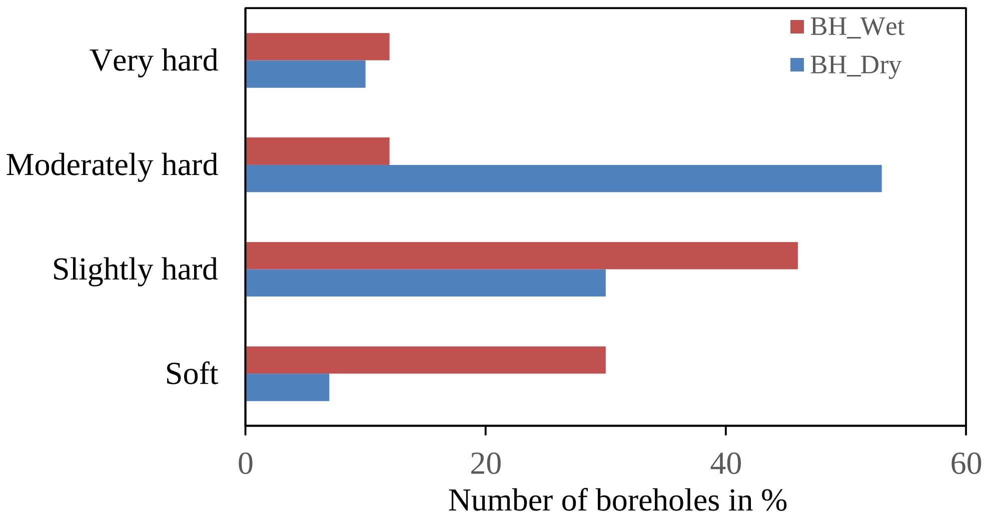
	Depth	**Temp**	**pH**	**DO**	**EC**	**TDS**	**Turb**	**TA**	**TH**	**Ca^{2+}**	**Mg^{2+}**	Cl^-	**$SO4^{2-}$**
Depth	1.0												
Temp	0.4	1.0											
pH	0.3	0.2	1.0										
DO	0.4	0.2	0.2	1.0									
EC	0.0	0.1	0.4	0.1	1.0								
TDS	0.0	0.1	0.4	0.1	**0.9**	0.1							
Turb.	-0.3	-0.3	-0.3	-0.3	-0.3	-0.4	1.0						
TA	0.1	0.0	0.**6**	0.0	**0.7**	0.7	-0.3	1.0					
TH	0.0	0.0	0.3	0.0	**0.7**	0.6	-0.3	0.6	1.0				
Ca^{2+}	0.0	-0.1	0.2	0.0	**0.7**	0.6	-0.3	0.6	1.0	1.0			
Mg^{2+}	0.1	0.2	0.3	0.0	0.2	0.3	-0.1	0.3	**0.5**	0.3	1.0		
Cl^-	0.1	0.1	0.2	0.1	**0.8**	**0.8**	-0.3	**0.5**	**0.5**	0.0	**0.5**	1.0	
SO_4^{2-}	-0.1	-0.1	0.3	0.1	**0.8**	**0.8**	-0.2	**0.5**	**0.6**	0.6	0.2	**0.8**	1.0

Depth (m), Temp (°C), pH = no unit, DO (mg/L), EC (μS/cm), TDS mg/L), Turb (NTU), TA (mg//l), TH (mg/L), Ca^{2+} (mg/L), Mg^{2+} (mg/L), Cl^-(mg/L), SO_4^{2-} (mg/L), bolded values showed significance difference ($p \leq 0.05$), n= 53

Total alkalinity ranged from 8 to 460 mg/L and from 4 mg/L up to 120 mg/L with the mean values of 89.1 ± 64.5 mg/L and 41.1± 31.5 mg/L in dry and wet seasons respectively (Table 1 and 2). The Total Hardness (TH) ranged from 12 to 786 mg/L and 13 mg/L to 690mg/L in dry and wet seasons (Table 1 and 2). The Sawyer and McCarty's (1967) classification of water based on TH, as water with TH < 75, 75–150, 150–300 and >300 mg/L, are soft, slightly hard, moderately hard and very hard, respectively (Table 3). According to the above classification, 36 % and 46% of shallow wells and boreholes had soft and slightly hard water during wet season, while during dry season 44% of shallow wells and 53% of boreholes had soft and moderately hard water (Fig. 8).



(a)



(b)

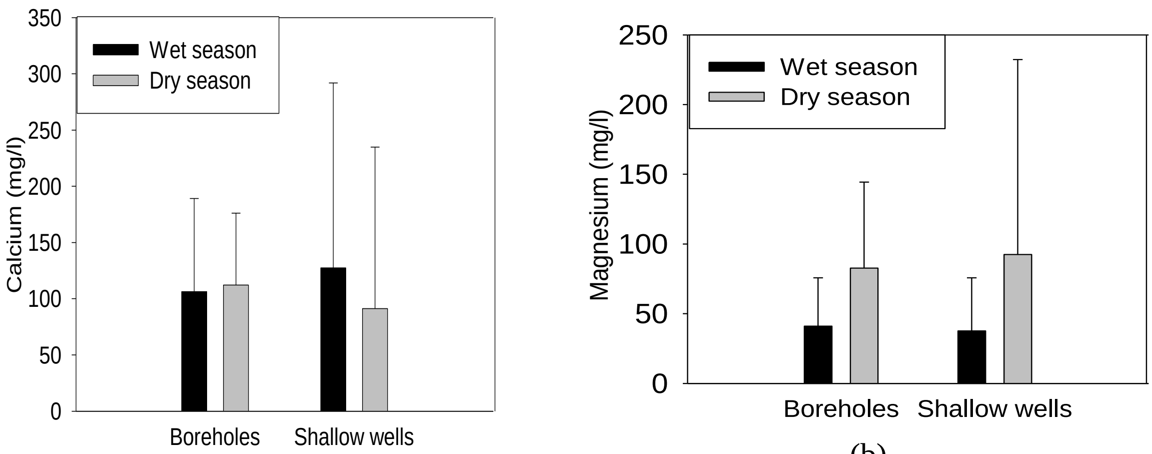
Figure 8: Clustered bar chart showing water hardness classification in (a) shallow wells (b) boreholes during dry season and wet season

Calcium concentrations showed an average value of 101.7 and 116.8 mg/L in dry and wet seasons respectively (Tables 1 and 2). In dry season, 9% of boreholes and 38% of all samples were above TBS and WHO standards. While in wet season, 15 and 36% of boreholes and shallow wells were above TBS and WHO drinking water standards were respectively.

Magnesium concentration ranged between 4-558 mg/L and 4-147.2 mg/L in wells and between 4 -18.4 and 4.6 -138 mg/L in boreholes during dry and wet season respectively. The highest Mg^{2+} value recorded was 558 mg/L in SW 25 during dry season. A total of 27% of shallow wells had Mg^{2+} concentration above WHO (200 mg/L) guideline for drinking water during dry season.

Results showed that, Cl^- values ranged from 3.9 to 893.7 mg/L and 9.9 to 675.7 mg/L in wet and dry seasons respectively (Table 1 and 2**)**. The highest Cl^- concentration recorded was 893.7 mg/L from SW 49 during the wet season. There was no significant difference on the mean concentration of chloride during dry and wet season (Fig. 9). Based on the Cl^- classification (Table 2.5) by Stuyfzand (1989), no water samples in both seasons fall in extremely fresh and very fresh categories. Only one sample was in fresh category during wet season. Two samples during wet season were in fresh brackish category. Four samples in dry season and three samples in wet season fall in brackish class. The class with highest samples was brackish water, i.e. 51 and 35 samples from dry and wet seasons respectively. Salt category had 2 samples in dry season and 10 samples in wet season. The hyperhaline category had one sample from each season. In both sources, brackish saltwater dominated followed by salt water (Fig. 9). No significant difference was noted between dry and wet season. Yet, the higher Cl^- concentrations were observed during the wet season than dry seasons.

The mean concentration of sulphate in dry and wet season were 23.7 and 54.46 mg/L respectively (Tables 1 and 2, Fig. 9), with the highest reading of 540 mg/L from SW 49 during wet season. Only one sample had higher value above the recommended drinking water guidelines by WHO (400 mg/L) (Table 3).



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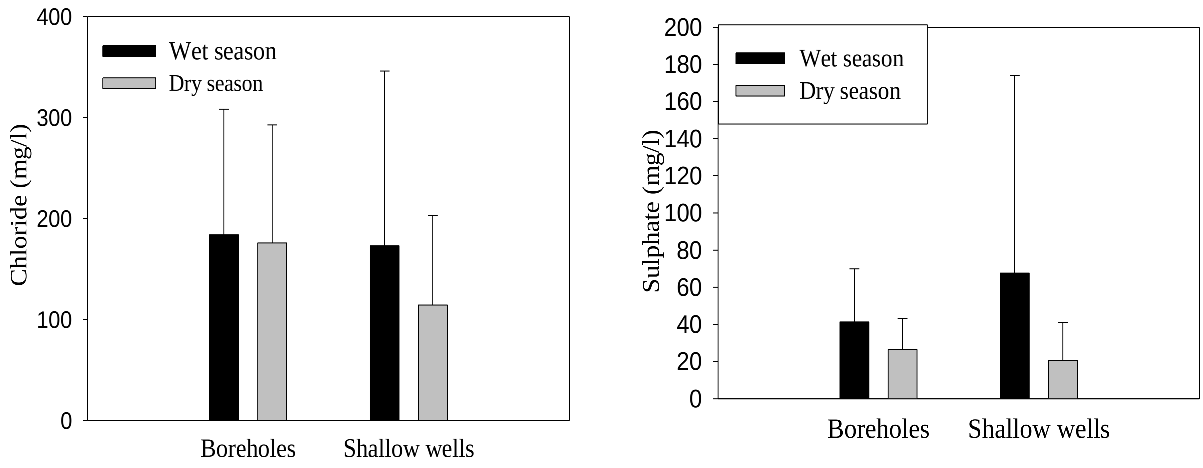


(c)

(d)

Figure 9: Seasonal variation in the concentrations of (a) Ca2+ (mg/L), (b) Mg 2+(mg/L), (a) Cl- (mg/L), (d) SO42- (mg/L), in boreholes and shallow wells during dry and wet seasons

2.4 Discussion

2.4.1 Suitability of groundwater for drinking

The findings thus far presented have indicated that, there was relatively high variation in physicochemical parameters (Table 1 and 2), from different groundwater samples of the study area. This situation suggests that anthropogenic and natural processes in the study area affect the quality of groundwater.

(i) pH

Majority of the groundwater sources in the study area recorded neutral pH, reflecting their suitability for drinking purposes. However, 16 % - 37 % of boreholes and shallow wells recorded slightly acidic to acidic pH (4.0 - 6.4) during the wet season, possibly due to an increase in dilution from rainwater that lowers the concentration of hydrogen ion (H^+). However, SW 11 recorded the highest pH (8.7) during dry and wet seasons evidently due to the nature of the recharge water. Generally, the pH of a place reflects both the geology, nature of the recharge water, and anthropogenic input (CAWST, 2013; EPA, 2000). During dry season, 54 % of the shallow wells indicated pH values below the recommended standards by TBS and WHO i.e. < 6.5, apparently due to most of them being poorly constructed, hence favoring easiness of surface runoff and deposition of organic matters which tend to produce soluble organic acids that increase water acidity when they decompose (Flynn, 2015). Dissolution of atmospheric carbondioxide from the air that reacts with water to form carbonic acid may also contributed to acidic condition of the boreholes and shallow wells (Lin *et al.*, 2010). Viewed from health perspectives, the water of pH values below 6.5 tend to enhance corrosion particularly from metal piping materials which may release toxic metals such as Lead, Zinc, Copper, Manganese and make water unsuitable for drinking due to their health adverse effect (Cowling, 1982; Nielsen, *et al.*, 1980).

(ii) Dissolved Oxygen

Dissolved oxygen (DO) is an important indicator of overall water quality because it can predict the level of water pollution from different contaminants (US-EPA, 2001). The mean DO value during dry and wet seasons in the study area were 5.8 and 5.9 mg/L respectively. This signifies that these water sources are suitable for drinking purposes. In Tanzania, the threshold for DO in drinking water has not been set. Nonetheless, Cruise and Miller, (1994), suggested a DO of 6.0 mg/L as a maximum value for drinking water. The DO value in the range of 0.0-3.5 mg/L recorded by 70% of all shallow wells during dry season, could be due to poor aeration, high level of turbidity and presence of organic matter into the source since most of them were poorly constructed, lacked proper well head elevation and lids/covers hence allowed easy entrance of organic matter directly into the source. During their decomposition they consume oxygen. Relatively, higher DO values recorded in boreholes during the wet season could be due to rain interaction with oxygen in the atmosphere leading to recharge oxygen to the aquifer through infiltration. Very low DO may result in anaerobic conditions that cause bad odors (Ewusi *et al.*, 2013).

(iii) Electrical Conductivity (EC) and Total Dissolved Solids (TDS)

Total dissolved solids (TDSs) and electrical conductivity (EC) are both used as water quality parameters and both reflect the salinity level also may give an indication of seawater intrusion (Huang *et al.*, 2013; Makwe & Chup, 2013). TDS concentrations in water basically, describe the presence of inorganic salts and organic matter while EC refers to the measure of water capacity to conduct electric current, due to presence of dissolved solids (Lin *et al.*, 2010). In boreholes, the relatively, high TDS and EC values in dry season might be due to their concentration due to lack dilution from rainwater. In shallow wells, the high, TDS and EC during wet season might be associated with surface runoff from external surface thus increase inorganic salts and organic matter into the source (Islam *et al.,* 2017; Lin *et al.,* 2010). The strong correlation between TDS and Cl^- ($r= 0.8$), and SO_4^{-2} ($r= 0.8$) suggests that both are affected/released with the same sources such as the geological deposit, domestic waste, and/or agricultural runoff. The relatively wide range of EC values 17.8 - 4790 (µS/cm) obtained indicated that the groundwater varies from location to location. Only 4 % of all boreholes and 15 % of all shallow wells during the wet season had TDS values above WHO standards. Drinking water with higher EC may lead to hypertension or kidney stone disease to human beings (Rahman & Hashem, 2016).

(iv) Turbidity

Turbidity is defined as the measure of clarity or cloudiness of water due to the presence of micro-organisms, clays particles, sewage solids, silts, or sand particles and its health effect depends on the composition of turbidity causing material (Prakash & Somashekar, 2006a; EPA, 2001). The extremely higher turbidity ($p =0.0001$) observed in most of the shallow wells was probably contributed by poor well completion design such as lack of lids/covers, improper well head elevation, and being situated under trees. These conditions favor the receiving of a high amount of surface runoff which carries anthropogenic input from land-use activities, nutrients such as (nitrogen and phosphorus) from agricultural runoff which may stimulate the growth of algae in the groundwater source as observed in some wells (SW 29, 32, 33, 39, and 51), which also increase turbidity. The observed high turbidity in shallow wells during dry season than in wet season is likely due to evaporation particularly in wells that had wide mouth and uncovered, conditions favors concentrations of clay, silt and suspended materials that turns high turbid values. The highest turbid value of 1865 NTU was from well (SW) 51, that was 10 m deep and was producing milky colored water, perhaps were due to the dissolution of the rock material. The well also had a fractured lid and was situated under trees, a condition that favored the easiness of leaves and other dust from air be dropped into the well and increase turbidity. Plastic buckets used in collecting water from this well may act as a source of water enrichment with organic matters especially when contacted with the soil before and after being used. Similar results of high turbidity due to poor wells completion was reported by (Mdoe & Buchweishaija, 2014; Behailu, 2017; Elisante & Muzuka, 2016; Pritchard *et al.,* 2007). Furthermore, the effect of extreme turbidity values showed by poorly developed well in dry season, influenced the mean concentrations of the dry season hence records of higher turbidity observed in dry season. Water with high turbid values favors growth of microorganism and protects them against disinfection, leading to the use of a high amount of disinfectant which can lead to a health threat. For example, when chlorine is applied and becomes excessive due to shielding by microbes, the excess may mix with organic matter leading to the formation of harmful byproduct such as trihalomethanes (THMs) which can lead to gastrointestinal illness (Prakash & Somashekar, 2006).

(v) Alkalinity

Alkalinity refers to the buffering capacity of water mainly on ability of water to neutralize acids. The variation of alkalinity from 4-121 mg/L and from 8-460 mg/L during wet and dry season showed that alkalinity of the study varied from area to area due to geology, since alkalinity is mainly affected by the soil and bedrock through which water passes (Khan *et al.*, 2013). Hence, the sources showing high alkalinity may have minerals of chloride, sulfates, and carbonates that become easily available to the groundwater. The significant correlation between total alkalinity (TA) and SO_4^{-2}, and Cl^- revealed their contribution in the alkalinity of the groundwater sources of the study area since ions mostly contributing to alkalinity are chlorides, carbonates, bicarbonate, and sulphate (Prakash & Somashekar, 2006a; Khan *et al.*, 2012).

(vi) Total hardness

About 46% - 53% of the boreholes had are characterized by having slightly to moderately hard water during dry and wet season respectively (Fig. 8), probably due to presence of high amount of Ca^+ and Mg^{2+}, that was indicated by a strong positive correlation of Ca^+($r=0.8$, $p< 0.001$) and Mg^{2+} ($r=0.8$, $p < 0.001$), that may have leaching from minerals such as calcium carbonates and/or magnesium carbonates (Srivastava & Pandey, 2012). Generally, Ca^+ and Mg^{2+} are suggested to be the principal hardness causing ions in the groundwater sources (Istifanus *et al.*, 2013). When hard water is used for bathing may interfere with skin through formation of soap curd and may lead to irritation even in hair and make them lifeless (Istifanus *et al.*, 2013; James, 2013; Ewusi *et al.*, 2013; Vasanthavigar & Srinivasamoorthy, 2012). Approximately, 44% - 36% of shallow wells were characterized into soft water category. Soft water are susceptible to pH fluctuation from contaminants (Sawyer & McCarthy, 1967). According to TBS, the maximum permissible level of calcium in drinking water is 100 mg/L. In this study 43% and 71% of all boreholes and shallow wells during wet and dry season recorded higher value above TBS standards for drinking water. Excessive hardness of water causes corrosion and choking of pipes and utensils, thus contributes to economic damages. It is also reported that excessive hardness may cause kidney stones and heart problems (Shakirullah, *et al.*, 2005). For the case of suitability for drinking 27 % of all samples recorded values of above WHO (75 mg/L) standards.

(vii) Chloride

Based on the chloride classification by Stuyfzand, (1989), majority of sources in the study area during dry and wet seasons were dominated by brackish water (a mixture of fresh and saltwater), which indicate the possibilities of intrusion of saltwater into freshwater aquifer due to hydraulic connection between groundwater and sea or lakes. Generally, salt present in the lakes may behave as a reservoir of Cl^- by first acting as a sink and eventually act as a source to other groundwater systems (Kincaid & Findlay, 2009). The strong positive correlation between Cl^- and SO_4^{-2} in wet ($r = 0.8, p < 0.01$) and dry ($r = 0.5, p < 0.01$) seasons, indicate the possibilities of them being originating from the same source, such as municipal/industrial discharge, runoff from fertilized agricultural lands, or ore deposit (Bashir *et al.,* 2012). Although there are no known health risks from chloride in drinking water, 19% of boreholes and 25% of the shallow wells recorded chloride concentrations above i.e., 250 mg/L that affect the taste and acceptability of water for consumption (WHO, 2011).

Chloride has no adverse effect on water but impart bad taste to drinking water. In this study, it recorded the highest concentrations compared to other physico-chemical parameters (Table 4 and 5), with a mean value of 147 mg/L and 178 mg/L during dry and wet seasons indicating that some sources have salty taste, since chloride in excess of 100 mg/L imparts a salty taste (Prakash & Somashekar, 2006a). However, higher chloride concentrations recorded in shallow wells (9.9 -343.8 mg/L and 3.9 – 893.7 mg/L during dry and wet seasons) might be due to infiltration of sewage effluent from onsite sanitation facilities situated at close proximity to most wells during wet season, as high chloride concentration sometimes serves as an indicator of sewage pollution. Furthermore, the highest Cl^- concentrations of 893.7 mg/L which is above the recommended standard by WHO i.e., 600 mg/L (WHO, 2008), was recorded from well 49 during wet and dry seasons. The well is situated 10 m from pit latrine indicating a possibility of receiving chloride from domestic waste due to flashing of domestic waste from pit latrine which is situated closer to recharge sources (USGS, 2009; Sehar *et al.,* 2011). Human excreta, particularly the urine, contain chloride in an amount equal to the chlorides consumed with food and water (averages to about 6 g of chlorides per person per day), the amount of chloride in municipal wastewater increases to about 15 mg/L above that of the carriage water in lotic systems (McCarthy, 1967). In addition septic tanks and pit latrines (Bashir *et al.,* 2012), also contributes a significant amount of chlorides to groundwater.

(viii) Sulphate

High sulphate of groundwater sources of the study area was from samples taken during dry season and the highest concentrations above WHO guidelines were 540 mg/L were from shallow well 49. The rest of the samples were within permissible range thus safe for drinking purposes. Significant correlation of sulphate with calcium and chloride during wet season was attributed by high surface runoff from external surface to the groundwater source. Most sulphate compounds originate from the oxidation of sulphate ores and are readily soluble in water (Bashir *et al.*, 2012; EPA, 2001; Greenwood, 1984). High intake of SO_4^- may result in gastrointestinal irritation and respiratory problems to the human system (EPA, 2001).

2.5 Conclusion

Understanding of the physical-chemical properties of groundwater used for consumption is important in safeguarding the end user. The objective of this study was to analyze the physical-chemical parameters of the selected boreholes and shallow wells in the study area and their suitability for drinking purposes based on the recommended standards set by TBS and WHO. Results revealed that, the levels of contamination were generally decreasing during the wet season due to dilution the effect of rainfall. The factors such as poor well completion contributed to high turbidity in most shallow wells, while geology of an area was attributable to relatively higher alkalinity and total hardness of the groundwater sources. Additionally, more than 25% of all shallow wells had high chloride contamination above the WHO recommended standards. The study uncovered that about 25% of Singida population are prone to unacceptable chloride contamination. Therefore, study recommends proper covering of the well mouth and construction of proper well elevation so as to prevent further contamination from external surface. Also, sand filter or bio-sand can be used to reduce water turbidity before consumption. However, suitability of groundwater sources for dinking purposes cannot be achieved by the evaluation of physico-chemical parameters alone. Microbial quality analysis is also an important aspect in safeguarding the end users and is recommended for further characterization of the selected groundwater.

CHAPTER THREE

Sources and Seasonal Variations of Coliform Bacteria in Selected Groundwater Sources of Tanzania's Semi-arid Region, Singida[1]

Abstract

This study reports the microbial quality in terms of total coliform (TC), fecal coliform (FC) and *Escherichia coli* (*E.coli*), of groundwater sources in Singida Urban and Manyoni Districts in Central Tanzania. A total of 58 randomly selected samples were collected during dry and wet seasons and analyzed using the Membrane Filtration Technique in order to ascertain the effect of seasonal change in microbial quality. Higher microbial contaminations were found to occur during the wet season due to increased surface runoff from onsite sanitation facilities or heaps of poultry manure in vegetable farms that infiltrate into groundwater sources. Most of the shallow wells yield water of poor quality compared to boreholes since most of them had been poorly constructed and positioned in close proximity to potential contaminants. Significant higher ($n=58$, $p<0.05$) contamination of FC and *E. coli* were observed in shallow wells that lack covers and are utilizing buckets in withdrawing water from the source. Bucket favours easy inoculation of microbes from external sources to the groundwater. The wells with poor wellhead elevation and characterized with poor hygiene surroundings recorded higher coliform contamination, as proper wellhead elevation prevents easy injection of contaminated storm water to the source. Human health risky classification based on FC and *E.coli* counts indicated that most of the water supplied from shallow wells ranged from high risk to very high-risk categories, hence had to be treated before consumed. The majority of boreholes produce water of reasonable quality, nevertheless. Proper covering of wells mouth and use of water pumps to withdraw water instead of buckets are highly recommended to prevent further microbial contamination.

Keywords: Groundwater quality, water borne diseases, microbial contamination, coliform, seasonal variation.

This chapter is based on a published paper:

Rita Alex[1*], and Karoli Njau[1] (2020). Factors Affecting Distribution of Coliforms Bacteria in Semi-arid Groundwater Sources - Tanzania. *International Journal of Biosciences*, http://dx.doi.org/10.12692/ijb/4.12.1-8

3.1 Introduction

Globally, at least 2 billion people use a drinking water source contaminated with faeces due to lack of clean and safe drinking water (WHO, 2019). Worldwide, 435 million people depend on water from unprotected wells and springs, and 144 million people depend on untreated surface water from lakes, ponds, rivers and streams (WHO, 2019). Such sources are susceptible to biological or physico-chemical contamination hence are at risk of contacting water borne diseases which are among the leading causes of death in developing countries, specifically for children under the age of five (WHO, 2008).

Use of water contaminated with pathogenic bacteria, virus, protozoa and/or fungi may lead to transmission of water borne diseases such as cholera, diarrhoea, dysentery, typhoid, and gastroenteritis (Aller *et al.*, 2013; Kihupi, *et al.*, 2016) Globally, contaminated drinking water is estimated to cause 485 000 diarrhoea deaths each year (WHO, 2019). In Tanzania, about 90 % of deaths are attributed to poor water, hygiene, and sanitation conditions and the 2014 census showed almost 5 800 death cases of cholera occurred and 18 500 children under the age of five were reported to die from diarrhoea annually (URT, 2014a). Despite the number of deaths reported, most drinking water sources, particularly from unprotected groundwater sources in Tanzania remain poorly understood a situation that may pose a serious challenge in efforts towards reducing and preventing water borne diseases.

Presence of coliform bacteria (Total coliform) (TC), fecal coliform (FC), and/or *Esherichia coli* (*E. coli*) in drinking water may indicates the existence of disease-causing organisms (pathogens) or treatment ineffectiveness of the water source (Pal, 2014). In Tanzania, studies on coliform contamination in groundwater sources have been reported in Dar es salaam (Mdoe & Buchweishaija, 2014; Kihupi, *et al.,* 2016), in Arusha (Elisante & Muzuka, 2015a), in Morogoro (Katto *et al.*, 2016). However, the empirical based information on coliform contamination is unavailable in some areas of Tanzania where unprotected groundwater sources are entirely depended upon for drinking purposes.

Groundwaters are heavily depended upon for domestic purposes globally and in Tanzania they contribute to more than 25% of the domestic water supply. Additionally, groundwaters are considered to be the primary water source in most of the semi-arid and arid regions such as Singida, Dodoma, Manyara, and Shinyanga of Tanzania (Baumann *et al.*, 2005). However, most of the sources are prone to contamination from natural and anthropogenic sources such as domestic waste disposal, manure application, and the use of onsite sanitation facilities in closer proximity to groundwater sources (Elisante & Muzuka, 2016b). However, monitoring of microbial quality of groundwater sources particularly from private owned sources is poorly documented or unavailable; hence water from most shallow wells sources in Tanzania remain to be of unknown quality despite being used for domestic purposes.

Other technical factors such as poor well completion and lack of proper setting such as poor well head elevation, well cover, improper distance from potential contaminants and/or poor mode of water collection from the source both have been found to contribute to higher microbial contamination (And & Buchweishaija, 2014; Elisante & Muzuka, 2016b; Kanyerere *et al.*, 2012; Kihupi, *et al.*, 2016). Therefore, proper understanding of the factors that facilitate microbial contamination in groundwater will pave the way for proper protection of the sources.

In Singida Region, groundwater sources of unknown quality are highly depended upon for domestic purposes. At the same time, majority of the population use onsite sanitation facility such as pit latrines that pause the risk to groundwater source if are not properly made and positioned. Furthermore, groundwater sources of Singida have been revealed to have high levels of nitrate which may signify the contamination by organic matters hence the presence of fecal bacteria and/or pathogenic bacteria (Frisbie *et al.*, 2002). Likewise, data from Singida District Health Information System (dhis) showed that water-borne diseases were among the top three reported diseases by outpatients in the years 2014, 2015, and 2016 consecutively (http://dhis.moh.go.tz). Additionally, early 2015 and late 2016 data showed that Singida was amongst the regions affected by the massive cholera outbreak in Tanzania (Kessy & Mahali, 2017). Therefore, based on these evidences, it is crucial to quantify the coliform concentrations of the groundwater sources in Singida, which are used for drinking purposes as their presence indicates the likelihood of the source being contaminated with feces and its risk of causing water-borne diseases. Similarly, since the abundance and variation of microorganism in most of the groundwater sources of the study area are not well documented at present, as well as the factors affecting them, while at the same time people continue to rely on them for consumption purposes, it is therefore very important to assess them and improve the state of knowledge about the quality of these sources.

Therefore, the present work aimed to (i) determines the coliform concentrations of the selected groundwater sources that are used for drinking purposes (ii) to determine the key features facilitating high coliform contamination so as to lay a foundation for proper intervention and effective improvement of the water quality management.

3.2 Materials and methods

3.2.1 Description of the study area

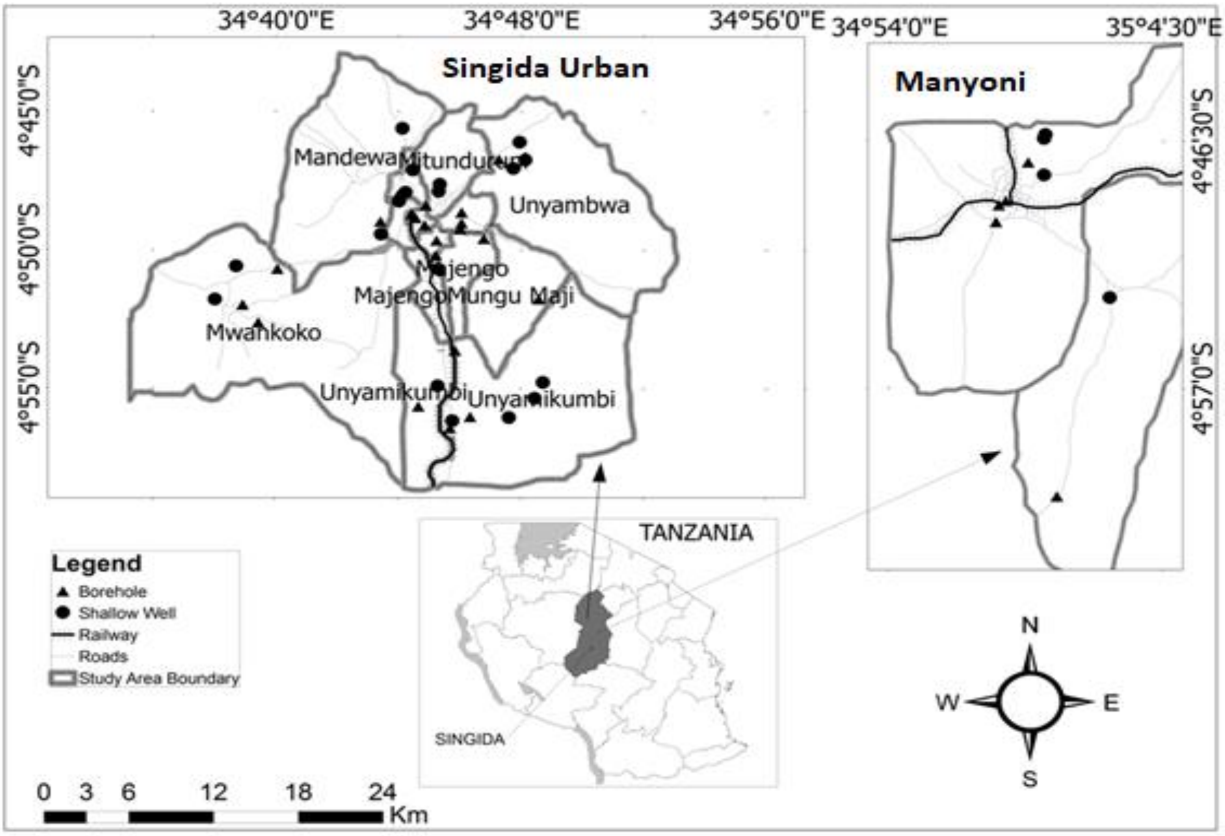


Figure 10: Map of Singida Urban and Manyoni District showing the sampling stations

Manyoni and Singida Urban Districts are located in Central zone of Tanzania (Fig. 10). The Region covers a total area of 49 438 km^2. According to Tanzania National Census of 2012, the population of Singida Region was 1 370 637 with a population growth of 2.3 per year (National Bureau of Statistics, 2013). Singida Urban and Manyoni Districts had a population of 150 379 and 296 763 respectively (URT, 2014a). The main source of livelihood in this region includes livestock keeping and farming. It is estimated that 10.1% households lack toilet facility. This amount is higher than the national average level of 7.8 % (URT, 2014b). Lack of toilets facility favours open defecation which might increase a threat to groundwater sources through run-off and leaching especially in wet season. Singida has no sewerage system, and many people depend on site sanitation facilities such as cesspit and when they become full, the waste water is collected and dumped in an open area which is situated about 4 kilometer from Lake Kindai and 9 km from Singida Town. Meteorologically, Singida region is classified as a semi-arid zone with an average of a mean annual rainfall of 600 - 650 mm. The area experiences a unimodal type of rainfall from December to March or sometimes goes to April (Davies, 2005). The region lack piped water supply and the whole population rely totally on boreholes and shallow wells. However, shallow wells that are privately owned are commonly available because they are relatively cheaper to construct as compared to boreholes.

3.2.2 Groundwater classification and selection of sampling sites

Water samples were collected from 12 selected wards (Fig. 10) that rely on public and private owned boreholes and shallow wells for their daily need. Eleven shallow wells were constructed by Water Aid Project and 2010-2015 Member of Parliament, 8 boreholes were under Internal Drainage Basin and others were privately owned. Groundwater sources of the study area were classified as shallow well with a depth of 1- 20 m and boreholes from 21->100 m. Most of the sampled sources are not disinfected except for shallow well 6 (Yugo) and boreholes 2, 7, 15, and 16 which are chlorinated twice a year (Appendix 1). Singida Urban District has two major boreholes Mwankoko and Erao. Both boreholes contained underground tank with a capacity of 2.5 million litres and an elevated tank of 0.5 million litres. They both receive water from three boreholes each with a depth of above 100 meter. These collection tanks are the main supply of water to the population of Singida town. However, these two supplies are inadequate for the entire population. Hence, most of the inhabitants depend on private owned boreholes and wells which most of them are of unknown quality in terms of microbial concentrations.

Groundwater sources were identified from Singida groundwater sources list provided by Singida Regional Water Engineering Department. Private owned wells and boreholes were accessible through information obtained from local people and ward officers. A total of 28 (i.e. 23 and 5) shallow wells and 30 (i.e. 15 and 11) boreholes from Singida Urban and Manyoni were sampled respectively**.**

3.2.3 Sample collection

Water samples were randomly collected during dry (September – October) and wet (April) seasons. Physical parameters like temperature, electrical conductivity (EC), dissolved oxygen (DO), pH, and total dissolved solids (TDS) were first determined onsite using a HANNA multi-parameter equipment Model HI 9828 and are reported in Chapter 2. In hand/mortar pumped sources, water samples were pumped, for at least five minutes before sampling so as to ensure the collected water has not overstayed in pipe rather fresh from aquifer. For the shallow wells without lid and pump, buckets were used to collect water. Water samples were collected in sterile 0.5 L prewashed, sterile glass bottles that were rinsed thoroughly with sample water and finally filled to the beam. A total of 58 and 53 water samples were collected from shallow wells and boreholes during dry and wet seasons respectively. All collected water samples were stored in ice-packed cool box and transported to Water Quality laboratory at Internal Drainage Basin office in Singida for analysis of TC, FC and *E.coli* bacteria. Features attenuated with sampling site such as well head height from ground, lateral distance from pit latrine or any potential contaminants, disinfection status, depth, types of cover and water collection mechanisms were also documented. Sample location points were fixed using Etrex Geographical Positioning System (GPS), with an accuracy of ± 3 meter.

3.2.4 Microbiological analysis

The collected water samples were analyzed for TC, FC and *E.coli* at the Singida Water Quality Laboratory by using membrane filtration technique (APHA, 2005). M-Endo agar, M-FC Agar and HiCrome Agar were prepared as per manufacturer instructions and used for incubating TC, FC and *E.coli* respectively. All samples were subjected to 100 ml which was not diluted and 50 ml which was diluted with sterilized water to 100 ml. Each aliquot was filtered using Millipore 0.45 µm nitro-cellulose filters, followed by incubation into the respective agar plate. TC and *E. coli* samples were incubated at 37°C and FC at 44°C for 24 hours. The viable colonies were counted and recorded as colony forming units (CFU) per 100 mL of the original sample. Results were averaged to reduce any error related to measurements. In addition, 100 mL of double distilled water used for dilution was filtered followed similar procedures for incubation as control.

3.2.5 Statistical analysis

Stastistical data analyses (Min, Max, Mean, Median and Standard Deviation) were achieved using STATISTICA StaSoft version 10.1. Manny Whiney Test was done to determine the relationship between microbial quality and wells characteristics features (type pf cover, and pumping mechanism) during dry and wet seasons and Kruskal-Wallis test was used to test the statistical differences between bacterial medians during wet and dry seasons. Scatter plot analysis was done to determine the existing relationship between well depth and TC, FC and *E.coli* counts. Sigma- histogram was used to show the mean differences.

3.3 Results

This section presents the contamination levels of TC, FC and *E.coli* in boreholes and shallow wells of the study area during dry and wet season, together with the factors causing such contamination.

3.3.1 Microbial occurrence in groundwater sources

Coliform counts for groundwater sources of the study area are presented in Appendix 2 and Appendix 3. The descriptive statistics (minimum, maximum, mean, median and standard deviation) of TC, FC and *E. coli* counts from boreholes and shallow wells during dry and wet seasons are presented in (Table 6). Results showed that, TC were detected in almost all boreholes in wet season, with the lowest number of 6 and highest of 200 CFU/100 ml. Whereas FC contamination were observed in 14 % and 33 % of all boreholes during dry and wet seasons respectively, with the maximum record of 49 CFU/100 ml. *E. coli* contamination were observed in 7 % and 8 % of all boreholes during dry and wet season respectively with the highest record of 24 CFU/100 ml. For the case of shallow wells, TC was detected in all sources during dry and wet season respectively with the highest record of 900 CFU/ml. Whereas, FC records were 0 to 618 CFU/100 ml minimum and maximum respectively, with percentage contamination of 47 and 63 during dry and wet season. While *E. coli* contamination was recorded in 57 % and 78 % in dry and wet season, with minimal and maximum counts of 0 and 250 CFU/100 ml respectively.

Table 6: Statistical summary of TC, FC and E.coli counts in shallow wells and boreholes of the study area during dry and wet seasons

Type of Coliform Bacteria	Water Source	Min		Max		Mean		Median		SD	
		Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season
TC	BH	6	14	100	200	32	66	26	67	25	38
	SW	8	12	350	900	87	298	67	241	85	259
FC	BH	0	0	17	49	1	5	0	0	11	5
	SW	0	0	53	618	17	90	14	35	15	143
E.coli	BH	0	0	6	24	0	1	0	0	2	5
	SW	0	0	98	250	14	43	5	13	22	65

n=58, Min = minimum, Max = maximum, SD = Standard Deviation TC = Total coliform, FC = Feacal coliform, E.*coli* = *Escherichia coli*, BH = boreholes, SW = shallow wells. All values are in mg/L.

Variation among microbial median within the groundwater sources in different seasons (Table 7) showed that, there was extremely significant difference in TC counts against FC and *E. coli* counts ($n=58, p\leq 0.001$) in boreholes during wet and dry seasons. Whereas in wells, there was extremely significant difference in TC against *E. coli* counts in both wet and dry seasons ($n=58, p\leq 0.001$). There was no significant difference between FC and *E. coli* ($n=58, p>0.05$) in all sources during dry and wet seasons.

Table 7: Kruskal-Wallis test for differences in microbial concentrations between wet and dry seasons in boreholes and shallow well

Water sources	Season	Pair of variables	p value	Significance
		TC vs FC	≤ 0.001	*** S
Boreholes	**Wet**	TC vs *E.coli*	≤ 0.001	*** S
		FC vs *E.coli*	≥0.05	NS
		TC vs FC	≤ 0.001	*** S
Boreholes	**Dry**	TC vs *E.coli*	≤ 0.001	*** S
		FC vs *E.coli*	≥0.05	NS
		TC vs FC	≥0.05	NS
Wells	**Wet**	TC vs *E.coli*	≤ 0.001	*** S
		FC vs *E.coli*	≥0.05	NS
		TC vs FC	≤ 0.05	* S
Wells	**Dry**	TC vs *E.coli*	≤ 0.001	*** S
		FC vs *E.coli*	≥0.05	NS

3.3.2 Classification of Groundwater Quality Based on WHO and TBS Standard

The microbial concentrations in shallow wells and boreholes were compared with the standards set by TBS and WHO for drinking water.

Table 8: Coliform Counts (CFU/100 ml) and % exceeded the permissible limit of TBS (2005) and WHO standards (2008)

Coliform (CFU/100 ml)	**TBS STD**	**WHO STD**	**%Exceeds TBS**		**% Exceeds WHO**	
			Dry season	**Wet season**	**Dry season**	**Wet season**
TC	10	4	100	100	100	100
FC	0	0	48	61	48	61
E.coli	0	0	32	47	32	47

TC = Total Coliform, FC = Fecal coliform, *E.coli* = *Escherichia coli*

Results showed that, 100% of all sources had TC concentrations above TBS and WHO standards respectively. While FC counts exceeded TBS and WHO by 48% and 61% during dry and wet seasons. Percentage of *E.coli* counts which exceeds TBS and WHO standards were 32% and 47% during dry and wet seasons (Table 8).

3.3.3 Key features of groundwater sources

Features exhibited by some shallow wells were: lack of proper well head elevation 12 % (wellhead below 60 cm from the ground) and 60 % of wells were situated at a distance of less than 50 m from a sanitation facility i.e. pit latrine, cesspit or flash toilet. Whereas in boreholes, 7 % situated at a distance of 2-20 m from vegetable farms and 22 % of the wells were situated at a distance of 2-20 m from farms where animal/poultry manure or synthetic fertilizers were applied (Appendix 1).

(a)

(b)

Plate 1: Typical setting of wells in the study area (a) shallow wells with a poor well head elevation (b) water withdrawn from a shallow well using a bucket

3.3.4 Lateral distance from pit latrine

According to TBS standards of sanitary protection, the recommended distance from groundwater source to potential contamination, are as follows: distance of 50 meter (m) from pit latrine, septic tanks and sewers, 100 m from seeping pits and 150 m from cesspools and graves. Results showed that, 33 % of wells were located at a lateral distance of less than 10 m from the pit latrine, 50 % were between 11m – 20 m and 17 % were at a distance of 21m – 30 m from the pit latrine (Fig. 11). In boreholes, only 20 % were located at a distance of 21m-30 m from the pit latrine.

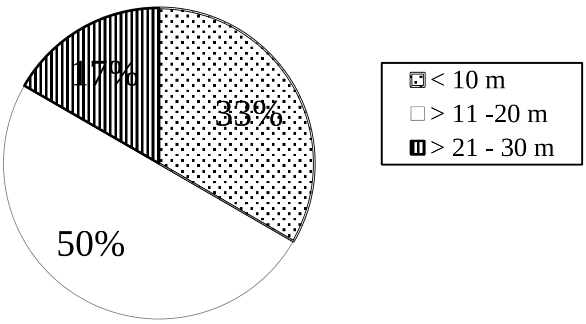


Figure 11: Lateral distance in meter (m) from onsite sanitation facilities to shallow wells

3.3.5 Features of the shallow well lids/ covers

Different types of covers were observed in groundwater sources, these included fractured metal sheets cover (4), wooden lid (4), mixture of fractured metal sheet with wood cover (4) and uncovered lid (4) (Plate 2).

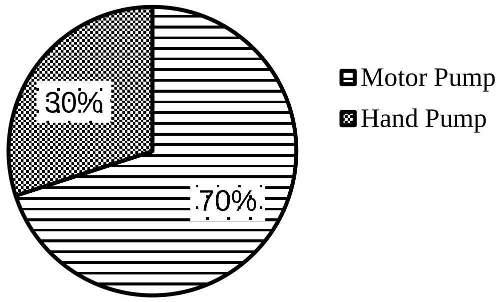
(a) (b)

(c) (d)

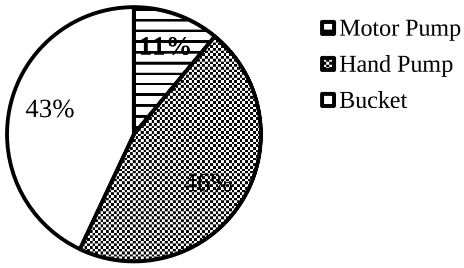
Plate 2: Types of covers and well conditions observed from study area (a) fractured metal cover (b) properly covered (c) well mouth open with improper wellhead elevation, no fence and possess unhygienic surroundings (d) wooden cover

3.3.6 Water withdrawing mechanism

Two different water withdrawing mechanisms were employed in boreholes, whereby 30 % were using motor pumps and 70 % using hand pumps. While in wells, 3 different methods were used; 46 % were using hand pumps, 43 % buckets and 11 % motor pumps **(**Fig. 12).



(a)



(b)

Figure 12: Water withdrawing mechanisms in percentage for (a) boreholes and (b) shallow wells

3.3.7 Relationship between well features and microbial quality of water

The number of groundwater features were analyzed in order to assess their influence/impact on microbial pollution in the selected water sources. Features investigated included type of well cover, well mouth lid/cover, wellhead elevation and water withdrawing mechanisms (Table 9). Results showed that, the uncovered or partially covered well-mouth and covers with gaps had significantly higher coliform contamination (*n=15,* $p \leq 0.01$) than the properly covered wells (concrete covers) in both seasons. Likewise, wells which uses bucket as a means of water withdrawing had significantly higher TC (*n=11, p ≤0.01*), FC (*n=11, p≤0.01*) and *E.coli (n=11, p≤ 0.01*) than wells where motor or hand pump were used in both seasons. (Table 9).

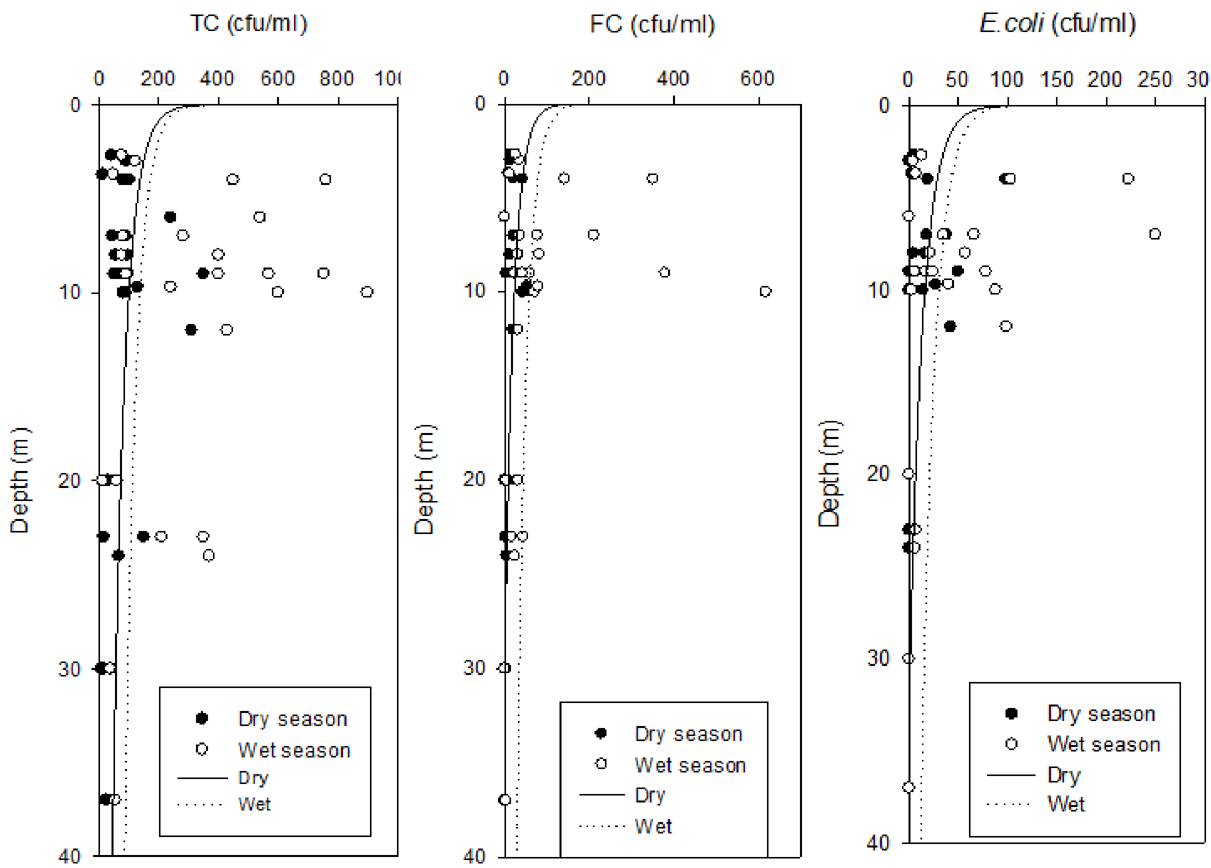
Table 9: Man-Whitney U test for lid cover and water pumping mechanism as factors affecting water quality in groundwater sources during dry and wet seasons

Season	Factors	TC					FC					*E. coli*				
	Lid cover:	**n**	**Rank**	***U***	***z***	**p-value**	**n**	**Rank**	***U***	***z***	**p-value**	**n**	**Rank**	***U***	***z***	**p-value**
Dry	Uncovered/ partially covered/ lid with gaps	15	10.7	96.5	3.8	0.0	15	12.3	53	5.2	0.0	15	14.2	77.5	5.9	0.0
	Completely covered	43	18.3				43	17.2				43	16.3			
	Water pumping:															
	Motor/hand pump	44	13.0	70	2.4	0.0	44	17.8	43	5.2	0.0	44	17.6	31.5	6.1	0.0
	Bucket pulley	11	7.1				14	11.7				14	11.9			
Wet	Uncovered/ partially covered/ lid with gaps	14	10.2	108	3.2	0.0	14	11.6	35	4.9	0.0	14	11.8	23.5	5.5	0.0
	Completely covered	38	16.3				38	14.9				38	14.7			
	Water pumping:															
	Motor/hand pump	39	17	104	3.1	0.0	39	15.7	37	4.7	0.0	39	16.6	94.5	4.2	0.0
	Bucket pulley	11	9.5				13	10.8				13	11.4			

n-the number of samples, z- z score value, U-Mann-Whitney test value, p-statistical significance at stated *p* value

3.3.8 Coliform occurrence with depth

Generally, coliform counts decreased with the depth of shallow wells **(**Fig. 13**)** and significant decrease was observed in TC and FC counts (*n=28, p=0.02*). While in boreholes there were no significant trend that was obvious in relation to depth.

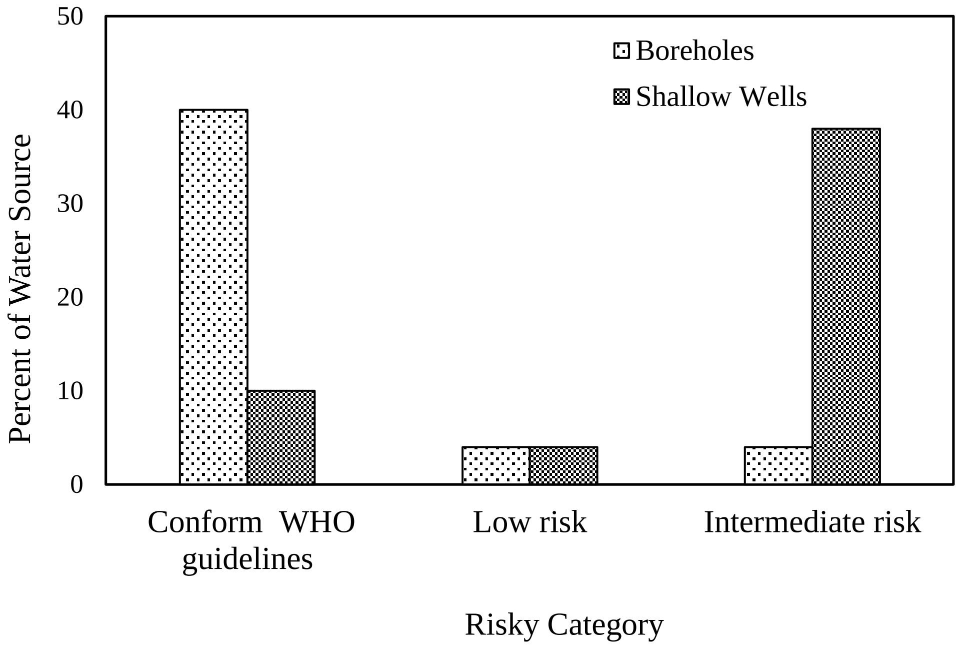


(a) (b) (c)

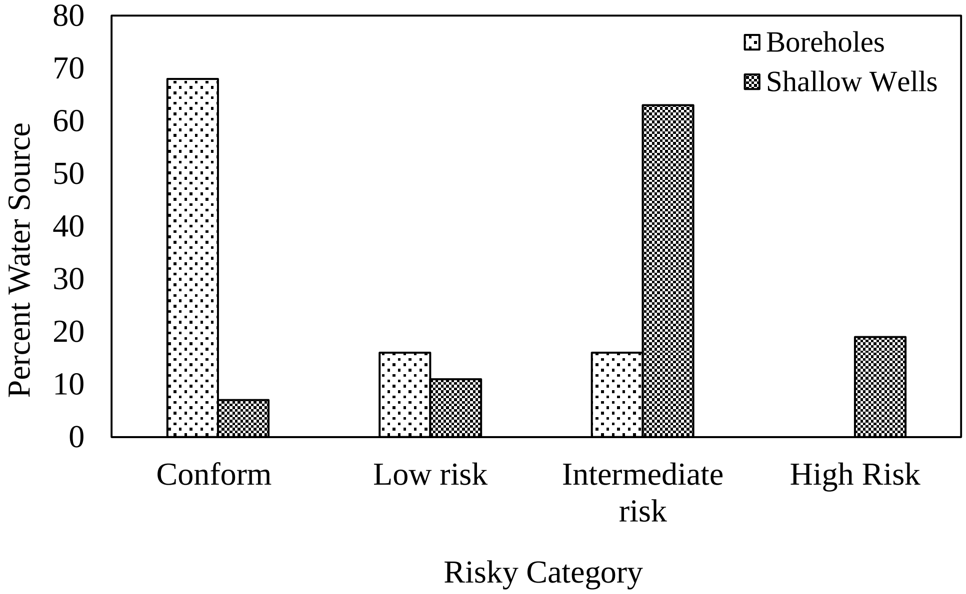
Figure 13: Scatter plot showing variations of shallow well depth (m) with coliform counts (a) TC (CFU/100 ml), (b) FC (CFU/100 ml), and (c) *E.coli* (CFU/100 ml)

3.3.9 Classification of groundwater quality based on FC Counts (CFU/100 ml)

Groundwater samples were classified based on the FC counts (CFU/100 ml) as per WHO standards (1997) (Fig. 14). During dry season, about 40 % of all boreholes and 8 % of all shallow wells conformed to WHO standards, while less than 8 % of all boreholes and shallow wells were at low risk category. Most of the water collected from wells were found in intermediate risk category and needed to be treated before consumption (Fig. 14). While wet season results showed that, high risk and intermediate risk category were comprised of water from shallow wells i.e. 63 %. Borehole water conformed to the WHO standard by 68 % while 16 % of boreholes samples and 11 % of shallow wells samples were at low risk category. No borehole samples were found at high risk category (Fig. 14).



(a)

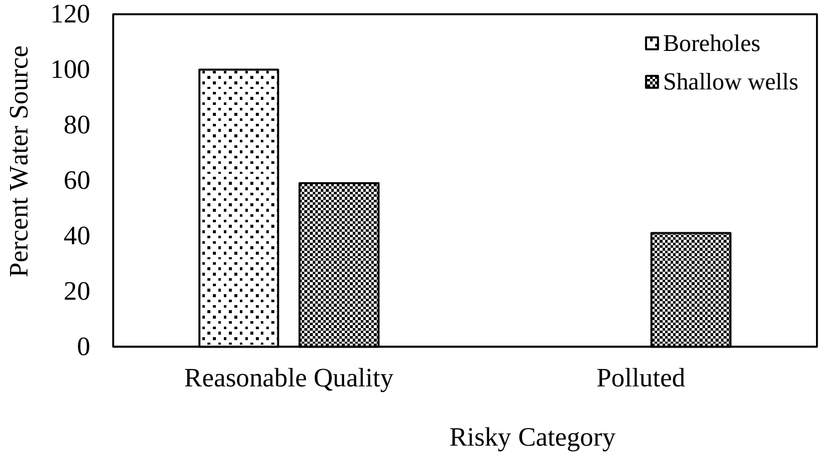


(b)

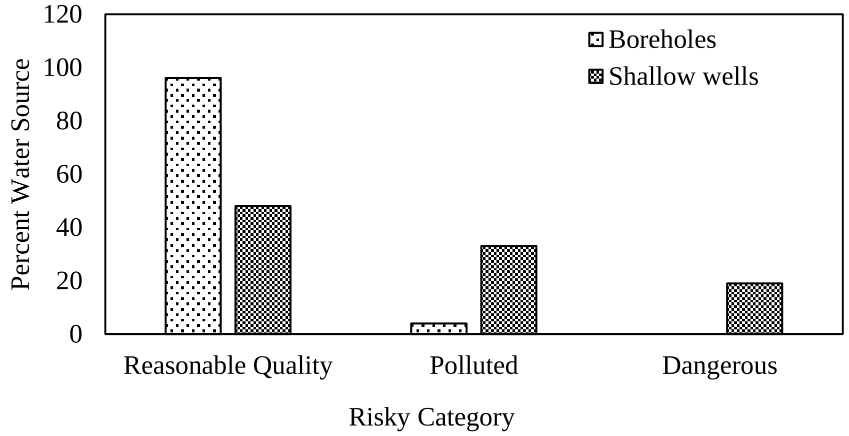
Figure 14: **Groundwater health risks measured using FC counts (CFU/100 ml) in boreholes and shallow as per WHO (1997) wells during (a) dry season and (b) wet season**

3.3.10 Classification of groundwater quality based on E.coli Counts (CFU/100ml)

Groundwater samples were classified based on the E.*coli* counts (CFU/100 ml) as per WHO standards (1997) **(**Fig. 15), showed that, during dry season all boreholes and 59 % of all shallow wells conformed to reasonable quality and about 41% of shallow wells were in polluted category. While during wet season, 96 % of boreholes and 48 % of shallow wells were in reasonable quality. Dangerous category had 19 % of shallow wells, no boreholes were found in this category.



(a)



(b)

Figure 15: **Groundwater health risks measured using the *E.coli* counts (CFU/100mL) in boreholes and shallow wells as per WHO (1997) during a) dry season and b) wet season**

3.4 Discussion

3.4.1 Microbial quality of the groundwater

The analysis of groundwater quality from selected boreholes and shallow wells in Singida Urban and Manyoni –Tanzania, showed that all sources were contaminated with TC during dry and wet seasons. The TC contamination in all sources could be attributed by the surface runoff of pollutants present in the soil and the surrounding environment into groundwater source (Mdoe & Buchweishaija, 2014; Elisante & Muzuka, 2016b). Despite the disinfection of shallow wells (SW) 6 and boreholes (BH) 1, 6, 7, 15, 16 (Appendix 1), they still indicated positive for coliform suggesting the possibilities of poor or delayed re-disinfection process (Sobsey *et al.,* 2003; Katto *et al.,* 2016). Therefore, timely and proper disinfection must be emphasized to decrease microbial contamination. Usually, disinfection process involves use of a physical (ultraviolet light, electronic radiation) or chemical (chlorine, chlorine dioxide) process to deactivate or kill microorganisms. A study by Sobsey *et al.*, (2003), in Bangladesh showed that consumption of chlorine treated water reduced diarrhoea cases to children below five years by 20.8 %. Also, a research by Mahfouz *et al.*, (1995), showed significant decrease of coliforms from 100 % to 3 % after chlorination. Also, sand filter technique could be used to purify the contaminated water of the study area, since is most effective against turbidity and coliform bacteria. Moreover, sand filter is of low cost, easy to build and need less materials, maintenance is also simple, and produce low sludge volume (Khan *et al.,* 2012). Similar disinfection processes can be adopted since treated drinking water helps to reduce bacterial load which may cause water-borne diseases.

Relatively, higher FC counts observed in shallow wells compared to boreholes was probably due to most of them being poorly constructed and situated at a short distance from pollutants sources such as sanitary facilities, heaps of manure and farms which allow easy leaching and/or seepage into groundwater source (Appendix 1) (Mdoe & Buchweishaija, 2014; Elisante & Muzuka, 2016b). For example, wells 46, 47, and 48 were situated at a lateral distance of < 10m below pit latrine and farms, a distance which is less than the recommended standard from Tanzania Bureau of Standards which requires 50m from any sanitary facilities (TBS, 2005). The short distance to pollution sources threatens the groundwater source due to possibilities of horizontal movement of contaminants to the water source. Studies by Adekunle *et al.,* (2007), Joseph and David, (2011), Kiptum and Nbambuki, (2012) and (Tairu *et al.,* (2015), also reported higher FC counts in groundwater sources situated in a short distance from sanitary facilities. On the other case, the FC contamination of boreholes 1, 9, 14, 42, and 45 could be linked with poor water storage facilities as water was pumped into roof tanks which lack lids or covers, hence easy to receive contamination from different sources including flying birds.

E. coli contamination results showed that all sources contaminated with *E.coli* were also contaminated with FC (Appendix 1, 2 and 3), signifying a possibility of pollution originating from the same source, either septic system, domestic sewage or animal fecal matter as most of them were at close proximity to them (British Geological Survey, 2000). Furthermore, FC and

E.coli pollution of boreholes was likely due to lack of lid on the roof storage tank thereby allowing easy access of contaminants into the tanks as it was situated under a tree (field observations). Likewise, Sobsey *et al.,* (2003), reported on FC and *E.coli* contamination from storage containers in 84 % of all sampled water sources.

The overall results of coliform counts showed higher microbial contaminations were in shallow wells compared to the boreholes in both seasons. The higher microbial contamination is not accidental given the poor sanitation of the surroundings and most being poorly constructed, placed very close to sanitary facilities and human settlements (Appendix 1). Meanwhile, most of the settlements lack proper domestic waste discharge and pit latrines are commonly used hence their discharge may interfere with the underground aquifer thus leading to pollution of water sources.

3.4.2 Factors Facilitating Microbial Contamination

The results showed that factors like poor well cover/lid, use of bucket in withdrawing of water from source, and possession of wells with short depth (1-20 meter), appear to have significant impact on the level of microbial contamination in groundwater sources of the study area.

Shallow wells with the uncovered or partially covered well-mouths and those with gaps in their cover/lid had significant higher coliform contamination ($n=15,\ p\leq 0.01$) than those complete covered in both seasons (Table 9)**.** Concrete covers prevent the groundwater sources from receiving external contaminants such as surface runoff, windblown substances which may be carrying fecal matters from the surrounding environment. Study by (Mdoe and & Buchweishaija, (2014), in assessing the quality of groundwater from wells in squatter and non-squatter settlements in Dar es Salaam City- Tanzania, linked improperly covered wells with high colour values due to dissolved organic debris. The study by (Elisante & Muzuka, (2016b), associated 84 % of wells with gaps on their cover/ lid with high microbial contamination from storm water and dust from the surrounding environment. In the study area, the shallow wells with uncovered well mouth and situated under trees recorded relatively higher microbial contamination than the covered wells due to the fact that, the uncovered wells increase the possibility of getting fecal contamination from different sources such as flying birds or tree leaves which can easily introduce organic matters into water source which in turn increases turbidity levels and favours easy attachment of microbes to the suspended particles (Elisante & Muzuka, 2016b; Mdoe & Buchweishaija, 2014). A study by (Tairu, *et al.,* (2015), in South-western Nigeria reported high bacteria counts on uncovered wells (9.2 ± 0.49 CFU/100 ml) compared to those properly covered (1.40 ± 0.16 CFU/100 ml). Therefore, much emphasis has to be on improving the types of covers and the surrounding conditions of the well so as to improve the quality of water for domestic consumption.

Likewise, wells which use bucket as a means of water withdrawing had significant higher TC (*n=14,* $p \le 0.01$) and FC (*n=14,* $p \le 0.01$), than wells where the motor or hand pump were used. Use of a common bucket favor easy introduction of microbes from the surrounding environment depending on the hygienic condition of a place a bucket is kept (Cronin *et al.,* 2006; Kanyerere *et al.,* 2012). For example, wells 20, 21, 22, 23, 33, 34, and 46 which used bucket to withdraw water recorded extreme FC (> 100 CFU/100 ml) and *E.coli* (>30 CFU/100 ml) counts during both the dry and wet seasons **(**Appendix 2 and 3). The extreme mode of water collection was observed in well 33 during the peak of dry season when water well decreased and individual has to enter inside the well to collect water. Such behavior contributes to higher microbial contamination due to the re-introduction of microbes into the recharge from each person entering the well and from their buckets (Alex & Njau, 2020). Moreover, the poor sanitary condition of most of the wells such as lack of fence provides an opportunity for domestic animals such as cows, dogs, goats, and sheep to drink and defecate around the water source. Despite the recommendation by Tanzania Bureau of Standards (TBS, 2005b), on the importance of fencing water sources and prohibiting animal defecation around 50m radius from the water source, still most groundwater sources in the study area did not adhere to this regulation. This may enhance bacterial contamination to the water sources in case there is a crack or break in the well slab (CAWST, 2013).

Lack of proper wellhead (well mouth) elevation, seems to contribute to higher contamination in wells 33 (Plate 2c) and 21, recorded FC of 212 CFU/100 ml, 143 CFU/100 ml, and *E.coli* 250, 223 CFU/100 ml counts during dry and wet season respectively. Although TBS has not set a standard to be adhered to, however, 60 cm above ground level has been suggested elsewhere (CAWST, 2013). Normally, proper well head elevation prevents the entrance of surface runoff directly to the source hence lower contamination impact. Also, results by O’Connor, (2002), showed that poor wellhead completion played a role in the outbreak of the pathogenic strain of E. *coli* (O157: H7) in Walkerton, Canada.

Depth was also one of the factors contributing to high microbial count in the sources (Fig. 13). The significant decrease in TC and FC ($p=0.002$) due to depth was likely a result of retention by soil and rock as they naturally tend to filter bacteria as the flow along the source

(Kelly *et al.*, 2016). Similar results of high coliform contamination due to shallow depth were reported by other studies in other regions (Elisante & Muzuka, 2016b). Significant correlation of TC and *E.coli* ($p<0.001$) in borehole and shallow well during dry and wet season (Table 7), probably specified their common origin and transportation mechanisms.

3.4.3 Classification on contamination risky

According to WHO (1997), there are fifth risk categories on water quality which are based on FC counts. The first category; (0) CFU/100 ml- conform to WHO standards of drinking water, second category (1-10) CFU/100 ml- low risk, third category (10-100) CFU/100 ml- intermediate risk, fourth category (100-1000) CFU/100 ml high risk and fifth category (> 1000) CFU/100 ml –very high risk. Classification of groundwater sample based on FC counts as per WHO (1997), showed that most of the boreholes conform to WHO and relatively few were at low risk and very few at intermediate risk during the dry and wet seasons. Whereas most of the shallow wells were at intermediate risk and high risk during dry and wet seasons **(**Fig. 14). Such observation indicated that most waters from the shallow wells are unsuitable for drinking without prior treatment. Other studies on drinking water in Tanzania indicated very high risky (0-3000) CFU/100 ml from slopes of Mount Meru (Elisante & Muzuka, 2016b), high risky (25-124) CFU/100 ml in squatter and non-squatter areas of Dar es Salaam (Mdoe & Buchweishaija, 2014).

WHO (1997) reported that there are fifth risk categories associated with fecal contamination based on FC counts. The first category; (0 -10) CFU/100 ml- reasonable quality, (11-100) CFU/100 ml- polluted, third category (101-1000) CFU/100 ml- dangerous risk, fourth category (> 1000) CFU/100 ml very dangerous. Most of the water in boreholes of the study area produce the water of reasonable quality which can be consumed as they are, while shallow wells were dominated with polluted water which need to be treated before consumed. In wet season, shallow wells produce water of dangerous category which must be treated.

3.5 Conclusion

This study assessed the seasonal variations, abundance and factors contributing to microbial contamination in selected groundwater sources in the Singida and Manyoni Districts. Results revealed that there was higher coliform contamination during the rainy season, but mostly in shallow wells (1- 20 meters) than in boreholes due to, most of them being poorly constructed, situated in close proximity to the pollution source, lack proper well cover and use of buckets to withdraw water from the source. This observation corresponds well with the prevalence and outbreak of diarrhoea and cholera experienced in Singida and Manyoni Districts during the rainy season (http://dhis.moh.go.tz). Boreholes which are monitored by Internal Drainage Basin -Singida Urban Water Supply in Singida Region recorded zero FC nor did *E.coli* counts in both seasons as they all adhere to the TBS recommended guideline in regard to sitting, design and disinfection status. Also according to WHO risky category classification they all conform to the guidelines which require zero count on FC and *E.coli* per 100 ml, hence they are suitable for drinking purpose.

Therefore, based on the results, the study recommends timely chlorination of groundwater source and/or boiling of water before consumption. However, boiling and chlorination processes can be replaced by low cost technology such as sand filtration, which does not need electricity, chemicals, instead it use local materials i.e. gravel and sand which are readily available in the study area, and produce very high quality water with microbes removal up to 99%. In addition, maintaining of the clean and hygienic environment, fencing the sources and use of proper covers must be emphasized. However, assessing groundwater based on microbiological quality alone is not enough, as other contamination such as toxic metals may be present in a concentration that can be dangerous and toxic to human health hence study recommends for further analysis on heavy metals contamination in the same selected groundwater sources.

CHAPTER FOUR

Assessment of Toxic Metals in Selected Groundwater from Semi-Arid Districts of Singida Region, Tanzania

Abstract

The study examined the seasonal variation of toxic metals concentrations in the groundwater sources of Singida Region. The concentrations of Uranium (U), Lead (Pb), Aluminium (Al), Manganese (Mn), Chromium (Cr), and Arsenic (As) were analyzed using Inductively Coupled Plasma Optical Emission Spectrometer. The results were compared with the international (WHO) and local (TBS) drinking water standards to verify their suitability for drinking. Result showed there were significant higher concentrations for all the metals ($p<0.05$) in sample taken during the dry season than in those taken in the wet season possibly due to lack of dilution from rainfall. The comparison of the mean values of all metals, indicated that the intensity of metal contamination was from U > Pb > Al > Mn > Cr > As with mean concentration of 3.8 mg/L, 1.75 mg/L, 1.4 mg/L, 0.75 mg/L, 0.04 mg/L and 0.01 mg/L. Generally, 40- 66 % of all sampled had elevated levels of Mn, Cr, Pb and Al above the recommended standard by WHO and TBS. Relatively higher Uranium concentrations were in Manyoni groundwater sources than in Singida Urban due to the existence of granitic rocky. Geology of the area appears to be the natural source of most of the metals contamination of the groundwater in the study area. These results suggest that the sources with metal contamination above recommended standards are unsuitable for drinking purposes as they may pose a significant health hazards to the local community.

Key words: Borehole, shallow wells, contamination, health risk, toxic metals

4.1 Introduction

Proper water resources management requires identification of metals in sources that are used for drinking purposes due to their influence in the quality of groundwater and in human being. In Tanzania, the water required for human consumption should be free from chemical substances which may be hazardous to health (TBS, 2005). Groundwater is the principal natural water resources for agricultural, industrial, and domestic purposes in both arid and semi-arid zones of the world (Baumann *et al.*, 2005; Jordana & Batista, 2004). It is considered as an alternative safe drinking water supply because of the natural infiltration process which takes place in the subsurface. However, pollutants are being added to the groundwater sources through natural processes and human activities (EPA, 2001). Naturally, metals contamination in groundwater occurs when metal ion components in the soil or rocks leach preferentially and reach the groundwater (Huang *et al.,* 2013, 2014). While human activities such as mining, industrial, and agricultural activities may release metals which percolate the soil and reaches the groundwater and degrade its quality (Frisbie *et al.,* 2002; Mishra *et al.,* 2009; Sankhla & Kumar, 2019). It was therefore important to analyze the metals concentrations in groundwater sources which are used for drinking purpose for a better understanding of their levels.

Heavy metals are among the major contaminants of groundwater sources (Diamantis *et al.*, 2016; Järup, 2003; Mwegoha & Kihampa, 2010). Some of these metals that are present in groundwater play an important role in human health only when their concentration levels are within the permissible ranges. However, the consumption of water with metals above the recommended intake over a certain period of time may result in health effects (Arbor, 2013; Chowdhury *et al.,* 2016; Frisbie *et al.,* 2002; Järup, 2003; Nriagu *et al.,* 2012; Pandey *et al.,* 2010). Metals are categorized into various groups based on their toxicity: i) Toxic metals: these pose a great threat to human health and can induce multiple organ damage even at lower levels of exposure e.g. arsenic, lead, cadmium, chromium, selenium, barium, and mercury (Järup, 2003;TBS, 2005), ii) Trace elements: required by body in trace amount but become toxic at high concentrations e.g. manganese and iii) radioactive metals: these are subject to spontaneous degeneration of their nucleus e.g. uranium (ATSDR, 2011).

Some of the most common toxic metals that humans are exposed include Lead (Pb), Arsenic (As), Aluminium (Al), Uranium (U), and Chromium (Cr) (Buragohain & Bhuyan, 2010; Momodu & Anyakora, 2010; Wu *et al.,* 2015). The Higher intake of such metals through ingestion, inhalation, or drinking water over time may result in health disorders (Nyanda, 2014). For example, exposure to high levels of arsenic may lead to lung and skin cancer as it has been suspected to be a carcinogen (Karim, 2000). High levels of Pb from pesticides such as lead arsenate have been associated with hearing loss, blood disorders, and hypertension (Umar & Habibah, 2010), while chromium may cause gastric and liver diseases (Robles-Camacho & Armienta, 2000). On the other hand, the effect of Aluminum is linked to Alzheimer's disease (Flaten, 1990), and osteomalacia (Pierides *et al.,* 1980). It is therefore important to analyze the levels of concentration of metals in vast number of water sources which are used for consumption as their effect in water range from beneficial to dangerously toxic to human health (Adithya *et al.*, 2016; Luiz & Marcos, 2015; Wu *et al.*, 2014).

There has been an extensive exploitation of groundwater in Singida Region, and evidence exists of high levels of uranium (Baumann *et al.,* 2005; Kaishwa *et al.,* 2018; Nyanda, 2014). A pilot study conducted in Singida Urban showed existence of uranium and sulphate in some groundwater sources (Ministry of Water and Irrigation through Internal Drainage Basin- 2016 Report). Despite, the existing threats, there is still a lack of information on uranium, sulphate, and other toxic metals and their distribution in the study area due to limited studies.

It is therefore against this background that the study was carried out to determine the possible sources and contamination levels of U, Mn, Pb, As, Al, and Cr and their seasonal variations in selected groundwater sources of Manyoni and Singida Urban Districts and compare their concentration levels with the national and international organization standards recommended for drinking water.

4.2 Material and Methods

4.2.1 Description of the study area

The study was conducted in Singida Urban and Manyoni Districts in Singida Region**.** Singida Region is located in central Tanzania and it borders Shinyanga, Simiyu and Arusha Regions to the North, Manyara region to the East, Tabora Regions to the West and Dodoma, Iringa and Mbeya Regions to the South. The Region covers a total area of 49 438 km^2. The region can be classified as a semi-arid zone because it receives an annual rainfall averaging 650 mm (UNEP/FAO/UNESCO/WMO, 1977). The area experiences a unimodal type of rainfall during the months of December to March and sometimes extends to April. Singida Urban is divided into sixteen Wards and has an estimated population of about 150 379 people by 2012 with water demand of approximately 294 000 m^3/month while quantity produced is 256 322 m^3/month (SUWASA, 2014). The main sources of livelihood in this Region include livestock keeping and agricultural activities (URT, 2014a). The two districts mostly depend on boreholes and wells for domestic and drinking purposes

4.2.2 Sample collection

Water samples were collected from 53 groundwater sources (boreholes, shallow wells) from Manyoni and Singida Urban Districts during dry season (September – October 2015) and 53 sources in wet season (April 2016). The boreholes and shallow wells which are connected to motor pump, their samples were collected after pumping for at least two minutes so as to ensure collected water was fresh from the aquifer. Also, the shallow wells without installed pump, buckets were used for collection. Water samples for heavy metals analysis were collected in a 500 ml high density polyethylene bottles, filtered, acidified with supra pure nitric acid to pH<2 then refrigerated at 4°C before transported for storage in a 4°C refrigerator at the Water Quality Laboratory in Singida Urban and subsequently transported to the Southern and Eastern African Mineral Centre (SEAMIC) for toxic metals analysis.

4.2.3 Sample preparation and analysis

Digestion process was done to ensure removal of organic impurities and conversion of metals complex into free metal ions in water samples. To this end, 95 ml of water sample were boiled with 5 ml of 1 M HNO_3, to nearly dryness and then allowed to cool and finally filtered using filter fiber. After filtering the filter paper was rinsed thoroughly with distilled water to ensure no sample was lost. The filtered portion was then transferred into a volumetric flask and diluted to 100 ml with distilled water. The portion of this solution was used for the required metal determination in ICP-OES. Similar procedure was done for blank samples which acted as a control.

(i) Preparation of stock solution

A mixed standard solution of 50 mg/L was prepared by pipetting 5 ml of of U, Al, Mn, As, Pb and Cr from the 1000 mg/L bottle to 100 ml volumetric flask then diluted to mark with distilled water. Then working solution of various concentrations i.e., 0.25 mg/L, 0.5 mg/L, 1.0 mg/L, 2.0mg/L, and 5.0 mg/L were prepared by serial dilution with distilled water. A calibration curve was obtained from the standard samples obtained from the ICP-OES measurements. A blank determination was also done as a control.

(ii) Instrumentation

The ICP-OES was used to measure the concentration of each metal. Emission temperature was around 5726.85ºC (6000K) and the pump rate of 50 rpm for Nitrogen and Argon gas of 99.99% purity and auxiliary gas flow at 0.5 L/ min. were used.

(iii) Analytical Quality Assurance

Duplicate measurements for the metal concentrations of As, Al, Cr, Pb, Mn and U were done. The average concentrations of the metals were reported in mg/L. The wavelengths for the lamp of each metal measurement were 193.696 nm, 193.696 nm, 267.716 nm, 257.610 nm, 283.306 nm, and 591.5 nm for Al, As, Cr, Mn, Pb, and U, respectively. The limit of detection for all metal ions was 0.001mg/L (1 ppb). Linearity of the method and instrument was checked and recalibrated after every 10 samples. A blank determination was also done as a control. Also, the distilled water that was used for rinsing all the instruments and apparatus was tested to check if it is free from any contamination before use. Instruments were rinsed thrice with distilled water to ensure they are free from contamination.

Onsite measurement of temperature, pH, Total Dissolved Solids (TDS) and Electrical Conductivity (EC) were done using HANNA Multiparameter Model HI9829.

4.2.4 Statistical analysis

Descriptive statistics were used to characterize the concentrations of the metals and to examine the statistical variations between dry and wet seasons of all metals samples and Sigma Plot software version 11 was used to draw the histograms. Significant difference was considered when p value < 0.05. Pearson correlation coefficient (r) was used to find the strength of linear relationship between metals concentrations, pH, and temperature and significant difference was considered when p value < 0.05.

4.3 Results

4.3.1 Occurrence of metals in groundwater sources

The concentrations of toxic metals in different water sources during dry and wet season are presented in Appendix 2 and Appendix 3 respectively. Results for temperature, pH, TDS and EC have been reported and discussed in Chapter Two. The descriptive statistics summary (minimum, maximum, median, mean and standard deviation values) of U, Al, As, Cr, Mn, Pb, temperature and pH, analyzed during dry and wet seasons are shown in Table 10 and 11.

Table 10: Statistical summary of metal concentrations, pH, and temperature in the boreholes and shallow wells during dry season

	WELLS	BOREHOLES

Parameters	Min.	Max.	Median	Mean	SD	Min.	Max.	Median	Mean	SD
U	BDL	4.50	3.40	3.30	0.70	BDL	4.30	2.60	2.70	1.00
Al	BDL	6.20	0.90	1.40	1.20	BDL	3.50	1.00	1.40	0.90
As	BDL	0.17	0.10	0.10	0.00	BDL	0.10	0.10	0.10	0.00
Cr	BDL	0.40	0.40	0.40	0.00	BDL	0.40	0.40	0.40	0.00
Mn	BDL	1.30	0.80	0.80	0.20	BDL	1.40	0.60	0.70	0.20
Pb	BDL	2.10	1.80	1.80	0.20	BDL	2.00	1.80	1.70	0.20
Temperature	21.10	28.10	25.20	24.70	1.90	24.70	30.90	26.00	26.50	1.40
pH	4.40	8.70	6.40	6.40	0.90	6.10	8.10	7.20	7.20	0.60

All parameters were in mg/L except pH has no value, Temperature in °C. Min. = minimum, Max. = maximum, SD= standard deviation. U = uranium, Mn= Manganese, Pb= lead, As= Asenic, Cr= chromium, Al= Aluminium.

During dry season, the concentrations of U ranged from below the detection limit (BDL) to 4.5 mg/L with an average of 3.3 ± 0.7 mg/L in wells and 2.7±1.0 mg/L in boreholes, while in wet season it were BDL to 0.1 mg/L and BDL to 0.05 mg/L in wells and boreholes, respectively.

Table 11: Statistical summary of metal concentrations, pH, and temperature in the boreholes and shallow wells during the wet season

	WELLS					BOREHOLES				
Parameters	**Min.**	**Max.**	**Median**	**Mean**	**SD**	**Min**	**Max**	**Median**	**Mean**	**SD**
U	BDL	0.10	0.03	0.04	0.04	BDL	0.05	0.03	0.02	0.01
Mn	BDL	0.33	0.02	0.10	0.08	BDL	0.28	0.02	0.05	0.07
Temperature	22.70	28.50	25.10	25.0	1.30	22.7	28.8	26.2	26.3	1.20
pH	5.40	8.70	6.80	6.80	0.70	5.80	7.90	7.10	7.00	0.60

All parameters were in mg/L except pH has no value, Temperature in °C. Min = minimum, Max = maximum, SD= standard deviation, U = uranium, Mn = Manganese

Cr concentrations ranged from BDL to 0.4 mg/L in boreholes and wells during dry season with a mean concentration of 0.4 mg/L. The Mn concentrations in dry season ranged from BDL to 1.4 mg/L from the mean concentration of 0.8 ± 0.2 mg/L and 0.7 ± 0.2 mg/L in wells and boreholes respectively. During the wet season, Mn ranges from BDL to 0.33 mg/L with an average of 0.10 ± 0.08 mg/L in wells and 0.05 ± 0.07mg/L in boreholes. Arsenic levels in dry season ranged from BDL to 0.17 mg/L in shallow wells with an average of 0.1 mg/L and in boreholes from BDL to 0.1 mg/L with an average of 0.1 mg/L. Lead concentrations ranged from BDL to 2.1 mg/L with an average of 0.8 ± 0.2 mg/L in wells while in boreholes ranged from BDL to 2.0 mg/L with an average of.78 ± 0.2 mg/L. Aluminum concentrations ranged from BDL to 6.2 mg/L in wells with an average of 1.4 ± 1.2 mg/L and in boreholes it ranged from BDL to 3.5 mg/L with an average of 1.4 ± 0.9 mg/L during dry season. The concentrations of Cr, Pb and As were below detection level during wet season (Table 10 and 11).

4.3.2 Metals concentration trend in wet and dry seasons

A significant higher metals contamination (*n=53, p<0.05*) was observed in dry season than in wet season and the trend of all the metals contamination measured were from U > Pb > Al > Mn > Cr > As with mean concentration of 3.8 mg/L, 1.75 mg/L, 1.4 mg/L, 0.75 mg/L, 0.04 and 0.01 mg/L respectively. That means during the dry season, arsenic was present in very low concentrations 0.01 mg/L followed by Cr, Mn, Al, Pb and U. Conversely, in the wet season the concentrations of Cr, As, and Pb were below detectable levels i.e. < 0.001 mg/L while the mean concentration of U was 0.03 mg/L which is relatively lower than that of Mn (0.03) mg/L (Fig. 16).

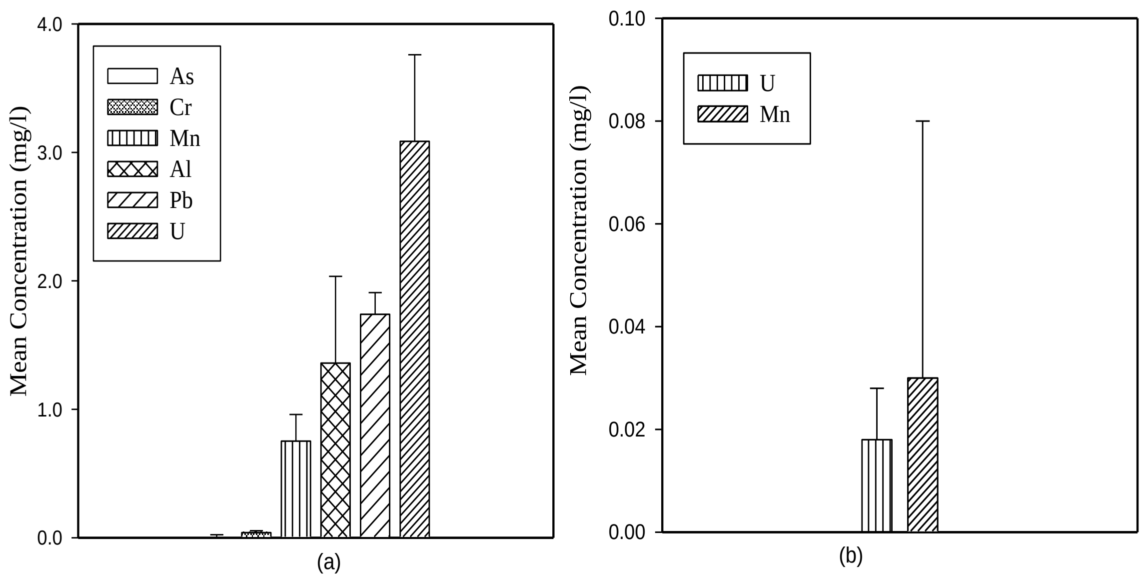


Figure 16: Mean concentrations of As, Cr, Mn, Al, Pb, and U in (mg/L) in the boreholes and shallow wells during (a) dry season and (b) Mean concentrations of Mn and U in (mg/L) in the boreholes and shallow wells during wet season

During dry season, 45% of all samples had U concentrations above WHO standards for drinking water. While in the case of Cr, Pb and Al, 66% of all samples recorded concentrations above TBS and WHO standards. Also, 42% of all samples had arsenic concentrations above TBS and 60% of all samples had As levels above WHO standards respectively. The Mn concentrations above the recommended standards by WHO and TBS, were observed in 64 and 65% % of all samples recorded respectively. During wet season, 19% of all sample had U concentrations above WHO standards respectively, while 14% and 19% of all samples exceeded the TBS and WHO standards for Mn concentrations in drinking water (Table 12).

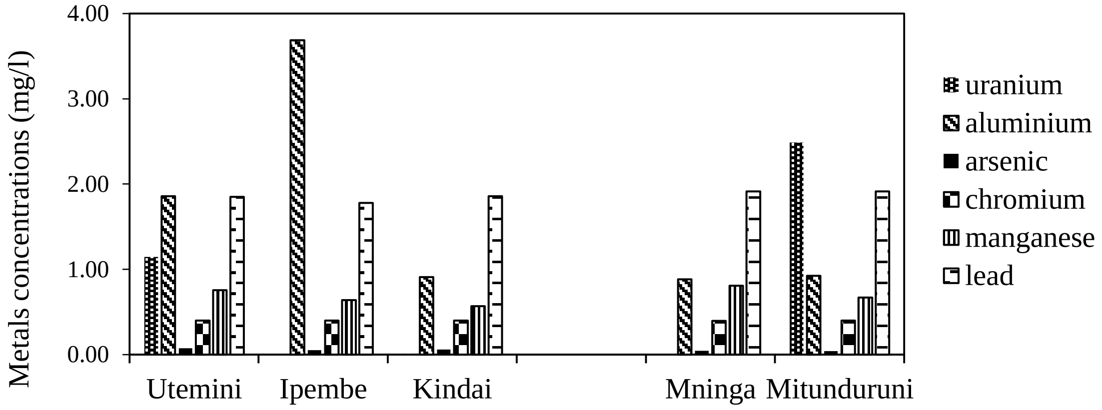
Table 12: Ranges of metals concentrations during dry and wet seasons compared with TBS and WHO Standards and the number of groundwater sources in % that exceeded the WHO and TBS permissible limit

Metal (mg/L)	Dry Season Range	Wet Season Range	TBS 2005 (mg/L)	WHO 2006 (mg/L)	Samples (%) exceeded TBS	Samples (%) exceeded WHO
U	BDL- 4.49	BDL- 0.10	NA	0.02	NA	45
As	BDL- 0.17	BDL	0.05	0.01	42	60
Cr	BDL - 0.44	BDL	0.05	0.05	66	66
Mn	BDL - 1.38	BDL- 0.33	0.5	0.4	64	65
Pb	BDL - 2.12	BDL	0.1	0.4	66	66
Al	BDL - 6.20	NIL	NA	0.03	NA	66
pH	4.43 - 8.71	5.4- 8.69	6.5 - 9.2	6.5- 9.5	NIL	NIL

BDL = Below Detected Limit NA = No set standard, NIL = no sample, except for pH all values are in mg/L. U = uranium, As = Arsenic, Cr = chromium, Mn = Manganese, Pb = Lead, Al = aluminium

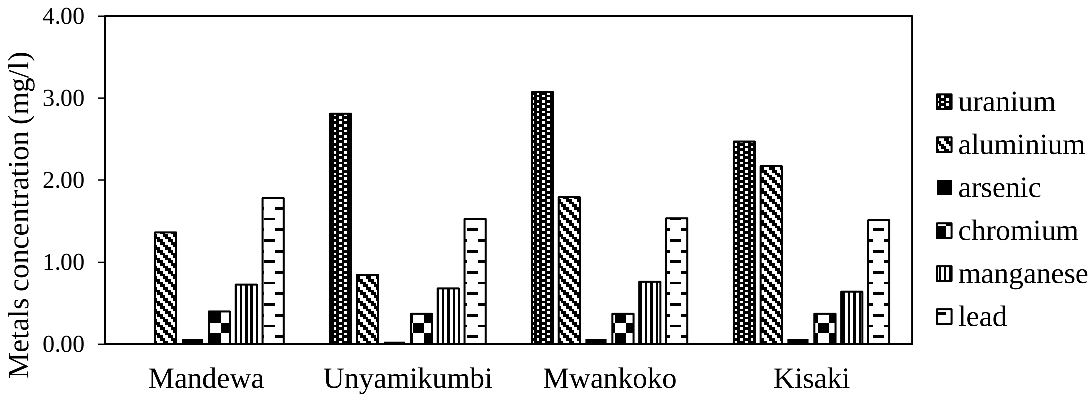
4.3.3 Distribution of Metals in the Study Area

Comparison of metal concentrations in town and peri-urban, showed that the wards recorded highest metals concentrations were Ipembe, Mitunduruni, Utemini, Kindai, Unyamikumbi in Singida Town while in peri-urban were Mwankoko and Unyamikumbi wards during dry season (Fig. 17).



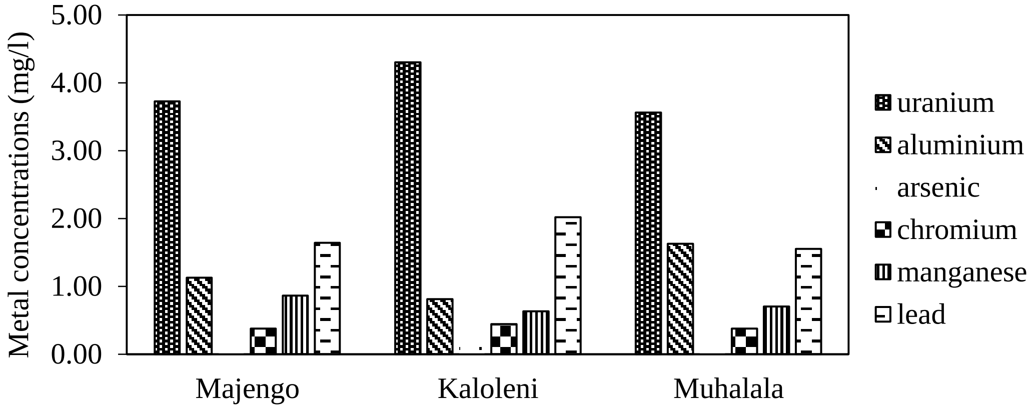
(a) Singida Town Wards

(a)



(b) Singida peri-urban wards

(b)

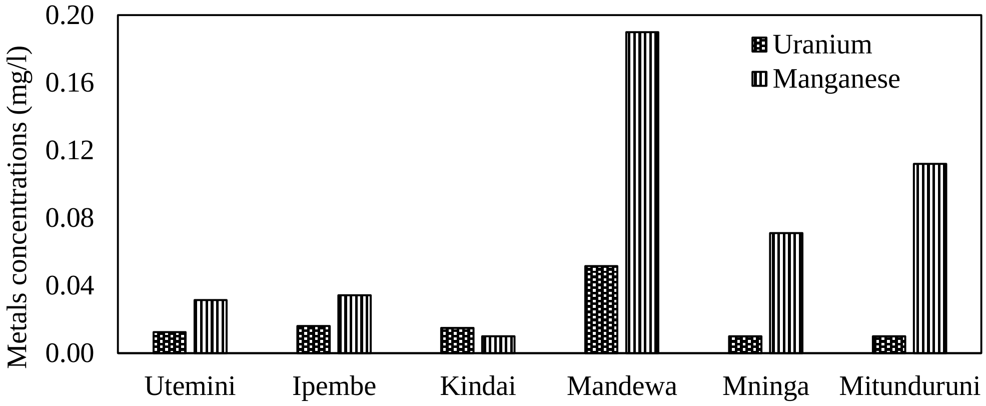


(c) Manyoni Town and peri-urban wards

(c)

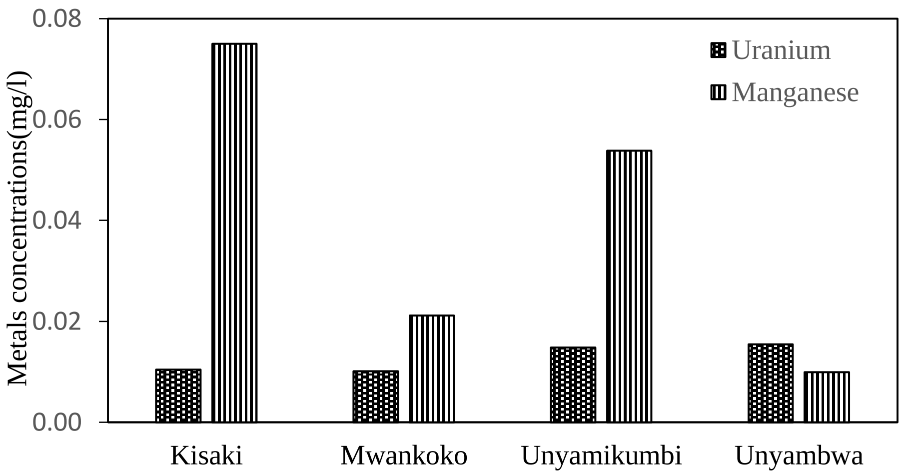
Figure 17: Concentrations of U, Al, As, Cr, Mn and Pb in (mg/L) in (a) Singida Urban (b) Singida peri-urban (c) Manyoni town and peri-urban wards during dry season

The highest concentrations of U and Mn in wet season were recorded in Mandewa ward of Singida Town and in Kisaki and Unyamikumbi from peri-urban wards and Majengo in Manyoni District. (Fig. 18**).**



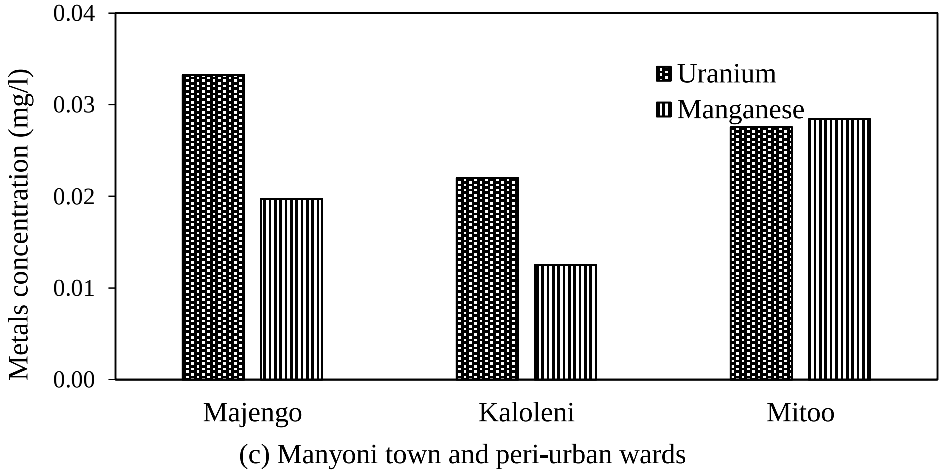
(a) Singida town- wards wet

(a)



(b) Singida peri-urban wards

(b)



(c)

Figure 18: Concentrations of U and Mn in (mg/L) in (a) Singida Urban (b) Singida peri-urban (c) Manyoni town and peri-urban wards during wet season

The concentrations of U was significantly higher (*n=53, p ≤0.05*) in dry than in the wet seasons, ranged from < 0.001 to 4.49 mg/L with an average of 3.0 ± 0.85 mg/L and during the wet season it ranged from below <0.001) to 0.1 mg/L with an average at 0.03 ± 0.025 mg/L (Fig. 19).

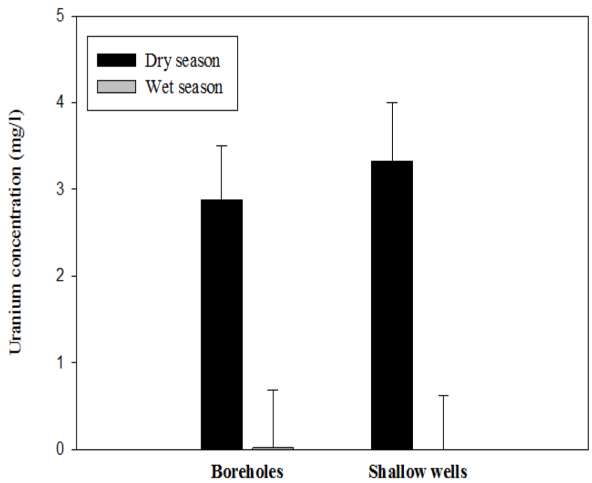
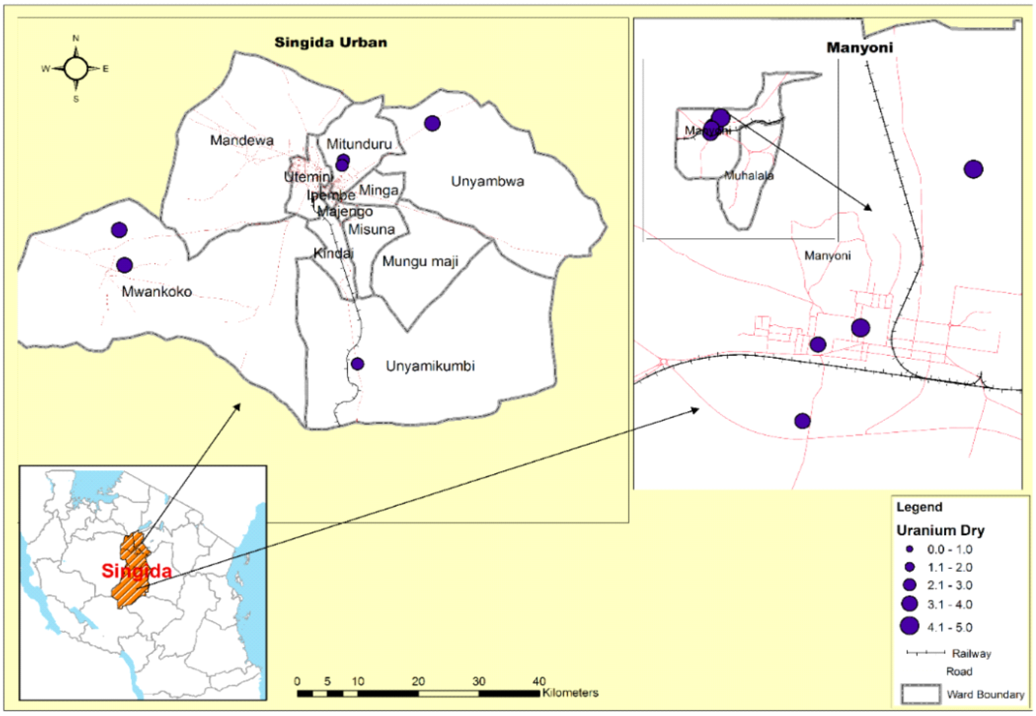
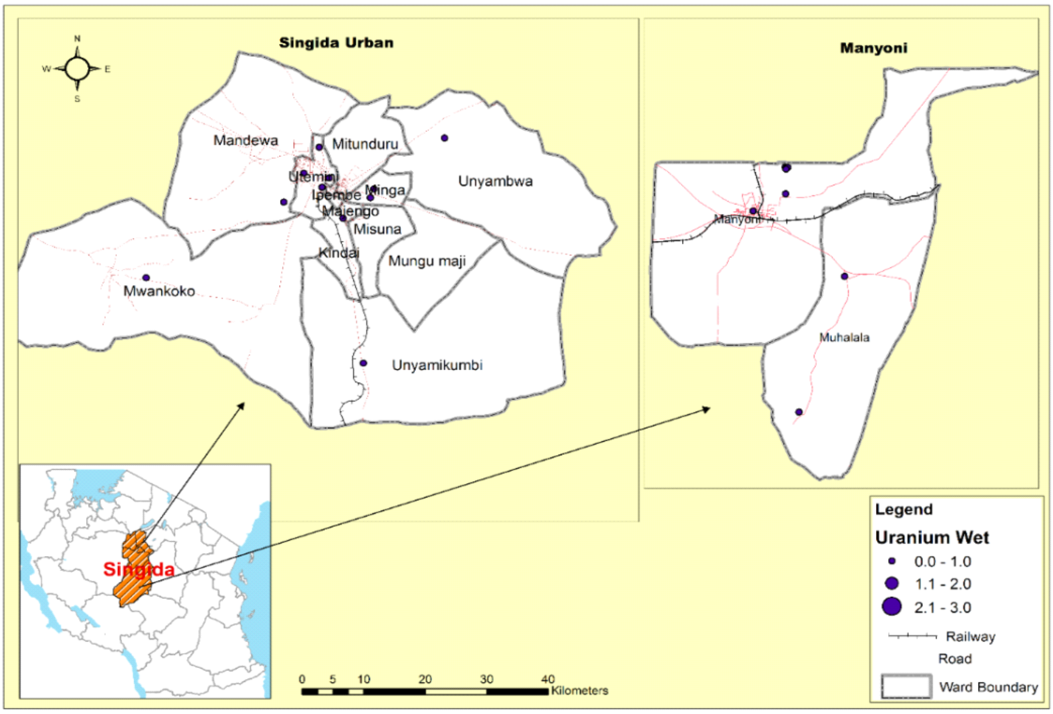


Figure 19: Uranium concentrations (mg/L) in boreholes and shallow wells during dry and wet seasons

Uranium distribution in different sampling points showed that during dry season, relatively higher U concentrations were observed in Manyoni District than Singida Urban (shown with bigger blue dots) compared to small dots (Fig. 20).



(a)



(b)

Figure 20: **Distribution of Uranium in boreholes and shallow wells of the study area during (a) dry season and (b) wet season. The blue dots represent U concentrations (mg/L)**

Wards recorded highest Al, U and Mn were, Ipembe, Kaloleni and Majengo respectively during dry season. On the side of wet season highest U and Mn concentrations were recorded in Mandewa ward (Fig. 17 and 18).

Table 13: Kruskal-Wallis test comparing Mn concentrations (mg/L) in boreholes and shallow wells during dry and wet season

Comparison of variables in different seasons	p value	Significant level
Shallow wells in dry *vs* wet seasons	$p \leq 0.001$	significant
Shallow wells *vs* boreholes in dry season	$p \geq 0.05$	not significant
Shallow wells in dry season *vs* boreholes in wet season	$p \leq 0.001$	significant
Shallow wells in wet season *vs* boreholes in dry season	$p \geq 0.05$	not significant
Boreholes in dry season *vs* wet season	$p \leq 0.001$	significant

p is significant at ≤ 0.05, *vs* = versus

Kruskal-Wallis comparison test showed that, there was very high Mn concentrations in shallo wells during dry season than in boreholes in wet season, shallow wells in dry versus wet seasons, boreholes in dry season versus wet season, *(n=26, $p \leq 0.001$)* (Table 13).

4.3.4 Correlation analysis between metals

The correlation analysis between metals was performed to assess their relationship (Table 4.5). Correlation results showed that, there was positive very strong correlation between Cr and Pb ($p=0.2\times 10^{-11}$), and moderate positive correlation between As and Cr *(p=0.03)* (Table 14).

Table 14: Pearson correlation coefficient matrix on pH and metals concentrations (mg/L) in boreholes and shallow wells during dry and wet seasons

Parameter	Correlation coefficient in dry season						Correlation coefficient in wet season	
	U	**Al**	**As**	**Cr**	**Mn**	**Pb**	**U**	**Mn**
pH	-0.1	-0.2	-0.2	0.0	-0.2	0.1	0.0	-0.2
U	0.1	-0.1	0.2	0.0	0.1	-0.2	1.0	0.1
Al	-0.1	1.0	1.0	0.0	-0.1	-0.1	BDL	BDL
As	0.2	0.1	1.0	**0.4**	0.0	0.2	BDL	BDL
Cr	0.0	0.0	**0.4**	1.0	-0.2	**0.8**	BDL	BDL
Mn	0.1	-0.1	0.0	-0.2	1.0	0.0	0.1	1.0
Pb	-0.2	-0.1	0.2	**0.8**	0.0	1.0	BDL	BDL

Significant relationship was observed at *$p < 0.05$*, number of sample (n) = 36, bolded numbers shows sample with significant correlations. BDL = Below Detected Limit. Except for pH all values are in mg/L. U = uranium, As = Arsenic, Cr = chromium, Mn = Manganese, Pb = Lead, Al = aluminium

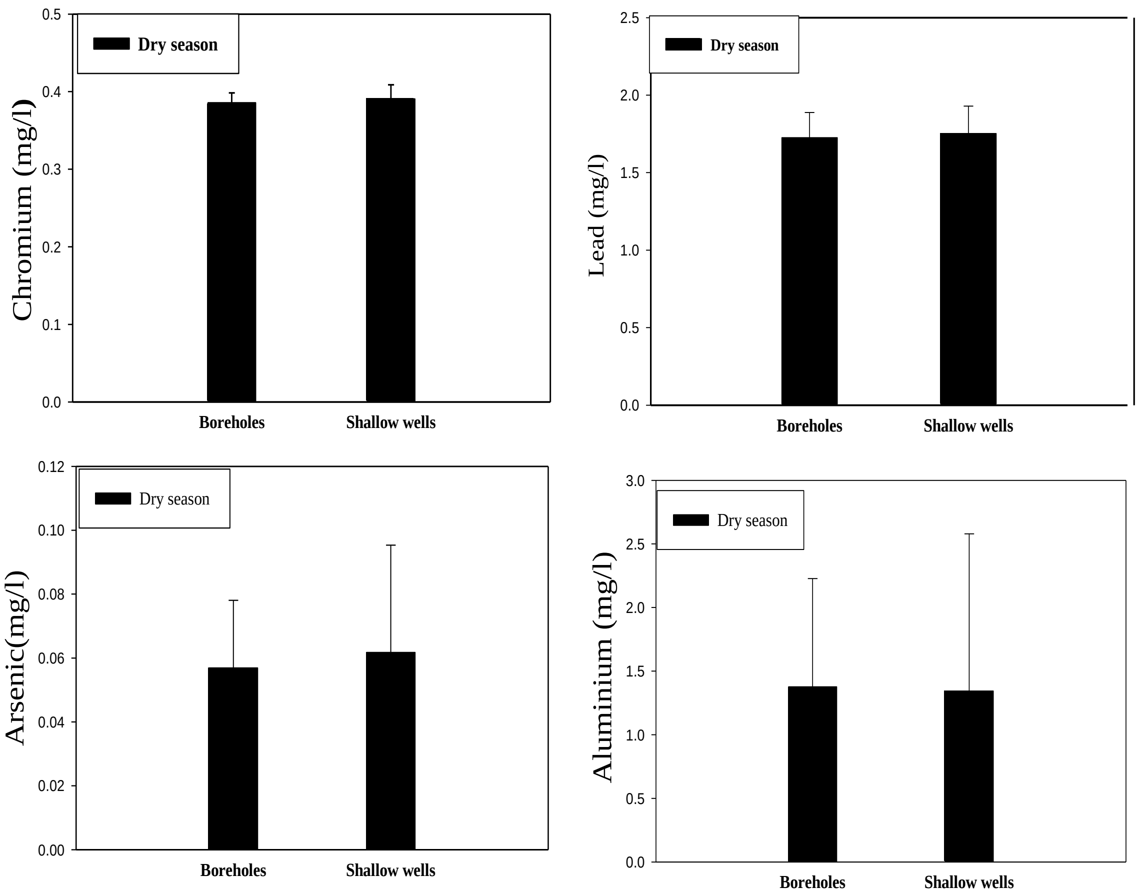


Figure 21: **Mean concentrations of (a) Cr (mg/L) (b) Pb (mg/L) (c) As (mg/L) and (d) Al (mg/L) metals in boreholes and wells during dry season**

4.4 Discussion

4.4.1 Metals contamination in groundwater

Generally, the concentration of U, Al, Mn and Pb in the study area showed wide concentrations range during dry season indicating that metals contamination varied from place to place. Additionally, the overall results showed higher values for all toxic metals concentrations were obtained in the dry season due to concentration effect. Similar results of higher concentrations of Pb, As, Cd, and Al during dry season was reported by Buragohain & Bhuyan, (2010). During dry season, the intensity of metals contamination based on their mean values were from U > Pb > Al > Mn > Cr > As, meaning that U had the highest contamination and As had smallest contamination (Fig. 16).

Arsenic in drinking water has been a great problem in several parts of the World including India (Buragohain & Bhuyan, 2010), Bangladesh (Karim, 2000), USA (Magdo *et al.,* 2007), Peru (de Meyer *et al.,* 2017), and Vietnam (Berg *et al.,* 2001). In this study, As had the lowest concentrations among all metals in the study area, yet 60 % of all sampled sources had arsenic above the recommended levels by WHO and 42 % above TBS standards for drinking water. Such high As concentrations might be attributed by natural dissolution of rock or soil (EPA, 2001). Other sources of As in study area could be from agrochemicals like phosphate fertilizers or pesticides (Fu, *et al.,* 2014)(Aziz & Moneim, 2016). Phosphate fertilizers were commonly used in some parts of the study areas. However, more research is needed to confirm if the phosphate fertilizers used has As content. Study by Wu *et al.,* (2015), linked As contamination in soil solution with phosphate fertilizers mainly the TSP (triple superphosphate). Additionally, the existed strong correlation between As and Cr *(n=36; r=0.4)* may reflect identical behaviour of metals, mutual dependence and/or similar levels of contamination released from the same sources of pollution (Huang *et al.,* 2014; Wu *et al.,* 2015).

The mean concentration of Cr in the study area was 0.4 mg/L, possibly leaching from ore deposit. A Study by Pokkate *et al.,* (2012) reported maximum Cr concentrations of 0.03 mg/L from groundwater sources in Thailand, which was below 0.05 mg/L of WHO standards suggesting an acceptable level of non-carcinogenic adverse health risk. However, in this study, 66 % of all samples recorded concentrations above WHO and TBS standards thus posing health risks to the surrounding community because they are used for drinking purposes.

Significant higher Mn concentrations ($p \leq 0.0001$) during the dry season is likely due to dissolution from rock materials after contacting water for a long period (ATSDR, 2005), and the decreased in concentrations during wet season was due to dilution from rainfall. Moreover, the highest concentration of Mn (1.58 mg/L) measured at borehole 58 which had a depth of 100 meters was probably leaching from ore deposit and facilitated with the existence of low pH (5.0 - 5.5) in the study area. Low pH tends to enhance the dissolution of manganese from ore and causes unpleasant taste in water (ATSDR, 2005).

Higher Al concentrations observed compared to Mn, Cr, and As (Fig. 16) in the study area, specifically in Ipembe and Utemini wards were probably due to low pH of a study area that favors its leaching from soil and dissolution from natural deposit, since other potential related sources of Al in the study area such as, industrial waste, fossil fuel, and mining activities were not practised (Srinivasan *et al.,* 1999). Continuous exposure of Al in drinking water may result in neurological disorders such as Alzheimer's disease (Momodu & Anyakora, 2010; Srinivasan *et al.*, 1999).

Lead was the second metal among all six metals with higher contamination in the study area and 66 % of all sources had concentrations above the WHO and TBS standards for drinking. Such higher contamination suggests the possibility of being mobilized from natural or plumbing systems especially pipes and fittings which contains lead (Brian *et al.,* 1999). A study by Brian *et al.,* (1999), found significant higher concentrations of Pb in groundwater sources cased by iron and steel than in PVC-cased wells due to the different capacity in leaching out Pb. Furthermore, the strong positive correlation between Pb and Cr concentrations ($r= 0.8, p =1.99^{-11}$)**,** indicates the possibility of being originating from the same source. Health wise, long term exposure to Pb may cause kidney damage or cancer as Pb has been considered to be carcinogen due to sufficient evidence of animal carcinogenicity (Frisbie *et al.*, 2002; Järup, 2003).

Uranium recorded the highest concentrations of all metals in the study area during dry season and relatively higher concentrations were from Kaloleni and Majengo wards of Manyoni District probably due to the existence of granitic rocky in the area (Kaishwa *et al.*, 2018; Nyanda, 2014). Granite rocks are the primary source of U and release it during weathering. The released metal may potentially elevate its concentrations in groundwater due to water-rock interactions. Study by Kaishwa *et al.,* (2018), showed that the uranium levels found in the groundwater sources of Bahi, Manyoni, and few sources in Singida town were originating from the soil and rock deposit. Furthermore, the significant higher U concentrations observed in shallow wells than in boreholes ($n=17, p\leq0.05$) in Manyoni District were probably due to U deposits in Manyoni which are mostly found in shallow depth (Nyanda, 2014). Report by USA-Center for Diseases Control suggests the same that shallow wells are likely to have elevated levels of uranium than boreholes in granitic areas(Fawell & Nieuwenhuijsen, 2003). Several studies have reported higher U level in groundwater leaching from natural deposits (Jordana & Batista, 2004; Luiz & Marcos, 2015; Magdo *et al.*, 2007; Nriagu *et al.*, 2012). On the other hand, uranium recorded from SW 51, BH 50, 52, and 58 during dry season could be associated with agricultural run-off.

For example, SW 51 had poor wellhead elevation that set it on a high risk of receiving runoff from surroundings particularly from agricultural areas where phosphate fertilizers rich in U is commonly used. Phosphate fertilizers contain various toxic metals including Uranium which tend to accumulate in the soil and leach into groundwater sources during the rainy season

(Dissanayake & Chandrajith, 2009). Phosphate fertilizers are produced in a factory situated 200 km from Singida Region thus creates a possibility of being easily distributed and used for agricultural activities as they are available to most farmers through the government subsidy programme. A study by Makweba and Holm, (1993), in Tanzania, showed U concentrations correlates with superphosphate, triple superphosphate, and phosphogypsum concentrations in phosphate fertilizers. Studies by Yamazakia, (2003), associated U contamination in soil and groundwater with the long-term use of phosphate-based fertilizers. Uranium above recommended level by WHO was detected in 45% and 19 % of all sources during dry and wet seasons, making them unsuitable for drinking purposes. Exposure to elevated levels of Uranium in drinking water may lead to cancer, kidney or lungs, problems in human (Magdo *et al.,* 2007). Unfortunately, there were no epidemiological studies to relate the diseases and observed uranium exposure. Therefore, further investigation and proper mitigation plans on the drinking water supply sources should be conducted.

4.4 Conclusion

Results of the metal contamination showed 40-66 % of all groundwater sources were unsuitable for drinking due to high concentrations of Mn, Cr, Pb, and Al, above recommended standards by WHO and TBS. The overall metal pollution was higher during the dry season due to lack of dilution from rainwater. Results also suggest a possibility of the geology of the study area being the major contributor of the observed metal concentrations in the groundwater of the study area. The suggestion is supported by an exploration work conducted in Singida which confirmed the presence of high Uranium deposits in Manyoni region (Nyanda, 2014). Despite the high contamination reported, two main boreholes i.e. Mwankoko and Erao that supply domestic water to the majority of the population in Singida town recorded value below WHO and TBS standards for drinking purposes hence remain suitable for drinking purposes.

The study also recommends geological mapping of the whole region should be done so as to understand, areas with high metals concentration and to avoid them in future drilling plans. Future focus should be on constructing private shared boreholes instead of everyone having his/her well on already contaminated cite. Also, deep > 50 m depth avoid metals such as uranium which are found in shallow depth. Despite the identification of metals concentrations in the study area, analysis of the nutrients contamination in groundwater sources is important in safeguarding human health.

CHAPTER FIVE

Assessment of Sources of Nitrate Contamination in Groundwater Aquifers of Singida Urban and Manyoni -Tanzania

Abstract

Nitrate isotopic values are often used as a tool to identify sources of nitrate in order to effectively manage groundwater quality. In this study, the concentrations of NO_3^-, NO_2^- and NH_4^+ from 50 boreholes and shallow wells in Singida and Manyoni Districts were analyzed during dry and wet seasons, followed by identification of nitrate sources using hydro-chemical method (NO_3 /Cl^-) and stable isotope ($\delta^{15}N$ and $\delta^{18}O$) techniques. Results showed that, NO_2^- and NH_4^+ concentrations were very low in both seasons due to nitrification process. The concentrations of NO_3^- ranged from 2.4 mg/L to 929.6 mg/L with the mean values of 118.5 mg/L ± 118.5 mg/L, during dry season and from 2.4 mg/L to 1620.0 mg/L with mean values of 171.6 mg/L ± 312.3 mg/L, during wet season. The higher NO_3^- contamination observed in the wet season could be due to rainfall which accelerated surface runoff that collects different materials from various settings into the groundwater sources. Nitrate sources identification through hydro-chemical technique revealed that most nitrates originated from sewage effluents and/or organic wastes such as manure. Likewise, the mean value of $\delta^{15}N$-NO_3^- (+20.90 0 ± 5.17 ‰) and (+18.30 ‰ ± 6.33‰) and the mean values of $\delta^{18}O$-NO_3^- (+13.86 ‰ ± 3.18 ‰) and (+13.69 ‰ ± 3.97 ‰), suggest that 80 % of boreholes and 52 % of shallow wells were dominated with nitrate from sewage effluents and/or manure as most groundwater sources were situated in densely populated areas with congested and poorly constructed onsite sanitation facilities such as pit latrines and manure. Therefore, to reduce the nitrate pollution in the study area, a central sewer must be constructed to treat the discharged wastes. Groundwater harvesting should also consider the proper principles for groundwater harvesting recommended by the respective authority to minimize the chance of contamination, hence prevention of health risk.

Key Words: Nitrate, nitrite, ammonium, groundwater contamination, isotope.

This chapter is based on a published paper:

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Geofluid – Hindawi, http://dx.doi.org/10.1155/2021/6673013

5.1 Introduction

Globally, nitrate is among the common contaminants in the groundwater and surface water, (Anornu *et al.,* 2017; Lohse *et al.,* 1996; Mahler *et al.,* 2007). It is extremely soluble in water and tends to be adsorbed in soils or leaches easily and elevate its concentrations into groundwater sources (Council *et al.,* 2015; Elisante & Muzuka, 2015b; Ohte *et al.,* 2008; Xue *et al.,* 2009). The elevated nitrate concentrations in groundwater are a significant threat facing water resources as they compromise water quality (Chen *et al.,* 2006).

The presence of high nitrate concentrations in water and food poses a serious risk to human health as nitrate has been linked to stomach, gastrointestinal cancers, hypertension and methemoglobinemia in newborn infants (Kazmi & Khan, 2005; Knobeloch *et al.,* 2000; Shuval & Gruener, 1977). In an aquatic environment, high nitrate concentrations may lead to nutrients enrichment that affects the ecosystems and general deterioration of water quality (Burns *et al.,* 2004; Fawell & Nieuwenhuijsen, 2003;Järup, 2003). As a result of these health concerns, the World Health Organization (WHO) has recommended that the maximum nitrate concentration level in drinking water to be 50 mg/L (WHO, 2010).

In Tanzania, a review study by Elisante and Muzuka (2015), reported higher nitrate concentrations in groundwater sources that exceeded the recommended WHO limits (50 mg/L) due to increased anthropogenic activities (in Tanga (up to 747 mg/L), Dar es Salaam (up to 477.6 mg/L), Dodoma (up to 441.1 mg/L) and Arusha (up to 180 mg/L). However, the measurement of nitrate concentrations alone does not address the problem of nitrate pollution in groundwater sources effectively. To this end, identification of the origin of nitrate pollution must be conducted for proper protection of groundwater sources.

The Isotope technique is among the approaches that have successfully been used to identify different sources of nitrate in groundwater (Anornu *et al.,* 2017; Marjorie *et al.,* 2010; Choi *et al.,* 2007; Heaton *et al.,* 2006; Ohte *et al.,* 2008; Wankel *et al.,* 2006; Xue *et al.,* 2009). This is because nitrates from different sources carry distinct N and O isotopic composition which behave conservatively (Kendall and Aravena, 2000). In this technique, nitrogen-isotope ratios ($\delta^{15}N/\delta^{14}N$) of nitrate from different environments are compared with the nitrogen-isotope ratios of nitrate in groundwater. In most cases, these sources produce nitrate with distinguishable ($\delta^{15}N/\delta^{14}N$) ratios. For example, $\delta^{15}N$ values from -1‰ to +2‰ are commonly for synthetic fertilizers, +2‰ to +8‰ for soil organic nitrogen and, +8‰ to +20‰ for livestock waste and sewage (Kendall & McDonnell, 1998; Panno *et al.,* 2001; Xue *et al.,* 2009). Nevertheless, the δ ^{15}N ranges of some nitrate sources are wide and tend to overlap resulting in ambiguous results (Aravena *et al.*, 1993; Kendall & McDonnell, 1998).

Therefore, due to that ambiguity, the dual (combined) isotope of (δ^{15}N and δ^{18}O) of nitrate has been used for proper identification of nitrate sources (Chen *et al.*, 2006), because the two oxygen atoms in nitrate are derived from water and one derived from the air during microbial nitrification. Several studies have used δ^{15}N analysis to evaluate sources of nitrate in areas where industrial fertilizers, agricultural activities, livestock keeping and animal waste (manure) were potential sources of nitrate (Marjorie *et al.*, 2010; R. Aravena & Robertson, 1998; Burns *et al.*, 2004; Elisante & Muzuka, 2015b; Kaown *et al.*, 2009; Kreitler & Browning, 1983; Ohte *et al.*, 2008; Panno *et al.*, 2001; Wankel *et al.*, 2006). Also, other methods such as hydrochemistry have been used in understanding the origin of nitrate in various groundwater (Anornu *et al.*, 2017). In this study dual-isotope and hydrochemistry (nitrate-chloride molar ratios) techniques were used to unequivocally identify the origin of the nitrate contamination in groundwater sources in Singida Urban and Manyoni Districts where groundwater is the main domestic water supply.

Therefore, this study aimed to determine the concentrations of nitrate, nitrite, and ammonium from selected groundwater sources during the dry and wet season, and identify the sources of nitrate contamination. The results of this study will provide useful information on the quality status of groundwater contamination in the semi-arid region for both local users and decision-makers. The knowledge acquired from this study will help them to implement efficient strategies on the protection and management of groundwater sources.

5.2 Materials and methods

5.2.1 Description of the study area

Singida region is located in a semi-arid zone of central Tanzania. It is bordered to the north by Arusha Region, east with Dodoma, west with Tabora and south with Mbeya, and Iringa Regions. The region covers a total area of 49 438 km^2. In the 2014 Tanzania National Census, the reported population of Singida was 1.4 million with a population growth rate of 2.3 % per year (URT, 2014a). It is classified as a semi-arid zone because of a unimodal type of rainfall. The annual rainfall is about 600 - 650 mm which starts from December to April (Kashaigili, 2012). This study was conducted in two districts of Singida Region namely Manyoni and Singida Urban (Fig. 22). The major land-use activities in the Region include livestock keeping and crop agricultural. The livestock wastes (dung) are commonly used as manure during farming. The soil characteristics in this region are sandy type. The geology of the Region shows that, the water-bearing rocks in Singida are predominantly weathered with fractured granites/gneisses that allow potential infiltration and leaching of liquid wastes (British Geologically Survey, 2000), hence the vulnerability of the groundwater sources to contamination from anthropogenic activities in the region.

About 70 % of the population in Singida Urban District depends on two main boreholes for water supply while 30 % use water from unknown sources (Singida Urban, Water and Sanitation Authority- report). Moreover, the study area suffers from poor water hygiene and sanitation services. The area has poor sanitation practice due to open defecation, presence of poor onsite sanitation facilities which both threaten the groundwater quality through filtration and leaching. Pit latrines are the predominant sanitation facilities used in rural and peri-urban areas with some instances of open defecation (SUWASA, 2014). Privately owned vacuum trunks collect domestic wastewater and sludge from onsite sanitation facilities such as cesspit once full and dispose in an open space near Lake Kindai which is about 9 km from town. The reliance on pit latrines coupled with lack of proper disposal site for treatment facilities pose a significant risk to groundwater sources.

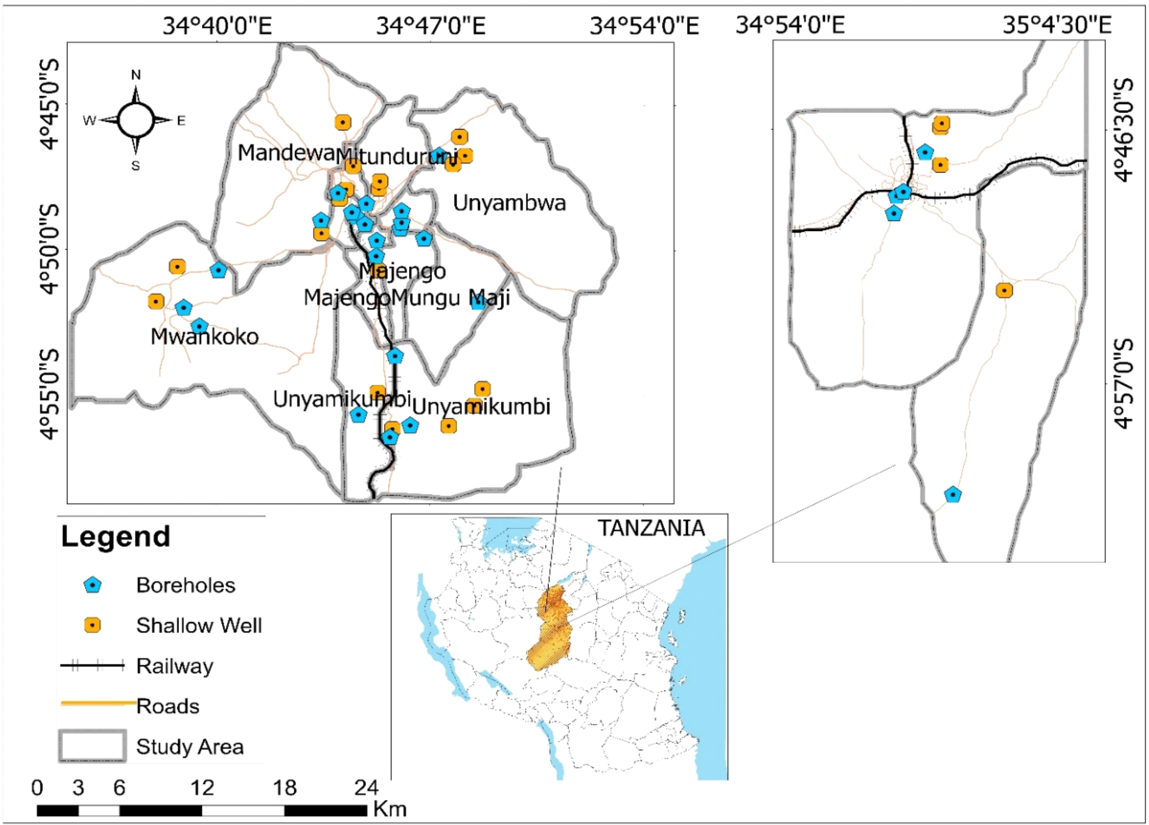


Figure 22: **Map of United republic of Tanzania showing Singida region and the sampling stations in Singida Urban and Manyoni Districts**

5.2.2 Field survey

Boreholes and shallow wells were identified with the help of local residents and local regional engineer and their locations were determined using a Geographical Positioning System (GPS), with an accuracy of ±3 m. The resulting positions were then plotted on a map with ArcGIS version 10.3 software.

5.2.3 Sample collection

A total of 150 groundwater samples were collected from boreholes and shallow wells three times each in two weeks interval. Thus, in each interval 50 samples were collected for analysis of nitrate (NO_3^-) nitrite (NO_2^-), ammonium (NH_4^+) and Chloride (Cl^-) during dry (September October) and wet seasons (April). For the boreholes water sample, samples were collected after purging for at least two minutes to ensure the water collected is fresh from the aquifer. For shallow wells, the same buckets used by villagers for collecting water were used to collect water samples after rinsing twice with sampling water. Samples for laboratory determination of NO_2^-, NO_3^-, Cl^- and NH_4^+ were collected using a 500 mL prewashed, high-density polyethylene (HDPE) bottles. Samples for ´$^{15}\delta$ N-NO_3^- and ´ δ ^{18}O-NO_3^-determination were collected in 100 mL HDPE bottles with Teflon lined caps. All samples were kept in a cooler box and transported for storage in a refrigerator at 4°C in the Water Quality Laboratory in Singida town. Thereafter, the samples were further transported to the laboratory at Nelson Mandela African Institution of Science and Technology (NM-AIST) for analysis.

5.2.4 Pre-treatment and groundwater analysis

All the instruments and electrodes were rinsed twice using double distilled and its cleaners were checked for presence of any analyte since analytical quality assurance is necessary for any analytical measurement. The blank determination was done in different matrices using the external standard calibration and the matrix effect was checked using standard addition method, and found to be negligible. The linearity and sensitivity (slope of the calibration curve) monitoring was done after every 5 sample measurements by measuring two standard solutions and calculating the sensitivity. The samples were measured in triplicates where the mean, standard deviation and the uncertainty were calculated. Limit of detection (LODs) for the instrument in each analyte type were determined by analyzing multiple samples of standards near zero-concentrations. The standard deviations (*s*) for each analyte type were calculated from them and their respective LODs were calculated at 3.182*s* and 95 %

confidence level ($p \leq 0.05$). Thus, the LODs for NH_4^- ' NO_2^-, and NO_3^- , were; 0.03 mg/L, 0.02 mg/L, and 0.08 mg/L, respectively.

5.2.5 Nutrients analysis

Concentrations measurements for NO_3^-, NO_2^- and NH_4^+ were done using HACH spectrophotometer, Model DR 2800, USA which was calibrated using certified reference standards from Sigma-Aldrich and HACH calibration standards, prepared at a high metrological level using reagent grade materials. Chloride concentrations were determined using the standard methods suggested by American Public Health Association (APHA, 2005), at the NM-AIST laboratory.

The stable isotope analyses were done using 43 samples. Nitrite was removed using sulfamic acid according to Granger and Sigman (2009), then frozen in 50 mL HDPE bottles before shipping to USA for analysis. The $\delta^{15}N$-NO_3^- and $\delta^{18}O$-NO_3^- analyses were determined at the University of California stable isotope facility Centre using the Elemental analyzer/ isotope ratio mass spectrometry (EA/IRMS). Values of $\delta^{15}N$ and $\delta^{18}O$ are expressed in per mill (‰) and delta notation in relation to isotopic composition of atmospheric nitrogen (AIR) with uncertainty of ± 0.3 ‰. The accuracy and values of $\delta^{18}O$ are reported with respect to Vienna-Standard Mean Oceanic Water (V-SMOW) with a ± 0.8 ‰ uncertainty.

5.2.6 Statistical analysis

Sigma Plot version 10.1 software was used to perform descriptive statistics where statistical mean, median and standard deviation were calculated for different parameters**.** Significant relationships between seasons were studied using the Wilcoxon signed rank t-test. The sources of nitrate in the groundwater were inferred using isotopic values of nitrogen-nitrate and oxygen-nitrate or chloride-nitrate ratios.

5.3 Results

5.3.1 Nitrates, Nitrite, and Ammonium distribution in study area

The descriptive summary (minimum, mean, maximum, and standard deviation) of NO_3^-, NO_2^- and NH_4^+ concentrations in boreholes and shallow wells during dry and wet seasons are shown in Table 15. The concentrations of NO_3^-, in water samples ranged from 1.76 mg/L to 929.6 mg/L and 2.4 to 1620 mg/L with an average of 110.15 mg/L and 171.56 mg/L during dry and wet seasons respectively. The highest NO_3^- level (1620 mg/L) was noted during wet season from shallow well 47, which is situated 9 m (lateral distance) from pit latrine and vegetable farms (Appendix 1). Also in the dry season the highest concentration (929.6 mg/L) was recorded from same source.

Table 15: Wilcox signed rank test analysis of NO3-, NO2- and NH4+ in groundwater during dry and wet seasons

	Dry Season				Sample size	Wet Season				Wilcox signed rank test	
Parameter	**Min**	**Max**	**Mean**	**SD**	**n**	**Min**	**Max**	**Mean**	**SD**	***z* value**	***p* value**
NO_3^-	1.76	929.6	110.15	115.62	50	2.4	1620	171.55	312.3	0.8	0.45
NO_2^-	0	6.47	0.22	0.85	50	0	2.3	0.2	0.45	1670	1.0
NH_4^+	0.02	1.8	0.18	0.12	50	0.01	8.5	0.59	1.71	1224	2.2

Min. = Minimum, Max. = Maximum, SD = Standard Deviation. All values are in mg/L.

The NO_2^- concentrations ranged from 0- 6.47 mg/L and 0-2.3 mg/L with an average of 0.2 mg/L and 0.22 mg/L in dry and wet seasons, respectively (Table 15)**.** The highest concentration of 2.3 mg/L was recorded in shallow well (SW) 47 which also recorded highest nitrate concentration.

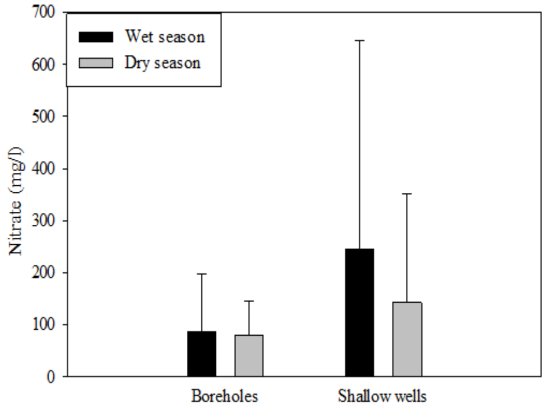
The concentrations of NH_4^+ were relatively high in wet season, with an average of 0.58 mg/L and 0.17 mg/L in wet and dry season respectively. The highest level of 8.50 mg/L was noted at well SW 51 in wet season (Appendix 3). The well had wellhead below ground level and located at the lower side of the hill and it has fractured wooden cover which allows easy collection of surface runoff

Table 16: The permissible limit of NO3-, NO2- and NH4+ in drinking water per WHO (2010) and TBS (2005) standards

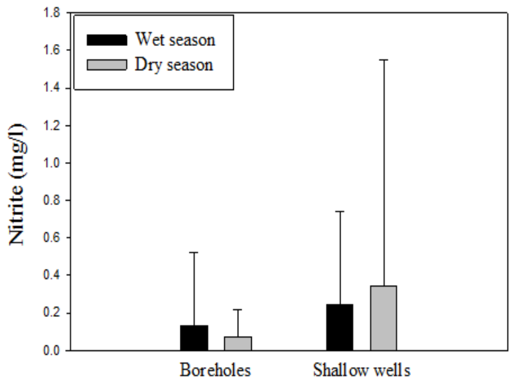
Standard	NO_3^-	NO_2^-	NH_4^+
WHO (2010)	50.0	3.0	1.5
TBS (2005)	10.0-75.0	NA	2.0

NA - no prescribed standard, all values are in mg/L

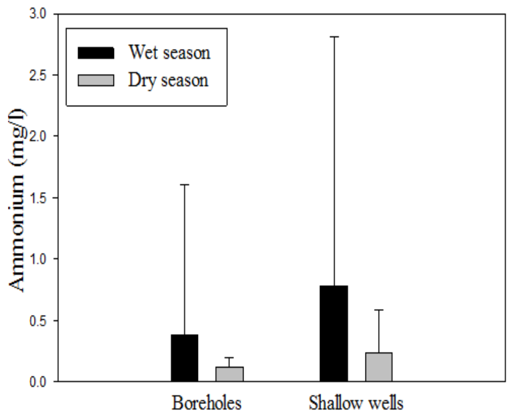
Results showed that 57 % and 43% of all the samples during dry season and 58% and 42% in wet season had NO_3^- concentrations above WHO (50 mg/L) and TBS (75 mg/L) respectively (Table 16). While 2 % of NO_2^- and NH_4^+ exceeded the WHO standard in dry season and 7 % exceeded WHO and TBS standards of $NH4^+$ concentrations in wet season.



(a)



(b)



(c)

Figure 23: Mean concentrations of (a) NO_3^- (mg/L) (b) NO_2^- (mg/L) and (c) NH_4^+ (mg/L) in boreholes and shallow wells during wet and dry seasons

5.3.2 Nitrate, Nitrite, and Ammonium variations in town vs peri-urban

Relatively higher NO_3^-, NO_2^-, and NH_4^+ concentrations were observed in towns than in peri-urban wards in both Singida Urban and Manyoni districts (Fig. 24). Utemini, Ipembe, Mitunduruni, and Minga wards of Singida Urban recorded highest concentrations of nitrate, nitrite, and ammonium during dry and wet seasons. While Majengo, Muhalala, and Kaloleni wards of Manyoni district recorded relatively higher nitrate, nitrite, and ammonium concentrations during wet season (Fig. 25).

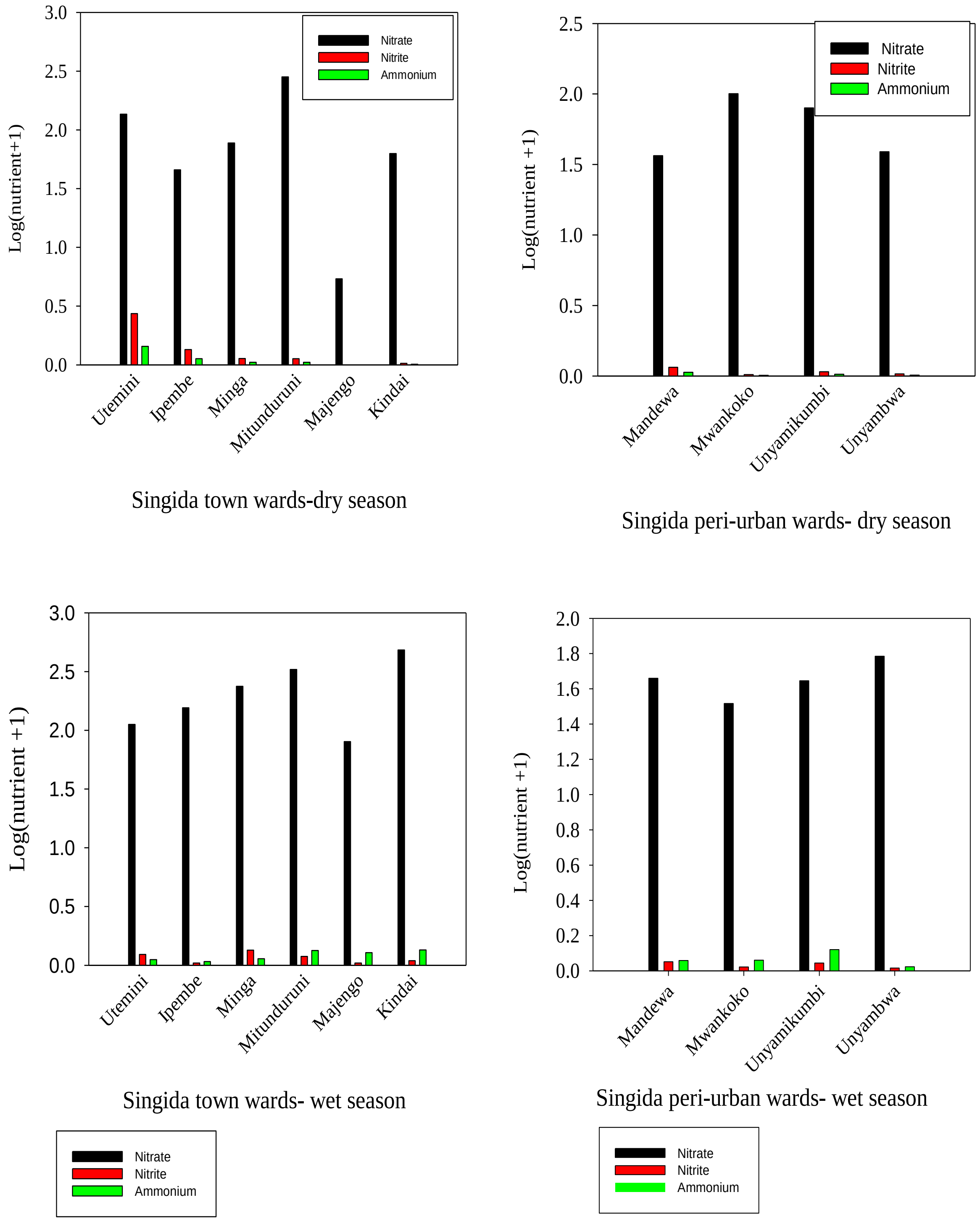
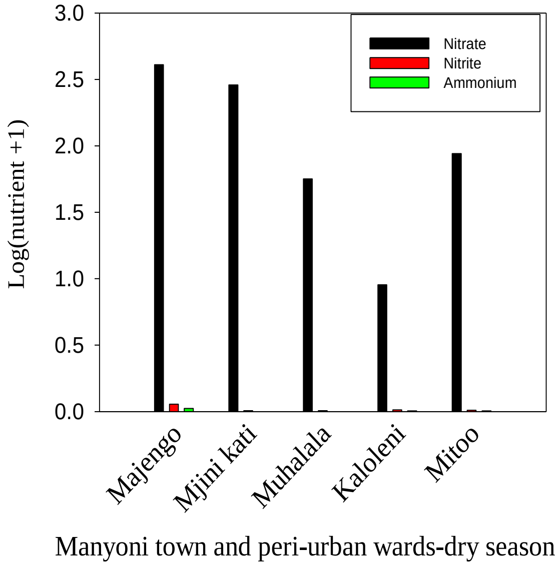
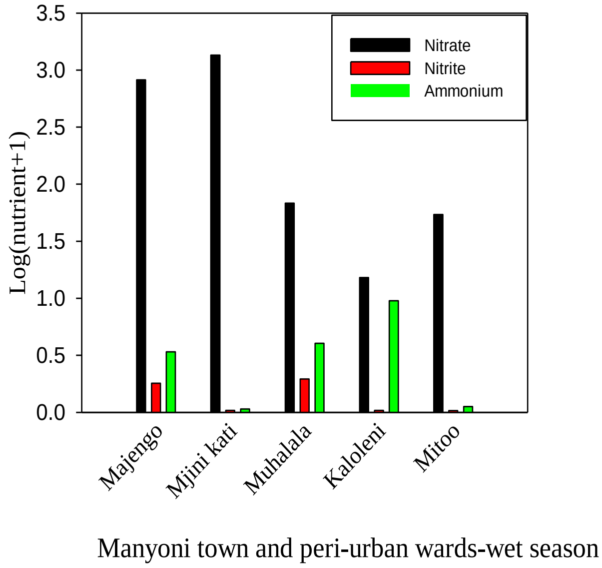


Figure 24: The logarithmic distribution of nitrates (mg/L), nitrite (mg/L), and ammonium (mg/L) in different wards of Singida town and peri-urban during dry and wet seasons



(a)



(b)

Figure 25: **The logarithmic distribution of nitrates (mg/L), nitrite (mg/L), and ammonium (mg/L) in different wards of Manyoni town and peri-urban during (a) dry season and (b) wet season**

5.3.3 Correlation analysis between Nitrate, Nitrite, Ammonium, and Chloride

In shallow wells, a strong positive correlations was observed between nitrate and nitrite (*n=23*, *r=0.61*) during wet season, also chloride correlate strongly with nitrate (*n=23*, *r=0.70*), on the same source (Table 17a). Cl^- concentrations ranged from 3.9 to 893.7 mg/L and 9.9 to 675.7 mg/L in wet and dry seasons respectively (Table 1 and 2 in Chapter Two**)**. The highest Cl^- concentration recorded was 893.7 mg/L from SW 49 (Appendix 1) during wet season. Also there was a moderate positive correlation between nitrite and ammonium (*n=23*, *r=0.47*) during wet season (Table 17a). While during dry season only a strong positive correlation was observed between nitrate and chloride concentrations (*n=23, r=0.58*) in shallow wells (Table 17b).

Table 17: Pearson correlation matrix of NO3- (mg/L), NO2- (mg/L), NH4+ (mg/L), and Cl- (mg/L), in shallow wells during (a) wet season and (b) dry season

	NH_4^+	NO_2^-	NO_3^-	Cl^-
NH_4^+	1			
NO_2^-	**0.47**	1		
NO_3^-	0.34	**0.61**	1	
Cl^-	0.12	0.19	**0.70**	1

(a)

	NH_4^+	NO_2^-	NO_3^-	Cl^-
NH_4^+	1			
NO_2^-	-0.02	1		
NO_3^-	0.23	0.35	1	
Cl^-	0.11	0.25	**0.58**	1

(b)

While in boreholes, very weak negative correlation was observed between nitrate and chloride (*n=23, r=-0.16,-0.20*) during the wet and dry seasons respectively (Table 18). A very strong positive correlation was observed between nitrite and ammonium (*n=23*, *r=0.99*) during dry season (Table 18a).

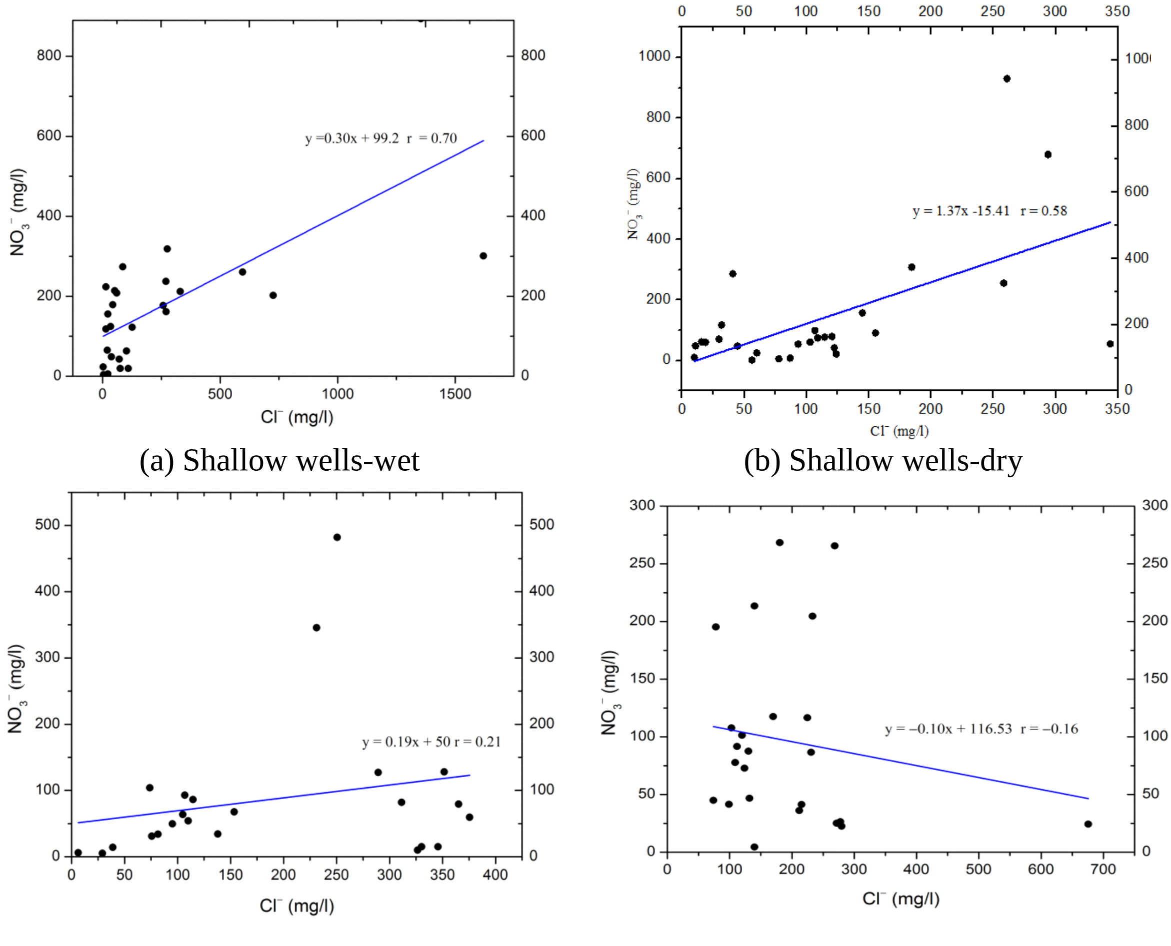
Table 18: Pearson correlation matrix of NO3- (mg/L), NO2- (mg/L), NH4+ (mg/L), and Cl- (mg/L), in boreholes during (a) wet season and (b) dry season

	NH_4^+	NO_2^-	NO_3^-	Cl^-
NH_4^+	1			
NO_2^-	**0.99**	1		
NO_3^-	0.11	0.11	1	
Cl^-	-0.23	-0.24	-0.20	1

(a)

	NH_4^+	NO_2^-	NO_3^-	Cl^-
NH_4^+	1			
NO_2^-	-0.29	1		
NO_3^-	-0.21	**0.46**	1	
Cl^-	-0.08	-0.03	-0.164	1

(b)



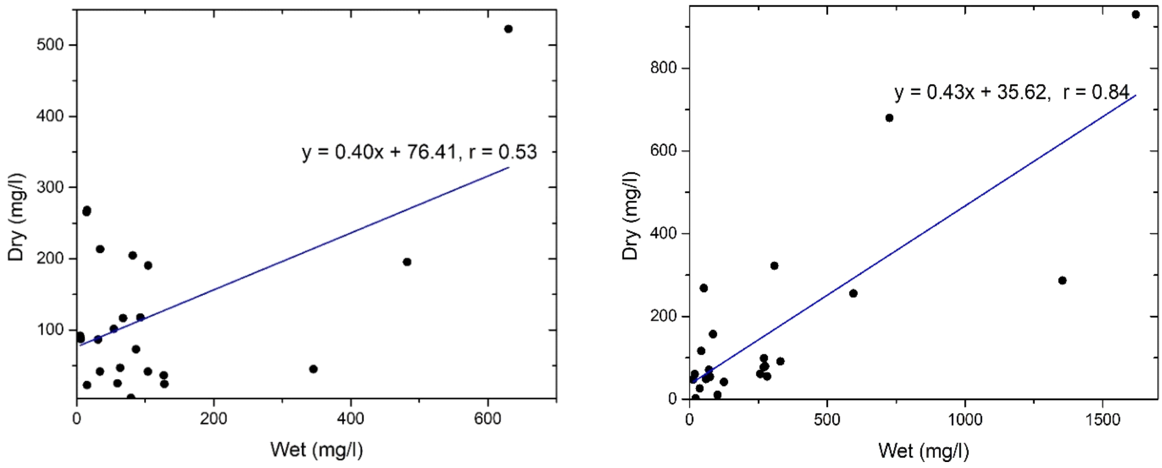
(a) Shallow wells-wet (b) Shallow wells-dry

(c) Boreholes-wet (d) Boreholes-dry

Figure 26: **Scatter plot of NO_3^- (mg/L) and Cl^- (mg/L) in shallow wells during (a) wet season (b) dry season and in boreholes during (c) wet season and (d) dry season**

5.3.4 Variations of Nitrate during dry and wet seasons

The variations of nitrate sources during wet and dry season showed existence of a positive correlation *(r= 0.53, n=23,)* in boreholes, and strong positive correlation in shallow wells (*r=84*, *n=23*) (Fig. 27).



(a) (b)

Figure 27: **Scatter plot for nitrates (mg/L) between wet and dry seasons in (a) boreholes and (b) shallow wells**

5.3.5 Outlier detection analysis

The interquartile range (IQR) for seasonally grouped data was calculated for outlier assessments. The statistical analyses revealed that [NO_3^-] were associated with negatively skewed majorities with outliers being it their high ends in both seasons. In boreholes, all values > 120 mg/L were outliers. In this context, 345.5 mg/L, 482 mg/L and 680 mg/L were detected as outliers in boreholes during wet season (Fig. 28a). Also, in the dry season, one outlier (522.7 mg/L) was detected (Fig. 28b). In shallow wells, outliers were above 304 mg/L in wet season. In this case three outliers (726 mg/L, 1354 mg/L and 1620 mg/L) were identified (Fig. 28c). In addition, during dry season two outliers (679.7 mg/L and 929.8 mg/L) were detected (Fig. 28d.)

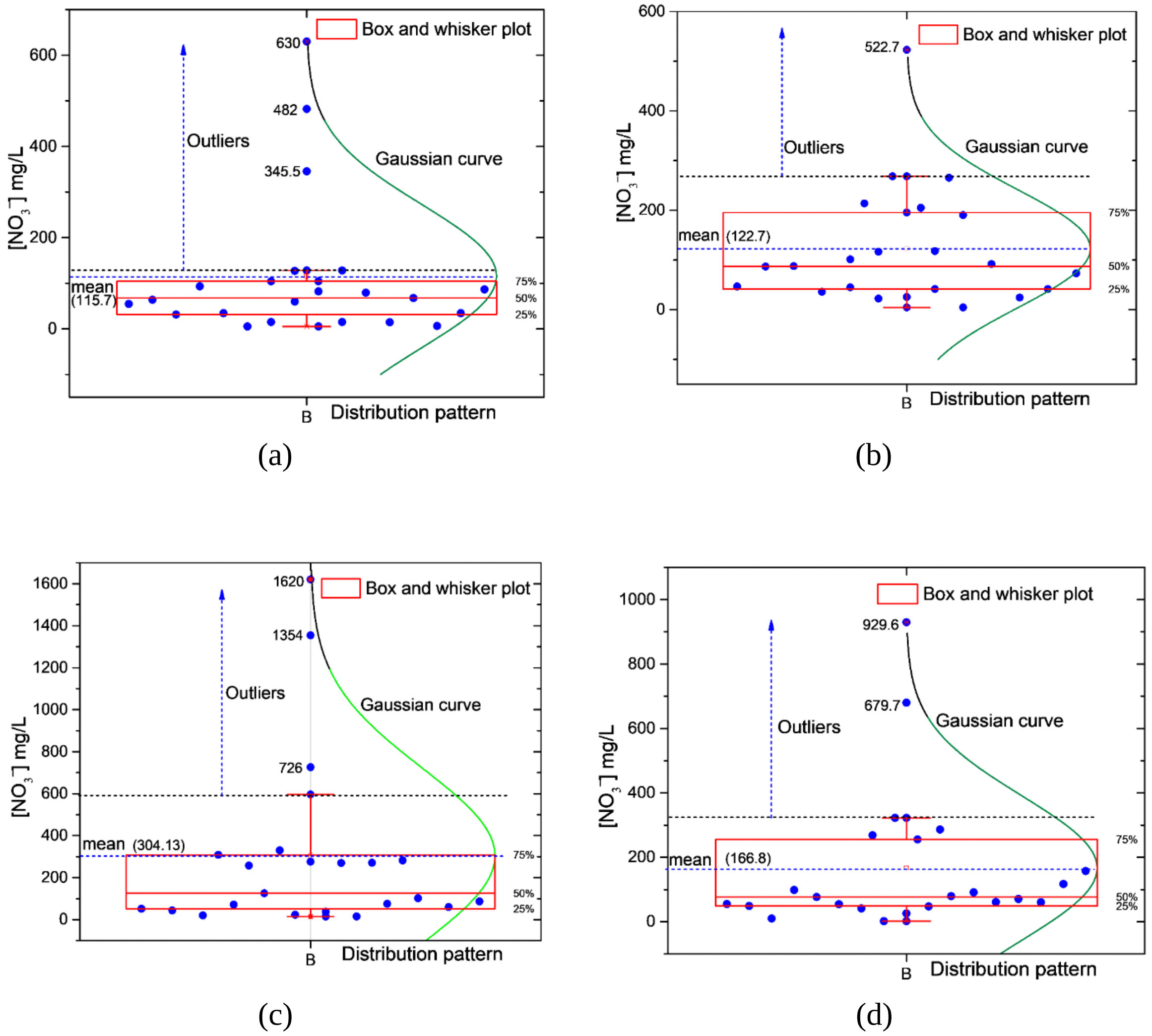


Figure 28: **Outliers analysis showing nitrate distribution patterns in in boreholes during (a) wet (b) dry and in shallow wells during (c) wet (d) dry seasons**

Despite the outlier analysis detecting such mentioned values, yet they should not be rejected. This is due to the fact that they are valid analytical results since they have been reported as average results from three independently determined results. Other relative distributions of NO_3^- in the study area (Fig. 29), showed areas with high nitrate concentrations were in town and characterized with high density population and with poor sanitation facilities. While in peri urban had relatively lower nitrate concentrations.

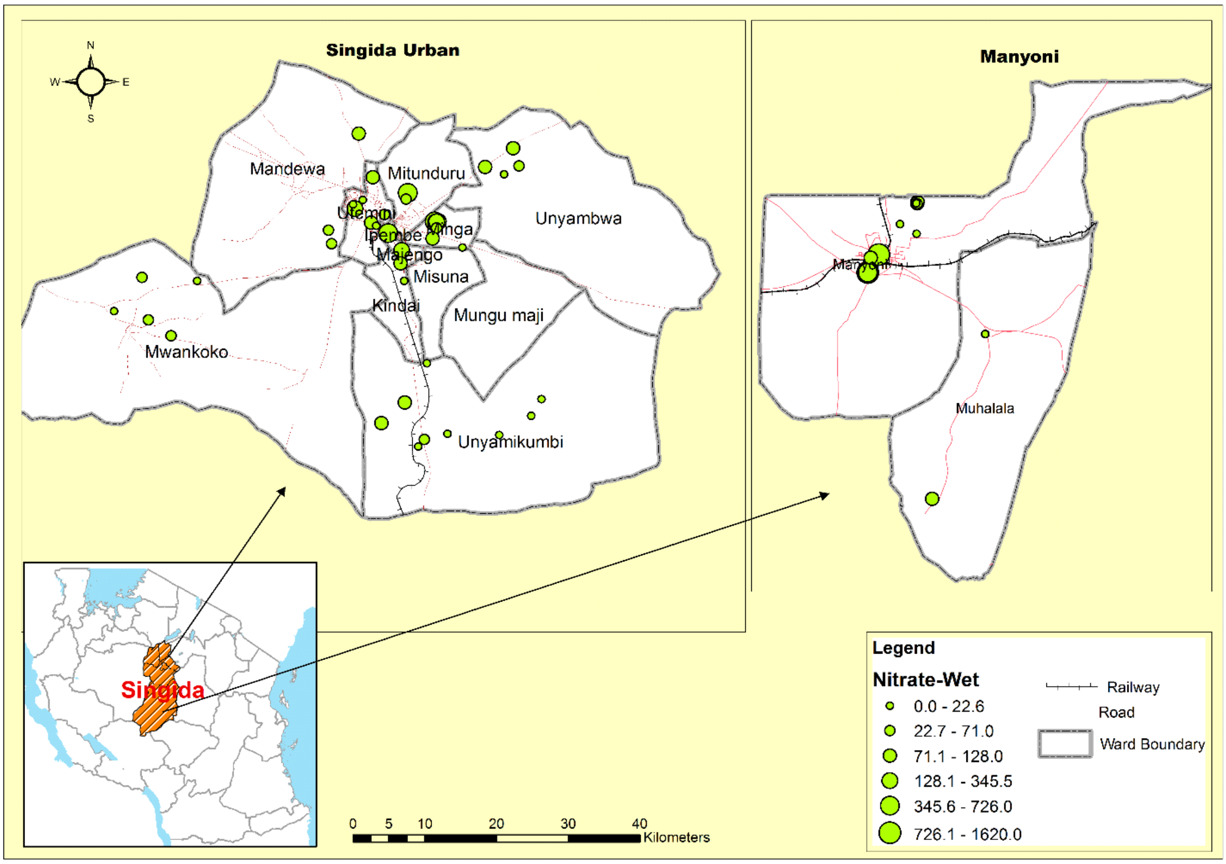
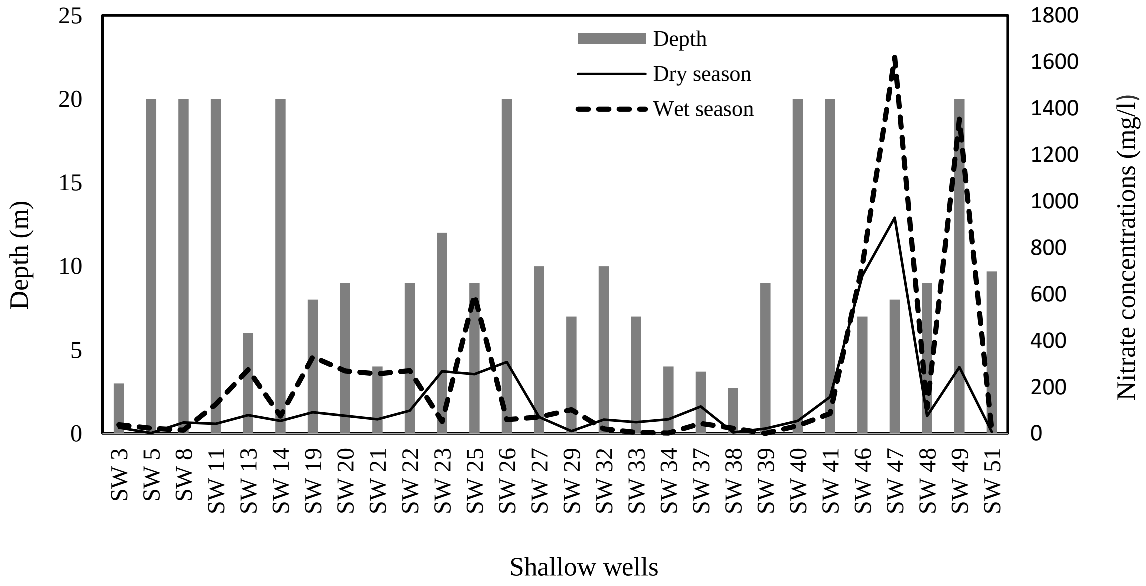
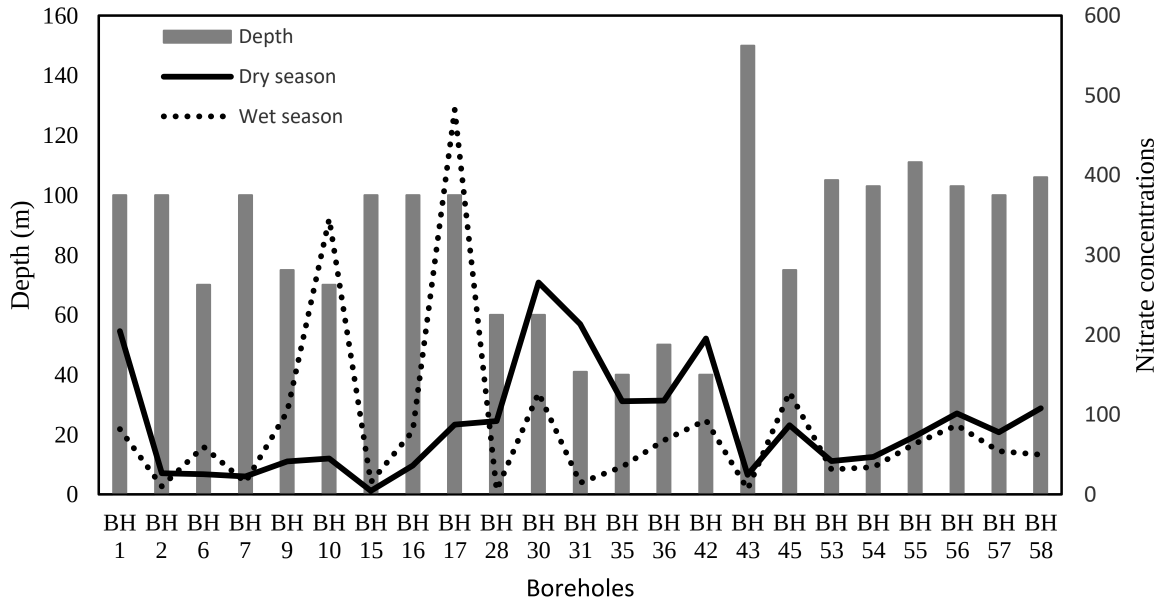


Figure 29: Map of Singida Urban and Manyoni showing nitrate distribution (green dots) in (mg/L) during wet seasons. All the nitrate concentrations values are in mg/L

Distribution of nitrate in relation to depth showed that there was a very weak relationship between depth and nitrate concentrations (Fig. 30) rather their distance in relation to a potential contaminant source. Shallow wells 46, and 47 recorded the highest nitrate concentrations while SW 48 maintained the low concentrations in both seasons. A sharp increase in nitrate concentrations during wet season was observed in SW 25, 46, 47, and 49 (Fig. 30a). The boreholes 10 and 17 recorded the highest nitrate concentrations during wet season and BH 1, 30, 31, 35, 36, and 42 recorded highest nitrate contaminations in dry season (Fig. 30b).



(a)



(b)

Figure 30: **Spatial distribution of Nitrate concentrations in relation to depth in (a) shallow wells and (b) boreholes during dry and wet seasons**

5.3.6 Origin of Nitrate using hydrochemistry (Nitrate/Chloride ratio)

Results of the nitrate sources identification from the borehole and shallow well samples using NO_3^-/Cl^- molar ratios revealed that the majority (70 – 94 %) of the samples during dry and wet seasons, recorded high Cl^- value (above 10 mg/L) and low ratio NO_3^-/Cl^- (below < 1molar concentrations). About 6 % – 29 % of all samples recorded NO_3^-/Cl^- ratio associated with agricultural input during dry and wet seasons (Table 19 and 20). The samples with high Cl^- value (>10 mg/L) and low NO_3^-/Cl^- (< 1) molar concentrations in boreholes were 92.5% and 96.3% while in shallow wells were 70.4% and 71.4% during wet and dry seasons respectively. Samples with high NO_3^-/Cl^- molar concentration and low Cl^- values (< 10mg/L) in boreholes were 7.5% and 3.7% and in shallow wells were 29.6% and 28.6% during wet and dry season respectively (Table 21).

Table 19: Identified nitrate sources for selected samples using nitrate-chloride ratio in boreholes during wet and dry season

		Wet						Dry					
ID	**D(m)**	**$**[NO_3^-]$**	**$**[Cl^-]$**	**$*[NO_3^-]$**	**$*[Cl^-]$**	**$[NO_3^-/Cl^-]$**	**Rem.**	**$**[NO_3^-]$**	**$**[Cl^-]$**	**$*[NO_3^-]$**	**$*[Cl^-]$**	**$[NO_3^-/Cl^-]$**	**Rem.**
BH 1	100	81.9	311.3	1.32	8.77	0.15	MN/SE	204.6	233.2	3.3	6.57	0.5	MN/SE
BH 2	100	630	326.4	10.16	9.19	1.11	FT	522.7	277.8	8.43	7.83	1.08	FT
BH 6	70	59.6	375.5	0.96	10.58	0.09	MN/SE	25.1	271.9	0.4	7.66	0.05	MN/SE
BH 7	100	15	330.3	0.24	9.3	0.03	MN/SE	22.4	279.6	0.36	7.88	0.05	MN/SE
BH 9	75	104	73.8	1.68	2.08	0.81	MN/SE	41.4	215.6	0.67	6.07	0.11	MN/SE
BH 10	70	345.5	231.2	5.57	6.51	0.86	MN/SE	45	73.8	0.73	2.08	0.35	MN/SE
BH 15	100	15	345.8	0.24	9.74	0.02	MN/SE	268.4	180.6	4.33	5.09	0.85	MN/SE
BH 16	100	79.25	365.2	1.28	10.29	0.12	MN/SE	4.4	139.8	0.07	3.94	0.02	MN/SE
BH 17	100	127	289.4	2.05	8.15	0.25	MN/SE	36.1	211.7	0.58	5.96	0.1	MN/SE
BH 28	60	5	29.1	0.08	0.82	0.1	MN/SE	91.7	111.9	1.48	3.15	0.47	MN/SE
BH 30	60	482	250.6	7.77	7.06	1.1	FT	195.3	77.9	3.15	2.19	1.44	FT
BH 31	41	14.2	38.8	0.23	1.09	0.21	MN/SE	265.5	268.9	4.28	7.57	0.57	MN/SE
BH 35	40	34.2	137.9	0.55	3.88	0.14	MN/SE	213.5	139.9	3.44	3.94	0.87	MN/SE
BH 36	50	67.6	153.4	1.09	4.32	0.25	MN/SE	116.5	224.9	1.88	6.34	0.3	MN/SE
BH 42	40	93	106.8	1.5	3.01	0.5	MN/SE	117.6	169.9	1.9	4.79	0.4	MN/SE
BH 43	150	6.15	6.2	0.1	0.17	0.57	MN/SE	87.5	130.1	1.41	3.67	0.39	MN/SE
BH 45	75	128	351.6	2.06	9.9	0.21	MN/SE	24.2	675.7	0.39	19.03	0.02	MN/SE
BH 53	105	31	75.7	0.5	2.13	0.23	MN/SE	86.5	230.9	1.4	6.5	0.21	MN/SE
BH 54	103	34	81.6	0.55	2.3	0.24	MN/SE	41.5	98.9	0.67	2.79	0.24	MN/SE
BH 55	111	63.6	104.9	1.03	2.95	0.35	MN/SE	46.7	131.9	0.75	3.72	0.2	MN/SE
BH 56	103	86.4	114.6	1.39	3.23	0.43	MN/SE	72.8	123.9	1.17	3.49	0.34	MN/SE
BH 57	100	54.2	110	0.87	3.1	0.28	MN/SE	101.3	119.9	1.63	3.38	0.48	MN/SE
BH 58	106	104.16	49.35	1.68	1.39	1.21	FT	190.34	79.875	3.07	2.25	1.36	FT

*MN/SE;-Manure/Sewage Effluents, FT;-Fertilizers, Rem.-Remarks, $*\times 10^{-3}$Mol/l , $**\times 10^{-3}$g/l

Table 20: Identified nitrate sources for samples using nitrate-chloride ratio in shallow wells during wet and dry season

		Wet						Dry					
ID	**D(m)**	**$**[NO_3]$**	**$**[Cl]$**	**$*[NO_3^-]$**	**$*[Cl^-]$**	**$[NO_3^-/Cl^-]$**	**Rem.**	**$**[NO_3^-]$**	**$**[Cl^-]$**	**$*[NO_3]$**	**$*[Cl^-]$**	**$[NO_3^-/Cl^-]$**	**Rem.**
SW 3	3	37.3	48.5	0.6	1.37	0.44	MN/SE	25.52	60.2	0.41	1.7	0.24	MN/SE
SW 5	20	22.4	155.4	0.36	4.38	0.08	MN/SE	1.76	56.31	0.03	1.59	0.02	MN/SE
SW 8	23	14.1	118	0.23	3.32	0.07	MN/SE	47.52	44.66	0.77	1.26	0.61	MN/SE
SW 11	37	125.24	60.63	3.45	2.02	1.71	FT	41.36	122.34	0.67	3.45	0.19	MN/SE
SW 13	6	275.28	71.72	8.97	4.44	2.02	FT	79.2	120.4	1.28	3.39	0.38	MN/SE
SW 14	20	74.5	19.4	1.2	0.55	2.2	MN/SE	54.12	93.21	0.87	2.63	0.33	MN/SE
SW 19	8	330	212	5.32	5.97	0.89	MN/SE	91.08	155.36	1.47	4.38	0.34	MN/SE
SW 20	9	269.5	237	4.35	6.68	0.65	MN/SE	77	114.57	1.24	3.23	0.38	MN/SE
SW 21	4	257.25	176.8	4.15	4.98	0.83	MN/SE	60.72	102.92	0.98	2.9	0.34	MN/SE
SW 22	9	270.5	161.2	4.36	4.54	0.96	MN/SE	98.56	106.81	1.59	3.01	0.53	MN/SE
SW 25	9	595.5	260.3	9.6	7.33	1.31	MN/SE	255.2	258.28	4.12	7.28	0.57	MN/SE
SW 26	24	308.14	137.03	4.97	3.86	1.29	FT	322.40	176.44	5.2	4.97	1.04	FT
SW 27	10	71	42.7	1.15	1.2	0.95	MN/SE	70.6	29.9	1.14	0.84	1.35	MN/SE
SW 29	7	102	63	1.65	1.77	0.93	MN/SE	9.9	9.9	0.16	0.28	0.57	MN/SE
SW 32	10	19.6	65	0.32	1.83	0.17	MN/SE	60.2	18.9	0.97	0.53	1.82	MN/SE
SW 33	7	60.14	21.66	0.97	0.61	1.59	FT	48.5	10.9	0.78	0.31	2.55	MN/SE
SW 37	3.7	42.78	18.82	0.69	0.53	1.30	FT	116.75	31.9	1.88	0.9	2.1	MN/SE
SW 40	30	282.1	124.25	4.55	3.5	1.3	FT	54.7	343.8	0.88	9.68	0.09	MN/SE
SW 41	30	85.8	273.9	1.38	7.72	0.18	MN/SE	157.25	144.9	2.54	4.08	0.62	MN/SE
SW 46	7	726	202	11.71	5.69	2.06	FT	679.77	293.9	10.96	8.28	1.32	FT
SW 47	8	1620	301.1	26.13	8.48	3.08	FT	929.6	261	14.99	7.35	2.04	FT
SW 49	23	1354	893.7	21.84	25.17	0.87	MN/SE	286.35	40.9	4.62	1.15	4.01	MN/SE
SW 23	12	51.75	213.7	0.83	6.02	0.14	MN/SE	268.4	180.6	4.33	5.09	0.85	MN/SE

*MN/SE;-Manure/Sewage Effluents, FT;-Fertilizers, Rem.-Remarks, *$\times 10^{-3}$Mol/l , **$\times 10^{-3}$g/

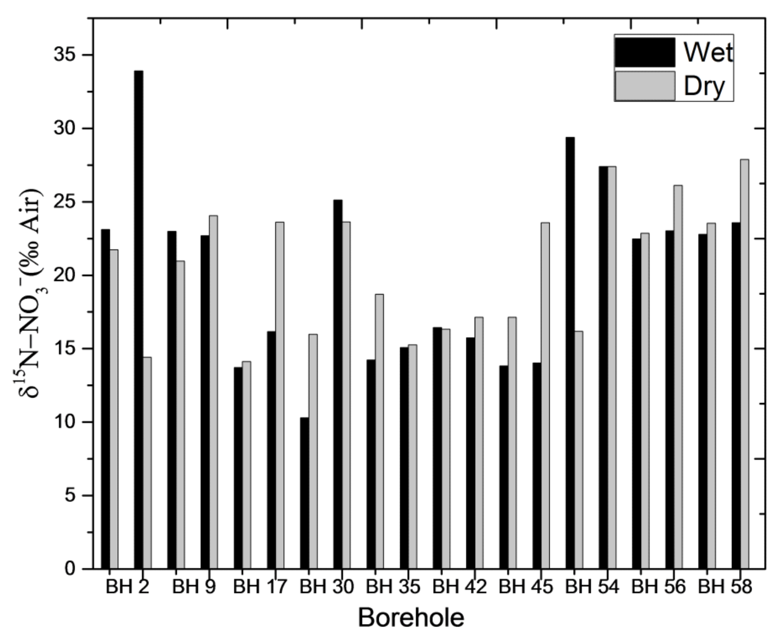
Table 21: Elucidated nitrate sources from borehole and shallow well samples using Nitrate/chloride ratio during wet and dry seasons

$[NO_3^-/Cl^-$ against $Cl^-]$	Associated waste	% of samples in wet and dry season			
		BH_W	BH_D	SW_W	SW_D
High Cl^- value (>10 mg/L) against low ratio NO_3^-/Cl^- < 1 molar concentrations)	Effluent, organic waste (Liu, *et al.*, 2006).	92.5	96.3	70.4	71.4
High NO_3^-/Cl^- >1.0 molar concentration and low Cl^- values < 10 mg/L	Agricultural input (Liu, *et al.*, 2006).	7.5	3.7	29.6	28.6

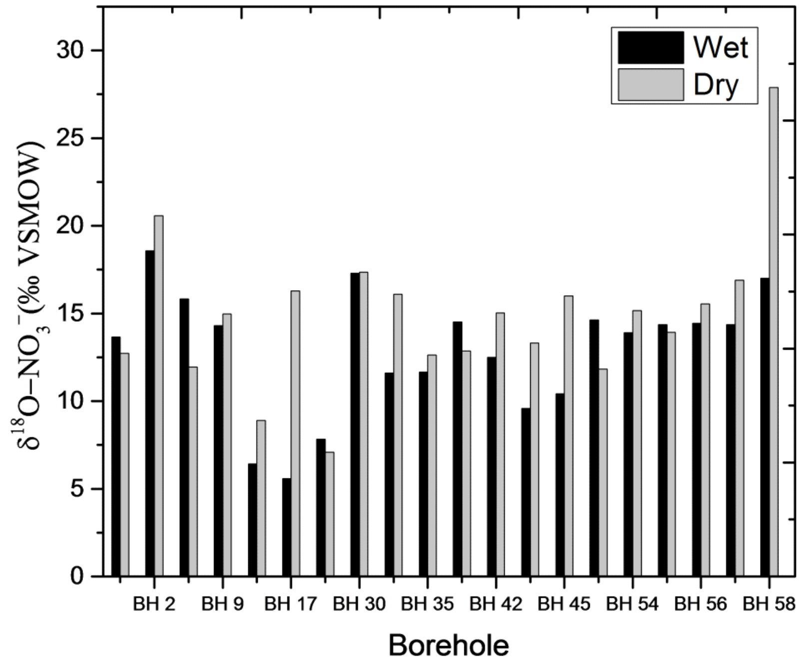
BH_W = boreholes wet season; BH_D = boreholes dry season; SW_W = shallow wells wet season; SW_D = shallow wells dry season.

5.3.7 Nitrate Identification using the dual Isotope $\delta^{15}N\text{-}NO_3^-$ and $\delta^{18}O\text{-}NO_3^-$.

The dual stable isotopes approach showed that the measured $\delta^{15}N\text{-}NO_3^-$ of the study area had a mean value of +20.9 0 ± 5.17 0 in boreholes and +18.3 0 ± 6.33 0 in shallow wells, however, most sources had values above +14‰ (Fig. 31a and 32a). The mean values of $\delta^{18}O\text{-}NO_3^-$ were +13.86 ‰ ± 3.18 ‰ from boreholes and +13.69 ‰ ±3.97 ‰ in shallow wells (Fig. 31b and 32b). The Nitrate contamination from fertilizer input was dominant in BH 2, BH 30, BH 31 and BH 58, SW26, SW46, and SW47 during the wet and dry seasons, respectively (Table 22). Borehole 17 and shallow well 29 had isotopic value at the margin of fertilizer and sewage and/or manure (Fig. 32 to 34) during dry and wet seasons respectively.

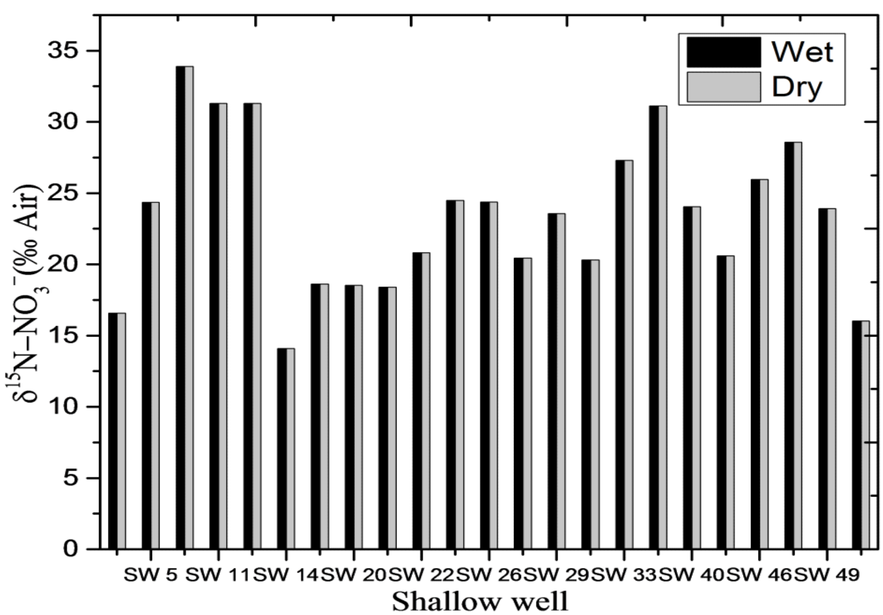


(a)

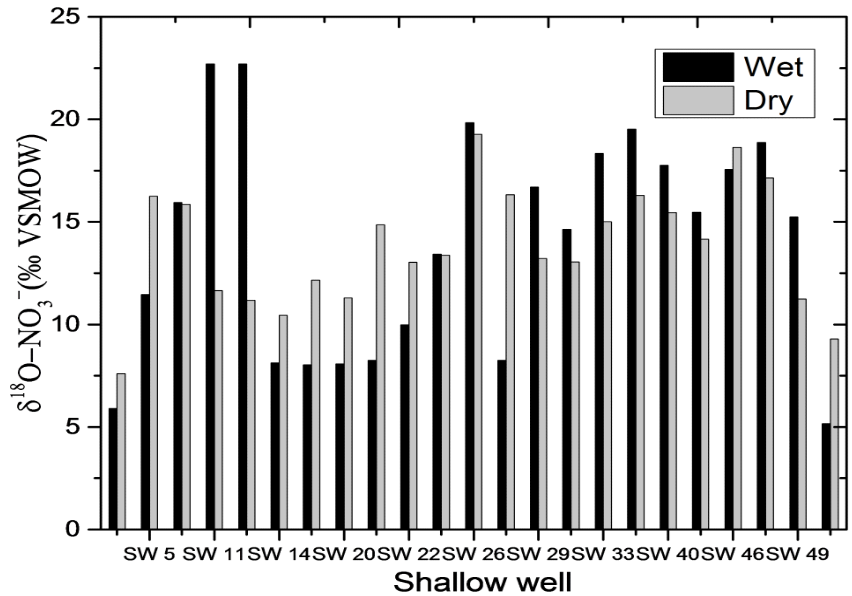


(b)

Figure 31: **The isotopic signatures for (a) δ ^{15}N-$NO_3^-$and (b) δ ^{18}O-$NO_3^-$of boreholes during dry and wet seasons**



(a)



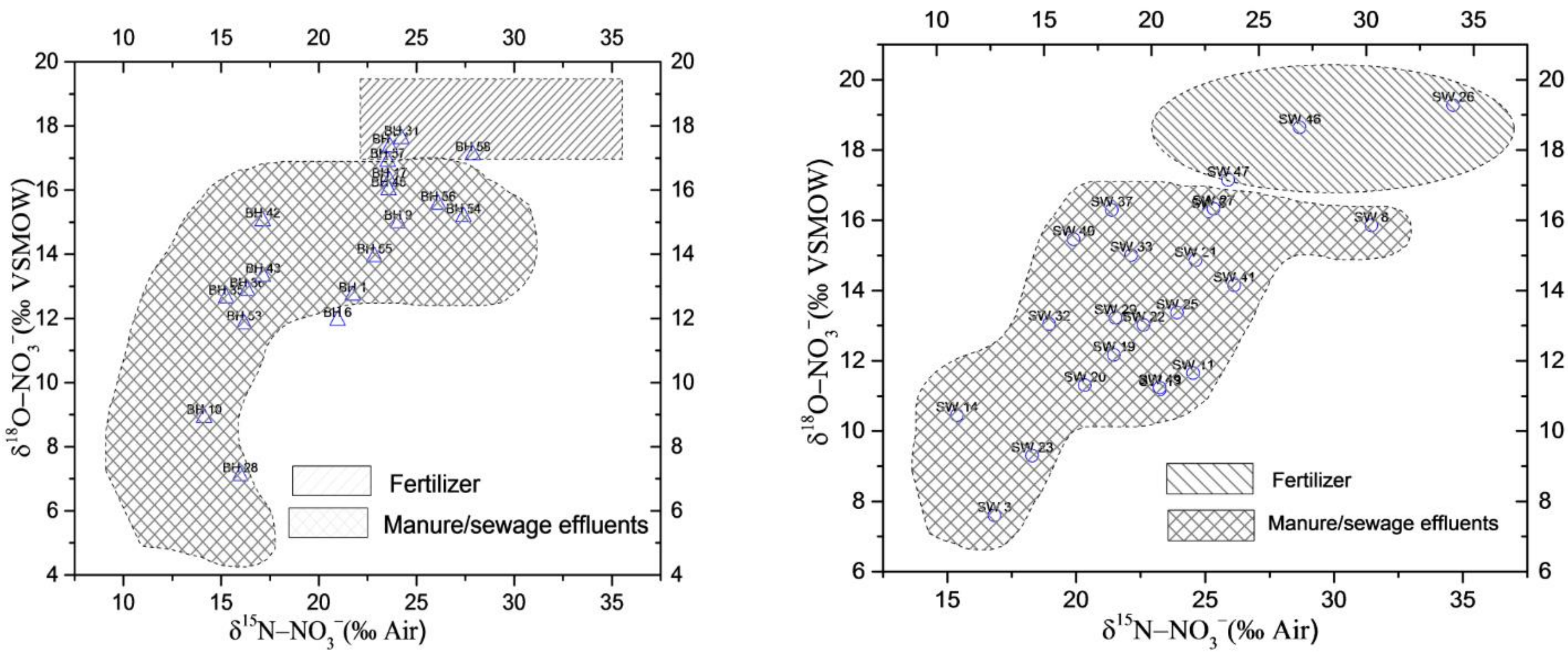
(b)

Figure 32: **The isotopic signatures for (a) δ $^{15}N\text{-}NO_3^-$ and (b) $\delta^{18}O\text{-}NO_3^-$ in shallow wells during dry and wet season**

Table 22: The δ 15N-NO3- and δ18O-NO3- isotope signatures for nitrate in boreholes and shallow wells during dry and wet seasons

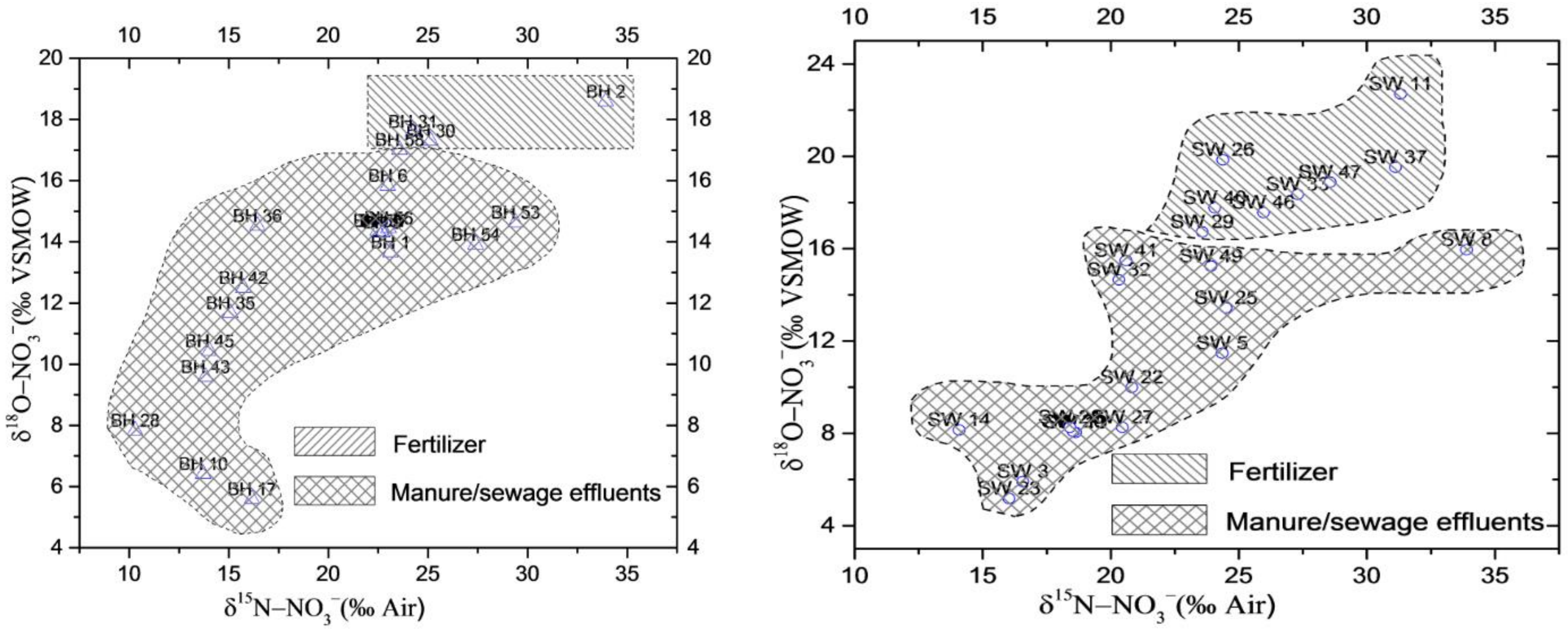
BOREHOLES							SHALLOW WELLS						
	Wet			Dry				Wet			Dry		
ID	**$\delta^{15}N_{Air}$ (‰)**	**$\delta^{18}O_{VSMOW}$ (‰)**	**Rem.**	**$\delta^{15}N_{Air}$ (‰)**	**$\delta^{18}O_{VSMOW}$ (‰)**	**Rem.**	**ID**	**$\delta^{15}N_{Air}$ (‰)**	**$\delta^{18}O_{VSMOW}$ (‰)**	**Rem.**	**$\delta^{15}N_{Air}$ (‰)**	**$\delta^{18}O_{VSMOW}$ (‰)**	**Rem.**
BH 1	23.11	13.66	MN/SE	21.74	12.72	MN/SE	**SW 3**	16.57	5.90	MN/SE	16.82	7.60	MN/SE
BH 2	33.92	18.58	FT	14.42	20.58	FT	**SW 5**	24.35	11.47	MN/SE	25.13	16.25	MN/SE
BH 6	22.98	15.83	MN/SE	20.97	11.94	MN/SE	**SW 8**	33.89	15.94	MN/SE	31.46	15.86	MN/SE
BH 9	22.70	14.30	MN/SE	24.06	14.97	MN/SE	**SW 11**	31.31	17.70	FT	24.54	11.65	MN/SE
BH 10	13.71	6.41	MN/SE	14.13	8.90	MN/SE	**SW 13**	21.18	18.79	FT	22.41	11.18	MN/SE
BH 17	16.46	16.59	MN/SE	23.62	16.28	MN/SE	**SW 14**	14.08	8.13	MN/SE	15.37	10.45	MN/SE
BH 28	10.29	7.83	MN/SE	15.97	7.09	MN/SE	**SW 19**	18.62	8.04	MN/SE	21.46	12.16	MN/SE
BH 30	25.13	17.29	FT	23.63	17.35	FT	**SW 20**	18.54	8.08	MN/SE	20.33	11.30	MN/SE
BH 31	24.24	17.60	FT	18.70	16.09	FT	**SW 21**	18.40	8.25	MN/SE	24.64	14.86	MN/SE
BH 35	15.08	11.67	MN/SE	15.26	12.63	MN/SE	**SW 22**	20.82	9.99	MN/SE	22.62	13.02	MN/SE
BH 36	16.43	14.52	MN/SE	16.34	12.86	MN/SE	**SW 23**	16.03	5.16	MN/SE	18.29	9.30	MN/SE
BH 42	15.74	12.50	MN/SE	17.14	15.04	MN/SE	**SW 25**	24.49	13.42	MN/SE	23.91	13.38	MN/SE
BH 43	13.83	9.58	MN/SE	17.14	13.31	MN/SE	**SW 26**	24.38	19.84	FT	34.63	19.27	FT
BH 45	14.03	10.43	MN/SE	23.58	16.00	MN/SE	**SW 27**	20.45	8.25	MN/SE	25.33	16.32	MN/SE
BH 53	29.39	14.63	MN/SE	16.18	11.83	MN/SE	**SW 29**	23.57	16.71	MN/SE	21.53	13.22	MN/SE
BH 54	27.40	13.91	MN/SE	27.41	15.17	MN/SE	**SW 32**	20.32	14.64	MN/SE	18.96	13.05	MN/SE
BH 55	22.48	14.36	MN/SE	22.86	13.92	MN/SE	**SW 33**	27.29	18.35	FT	22.14	15.01	MN/SE
BH 56	23.02	14.45	MN/SE	26.12	15.55	MN/SE	**SW 37**	31.12	19.52	FT	21.38	16.30	MN/SE
BH 57	22.78	14.36	MN/SE	23.54	16.89	MN/SE	**SW 40**	24.06	17.76	FT	19.90	15.46	MN/SE
BH 58	23.58	17.00	FT	27.88	17.10	FT	**SW 41**	20.60	15.48	MN/SE	26.14	14.15	MN/SE
							SW 46	25.96	17.55	FT	28.67	18.64	FT
							SW 47	28.57	18.87	FT	25.90	17.15	FT
							SW 49	23.92	15.24	MN/SE	23.25	11.24	MN/SE

*MN/SE;-Manure/Sewage Effluents, FT;-Fertilizers, *Rem;-Remarks.



(a) (b)

Figure 33: Dual nitrate isotopes signatures plot in (a) boreholes and (b) shallow wells during dry season



(a) (b)

Figure 34: Dual nitrate isotopes signatures plot in (a) boreholes and (b) shallow wells during wet season

5.4 Discussion

5.4.1 Concentration of nutrients in the groundwater

Generally, the higher levels of nitrates concentrations above the maximum limit recommended by WHO and TBS standards were from the sample collected during the wet season in both boreholes and shallow wells. The vertical infiltration of manure solution and other dissolved salts was much more experienced during the wet season. Similar results were reported by (Tairu *et al.,* (2015). The higher nitrate levels in wet season were accelerated by runoff that collects different materials from the various environments into the groundwater sources. Shallow well (SW 47) which recorded the highest concentration of NO_3^- was located 9 meter down gradient of an old pit latrine surrounded by vegetable farms in a densely populated area in Manyoni town (Appendix 1). The higher contamination could indicate the chance that the well building materials was incapable of holding the wastes from pit latrine resulting to the lateral flow into the shallow well (Council *et al.,* 2015; Tredoux *et al.,* 2000).

The results of NO_3^-, NO_2^- and NH_4^+ contamination in boreholes and shallow wells of the study area varied from place to place during dry and wet seasons, indicating the possibility of being received from various sources due to different land use activities. The increased NH_4^+ level during the wet season is likely due to a rise of water level due to rainfall that leads to the dissolution of nitrogenous compound (NH_4^+ and NO_2^-) from the surrounding environment into the groundwater sources, similar results of higher NH_4^+ contamination in wet season were reported by Elisante and Muzuka, (2016a). Moreover, the concentrations of $NH4^+$ were generally higher in shallow wells during the wet season due to most of them being situated at close proximity to pit latrine or farms where heaps of animal/poultry manure are kept or used hence disposed to nutrients loads and other materials due to rainfall.

Shallow wells and boreholes found in town areas such as Utemini, Ipembe, Mitunduruni, and Minga, recorded higher nitrate, nitrite, and ammonium contamination than those found in peri-urban areas in both districts. The higher contamination in town than peri-urbans areas were likely due to presence of high numbers of onsite sanitary facilities such as soak-away pits, septic tanks, cesspits, and pit latrine, which most are old and poorly constructed thus increase the chance of nitrate contamination through percolation to the source (Anornu *et al.,* 2017; Rutkoviene *et al.,* 2005).

Wells situated at a distance of less than 10 meter recorded highest nitrate concentrations (Appendices 2 and 3). For example, shallow wells 47, 48, and 49 found in densely populated ward (Mjinikati) in Manyoni town and situated at a distance of 10 m and 20 m respectively downgradient old pit latrines and farms recorded the highest nitrate concentrations in both seasons, suggesting the possibility of receiving organic waste due to infiltration. Usually, pollutions derived from onsite sanitation percolate into the unsaturated zone and collected above the water table and in the next rainfall event of sufficient magnitude, pollution may be transported to the groundwater body and degrade its quality (Pastén-zapata *et al.*, 2014; Tredoux *et al.*, 2009). Similar results that linked groundwater nitrate contamination due to pit latrine located at close proximity to the groundwater sources were reported by Elisante and Muzuka, 2016a; Pastén-zapata *et al.*, 2014.

Distribution of nitrate in relation to depth showed that there was a very weak relationship between depth and nitrate concentrations meaning that well depths were not necessarily describing the amount of NO_3^- pollution (Fig. 29) rather their distance in relation to a potential contaminant source. For example, SW 49 recorded 286.4 mg/L of nitrate levels in dry season and very high concentrations (1354 mg/L) in wet season suggests the possibility of receiving nitrate loads from surface run-off due to rainfall. While SW 3 and 32 maintained low nitrate concentrations (37.3 mg/L and 19.6 mg/L) in wet season and (25.5 mg/L and 60.2 mg/L) in dry season as they were properly constructed and situated at 40 meters from potential contaminant. Moreover, SW 46 and 47 which recorded highest NO_3^- concentrations (726 mg/L and 1629 mg/L) in wet seasons and (679.8 mg/L and 929.6 mg/L) in dry season, were situated at a distance of 9 m, and 10 m, respectively from pit latrines which is below the recommended distance of 50 m from onsite sanitation facilities. Such short distance suggests a possibility of the wells receiving high nitrate loads from pit latrines in both seasons. The same high concentrations (345.5 mg/L and 127 mg/L) in wet season were observed in boreholes 10 and 17 situated 15 m from pit latrine and cesspit respectively **(**Appendix 1). Despite the recommendation by TBS (2005) on the significance of proper distance of 50 m from sanitary facilities, still 36 % of all the groundwater sources in the study area did not follow the recommended standard.

5.4.2 Outliers detection of highest nitrate contamination

The existence of a positive nitrate correlation (*r= 0.5)* in boreholes and (*r= 0.84)* in shallow wells during wet and dry seasons indicated that, majority of nitrate contamination in study area were originating from same sources. However, all boreholes sources recorded nitrate values of above 120 mg/L and 522.7 mg/L and 304 mg/L and 679.7 mg/L in shallow wells during wet and dry seasons were detected as outliers (Fig. 28), nevertheless they were included in the study area due to the fact that, they were obtained from different areas which their samples contained very diverse (discrete) nitrate levels due to different pollution sources they are subjected. Therefore, the findings in this case gives important information which can be used for solving NO_3^- problems in the study area and may contribute substantial scientific contributions towards valid clustered data analysis. Consequently, if the data could be analyzed separately, they could not show such variation despite the fact that inclusion in the entire group of data may have affected the entire results analysis. On the other hand, these data could be rejected if their results were obtained from similar sampling areas since we could expect gradual change in NO_3^- concentrations with uniform distribution in the entire assumed population.

5.4.3 Origin of nitrate using nitrate-chloride ratio

The existed strong correlation between chloride and nitrate ($n=23$, $r=0.70$), provides a preliminary information on the dominance of domestic wastewater as the main source of nitrate in the study area, since a strong correlation between nitrate ions and chloride ions has been linked to anthropogenic activities mainly from organic sources (Panno *et al.*, 2001; Prakash & Somashekar, 2006; Vasanthavigar & Srinivasamoorthy, 2012). Domestic wastewater could have got access to wells through their close proximity to sanitation facilities or infiltration from the old and poorly constructed cesspit, soak away pits present in the study area. However, the chloride and nitrate relation does not confirm pollution originality for individual sampling points because the correlation relation is an outcome of several data of which some may be absorbed by the relationship while they originate from a different pollution source. Hence other methods were used to confirm the existence of domestic wastewater.

The NO_3^-/Cl^- molar ratio has been used to trace the origin of nitrate contamination in certain areas globally (Anornu *et al.*, 2017). This approach compares the molar concentration ratios of nitrate and chloride ions with an assumption that halogens in the environment are difficult to transform into another component but exist as soluble salts in ionic form in the environment (Liu *et al.*, 2006). Hence, this property establishes a relationship that high Cl^- values against low NO_3^-/Cl^- (< molar concentration ratio) are associated with effluents and organic waste such as manure. Agricultural inputs are typically characterized by high NO_3^-/Cl^- (> molar concentration ratio) and low Cl^{-} values. This method has been used by different scholars including Anornu *et al*, (2017) in the identification of nitrate sources in Karst groundwater, Guiyang, Southwest China. The result of NO_3^-/Cl^- molar ratio indicated that most nitrates in the boreholes of the study area (96 -92 %) and shallow wells (71- 70 %) during dry and wet seasons originated from sewage effluents and/or organic wastes such as manure. These results relate with the land use activities of the study area as the sources contaminated with sewage effluents were situated in densely populated areas with congested onsite sanitation facilities while those contaminated with manure were in areas where livestock keeping was practiced and poultry manure is commonly used for agricultural activities. Likewise, observations showed most sources which contained their nitrate from manure as opposed to synthetic fertilizers, were about 4 -8 % of all boreholes and 30 - 29% of all shallow wells during dry and wet seasons respectively. The results correspond to the agricultural activities practiced in the study area as the majority of the farms use organic manure during farming (Kangalawe & Lyimo, 2013) and not mineral fertilizers.

5.4.4 Nitrate identification using dual isotope method ($\delta^{15}N-NO_3^-$ and $\delta^{18}O-NO_3^-$)

The measured $\delta^{15}N-NO_3^{--}$ of the study area had a mean value of +20.9 ‰ ± 5.17 ‰ in boreholes and +18.3 ‰ ± 6.33 ‰ in shallow wells, however, most sources had values of above +14 ‰ (Fig. 31a and 32a), probably suggest more than one source of groundwater nitrate contamination. According to Kendall, 1998 and Aravena and Mayer, (2010), some of these isotopic values fall within the $\delta^{18}O-NO_3^-$ values for nitrate from manure (+10 to +20.3 ‰) and sewage (+9 to +19 ‰). A study by Anornu *et al.*, (2017) reported a similar range of the $\delta^{18}O-NO_3^-$ values ranged from +6.75 ‰ to +22.1‰ from Ghana and associated them with manure and/or sewage.

Additionally, the elevated $\delta^{18}O-NO_3^-$ ranged between +10.29 to +33.92 ‰ in boreholes and between +14.08 to +34.63 ‰, were linked with values reported for nitrate-rich groundwater sources. Most shallow wells and boreholes dominated with pollution from fertilizers were located in areas with peasant agricultural activities that use fertilizers or manure for farming. In these areas, groundwater pollution was accelerated by agriculture runoff contaminated with fertilizers during the wet season. Most of the sampling points dominated by pollution from sewage effluents and/or manure were located in the township and the peri-urban/village areas.

This indicates existence of improper domestic waste management in households leading into seepage and lateral movement of such wastes from pit latrines, cesspits and septic tanks into nearby shallow wells and boreholes. According to Heaton *et al.*, (2006), and Kaown *et al.*, (2009), there are specific isotopic fractionation values for $\delta^{15}N\text{-}NO_3^-$ and ´ $\delta^{18}O\text{-}NO_3^-$which may specifically depict a particular source of nutrients. The values have been further proved by Kendall and McDonnell (1998), for manure and sewage which showed specific fractionation of $\delta^{15}N\text{-}NO_3^-$ at +4 ‰ to +25 ‰ with variations of $\delta^{18}O$ fractionation. However, synthetic fertilizers are predominant in an isotopic signature of $\delta^{18}O$ with specific values of $\delta^{18}O\text{-}NO_{3\text{-}}^-$range from +17 0 to +25 0. The main source for synthetic fertilizers is contributed by atmospheric oxygen with average isotopic signatures of +23.5‰ (Mayer *et al.*, 2002). Challenges occurs in the decision for $\delta^{18}O$ isotopic signatures with marginal values such as BH 17 ($\delta^{18}O$, +16.5 ‰, Fig. 33**)** and SW 29 ($\delta^{18}O$, +16.71 ‰ Fig. 34) which are very close to the standard baseline value for fertilizers pollution sources of $\delta^{18}O$, +17.00 ‰. In such cases the decision is made in the condition that the sample qualifies for both geochemical and dual isotope techniques. Therefore, the dual isotope results have shown high similarity with the hydrochemistry results that most sources are polluted with nitrates from sewage effluents and or manure (organic waste).

5.5 Conclusion

Nitrate contamination results showed that, nitrate contamination in the peri-urban sources were mostly caused by animal manure that was probably been carried to water systems during rainy season. About 60 % of Singida populations are prone to unacceptable nitrate contamination which is above the recommended standards by WHO and TBS and may lead to a serious health risk to the community. The nitrate contamination in boreholes and shallow wells situated in town area were mainly caused by sewage effluent/ manure since most sources were situated in close proximity to onsite sanitation facilities such as pit latrines which are commonly available in the study area. Very few groundwater samples were contaminated with nitrate from fertilizers, since fertilizers are not commonly used in the study area as compared to livestock manure.

To this end, this study recommends further investigation on the impact of high NO_3^- concentrations on the human population and livestock in the region. In addition, the construction of new wells should adhere to the rules and regulations instituted by the respective authority so as to minimize the chances of nitrate contamination and human health risks.

CHAPTER SIX

General Discussion, Conclusions and Recommendations

6. 1 General Discussion

This study assessed 58 groundwater sources from Singida Urban and Manyoni Districts and analyzed their suitability for drinking purposes based on their physical chemical characteristics, microbiological quality, sources and levels of metals and nitrates contamination. Also, factors facilitating high contamination in the same sources were assessed too, since proper information about the main sources of contamination in the study area was lacking.

This study assessed 58 groundwater sources from Singida Urban and Manyoni Districts and analyzed their suitability for drinking purposes based on their physical chemical characteristics, microbiological quality, sources and levels of metals and nitrates contamination. Furthermore, the factors facilitating high contamination in the same sources were assessed. Proper information about the main sources of contamination in the study area was lacking.

The current findings revealed that most groundwater sources particularly shallow wells were contaminated with feacal coliform bacteria. Wells located at a distance of more than 50 m from sanitation facilities were less contaminated with fecal coliform compared to those situated at a distance of 50 m from sanitation facilities.

Furthermore, results showed that microbial contamination of the selected sources was frequently observed in wells with the following characteristics, shallow depth (1-20 m), uncovered, with poor wellhead elevation, and those utilize buckets as water withdrawing mechanisms. Therefore, contamination due to these factors, signify a potential health risk to the end users as they may lead to water borne diseases due to consumption of contaminated water.

Additionally, the study revealed that wells that recorded high turbidity, high chloride concentrations, and low DO were poorly constructed. Also, seasonal variation specifically the rainy season played a significant role in contributing to relatively higher contamination of most ions by facilitating their leaching from the natural deposit and/or surface runoff from the external environment to the source.

The overall analyses of metals contamination showed significantly higher metal pollution during the dry season compared to the wet season, due to lack of dilution from rain water. Relatively higher uranium concentrations were in Manyoni groundwater than in Singida Urban due to the existence of granitic rocky with huge deposits of Uranium ore. Moreover, 40- 66 % of all groundwater sources were unsuitable for drinking purposes due to high concentrations of Mn, Cr, Pb, and Al above recommended standards by WHO and TBS. The higher concentrations of these toxic metal, signify a potential health risk to the end users as they may lead to human effect if consumed over a long period of time and in high amount than the Maximum Contamination Limit (MCL) proposed by TBS and WHO.

Another scientific contribution from this study was achieved through the use of dual isotope and hydro-chemical techniques, which revealed that most nitrate contamination in study area was originating from anthropogenic sources especially domestic source, animal manure, and synthetic fertilizers depending on the lateral distance of the water source in relation to pit latrines or agricultural areas. Specifically, in the urban area, nitrate contamination in boreholes and shallow wells were mainly due to domestic sewage effluents infiltrated from old and poorly constructed sanitation facilities, while in peri-urban areas nitrate sources were a result of animal manure and synthetic fertilizers.

6. 2 General conclusions

Contamination in the groundwater of the study area was a result of both natural processes and man- made activities. For example, the higher uranium concentrations in Manyoni were attributed to the existence of granitic rocky with huge deposits of uranium ore. Microbial and nitrate contamination were associated with anthropogenic activities. For instance, higher microbial contamination were in shallow wells that did not adhere to the standards of sanitary protection of water intake and surrounding land, according to TBS guideline. Hence, well with shallow depth (1-20 m), uncovered/lids with gaps, poor wellhead elevation, utilize buckets as water withdrawing mechanisms and were located at a distance of less than 50 m from onsite sanitation facilities recorded higher microbial contamination than those which abide to the recommended standard. Nitrate contamination in study area was originating from domestic wastewater, animal manure, and/ or synthetic fertilizers depending on the lateral distance of the groundwater source in relation to pit latrines or agricultural areas. Specifically, in the urban area, nitrate contamination were associated with domestic sewage effluents infiltrated from old and poorly constructed on site sanitation facilities, while in most peri-urban areas nitrate sources were a result of animal manure and synthetic fertilizers.

Seasonal variation specifically the rainy season showed significant role in contributing to higher concentrations of calcium, chloride, sulphate, TDS, and EC in wells due to surface runoff from external surroundings to the soure. The water quality from the main boreholes of Singida Urban, Mwankoko, Erao, Mabomba manne, Karakana, and Utemini (BH 2, BH 7, BH 15, BH 16, and BH 6), which are under Internal Drainage Basin Office conform to WHO and TBS standards in terms of coliform count, physical-chemical parameters, and metal concentrations including uranium concentrations which recorded highest concentrations than all metals measured in the study area. The uranium deposits have been associated with shallow depths in the study areas (Nyanda, 2014). Hence, shallow wells should be avoided, so as to manage uranium concentration groundwater of the study area. Boreholes of depth > 50 meter should be considered in the future drilling. In terms of nitrate contamination, Erao and Karakana conform to TBS standards while Mwankoko and Mabomba manne, recorded higher nitrate concentration above WHO and TBS standards, which implies that the population that depend on these two boreholes for consumption are prone to unacceptable nitrate contamination. The present study has scientifically contributed to the baseline information on microbial quality of the groundwater sources of the study are which are used for drinking purpose, since that information was lacking. Furthermore, the present study has revealed information on the sources of nitrate concentration, through the use of hydrochemistry and dual isotope techniques and associated them with anthropogenic activities.

6.3: Recommendations for further studies

Based on the results, the study considers the following recommendations are made to:

i. Introduce a multi-facet approach in raising awareness of water quality issues. For example, to engage outreach, education, policy regulation, and financial assistance to the community in order to engage in regular water quality testing and disinfecting of sources so as to prevent further contamination.

ii. Enforce the community and local wells drilled to abide by the policies, laws, and regulations governing proper sitting and construction of shallow wells or boreholes in consideration of proper distance from sanitary facilities such as pit latrines and soak away cesspit so as to prevent lateral movement contamination.

iii. Advice the community to treat groundwater before drinking, by using simple methods such as boiling, or other low-cost alternatives like use of sand filter which are cheap, and readily available in the study area, and have the ability to remove up to 99 % of microbes from water.

iv. Educate the community on the importance of maintaining a good hygienic environment of the source such as fencing of the source, emphasize the use of proper covers/lid, maintaining a proper wellhead elevation, and disinfecting water sources so as to reduce contamination.

v. Advise the community especially in town areas, where there is congested pit latrine to construct shared boreholes > 40 m instead of having individual shallow wells, which are easily contaminated with microbes and metals available in shallow depth like uranium of the study area.

vi. Advise Singida Urban Water and Sanitation Authority to develop proper sewage treatment systems.

vii. To carry out geochemical studies on metals especially uranium with the highest concentrations for a better understanding of their sources and impacts in the human beings and environment.

viii. To perform an epidemiological study on the effects of higher nitrate contamination in the study area to livestock and infant.

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APPENDICES

Appendix 1: Summary of the features of the groundwater sources in study area

ID	Name	Depth (m)	Water availability	Mouth aperture/lid	Type of cover	Pumping system	Water stored or direct use	Possible contaminants around 100m from source	Distant from sanitary facility (m)	Well head elevation	Public/private use	Treatment
BH 1	Sido	100	Never Dries	Covered	No Fractures	Motor Pump	Tank Storage	Human Settlements	10	Proper	Public	No Treatment
BH 2	Mwankoko	100	Never Dries	Covered	No Fractures	Motor Pump	Tank Storage	Farms	50	Proper	Public	Chlorine Treatment
SW 3	Munangwi	3	Dries	Covered	No Fractures	Hand Pump	No Storage	Kindai Lake/Human settlements	20	Proper	Public	No Treatment
BH 4	Mwamtanda	75	Never Dries	Covered	No Fractures	Hand Pump	No Storage	Human Settlements	50	Proper	Public	No Treatment
SW 5	Rafiki	20	Dries	Covered	No Fractures	Motor Pump	Tank Storage	Cesspit	30	Proper	Private	No Treatment
BH 6	Utemini Booster	70	Never Dries	Covered	No Fractures	Motor Pump	Tank Storage	Cesspit	15	Proper	Public	Chlorine Treatment
BH7	Erao	100	Never Dries	Covered	No Fractures	Motor Pump	Tank Storage	Shrub/livestock rearing	50	Proper	Public	Chlorine Treatment
SW 8	Yugo	20	Never Dries	Partially Covered	Fractured Cover	Hand Pump	No Storage	Vegetable Farm	5	Proper	Public	Water Guard
BH 9	EFPCT	75	Never Dries	Partially Covered	Fractured Cover	Motor Pump	Tank Storage	Vegetable Farm	10	Proper	Public	No Treatment
BH 10	Afro Oil	70	Never Dries	Covered	No Fractures	Motor Pump	Tank Storage	Pit Latrine/ Densely Populated	15	Proper	Public	No Treatment
SW 11	Katale	20	Never Dries	Covered	No Fractures	Motor Pump	Tank Storage	Lake Singidani/ Human settlements	300	Proper	Private	No Treatment
BH 12	TCRS	60	Never Dries	Covered	No Fractures	Motor Pump	Tank Storage	Human Settlements	20	Proper	Public	No Treatment
SW 13	Sabasaba	6	New	Covered	No Fractures	Motor Pump	Tank Storage	Cesspits	5	Proper	Public	No Treatment
SW 14	Manguanjuki	20	Dries	Covered	No Fractures	Hand Pump	No Storage	Vegetable Farms	5	Proper	Public	No Treatment

BH 15	Mabomba Manne-Vendor Kioski	100	Neve Dries	Covered	No Fractures	Motor Pump	No Storage	Human Settlements	0	Proper	Public	Chlorine Treatment
BH 16	Karakana-Vendor Kioski	100	Never Dries	Covered	No Fractures	Motor Pump	No Storage	Human Settlements	0	Proper	Public	Chlorine Treatment
BH 17	KKKT	100	Never Dries	Covered	No Fractures	Motor Pump	Tank Storage	Cesspit/ Human Settlements	15	Proper	Public	No Treatment
BH 18	Kititimo	97	Dries	Covered	No Fractures	Motor Pump	Tank Storage	Highway/livestock rearing	50	Proper	Public	No Treatment
SW 19	Mnunguna Osward	8	Dries	Partially Covered	Fractured Cover	Hand Pump	No Storage	Pit latrine/ Vegetable Farm	5	Proper	Public	No Treatment
SW 20	Mlugu	9	Dries	Partially Covered	Fractured Cover	Bucket Pulley	No Storage	Pit Latrine/ Vegetable Farm	10	Proper	Private	No Treatment
SW 21	Malugu	4	Dries	Partially Covered	Fractured Cover	Bucket Pulley	No Storage	Pit Latrine/ Vegetable Farm	10	Not Proper	Private	No Treatment
SW 22	Osward	9	Dries	Partially Covered	Fractured Cover	Bucket Pulley	No Storage	Pit Latrine/ Human Settlements	10	Proper	Private	No Treatment
SW 23	Macha	12	Never Dries	Partially Covered	Fractured Cover	Bucket Pulley	No Storage	Pit Latrine//Vegetable Farms/ Human Settlements	10	Proper	Private	No Treatment
BH 24	Kaaya	133	Never Dries	Covered	No Fractures	Bucket Pulley	Tank Storage	Densely populated/pit latrines	10	Proper	Public	No Treatment
SW 25	Temba	9	Dries	Partially Covered	Fractured Cover	Bucket Pulley	No Storage	Densely populated/Pit Latrine	10	Proper	Private	No Treatment
SW 26	Ramadhan	20	Never Dries	Covered	No Fractures	Hand Pump	No Storage	Vegetable Farm /Densely populated	5	Proper	Public	No Treatment
SW 27	Iyangi	10	Dries	Covered	No Fractures	Hand Pump	No Storage	Cattle Rearing/pit latrine	20	Proper	Public	No Treatment
BH 28	Kisaki B	60	Dries	Covered	No Fractures	Hand Pump	No Storage	Cattle Rearing/Farms	20	Proper	Public	No Treatment

SW 29	Ngaida	7	Dries	Uncovered	No lid	Bucket Pulley	No Storage	Maize/Wheat Farms/Cattle Rearing	10	Proper	Public	No Treatment
BH 30	Kitope	60	Never Dries	Covered	No Fractures	Hand Pump	No Storage	Maize/Wheat Farms	10	Proper	Public	No Treatment
BH 31	Irao	41	Never Dries	Covered	No Fractures	Hand Pump	No Storage	Maize/Wheat Farms	100	Proper	Public	No Treatment
SW 32	Ghalu Juu	10	Dries	Covered	No Fractures	Hand Pump	No Storage	Maize/Wheat Farms	40	Proper	Public	No Treatment
SW 33	Mikutyu	7	Dries	Uncovered	No lid	Bucket Pulley	No Storage	Maize/Wheat Farms	20	Not Proper	Public	No Treatment
SW 34	Mikutyu	4	Dries	Uncovered	No lid	Bucket Pulley	No Storage	Maize/Wheat Farms	20	Proper	Public	No Treatment
BH 35	Mwankoko	40	Never Dries	Covered	No Fractures	Hand Pump	No Storage	Vegetable Farms	25	Proper	Public	No Treatment
BH 36	Mwankoko B"	50	Never Dries	Covered	No Fractures	Hand Pump	No Storage	Human Settlements/pit latrines	2	Proper	Public	No Treatment
SW 37	Darajani	3.7	Dries	Covered	No Fractures	Hand Pump	No Storage	Maize/Wheat Farms	15	Proper	Public	No Treatment
SW 38	Mwankoko A"	2.7	Dries	Covered	No Fractures	Hand Pump	No Storage	Potatoes Farm	15	Proper	Public	No Treatment
SW 39	Kinyakhae	9	Dries	Uncovered	No lid	Bucket Pulley	No Storage	Vegetable Farm	10	Not Proper	Public	No Treatment
SW 40	Milade	20	Never Dries	Covered	No Fractures	Hand Pump	No Storage	Maize Farms	15	Proper	Public	No Treatment
SW 41	Maghaie	20	Dries	Covered	No Fractures	Hand Pump	No Storage	Maize Farms/Cattle Rearing	10	Proper	Public	No Treatment
BH 42	Sanga	40	Dries	Covered	No Fractures	Hand Pump	No Storage	Human Settlements/pit latrines	20	Proper	Public	No Treatment
BH 43	Muhalala	105	Never Dries	Covered	No Fractures	Hand Pump	No Storage	Cattle Rearing/ Farms/pit latrine	10	Proper	Public	No Treatment
BH 44	Kapiti	105	Never Dries	Covered	No Fractures	Hand Pump	No Storage	Cattle Rearing	0	Proper	Public	No Treatment
BH 45	Afro Oil	57	Never Dries	Covered	No Fractures	Hand Pump	Tank Storage	Petrol Station/Pit latrine/cesspit	10	Proper	Public	No Treatment
SW 46	Jamal	7	Dries	Partially Covered	Fractured Cover	Bucket Pulley	No Storage	Pit Latrine /Vegetable Farms	8	Not Proper	Public	No Treatment
SW 47	Mwl Shaban	8	Dries	Partially Covered	Fractured Cover	Bucket Pulley	No Storage	Pit Latrine/ Vegetable Farms	9	Not Proper	Public	No Treatment

SW 48	Allamtala	9	Never Dries	Partially Covered	Fractured Cover	Bucket Pulley	No Storage	Pit Latrines/Densely poulated	10	Not Proper	Public	No Treatment
SW 49	Babla Ivan	20	Never Dries	Covered	No Fractures	Hand Pump	No Storage	Pit Latrine/Densely populated	10	Proper	Private	No Treatment
BH 50	Franco Mitoo	126	Never Dries	Covered	No Fractures	Motor Pump	Tank Storage	Wheat/Maize/Vegetable Farms	100	Proper	Public	No Treatment
SW 51	Maghole	9.7	Never Dries	Partially Covered	Fractured Cover	Bucket Pulley	No Storage	Wheat/Maize/Vegetable Farms	20	Not Proper	Private	No Treatment
BH 52	Mwanzi	100	Never Dries	Covered	No Fractures	Motor Pump	Tank Storage	Wheat/Maize/Vegetable Farms	50	Proper	Public	No Treatment
BH 53	Mitoo	133	Never Dries	Covered	No Fractures	Motor Pump	Tank Storage	Wheat/Maize/Vegetable Farms	60	Proper	Public	No Treatment
BH 54	Mitoo	131	Never Dries	Covered	No Fractures	Motor Pump	Tank Storage	Wheat/Maize/Vegetable Farms	60	Proper	Public	No Treatment
BH 55	Mitoo	100	Never Dries	Covered	No Fractures	Motor Pump	Tank Storage	Wheat/Maize/Vegetable Farms	60	Proper	Public	No Treatment
BH 56	Mitoo	103	Never Dries	Covered	No Fractures	Motor Pump	Tank Storage	Wheat/Maize/Vegetable Farms	90	Proper	Public	No Treatment
BH 57	Mitoo	130	Never Dries	Covered	No Fractures	Motor Pump	Tank Storage	Wheat/Maize/Vegetable Farms	72	Proper	Public	No Treatment
BH 58	Mitoo	130	Never Dries	Covered	No Fractures	Motor Pump	Tank Storage	Wheat/Maize/Vegetable Farms	103	Proper	Public	No Treatment

Appendix 2: Summary of the coliform counts and water quality parameters in the selected sources from study area during dry season

Source	**ID**	**TC**	**FC**	***E.Coli***	**Temp.**	**pH**	**DO**	**EC**	**TDS**	**Turb**	**TA**	**TH**	**Ca^{2+}**	**Mg^{2+}**	**Cl^-**	**SO_4^{2-}**	**NH_4^+**	**NO_2^-**
Munangwi	SW 3	91	13	0	25.9	8.1	3.4	967	483	0	200	22	18	4	60.2	20	0.0	0.2
Rafiki	SW 5	30	0	0	26.1	5.7	4.0	308	154	121	24	56	8	48	56.3	7	0.2	0.0
Yugo	SW 8	151	4	0	23.5	5.4	2.9	330	165	438	24	20	4	16	44.7	8	0.1	0.3
Katale	SW 11	24	0	0	25.8	8.7	2.5	17.81	890	29	460	18	4	14	122.3	8	0.1	0.3
Sabasaba	SW 13	240	0	0	20.9	7.5	5.8	1325	663	47.38	128	100	80	20	120.4	9	0.1	0.3

Manguanjuki	SW 14	21	10	0	25.7	6.4	2.3	329	165	100	44	48	20	28	93.2	7	0.2	0.2
Mnunguna	SW 19	97	12	4	23.1	6.0	3.8	978	489	6.51	44	222	58	164	155.4	7	0.2	0.0
Mlugu	SW 20	98	23	50	24.8	5.8	3.2	909	455	40.3	28	178	54	124	114.6	12	0.2	0.0
Malugu	SW 21	79	21	98	22.8	6.1	2.6	1018	509	0	44	258	20	238	102.9	12	0.0	0.1
Osward	SW 22	350	21	7	24.0	6.0	2.7	1016	507	0	28	120	76	44	106.8	14	0.0	0.4
Macha	SW 23	310	20	42	22.6	7.0	2.7	1523	762	0	92	482	160	322	180.6	8	0.1	6.5
Temba	SW 25	51	4	0	22.6	7.0	2.5	2945	1473	7.29	84	786	228	558	258.3	60	0.4	0.2
Ramadhan	SW 26	67	5	0	24.0	6.5	2.7	2195	1096	0	84	610	148	462	184.5	11	0.2	0.0
Iyangi	SW 27	90	43	0	21.5	7.5	4.8	1024	254	178	160	178	108	70	29.9	27	0.2	0.1
Ngaida	SW 29	45	22	18	25.4	5.3	4.2	124	62	1432	20	22	6	16	9.9	18	0.2	0.1
Ghalu Juu	SW 32	80	44	14	23.1	5.7	3.2	253	126	802	36	40	12	28	18.9	9	0.1	0.0
Mikutyu	SW 33	90	32	35	21.6	4.4	3.4	146	73	402	12	12	6	6	10.9	10	0.1	0.1
Mikutyu	SW 34	102	42	19	21.8	5.4	3.8	186	93	284	20	14	6	8	15.9	9	0.6	0.1
Darajani	SW 37	12	9	3	28.1	5.1	2.9	246	123	66	8	20	4	16	31.9	0	0.1	0.0
Mwankoko A	SW 38	42	14	5	26.0	4.7	3.3	142	71	757	20	20	6	14	77.9	11	0.0	0.0
Kinyakhae	SW 39	26	11	6	25.1	6.7	4.8	361	181	514	56	68	10	58	123.9	32	0.1	0.1
Milade	SW 40	16	0	0	27.2	7.0	2.2	993	496	21.89	184	162	140	22	343.8	29	0.1	0.0
Maghaie	SW 41	8	0	0	25.8	6.6	2.1	1525	763	0	96	352	230	122	144.9	70	0.1	0.1
Jamal	SW 46	45	21	38	25.9	7.0	3.7	1479	739	76	88	148	108	40	293.9	36	0.2	0.2
Mwl Shaban	SW 47	56	32	16	26.0	6.7	3.3	1890	945	50	128	134	100	34	261.0	55	0.8	0.3
Allamtala	SW 48	67	26	17	25.8	6.4	3.5	1555	778	3.4	72	296	222	74	108.9	12	1.8	0.1
Bala Ivan	SW 49	16	2	0	25.6	7.2	3.3	4547	2273	0	96	728	718	10	40.9	74	0.2	0.0
Maghole	SW 51	129	53	27	27.9	6.2	3.8	250	125	1865	32	30	2	28	86.9	5	0.3	0.0
Sido	BH 1	6	5	6	25.8	6.7	3.6	1617	809	0	104	310	130	180	233.2	19	0.1	0.1
Mwankoko	BH 2	223	0	0	26.5	8.0	3.8	1664	832	0	84	230	68	162	277.8	42	0.1	0.0
Mwamtanda	BH 4	221	0	0	25.0	6.1	2.9	428	214	194	32	64	34	30	40.8	8	0.4	0.6
Utemini Booster	BH 6	221	0	0	25.1	7.7	4.7	1660	82.9	0	104	252	96	156	271.9	24	0.2	0.1
Erao	BH 7	39	0	0	30.9	7.9	4.2	1684	442	0	80	170	152	18	279.6	16	0.1	0.1
Efpct	BH 9	36	0	0	25.9	6.2	3.1	1208	604	0	64	262	88	174	215.6	18	0.1	0.2
Afro Oil	BH 10	72	0	0	26.0	6.7	3.6	820	410	0	68	230	88	142	73.8	7	0.1	0.6
TCRS	BH 12	100	0	0	25.4	6.2	4.7	941	470	0	80	208	56	152	99.0	5	0.2	0.0
Mabomba Manne	BH 15	12	0	0	25.5	7.9	4.6	1640	820	0	80	220	64	156	139.8	10	0.1	0.0

Karakana	BH 16	10	0	0	28.3	7.7	4.4	1701	851	17.08	84	160	72	88	211.7	21	0.1	0.0
Kkkt	BH 17	17	0	0	29.6	7.0	4.2	1768	883	0	60	220	138	82	130.1	10	0.1	0.1
Kititimo	BH 18	71	0	0	25.3	8.0	4.6	1112	556	0		258	74		89.0		0.1	0.0
Kaaya	BH 24	51	14	6	27.1	7.1	3.3	1656	880	0	108	280	130	150	207.8	38	0.1	0.0
Kisaki B	BH 28	40	17	0	26.3	6.6	4.7	878	439	61	148	104	56	48	111.9	18	0.1	0.0
Kitope	BH 30	21	4	0	26.9	6.9	2.1	1598	799	51	196	386	284	102	268.9	44	0.1	0.2
Irao	BH 31	10	0	0	26.9	6.7	3.3	980	489	53	100	188	114	74	139.9	27	0.1	0.0
Mwankoko	BH 35	6	0	0	28.3	6.5	2.5	1102	551	129	104	88	84	4	224.9	26	0.0	0.0
Mwankoko B"	BH 36	12	0	0	27.1	6.7	2.1	978	489	0	124	70	52	18	169.9	18	0.1	0.0
Sanga	BH 42	11	0	0	26.0	6.5	2.1	913	457	40.23	84	176	160	16	77.9	31	0.1	0.0
Muhalala	BH 43	10	0	0	24.9	7.2	4.4	803	402	0	172	234	164	74	675.7	18	0.1	0.0
Kapiti	BH 44	15	0	0	25.2	7.5	4.3	927	465	0	196	198	142	56	201.0	43	0.1	0.0
Afro Oil	BH 45	12	0	0	26.6	7.1	4.1	1680	840	0	116	496	340	156	230.9	3	0.2	0.0
Franco	BH 50	70	0	0	26.0	8.1	4.2	766	383	0	72	144	98	46	123.9	44	0.1	0.0
Mwanzi	BH 52	0	0	0	27.0	7.1	4.0	649	324	0	80	106	82	24	90.9	1	0.1	0.0
Mitoo	BH 53	34	0	0	26.1	8.0	4.2	673	336	0	76	120	90	30	98.9	58	0.2	0.0
Mitoo	BH 54	27	0	0	25.9	8.0	3.8	675	337	0	72	118	96	22	131.9	48	0.1	0.0
Mitoo	BH 55	41	0	0	25.9	7.7	4.1	692	346	0	68	126	120	6	123.9	51	0.1	0.0
Mitoo	BH 56	24	0	0	25.8	7.4	3.9	803	401	0	76	122	92	30	119.9	43	0.1	0.0
Mitoo	BH 57	11	0	0	26.0	7.8	4.0	737	737	0	64	186	114.2	71.8	108.9	54	0.2	0.0
Mitoo	BH 58	32	0	0	26.4	7.6	4.0	737	368	0	80	104	86	30	102.9	35	0.1	0.0

Appendix 3: Summary of the coliform counts and water quality parameters in the selected sources from study area during wet season

Source	**ID**	**TC**	**FC**	***E.Coli***	**Temp.**	**pH**	**DO**	**EC**	**TDS**	**Turb**	**TA**	**TH**	**Ca^{2+}**	**Mg^{2+}**	**Cl^-**	**SO_4^{2-}**	**NH_4^+**	**NO_2^-**
Munangwi	SW 3	122	35	4	26.1	8.1	4.4	880.0	434.0	0.0	76.0	115.0	32.2	82.8	48.5	59.0	0.1	0.2
Rafiki	SW 5	12	5	0	25.3	5.9	5.1	610.0	299.0	7.0	22.0	64.4	55.2	9.2	155.4	33.0	0.0	0.0
Yugo	SW 8	210	44	6	23.6	6.2	4.6	414.0	203.0	8.0	8.8	46.0	38.0	8.0	118.0	8.0	0.1	0.1
Katale	SW 11	54	4	0	25.5	8.7	4.2	1563.0	766.0	0.0	116.4	25.3	18.4	6.9	122.4	35.0	0.3	0.2
Sabasaba	SW 13	540	0	0	25	7.2	5.4	2030.0	995.0	3.0	45.0	303.0	294.4	8.6	318.6	93.0	0.1	0.7
Manguanjuki	SW 14	60	32	0	25.5	6.5	4.5	249.5	122.0	7.0	11.6	43.7	23.0	20.7	19.4	8.0	0.3	0.1
Mnunguna	SW 19	400	82	21	25	7.0	4.4	1099.0	538.0	7.0	20.4	161.0	133.4	27.6	212.0	95.0	0.3	0.0
Mlugu	SW 20	754	380	78	25	6.1	4.2	1184.0	580.0	1.0	12.0	128.8	119.6	9.2	237.0	55.0	0.1	1.4

Malugu	SW 21	450	143	223	25.7	6.2	4.5	989.0	485.0	0.0	30.0	124.2	110.4	13.8	176.8	43.0	0.1	0.1
Osward	SW 22	570	59	17	28.5	6.3	4.3	967.0	475.0	3.0	22.8	124.2	115.0	9.2	161.2	32.0	0.1	0.2
Macha	SW 23	430	32	99	24	7.0	3.7	1326.0	650.0	1.0	92.0	259.9	202.0	57.9	213.7	30.0	0.1	0.0
Temba	SW 25	400	24	6	24	7.5	4.3	3110.0	1525.0	1.0	102.0	349.6	257.6	92.0	260.3	223.0	0.1	0.3
Ramadhan	SW 26	370	24	6	25.2	7.0	4.4	2151.0	1054.0	0.0	91.6	690.0	644.0	46.0	208.0	126.0	0.6	0.0
Iyangi	SW 27	600	71	3	25	7.4	4.2	816.0	400.0	0.0	78.4	598.0	450.8	147.2	42.7	30.0	0.1	0.0
Ngaida	SW 29	80	36	35	26.5	5.4	3.9	129.0	63.0	90.0	21.2	41.4	9.2	32.2	63.0	8.0	1.1	0.3
Ghalu Juu	SW 32	900	618	88	23.14	6.4	3.6	159.5	105.0	81.0	9.6	59.8	50.6	9.2	65.0	16.0	0.4	0.1
Mikutyu	SW 33	282	212	250	22.7	6.1	4.3	123.2	60.0	53.0	4.0	69.0	32.2	36.8	3.9	11.0	0.1	0.1
Mikutyu	SW 34	760	352	103	23.27	6.1	4.1	249.0	125.0	280.0	9.6		13.8	9.2	23.3	10.0	0.3	0.0
Darajani	SW 37	48	12	7	26.72	6.0	3.6	239.0	117.0	15.0	9.6	36.8	32.2	4.6	178.7	7.0	0.2	0.0
Mwankoko A"	SW 38	77	27	13	26.39	6.8	3.2	123.7	61.0	103.0	10.6	87.4	23.0	64.4	5.8	17.0	0.3	0.1
Kinyakhae	SW 39	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
Milade	SW 40	40	4	0	26.03	7.0	4.4	960.0	471.0	1.0	62.4	98.9	82.8	16.1	124.3	25.0	0.1	0.0
Maghaie	SW 41	38	0	0	25.3	6.8	4.4	1404.0	688.0	11.0	52.0	218.5	105.8	112.7	273.9	123.0	0.1	0.0
Jamal	SW 46	80	78	66	24.6	6.9	5.3	1630.0	799.0	1.0	24.4	82.8	55.2	33.6	202.0	58.0	0.1	0.0
Shaban	SW 47	76	31	57	25.2	6.5	4.2	232.0	1138.0	4.0	32.0	124.2	27.6	96.6	301.1	78.0	7.0	2.3
Allamtala	SW 48	91	42	24	24.7	6.8	4.6	1133.0	555.0	4.0	20.0	41.4	18.4	23.0	19.4	58.0	0.1	0.1
Bala Ivan	SW 49	350	16	7	25.6	7.6	4.6	4790.0	2347.0	0.0	120.8	519.8	487.6	32.2	893.7	540.0	0.1	0.0
Maghole	SW 51	241	79	40	22.9	7.0	4.3	195.7	96.0	97.0	14.8	13.8	9.2	4.6	223.4	4.0	8.5	0.0
Sido	BH 1	18	15	8	25.1	7.2	4.7	1573.0	742.0	4.0	60.0	423.2	322.0	101.2	311.3	110.0	0.1	0.0
Mwankoko	BH 2	380	0	0	28.8	7.9	4.6	1485.0	728.0	0.0	46.4	141.3	69.0	72.3	326.4	82.0	0.0	0.0
Mwamtanda	BH 4	450	0	0	26.6	5.9	4.0	290.0	142.0	33.0	15.2	138.0	59.8	78.2	33.6	14.0	0.1	0.0
Utemini	BH 6	63	0	0	26.6	5.9	4.0	1559.0	764.0	33.0	48.0	147.2	92.0	55.2	375.5	75.0	0.0	0.0
Erao	BH 7	72	0	0	27.2	7.7	5.9	1510.0	740.0	4.0	45.0	262.2	234.6	27.6	330.3	83.0	0.0	0.0
Efpct	BH 9	137	2	0	22.7	7.1	3.3	1082.0	530.0	0.0	25.6	128.8	69.0	59.8	73.8	65.0	0.1	0.0
Afro Oil	BH 10	67	0	0	25.4	6.4	5.0	751.0	368.0	0.0	22.0	92.0	69.0	23.0	231.2	17.0	0.1	0.1
TCRS	BH 12	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
Mabomba	BH 15	56	0	0	25.3	5.9	5.1	610.0	299.0	7.0	42.4	126.5	119.6	6.9	345.8	75.0	0.0	0.0
Karakana	BH 16	35	0	0	28.3	7.7	5.1	1552.0	760.0	2.0	46.0	124.2	36.8	87.4	365.2	8.0	0.3	0.0
Kkkt	BH 17	48	0	0	28.3	6.6	4.8	1583.0	776.0	4.0	15.2	310.5	239.2	71.3	250.6	41.0	0.4	0.1
Kititimo	BH 18	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL

Kaaya	BH 24	174	49	24	27.3	7.4	4.0	1717.0	841.0	13.0	58.4	312.8	174.8	138.0	254.5	50.0	0.2	0.1
Kisaki B	BH 28	400	26	0	26.5	5.8	4.6	211.0	103.0	2.0	8.8	27.6	13.8	13.8	29.1	3.0	0.4	0.3
Kitope	BH 30	400	26	0	26.5	5.8	4.6	2742.0	1344.0	0.0	118.2	220.8	208.3	12.5	289.4	50.0	0.1	0.0
Irao	BH 31	65	19	0	26.1	7.0	3.9	512.0	250.0	9.0	8.0	59.8	50.6	9.2	38.8	13.0	0.2	0.0
Mwankoko	BH 35	130	0	0	26.7	7.1	4.3	632.0	310.0	59.0	30.0	46.0	41.4	4.6	137.9	15.0	0.2	0.0
Mwankoko B"	BH 36	14	1	0	27.1	6.5	4.3	895.0	439.0	10.0	38.0	92.0	73.6	18.4	153.4	8.0	0.1	0.0
Sanga	BH 42	46	2	0	25.8	6.9	3.6	689.0	338.0	13.0	30.8	92.0	82.8	9.2	106.8	30.0	0.1	0.0
Muhalala	BH 43	31	0	0	26.8	6.9	4.5	711.0	348.0	2.0	71.6	135.0	82.8	52.2	6.2	25.0	0.1	0.0
Kapiti	BH 44	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
Afro Oil	BH 45	26	5	0	26.2	6.8.	4.3	1515.0	741.0	2.0	36.4	279.4	253.0	26.4	351.6	11.0	6.0	1.9
Franco	BH 50	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
Mwanzi	BH 52	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
Mitoo	BH 53	70	0	0	26.7	7.6	4.5	613.0	300.0	0.0	27.2	69.0	59.8	9.2	75.7	52.0	0.0	0.0
Mitoo	BH 54	111	0	0	26.2	7.5	5.0	624.0	306.0	0.0	28.0	52.9	9.2	43.7	81.6	45.0	0.2	0.0
Mitoo	BH 55	83	0	0	25.5	7.2	5.1	721.0	354.0	1.0	24.0	92.0	82.8	9.2	104.9	33.0	0.1	0.0
Mitoo	BH 56	126	0	0	25.9	7.2	4.8	743.0	364.0	4.0	39.2	78.2	105.8	41.4	114.6	60.0	0.1	0.0
Mitoo	BH 57	76	0	0	25.7	7.3	5.1	73.5	360.0	0.0	32.0	64.4	36.8	27.6	110.0	38.0	0.1	0.0
Mitoo	BH 58	90	0	0	25.2	7.2	4.9	70.2	344.0	2.0	38.0	95.8	69.0	26.8	95.2	30.0	0.2	0.0

Appendix 4: Summary of the metal concentrations during dry season

SOURCE	ID	Uranium	Aluminium	Arsenic	Chromium	Manganese	Lead
Munangwi	SW 3	<0.001	0.93	0.07	0.39	0.64	1.77
Rafiki	SW 5	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Yugo	SW 8	<0.001	6.2	0.06	0.4	0.67	1.79
Katale	SW 11	<0.001	1.04	0.06	0.41	0.57	1.79
Sabasaba	SW 13	<0.001	1.79	0.06	0.4	0.81	1.79
Manguanjuki	SW 14	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mnunguna	SW 19	<0.001	0.86	0.06	0.4	0.77	1.83
Mlugu	SW 20	<0.001	0.85	0.08	0.4	0.81	1.83
Malugu	SW 21	<0.001	0.79	0.03	0.4	0.84	2.12
Osward	SW 22	<0.001	1.03	<0.01	0.39	0.81	1.88
Macha	SW 23	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Temba	SW 25	2.53	0.92	0.04	0.39	0.75	1.88
Ramadhan	SW 26	2.45	0.93	0.04	0.41	0.59	1.95
Iyangi	SW 27	2.47	2.17	0.06	0.37	0.64	1.51
Ngaida	SW 29	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ghalu Juu	SW 32	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mikutyu	SW 33	3.29	0.72	<0.01	0.37	0.76	1.52
Mikutyu	SW 34	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Darajani	SW 37	3.32	1.25	0.05	0.37	1.09	1.52
Mwankoko A"	SW 38	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Kinyakhae	SW 39	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001
Milade	SW 40	<0.001	<0.001	<0.003	<0.001	<0.001	<0.001
Maghaie	SW 41	3.42	0.76	0.06	0.37	1.26	1.53
Jamal	SW 46	3.48	1.54	0.1	0.37	0.89	1.64
Mwl Shaban	SW 47	3.46	1.06	0.05	0.38	1.1	1.63
Allamtala	SW 48	3.47	1.02	0.04	0.38	0.82	1.66
Bala Ivan	SW 49	4.49	0.88	0.02	0.38	0.64	1.63
Maghole	SW 51	4.3	0.81	0.17	0.44	0.63	2.02
Sido	BH 1	2.12	1.82	0.08	0.39	0.59	1.8
Mwankoko	BH 2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mwamtanda	BH 4	0.01	3.47	0.06	0.4	0.74	1.82
Utemini Booster	BH 6	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Erao	BH 7	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Efpct	BH 9	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Afro Oil	BH 10	0.01	1.18	0.04	0.4	0.61	1.77
TCRC	BH 12	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mabomba Manne	BH 15	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Karakana	BH 16	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Kkkt	BH 17	0.01	0.91	0.06	0.4	0.57	1.86
Kititimo	BH 18	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Kaaya	BH 24	2.46	1.1	0.09	0.4	1.13	2

Kisaki B	BH 28	2.56	1.04	0.03	0.37	0.59	1.54
Kitope	BH 30	2.58	0.76	0.06	0.37	0.68	1.52
Irao	BH 31	2.5	1.05	0.07	0.37	0.59	1.52
Mwankoko	BH 35	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mwankoko B"	BH 36	3.39	3.07	0.06	0.37	0.6	1.56
Sanga	BH 42	3.48	2.36	0.08	0.38	0.7	1.55
Muhalala	BH 43	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Kapiti	BH 44	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Afro Oil	BH 45	3.64	0.89	0.03	0.37	0.7	1.55
Franco	BH 50	4.27	0.85	0.07	0.38	0.6	1.69
Mwanzi	BH 52	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mitoo	BH 53	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mitoo	BH 54	2.36	0.9	0.02	0.4	0.57	1.86
Mitoo	BH 55	2.45	0.83	0.08	0.39	0.58	1.87
Mitoo	BH 56	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mitoo	BH 57	2.81	0.92	0.04	0.39	0.59	1.88
Mitoo	BH 58	2.76	0.89	0.04	0.39	1.38	1.83

Appendix 5: Summary of the metal concentrations during wet season

Source	**ID**	**Uranium**	**Arsenic**	**Chromium**	**Manganese**	**Lead**
Munangwi	SW 3	0.093	<0.001	<0.001	0.047	<0.001
Rafiki	SW 5	0.01	<0.001	<0.001	0.333	<0.001
Yugo	SW 8	0.01	<0.001	<0.001	0.04	<0.001
Katale	SW 11	0.02	<0.001	<0.001	0.01	<0.001
Sabasaba	SW 13	0.011	<0.001	<0.001	0.01	<0.001
Manguanjuki	SW 14	<0.001	<0.001	<0.001	<0.001	<0.001
Mnunguna	SW 19	0.01	<0.001	<0.001	0.085	<0.001
Mlugu	SW 20	0.01	<0.001	<0.001	0.135	<0.001
Malugu	SW 21	<0.001	<0.001	<0.001	0.01	<0.001
Osward	SW 22	0.01	<0.001	<0.001	0.115	<0.001
Macha	SW 23	0.01	<0.001	<0.001	0.088	<0.001
Temba	SW 25	0.01	<0.001	<0.001	0.08	<0.001
Ramadhan	SW 26	0.01	<0.001	<0.001	0.144	<0.001
Iyangi	SW 27	0.011	<0.001	<0.001	0.14	<0.001
Ngaida	SW 29	<0.001	<0.001	<0.001	<0.001	<0.001
Ghalu Juu	SW 32	0.01	<0.001	<0.001	0.022	<0.001
Mikutyu	SW 33	0.01	<0.001	<0.001	0.03	<0.001
Mikutyu	SW 34	<0.001	<0.001	<0.001	<0.001	<0.001
Darajani	SW 37	0.01	<0.001	<0.001	0.063	<0.001
Mwankoko A"	SW 38	<0.001	<0.001	<0.001	<0.001	<0.001
Kinyakhae	SW 39	NIL	NIL	NIL	NIL	NIL

Milade	SW 40	0.021	<0.001	<0.001	0.01	<0.001
Maghaie	SW 41	0.01	<0.001	<0.001	0.097	<0.001
Jamal	SW 46	<0.001	<0.001	<0.001	<0.001	<0.001
Mwl Shaban	SW 47	<0.001	<0.001	<0.001	<0.001	<0.001
Allamtala	SW 48	0.01	<0.001	<0.001	0.049	<0.001
Bala Ivan	SW 49	0.102	<0.001	<0.001	0.01	<0.001
Maghole	SW 51	<0.001	<0.001	<0.001	<0.001	<0.001
Sido	BH 1	<0.001	<0.001	<0.001	<0.001	<0.001
Mwankoko	BH 2	<0.001	<0.001	<0.001	<0.001	<0.001
Mwamtanda	BH 4	0.01	<0.001	<0.001	0.034	<0.001
Utemini Booster	BH 6	0.013	<0.001	<0.001	0.01	<0.001
Erao	BH 7	0.001	<0.001	<0.001	0.01	<0.001
Efpct	BH 9	0.028	<0.001	<0.001	0.053	<0.001
Afro Oil	BH 10	0.001	<0.001	<0.001	0.01	<0.001
TCRC	BH 12	NIL	NIL	NIL	NIL	NIL
Mabomba Manne	BH 15	0.011	<0.001	<0.001	0.01	<0.001
Karakana	BH 16	0.02	<0.001	<0.001	0.01	<0.001
Kkkt	BH 17	0.001	<0.001	<0.001	0.01	<0.001
Kititimo	BH 18	NIL	NIL	NIL	NIL	NIL
Kaaya	BH 24	0.011	<0.001	<0.001	0.06	<0.001
Kisaki B	BH 28	0.001	<0.001	<0.001	0.01	<0.001
Kitope	BH 30	0.01	<0.001	<0.001	0.05	<0.001
Irao	BH 31	0.001	<0.001	<0.001	0.01	<0.001
Mwankoko	BH 35	0.01	<0.001	<0.001	0.015	<0.001
Mwankoko B"	BH 36	0.011	<0.001	<0.001	0.019	<0.001
Sanga	BH 42	0.001	<0.001	<0.001	0.01	<0.001
Muhalala	BH 43	0.013	<0.001	<0.001	0.015	<0.001
Kapiti	BH 44	NIL	NIL	NIL	NIL	NIL
Afro Oil	BH 45	0.046	<0.001	<0.001	0.284	<0.001
Franco	BH 50	NIL	NIL	NIL	NIL	NIL
Mwanzi	BH 52	NIL	NIL	NIL	NIL	NIL
Mitoo	BH 53	0.025	<0.001	<0.001	0.016	<0.001
Mitoo	BH 54	0.029	<0.001	<0.001	0.015	<0.001
Mitoo	BH 55	0.042	<0.001	<0.001	0.017	<0.001
Mitoo	BH 56	0.042	<0.001	<0.001	0.016	<0.001
Mitoo	BH 57	0.035	<0.001	<0.001	0.01	<0.001
Mitoo	BH 58	0.01	<0.001	<0.001	0.028	<0.001

RESEARCH OUTPUT

(i) **Alex, R.**, & Njau, K. (2020). *Factors affecting distribution of coliforms bacteria in semi-arid groundwater sources- Tanzania*. International Journal of Biosciences 16(4), 487-499.

https://innspub.net/ijb/factors-affecting-distribution-coliforms-bacteria-semi-arid-groundwater-sources-tanzania/

(ii) **Alex, R**., Kitalika, A., Mogusu, E., & Njau, K. *Sources of Nitrate in Groundwater Aquifers of Semi-arid Region of Tanzania*. Geofluid (2021).

(iii) Alex, Rita. Muzuka, A. & Njau, K. N. Assessment of Groundwater Microbial Contamination in Semi-Arid Region of Central Tanzania -A case study of Singida Region (Poster presentation)