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P.O. Box: 3900 Kigali, Rwanda.

**ASSESSMENT OF GROUNDWATER (BOREHOLES) QUALITY IN
NYAGATARE DISTRICT, EASTERN PROVINCE OF RWANDA”**

A MASTER DISSERTATION

Submitted in partial fulfilment of the requirements for the award of

**A MASTER OF SCIENCE DEGREE IN WATER RESOURCES AND
ENVIRONMENTAL MANAGEMENT**

Submitted by

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Under the Guidance of

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August 2024

BONAFIDE CERTIFICATE

This is to certify that the Thesis entitled "**Assessment of groundwater (boreholes) quality Nyagatare district**" is a record of original bonafide work done by NDABAMENYE THEOGENE In partial fulfill of the requirement for the award of Master of Science in Water Resource and Environmental Management of University of Rwanda College of Science and Technology during academic year 2023-2024.

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DECLARATION

I, **NDABAMENYE Theogene**, do hereby declare that this research project, being submitted to the University of Rwanda for the degree of MASTER'S OF SCIENCE in Water Resources and Environmental Management, is my own independent work; and complies with the Code of Academic Integrity, as well as other relevant policies, procedures, rules and regulations of the University of Rwanda, and has not been submitted before to any institution by myself or any other person in fulfillment (or partial fulfillment) of the requirements for the attainment of any qualification.

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DEDICATION

I dedicate this Dissertation to Almighty God for strength, knowledge, wisdom, protection and will continue and keep positive to finish this research. Mercy to my mother and sister who encouraged and gave me support. I really respect to all who were helped me different ways.

We also want to dedicate the success of our research to the residents of Nyagatare district, they are the respondents of the study, without their cooperation and support this study will not be completed, they are the very important part of the research. With their wise and honest insight, the data we've collected is enough to complete this research. Lastly, we would like to dedicate the success of this research study to our teachers, for not giving up on cheering us and for encouraging us that we can do a lot. For always giving us hope and for advising us that we should always think positive, to always think that we can finish this research and could submit it in the set time.

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ABSTRACT

Underground water is an important natural resource serving as a reliable source of drinking water for many people worldwide, especially in developing countries. Underground water quality needs to be given a primary research and quality control attention due to possible contamination.

It has limited number of surface water resources while groundwater exploration was favors in Nyagatare district as boreholes. They were not only the chemicals from fertilizers through the agriculture's activities and microbes from livestock but also there were not spatial distribution of boreholes water quality parameters concentrations in Nyagatare district. This study was therefore designed to determine the physico-chemical and bacteriological quality of borehole water and map prediction in Nyagatare district.

The study was conducted in nine sectors in Nyagatare district. The bacterial load of the water samples was determined using standard microbiological methods. Physicochemical properties including pH, total alkalinity, temperature, turbidity, total dissolved solids (TDS), electrical conductivity, total hardness, calcium hardness, magnesium hardness, total iron, Manganese, chloride ion, fluoride, Nitrate and sulfate were determined. The values obtained were compared with the WHO. The Kriging Interpolation methods was adopted by using Arc GIS 10.8 to analyze the geostatistical for interpolation of point-based distribution of measured groundwater quality.

The recorded pH, total turbidity and EC ranges were 4.99– 7.36mg/l, 0.99 to 19.0NTU 45.16-157.25 μ S/cm respectively. Furthermore, the mean concentrations of iron, calcium, magnesium, chloride, fluoride, sulfate, nitrate and manganese were 0.13, 49.24, 15.49, 37.45, 1.82, 99.4, 5.60, 0.03 respectively. In addition, the mean total hardness value was found to be 121.76 mg/l whereas Only 20% of the water samples tested positive for faecal coliforms. Physical, chemical and biological parameters assessed with Predicted maps Ca^{2+} and Mg^{2+} Hardness, turbidity, Nitrate, fluoride and faecal parameter resulted at the highest values exceeding the WHO limit from laboratory and Geospatial Analysis water samples 14 (66.67%) were classified as “excellent and 7 (33.33%) Good water. Therefore, all the water samples without the presence of coliforms were considered suitable for human drinking. This calls for regular monitoring and purification of boreholes to ensure good water quality.

Keywords: groundwater, borehole, physico-chemical, biological, water quality

ACRONYMS

EPA	Environmental Protection Agency
CFU	colony forming unit
GIS	Geographic Information System)
MPN	Most Probable Number
NTU	Nephelometric Turbidity unit
SADC	South African Development Community
WHO	World Health Organization
WQI	Water quality index

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CHAP I. INTRODUCTION

1.1 BACKGROUND

Groundwater is a primary source of potable water worldwide, predominantly derived from rainfall or snowmelt that seeps through soil into underground aquifers [1]. A vital component of all living organisms is water. For instance, about two thirds of the weight of an adult human is made up of water [2]. Approximately two billion people do not have access to clean drinking water globally at the moment (Ndakize Joseph et al., 2020). Drinking tainted water is one of the main causes of diarrheal illnesses, which are the second greatest cause of death for children under five, killing over 760,000 of them every year, according to the World Health Organization (WHO, 2011a). Because of this, the World Health Organization (WHO) has determined that the biggest factor adversely affecting the overall health and wellbeing of inhabitants in under developed nations is the lack of access to clean drinking water. In general, the availability of clean drinking water can enhance the standard of living for low-income households worldwide and help to decrease or eliminate unnecessary deaths (such as those resulting from waterborne infections)[1],(WHO, 2011a). A secure and consistent supply of water is a necessary precondition for long-term population expansion and development.

About one-third of the world's population depends on groundwater for their water supply [6]. For instance, more than half of the water needs of developed industrialized nations like as groundwater is the source of the United States of America, Germany, and Denmark sources[7]. States that almost 90% of the freshwater resources that are readily available worldwide are found in groundwater, with the remaining 10% coming from wetlands, rivers, lakes, and reservoirs. A further benefit of groundwater irrigation of arable land is that it is thought to sustain 40% of global agricultural growth. Manufacturing [8]. Groundwater in sub-Saharan Africa is the most dependable source of water for drinking [9]. Although surface water contamination is more frequent than groundwater contamination, treating contaminated groundwater is frequently challenging and time-consuming. One of the most important environmental problems of our time is contaminated underground water. Because of the inappropriate and careless disposal of chemical, industrial, and sewage waste [10]. Significant biological, physical, and chemical characteristics of groundwater may be impacted by these sources of contamination. Groundwater

(boreholes) receive the waste waters and septic system effluent contain high concentration of dissolved organic carbon, ammonia, pathogens and organic micro pollutants as well as heavy metals and trace elements. Physico-chemical characteristics of drinking water are therefore very important in determining its suitability for usage [11]. Spatial distribution of groundwater quality parameters concentrations to protect water resources and reduce its human health impacts. Worldwide, vulnerable people become concerned over the potential growth of diseases in various environmental including the agricultural land due to waste deposition and residues from surface water systems. The Kriging interpolation has been adopted to compute the concentration of missing data spatially from the available surrounding data. However, classical statistics, assuming that the measured data are independent, is not able to analyze the spatial dependency of variables. Therefore, before ground water is used for human consumption, its quality must be determined. However, in many developing nations, this isn't always the case, occasionally because of problems with finances and inadequate quality control [12]. Rwanda as a developing country is confronted with various challenges including the provision of potable water for its growing population to meet the Millennium Development Goals and the Sustainable Development Goals. Because, there are fewer surface water resources in the eastern province of Rwanda, people are forced to use subsurface water, which makes the problem even more apparent [8]. These findings imply that groundwater is a valuable natural resource that has an impact on the health and happiness of a large number of people worldwide. Because of this, primary research on the resource's quality is necessary and focus on quality control While it is advised to periodically assess the quality of drinking water, this is not the situation in many regions of Rwanda, especially in those where people exclusively rely on for their water needs, boreholes. There are no available water quality data on ground water in Rwanda. Groundwater analysis give a compelling argument for the importance of groundwater quality for human development and ecosystem health. It also provides a global overview of the current knowledge, with focus on data coverage, gaps and technological advances as contribution of research. The main aim of this study therefore, is assessment of the water quality of boreholes in the eastern province of Rwanda.

1. 2 RESEARCH PROBLEM

Almost all water sources used by community people for domestic purposes sourced their water from rivers and nearby streams directly or hand pumps or wells which are influenced by underground movement of water. If these sources are contaminated and there is no data to show how much contaminated and the types of contaminants/pollutants present then the future is dark.

Availability of safe and reliable source of water is an essential prerequisite for sustained population growth and development [13]. Groundwater is a vital source of water supply for about one-third of the world's population. According to [14] groundwater constitutes nearly 90% of the world's readily available freshwater resources, with the remaining 10% from lakes, reservoirs, rivers and wetlands. In addition, groundwater irrigation of arable lands supports the growth of an estimated 40% of the global agricultural production. In sub-Saharan Africa, groundwater is the most reliable source of drinking water [15]. Comparatively, groundwater contamination is not as common as surface water but once contaminated, treatment is often difficult and time consuming. Underground water contamination is one of the main environmental issues today due to improper and indiscriminate disposal of sewage, industrial and chemical waste. These sources of contamination may influence important biological, physical and chemical variables of groundwater [16]. Contaminants that are mainly associated with groundwater pollution include nitrates, pesticides and faecal coliforms. Furthermore, human activities such as land use, agriculture activities and the intervention in the natural flow patterns are often implicated in groundwater pollution [17]. It is therefore critical to first assess the quality of ground water before it can be exploited for human consumption. This is, however, not always the case in many developing countries, sometimes due to financial and poor-quality control issues [18]. In such countries, physico-chemical and microbiological monitoring of water quality could serve as a convenient tool for examining potential contamination and to help decision-makers in evaluating the effectiveness of regulatory programmes in managing water resources. These approaches are recognized by the WHO in its Guidelines for Drinking Water Quality [19]. Rwanda as developing country access to improved drinking water sources has increased in Rwanda, from 85% to 87% between 2013/14 and 2016/17 [20]. This challenge is even more evident in the Eastern Province of the country due to the limited number of surface water resources, compelling people to resort to

the use of underground water. Although periodical evaluation of drinking water quality is recommended. However, there are research gaps that need to be addressed in assessment of water quality of boreholes periodical due to this area is dominated by agricultures activities and livestock. The main objective of this study was Geospatial Analysis for groundwater (boreholes) quality assessment in selected districts of the eastern regions of Rwanda[17].

As motivation eastern province occupy greatest number of boreholes in Rwanda 9% of improved water. Few studies have statistically analyzed the prediction map of the groundwater quality components and come up with their intercorrelation profiles. Currently, there is no specific study that has been undertaken to evaluate levels of groundwater quality in the Nyagatare district and effects of groundwater quality useful in daily. For the purposes of this research on the groundwater suitability, the rationale of this study is to assess the geospatial analysis groundwater quality assessment in Nyagatare district in Rwanda and come up with proper recommended water to be used for a range of beneficial and realistic health care of people.

9% of improved water contribute to national water supply come from eastern province through the groundwater as described[20] in figure below

EICV5		% use improved	Improved drinking water source					
			Protected spring	Public standpipe	Piped into dwelling /yard	Borehole	Protected well	Rain water
All Rwanda		87.4	38.3	35.4	9.4	3.0	1.2	0.1
Province	Kigali City	95.9	12.6	46.3	34.0	1.0	1.9	0.0
	Southern	88.0	57.9	21.5	4.4	2	2.1	0.0
	Western	86.5	44.3	35.2	5.6	0.6	0.6	0.3
	Northern	87.5	44.9	35.9	5.7	0.1	0.9	0.0
	Eastern	82.6	26.6	41.4	4.7	9.0	0.9	0.1
Urban/ rural	Urban	95.8	10.5	41.5	39.2	2.5	2.0	0.0
	Rural	85.4	45.0	33.9	2.3	3.1	1.1	0.1

Figure 0.1:Existing status of borehole in Eastern province

The status of existing boreholes in Nyagatare district are damaged with unfence to protected the livestock activities contributed in biological parameters such E. coli and total and feacal coliform as shown below



Figure 0.2: boreholes status

1. 3 OBJECTIVES AND RESEARCH QUESTIONS

1.3.1 General objectives

The main aim of this research is Geospatial Analysis for groundwater (boreholes) quality assessment in eastern province of Rwanda. To achieve the main objective of this research, the specific objectives will be addressed:

To assess the groundwater (boreholes) quality parameters for

- ✚ physical parameters (The pH, temperature, conductivity and total dissolved solids (TDS))
- ✚ chemical parameters of boreholes (Ca²⁺, Mg²⁺, PO₄²⁻, Cl⁻ ...)
- ✚ biological parameters (E. coli, Faecal coliforms)
- ✚ Prediction map of the groundwater (boreholes) quality in Nyagatare district

1.3.2 Research questions

How is groundwater contaminated?

What are the parameters were analyzed?

How the test results will help decision makers to monitor boreholes?

CHAP II. LITERATURE REVIEW

In general, low temperatures, low redox potential, high mineral and carbon dioxide contents, low levels of suspended particles, and the absence of microbial pollutants are the characteristics of groundwater [21]. Groundwater pollution in urban areas is mostly due to infiltration of urban storm water, leakage of waste waters and septic reservoirs and improper industrial activities [13] Water has been accorded high priority in the global development agenda. Water quality refers to the chemical, physical, and biological characteristics of water based on the standards of its usage. It is most frequently used by reference to a set of standards against which compliance, generally achieved through treatment of the water, can be assessed [22]. The most common standards used to monitor and assess water quality convey the health of ecosystems, safety of human contact, extend of water pollution and condition of drinking water [23].

Drinking water plays an important role in the oral intake of trace elements in human beings. Physico-chemical characteristics of drinking water are therefore very important in determining its suitability for usage. Significant variations in physico-chemical parameters affect the quality of a water resource. Hence, it is necessary to obtain information on the variations of seasonal physico-chemical characteristics of water resources in order to decide on the type of water treatment process to be adopted. Even though some of the trace elements found in water are essential to man, at elevated levels, they cause morphological abnormalities, reduce growth, increase mortality and mutagenic effects [24].

Water quality has a significant impact on water supply and often times determines supply options.

Water quality refers to a range of measures including temperature, pH, nutrient and chemical levels. These levels naturally vary between different freshwater environments, but human activity can cause extreme changes in water quality, from which natural environments cannot always [25].

The demand for water globally varies remarkably amongst countries; this depends on the population, prevailing levels and patterns of socio-economic development, marked differences exist between developing and developed countries. For example, the average per capita domestic use in the United States of America is more than 70 times that in Ghana [26]. Water supplies continue to dwindle because of resource depletion and pollution, whilst population growth and expansion in industry and agriculture further exacerbate the problem of water scarcity. Contentious

competition for the water of international rivers such as the Nile, the Jordan and the Ganges is a symptom of the increasing scarcity of water[27] In the South African Development Community (SADC) the distribution, occurrence and availability of water resources is uneven in the region and within individual countries, the water availability depends on the rainfall [28]. There is a marked difference in water consumption at both global and regional levels. There is also an increasing trend of water scarcity leading to competition amongst different water users as well as amongst nations. Mostly human activities interfere with the quality of water resources in diverse ways. According to large amount of untreated industrial waste, agricultural pollutant and living pollutant, ground and surface water pollution have increased tremendously, which has affected drinking water sources. This situation has rendered the China with unsafe drinking water. Degradation of surface and groundwater sources has previously been an inherent consequence of economic development and remedial action to compensate for, or to reduce, environmental impacts have always been a lesser priority [29] . Preventing pollution is significantly less expensive than paying fines and cleanup costs. According to the United States Environmental Protection Agency (EPA) Americans spent U\$ 140 billion a year to control and clean up pollution[13]. A study in Harare indicated that the raw water quality in the city had deteriorated and for this reason chemical usage in treating the water has increased, in 1991 for example, only 35–40 g of aluminum sulphate treated 1m³ of water [14]. In this regard, the geospatial variation has been recognized for many years in water quality analysis where Water characteristics generally showed spatial dependence [30]. Samples close to each other have similar properties compared with samples distant from each other [31]. The Kriging interpolation has been adopted to compute the concentration of missing data spatially from the available surrounding data. However, classical statistics, assuming that the measured data are independent, is not able to analyze the spatial dependency of variables. Spatial variability of groundwater parameter based on Kriging interpolation indicated that the spatial correlation of wetland's total N, available P and K with random factors (fertilization, soil management and land use) was weak[32]

2.1 PARAMETERS AND METHOD USED

2.1.1 Ca+Mg (Hardness): EDTA Titrimetric Method

Principles

If Eriochrome black T is added to a water sample containing Ca and Mg ions at a PH 10.0 ± 0.1 , the solution becomes red wine. If EDTA is added, the Ca and Mg will be complexed. And when all the Ca and Mg has been complexed the solution turns from wine red to blue, marking the end point of titration. Mg ions must be present to yield a satisfactory end –point. To ensure this, a small amount of complexometrically method neutral Mg-EDTA is added to the buffer. This automatically introduces sufficient Mg. A limit of 5min. is set for duration of the titration to minimize the tendency towards CaCO_3 precipitation.

Reagent

Buffer:

- ✚ Dissolved 1.179g $\text{Na}_2\text{EDTA} \cdot 2\text{H}_2\text{O}$ and 780mg $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ in 50 ml
- ✚ Dissolved 16.9g NH_4Cl in 143 Conc. NH_4OH Add solution 1 to solution 2 with mixing and dilute to 250ml
- ✚ Eriochrome black T: Dissolve 0.5g in 90ml of triethanolamine.
- ✚ EDTA 0.01M: Dissolve 3.723g $\text{Na}_2\text{EDTA} \cdot 2\text{H}_2\text{O}$ in 1000ml. standardize this solution
1mmol EDTA = 1mmol Ca

Procedures.

- Take a sample volume that required less 15ml EDTA and complete titration in 5min measured from time of buffer addition. Dilute 25ml sample to 50 ml in borosilicate Erlenmeyer.
- Add 1-2 buffer, usually 1ml will be sufficient to produce a PH 10.0 ± 0.1
- Add 2 drops Eriochrome black T Indicator
- Titrate slowly with EDTA with continuous stirring; until the last reddish tinge disappears add the last drops at 3-5 Sec intervals.

Calculation

Hardness as Mg CaCO₃/ L = (V*M*100) *(1000/ml sample) where

V= ml EDTA Titrated

M= Molarity of EDTA

TMg=(THa - TCa)

Mg =(THa -TCa)*0.84*.29

2.1.2 Fe²⁺ phenanthroline Method

Principle

Iron is brought into solution reduced from Fe³⁺ to Fe²⁺ by boiling acid and hydroxylamine. Fe²⁺ will form an orange red colored complex with 1.10 phenanthroline. The intensity of color is independent of PH 3 to 9. A PH between 2.9 to 3.5 will ensures the rapid color development in the present of excess phenanthroline.

Apparatus

- ✚ Spectrophotometer, for use at 510nm with a 1cm cell
- ✚ Acid washed glassware with Conc. Hcl and rinse with distilled water before use. This removes deposits iron oxide.
- ✚ Separator funnels, only when samples are digested.

Reagent

The hydroxylamine, phenanthroline and stock iron solution

2.1.3 Cl⁻ -Argenometric Method

Principles.

Silver chloride is precipitated quantitatively prior to the formation of red silver chromate. The Argenometric method uses a silver nitrate solution to titrate. In the titration, the chloride ion precipitates as white silver chloride. Potassium chromate, which provides chromate ions.

Apparatus: Burette, conical flask, pipette, measuring cylinder.

Reagents: potassium chromate indicator solution and standard silver nitrate titrant.

Procedure.

- Use 100ml sample or suitable portion dilute to 100ml which contains 0.15 – 10mg Cl-
- If the sample is high colored or turbidity, add 3ml Al (OH)₃ suspension, mix, let settle and filter. If sulfide, sulfate or thiosulfate is present, add 1ml H₂O₂ and stir for 1min.
- Adjust PH 7-10, if necessary
- Add 1ml K₂CrO₄ indicator
- Titrate with AgNO₃, be consistent in endpoint recognition
- Carryout a blank, a titration volume for blank of 0.2-0.3ml is usual

Calculation

Mg Cl-/L = (A-B)*M*35.45 *(100mL/mL sample) Where

A=mL titration for sample

B=ML titration of blank

M= Morality of AgNO₃

2.1.4 NO₃- Spectrophotometric Method with 2, 6 dimethyl phenol

Apparatus: Spectrophotometer for use at 324nm of 1cm cells

Reagents:

- ✚ Dissolve 0.040g amino sulfonic acid in 10ml H₂O Transfer to 2L Beaker and add 500ml conc. H₂SO₄ and 500ml conc. H₃PO₄
- ✚ Dissolve 1.2g 2,6 dimethyl phenol in 1000mL glacial acetic acid
- ✚ Stock NO₃-N 1000mg/L: Dissolve 7.218gKNO₃(Dried at 105oc for 24h) into H₂O And dilute to 1000mL
- ✚ Standard NO₃-N 100mg/L: Dilute 10.00 ml stock solution to 100ml with 100ml

Calibration.

- Transfer the following amount of standard NO₃-N to 100ml Volumetric flasks:0,1.00,5.00,10.00,15.00,20.00,25.00 and 30.00ml and fill up to mark.
- Add 35ml of reagent 1 to a 50ml of volumetric flask
- Add 5.00ml of each solution from 1 to a 50ml of volumetric flask
- Mix well and wait 5-10 min
- Add 5.00ml of reagent 2, mix and wait 10 minutes.
- Measure the absorbance at 324nm between 10-60minutes with a 1cm quartz cuvet
- Plot the absorbance against NO₃-N Concentration (max 30 mg/L) and determine the mathematical expression of the calibration line.

Procedure.

- ❖ To 50ml clear sample add 1ml 1M Hcl and mix
- ❖ proceed as mentioned under calibration $\text{mgNO}_3\text{-N/L} = (\mu\text{g NO}_3\text{-N IN 50 mL 3rd volume}) / (\text{ml sample})$

2.1.5 SO₄²⁻- spectrophotometric Method

Principles

SO₄²⁻ is precipitated in acetic acid medium with BaCl₂ so as to form BaSO₄ crystals of uniform size. Light absorbance or scattered light is measured by photometer. The minimum detectable concentration is approximately 1mg/L.

Apparatus

- ✚ Magnet stirrer with constant stirring speed, use magnets of identical shape and size.
- ✚ spectrophotometer for use at 420nm with 5cm cells.
- ✚ stopwatch
- ✚ measuring spoon, capacity 0.2-0.3ml

Reagent

- Buffer: Dissolve 30g $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$, 5g $\text{CH}_3\text{COONa} \cdot 3\text{H}_2\text{O}$, 1g KNO_3 and 20mL CH_3COOH in 500mL H_2O and make up to 1000mL. use this buffer for sample containing $>10\text{mg SO}_4^{2-}/\text{L}$.
- BaCl_2 crystal of 20-30mesh (0.6-0.8mm)
- Stock SO_4^{2-} : Dissolve 1,479g dried Na_2SO_4 in 1000mL 1mL=1mg SO_4^{2-}
- Standard SO_4^{2-} : Dilute 100mL stock to 1000mL 1.00mL =100 $\mu\text{g SO}_4^{2-}$

Procedure for SO_4^{2-} Concentration between 10-40mg/L

- ❖ Measure 100mL Sample or suitable portion diluted to 100mL in volumetric flask to 250mL beaker + magnet; add 20mL buffer and mix.

$\text{mg SO}_4^{2-}/\text{L} = (\mu\text{g SO}_4 \text{ in } 100\text{mL end volume})/\text{mL sample}$.

CHAP III: MATERIAL AND METHOD

3.1. STUDY AREA

The study was conducted in eight out of the thirteen administrative sectors in Nyagatare districts in the eastern province of Rwanda. It has two rainy seasons from March to the end of May as Heavy rain season this is followed by dry season from early June to August and from September to December as low rain season also followed by dry season from early January to February with average annual rainfall of about 904 mm. in general Nyagatare District experiences small quantity of rain and hot temperatures. The mean monthly temperature ranges between 21 and 32 °C. The area has an almost flat topography with elevations generally between 1000 and 1500 m above sea level. Muvumba multipurpose dam of water and groundwater boreholes provide the source of water during the dry season. The study area covers Matimba, Musheru, Rwimiyaga, Nyagatare, Rwempasha, Tabarwe, Karangazi, and Katabagemu sectors in Nyagatare district in Table 3.1.

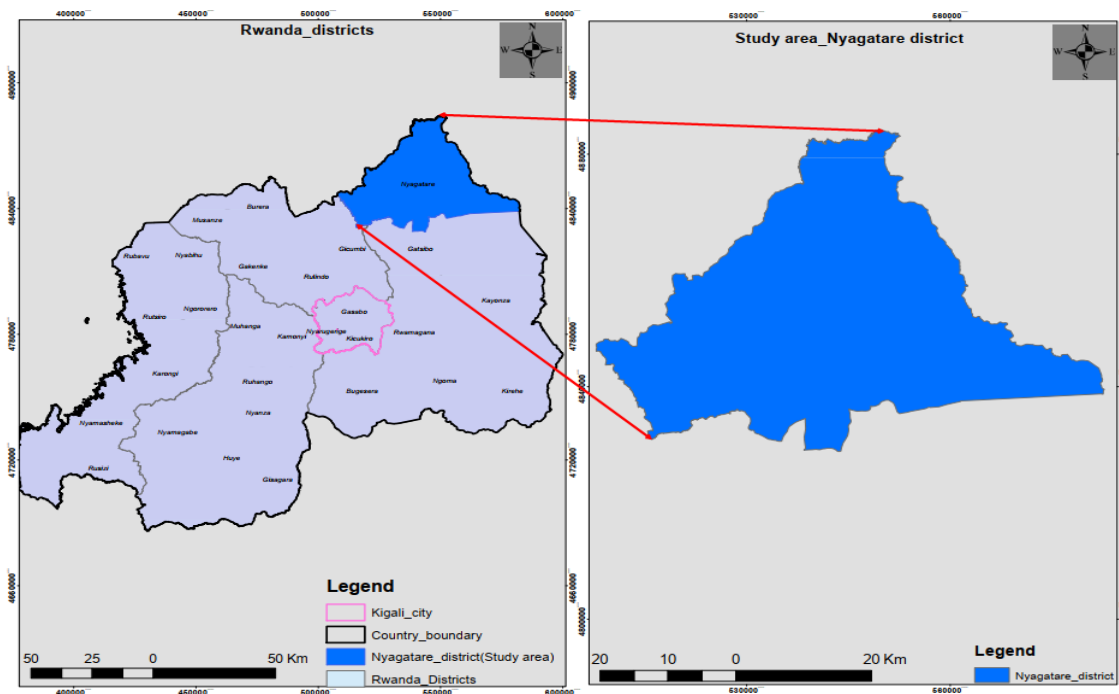


Figure 0.1:Description of Study area

The study area covered whole geographical area of Nyagatare district. Details of the sectors, cells where samples were taken are provided in Table 3.1. The selection area was motivated by the following reasons:

- Nyagatare districts communities are one of greatest part served by Groundwater(boreholes) in eastern province in Rwanda
- Nyagatare districts has great part of livestock farming area which can affecting surface and groundwater by discharging nitrates
- Regular quality analysis is not conducted on the boreholes that serve these communities.
- The borehole water often takes its source from streams and rivers that may become contaminated with solid waste, chemicals and faeces.

3.2. DESCRIPTION OF SITES AND SAMPLE COLLECTION

The study was conducted in nine out of the thirteen administrative sectors in Nyagatare districts in the eastern province of Rwanda (figure 3.2) and table 3.1

Table 0.1:Description of sites and sample collection

SN	Sectors	Number of boreholes	Date
1	Matimba	2	24/05/2024
2	Musheri	2	24/05/2024
3	Rwimiyaga	3	25/05/2024
4	Nyagatare	5	26/05/2024
5	Rwempasha	2	27/05/2024
6	Tabarwe	2	27/05/2024
7	Karangazi	2	28/05/2024
8	Katabagemu	2	28/05/2024
9	Rukomo	1	28/05/2024

Through the selected sectors site visit conducted on 12th February 2024 to make sure samples taken has been presented all study area based on resettlement plan and agricultures and livestock's activities.

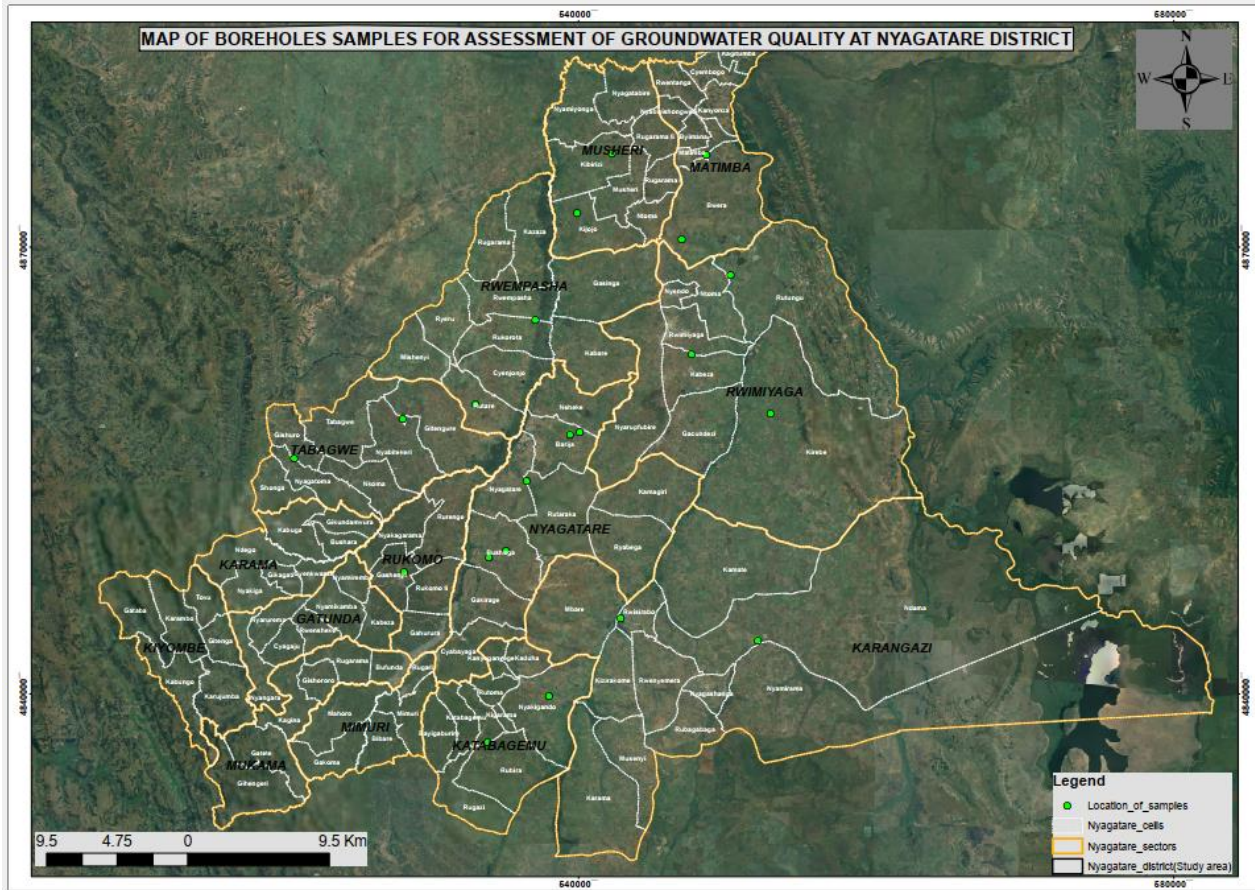


Figure 0.2: Map showing boreholes location using satellite image

Groundwater sampling also pick coordinates of boreholes using GPS to locate boreholes and prediction maps of nine sectors in Nyagatare district described in table below.

Table 0.2: Description of study areas using coordinates (ITRF 2005) system

SN	sector	Location/Cell	Easting	Northing
1	Rwimiyaga	Kabeza	547618.197	4862795.83
2	Rwimiyaga	Kirebe	552920.476	4858824.73
3	Rwimiyaga	Bwera/ Rutungu	550242.263	4868156.45
4	Matimba	Bwera	546951.677	4870491.38
5	Matimba	Matimba	548604.352	4876180.01
6	Rwempasha	Rukorota	537124.317	4865090.47
7	Rwempasha	Rutare	533106.487	4859399.42
8	Katabagemu	Nyakigando	538033.345	4839820.54
9	Katabagemu	Kigarama	533912.372	4836758.57
10	Tabagwe	Gishuro	520920.629	4855846.65
11	Tabagwe	Gitengure	528209.444	4858467.91
12	Karangazi	Rwisirabo	542863.555	4845115.42

13	Karangazi	Ndama	552074.296	4843613.59
14	Musheri	Kibirizi	542267.922	4876286.43
15	Musheri	Kijojo	539930.521	4872315.8
16	Nyagatare	Rutaraka	536520.706	4854269.43
17	Nyagatare	Bushoga	535146.019	4849566.8
18	Nyagatare	Bushoga (Cyonyo II)	534000.121	4849206
19	Nyagatare	Barija	539449.143	4857440.12
20	Nyagatare	Barija (Nyagatare P.S)	540105.908	4857540.39
21	Rukomo	Gashenyi (Rukomo HC)	528297.572	4848157.81

3.3. SECONDARY DATA COLLECTION

Journal articles, Government reports, Different shapefiles from UR-CGIS and RWB, collected groundwater data from WASAC group and land use and cover, soil data from National Land Authority.

3.4. ANALYSIS

In May 2024, a total of 21 borehole samples were gathered for the research. To attain sterility, the nozzles of every borehole were ignited using a cotton wool soaked in 98% alcohol and flamed for approximately two minutes[9], [21]. Following a two-minute water pumping cycle to clear away any stagnant water in the pipes, sterilized glass bottles were used to aseptically collect the borehole water samples[33]. After the physical parameters were established on the spot, all of the water samples were collected into 500 ml sterilized plastic bottles and kept in freezers at a temperature of roughly 4°C. The purpose of this was to make sure that there were no pollutants of any kind in the sample bottles. Next, an ice container was used to store the samples and transferred to the water quality analysis laboratory at university of Rwanda for analysis.

3.4.1 Soil types

In terms of soil texture classification, the greatest part of soil types from the selected sampling sites was classified by clay as show in figure below second class is sand clay, sandy loam, sand clay loam and loam.

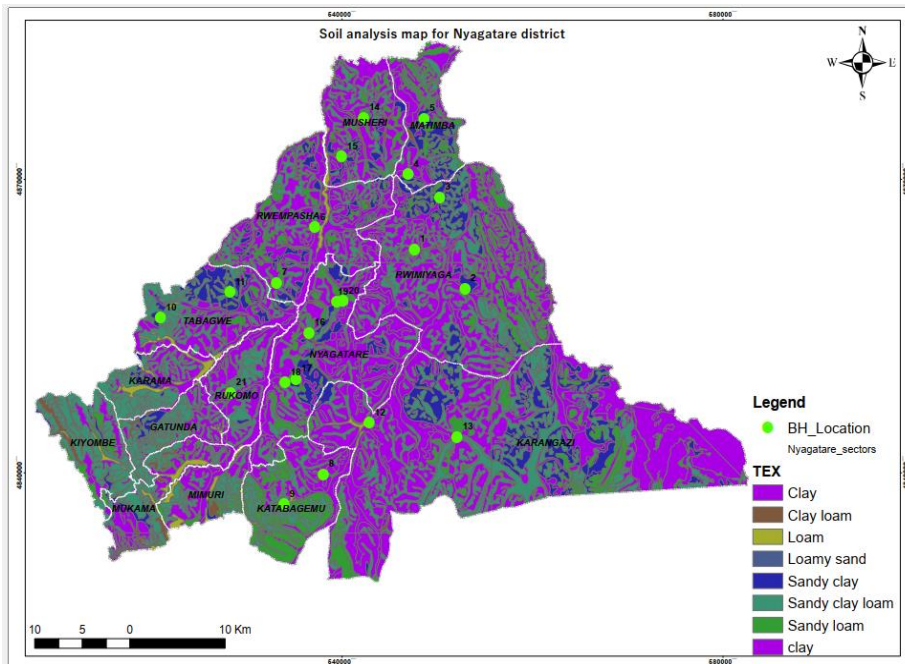


Figure 0.3: Layout of soil type

3.4.2 Land cover Land use (LCLU)

In terms of Land Cover Land Use, the greatest part of land use types from the selected sites was open land and agriculture activities. Second part are forest, settlement and building, wetland and water.

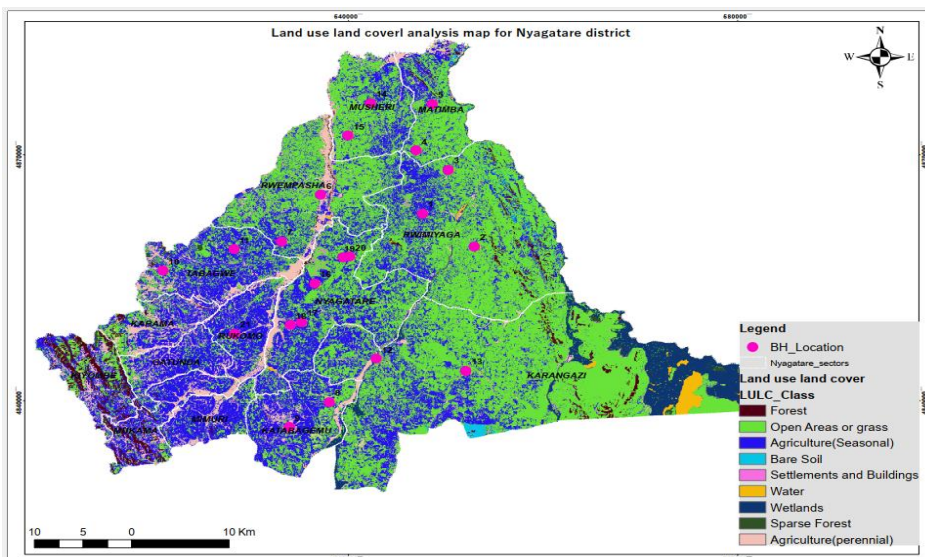


Figure 0.4:Layout of land use and land cover

3.4.3 Physico-chemical analysis

The water temperature, pH, conductivity and total dissolved solids were measured at the site using handheld multipurpose meters. Turbidity of each water sample were also determine using a turbidity meter. Nitrates (NO₃-), Sulphate (SO₄²⁻), Chloride (Cl-) Fluoride (F-) were determined UV spectrometric method, turbidimetric method, Silver chloride is precipitated quantitatively before red silver chromate is formed. The Argentometric method employs a solution of silver nitrate for titration. In the titration the chloride ion is precipitated as white silver chloride. potassium chromate, which supplies chromate ions[18] respectively. Iron (Fe) by Spectrophotometric, Total hardness, (TH) Calcium hardness, (CaH) were determined titrimetrically[34]. Calcium hardness were measured by ethylenediaminetetraacetic acid titrimetric method using powdered ammonium murixide as an indicator[35]. The magnesium hardness was calculated by subtracting the value for the calcium hardness from the value for the total hardness. Chloride ion concentration was determined by titrating each sample against 14 mM silver nitrate solution using 1 ml of 5% potassium chromate as an indicator. Fluoride ion concentration was determined by employing the Spadn's colorimetric method. UV/VIS spectrophotometer was used to determine the ionic concentrations of manganese and iron.

3.4.4 Determination of total and faecal coliforms

Faecal coliforms were found in the ground water samples using the Most Probable Number (MPN). Ten milliliters of water sample were used to inoculate a representative of double strength MacConkey broth tubes that contained inverted Durham tubes[2]. A representative of single strength broth tubes was given one milliliter of water, and a second set of single strength broth tubes received 0.1 milliliters of the same sample. The number of tubes exhibiting growth, positive color change, and gas production in each set will be compared with the MPN index following a 48-hour incubation period to ascertain the quantity of coliforms per 100 milliliters Moreover, favorable. MacConkey broth tubes from the highest dilutions were inoculated into Eosin-Methylene blue agar, brilliant green lactose bile broth and gram stained to confirm the presence of faecal coliforms.

3.4.5 Ground water quality analysis

Thirteen (13) parameters were considered in calculating the WQI. As shown in Table 3.3, based on their apparent impact on primary health or their relative significance in the overall quality of the water fit for drinking, each chemical parameter was given a weight (wi). The highest weight of 5 was assigned to parameters that have major effects on water quality and their importance in quality and a minimum of 1 was assigned to parameters that were considered as not harmful to human health (Table 3.3). The method used to determine the WQI was first proposed by Tiwari and Mishra (1985) and later modified by on groundwater samples which involves first calculating the quality of parameters, qi as presented in the equation below.

$$qi = \frac{Va}{Vs} \times 100 \quad . \quad (3.1)$$

where **qi** is the quality rating of each parameter for a total of n water samples, Va is the value of the water-quality parameter obtained from the laboratory analysis of the sample and Vs is the value of the water-quality parameter obtained from the WHO water-quality standard. The relative weight Wi was also calculated from the following equation:

Table 0.3: Assignment of weights in the ground water WQI

Parameter	Weight (wi)	Relative weight (Wi)	WHO standards
pH	3	0.073	6.5-8.5
Conductivity	3	0.073	1400
Total dissolved solutes	5	0.122	1000
Turbidity	1	0.024	≤5
Total Hardness	3	0.073	500
Calcium Hardness	3	0.073	75
Magnesium Hardness	3	0.073	50
Nitrate-nitrogen	5	0.122	10
Chloride ions	5	0.122	250

Fluoride	5	0.122	1.5
Sulphate	3	0.073	200
Total iron	1	0.024	0.3
Manganese	1	0.024	0.1
	$\sum w_i=41$	$\sum W_i=1$	

WHO World Health Organization

$$W_i = \frac{w_i}{\sum w_i} \quad \text{where } w_i \text{ is the weight of each parameter.} \quad (3.2)$$

Finally, the **WQI** was then determined by summing the product of the quality rating of each parameter and its relative weight.

$$WQI = \sum q_i w_i \quad (3.3)$$

The WQI obtained was afterwards used to determine the water quality of each sample according to Table 3 (Vasanthavigar et al., 2010b).

3.5. GEOSTATISTICAL METHODS

Arc GIS 10.8 the geostatistical analysis tools were used for interpolation of point-based distribution of measured groundwater quality to the full study areas. The Kriging Interpolation methods was adopted to spatially represent the pattern of groundwater quality in Nyagatare district results from laboratory. Spatial prediction to assess the variability of parameters implies the process of estimation of a target quantity's values at un-sampled locations. Ordinary Kriging (OK) interpolation is the geostatistical method employed for the spatial distribution of groundwater quality analysis. It entails the superior method for the estimation of interpolation weights and can provide error information for the creation of the thematic maps[17]. The following formula was used to estimate the Ordinary Kriging (OK):

$$\hat{z}(\mathbf{x}_0) = \sum_{i=1}^N \lambda_i z(\mathbf{x}_i) \quad (3.4)$$

Where $\hat{Z}(x_0)$ represents the interpolated or predicted value for x_0 point, and λ_i is the value for the equivalent weight of the $Z(x_i)$ values, while $Z(x_i)$ indicates the known value to satisfy the condition
And $\sum_{i=1}^n \lambda = 1$

3.6. GROUNDWATER FLOW MOVEMENT

The most abundant source of freshwater on earth, groundwater has accounted for the majority of nonfrozen freshwater of the world. And it is one of the most important natural resources that greatly contribute to human survival and economic development. It is also critical for populations living in arid rural areas to manage the production of irrigated crops that are located away from surface water available[37]. In addition, groundwater may also play a role in the sustainability of earth's ecosystems, especially in that it stabilizes the land in areas that have easily compressed soils. Aquifers can also have some buffer effects on seasonal variability and climate changes. Groundwater does not stop flowing at political borders. Therefore, the development of governance mechanisms for cross-border aquifers is an important task for ensuring the sustainability of these resources and of peaceful cooperation between countries. Referring to Rwanda water board installed groundwater stations in Nyagatare district and surrounded districts showed that the variation of groundwater levels affected by agricultural activities and farms through the chemical and microbe.

CHAP IV: RESULTS AND DISCUSSION

One important factor influencing a user's health is the quality of their drinking water[14][36]. Periodic quality control measures are therefore required. But many Rwandan rural villages' groundwater supplies aren't routinely subjected to quality monitoring measures. This study was therefore aimed at evaluating borehole water quality in selected area (Nyagatare district in eastern province). with a view to provide data that might be useful to policymakers and water service providers. Our physico-chemical and bacteriological quality investigation showed that the majority of the water samples fell within the WHO's acceptable quality guidelines. However, 12% of the samples tested positive for faecal contamination, emphasizing the importance of regular quality assessment measures by the responsible agencies. The physico-chemical parameters for all the water samples analyzed were within the standards of the WHO except PH, turbidity, Nitrate-nitrogen and fluoride concentration. The pH of all the water samples were within the range of 4.99–7.36 indicating that the water was slightly acidic to neutral with a mean value of 6.16 ± 0.13 . In fact, the geology of the sampling site could partly contribute to the final pH of the ground water. According to Pelig, the geology around the aquifers of the study area is dominated by crystalline silicate rocks and regolith which impart acidity to the water.

Table 0.1:Classification of water quality based on the WQI

SN	WQI range	Type of water
1	<50	Excellent water
2	50-100	Good water
3	100-200	Poor water
4	200-300	Very poor water
5	>300	Water unsuitable for drinking

4.1 BASIC STATISTICS OF WATER QUALITY ANALYSIS

The physical parameters include color, taste, odor, temperature, turbidity, solids, and electrical conductivity. The physical parameter of groundwater water different cells including Ph, total dissolved solid, conductivity and turbidity which was done at site during the data collection or groundwater sampling. Turbidity parameter was out of range of WHO however remaining parameters are in range as described in table below.

Table 0.2:Physical water quality parameters

Location/Cell	PH	TDS mg/L	EC s/cm	T.H mg/L	Turbidity NTU
Kabeza	6.78	57.8	124	47.72	3.84
Kirebe	6.15	66.17	143.9	89.11	2.14
Bwera/ Rutungu	6.03	111.2	97.2	166.22	7.5
Bwera	5.69	65.5	89.11	74.11	1.9
Matimba	7.36	75.14	111.5	77.99	4.4
Rukorota	5.88	25.89	121.1	58.14	2.71
Rutare	5.05	55.4	70.9	27.8	4.9
Nyakigando	6.87	43.58	157.3	36.14	5.5
Kigarama	5.92	27.95	66.77	19.85	2.47
Gishuro	6.02	35.14	97.41	87.27	3.17
Gitengure	5.26	28.21	52.1	19.74	1.87
Rwisirabo	6.98	220	180	56.58	11
Ndama	5.7	71.55	89.58	85.25	2.07
Kibirizi	5.21	100.05	84.58	35.74	1.11
Kijojo	4.99	66.41	64.41	51.89	3.75
Rutaraka	6.39	20.7	52.78	65.22	1.08
Bushoga	7.08	36.89	102.4	47.41	5.07
Bushoga(Cyonyo II)	6.41	181.24	66.44	174.54	10.5
Barija	6.49	37.48	77.48	61.44	3.04
Barija(Nyagatare P.S)	5.97	188.74	109.8	274	19
Gashenyi(Rukomo HC	7.22	201.55	87.52	202.22	12

Chemical parameters were analyzed by using laboratory standard equipment. Those parameters can include Chloride, Nitrate, sulfate Fluoride, acidity, alkalinity, hardness and heavy metals chemical and biological parameter of groundwater water different cells. however, boreholes contain hardness high than WHO recommended as described below:

Table 0.3: Chemical water quality parameters

Location/Cell	Cl⁻ mg/L	NO₃⁻ mg/L	SO₄²⁻ mg/L	F⁻ mg/L	Mn²⁺ mg/L	Fe²⁺ mg/L	Ca²⁺ mg/L	Mg²⁺ mg/L	MPN/100 ml
Kabeza	17.31	9.29	121.14	0.08	0.07	0.25	38.21	2.03	
Kirebe	10.06	12.12	124.55	0.29	0.09	0.06	98	25.42	0
Bwera/ Rutungu	28.54	13.21	21.22	3.33	ND	0.04	98	14.57	
Bwera	18.92	10.2	21.47	1.8	0.01	0.03	55.47	3.98	
Matimba	62.67	6.15	89.99	2.62	0.06	0.23	44.9	7.07	
Rukorota	10.06	4.24	110.74	1.82	0.09	0.3	147.14	43.55	
Rutare	17.25	2.09	160.41	0.87	0.01	0.05	24.2	0.77	
Nyakigando	34.54	13.89	77.98	0.98	0.05	0.11	18.95	3.67	
Kigarama	41.2	5.52	89.24	1.05	0.04	0.21	7.89	2.55	0
Gishuro	12.87	6.24	122.55	1.66	0.02	0.17	54.44	7.01	
Gitengure	66.12	3.14	154.87	1.11	0.02	0.05	11.07	1.85	
Rwisirabo	54.5	1.28	98.25	2.9	0.02	0.22	36.08	4.38	0
Ndama	28.47	0.98	95.26	4.87	0.02	0.04	88.74	23.8	0
Kibirizi	33.74	6.98	112.21	1.08	0.01	0.02	30.17	1.19	
Kijojo	18.05	5.44	166.14	0.77	ND	0.15	42.25	2.06	
Rutaraka	9.8	0.57	88.87	1.35	0.01	0.09	39.04	5.59	
Bushoga	12.08	0.88	91.1	1.44	ND	0.09	22.27	5.37	
Bushoga(Cyonyo II)	54.21	3.34	155.9	4.08	ND	0.11	120.08	11.63	
Barija	17.58	1.24	80.24	1.52	0.08	0.11	44.4	3.64	4.22
Barija(Nyagatare P.S)	99.82	2.97	78.78	5.94	0.03	ND	107	35.67	
Gashenyi(Rukomo HC	138.74	7.88	27.24	1.29	0.02	0.25	150.4	11.07	

Generally, water quality index showed that groundwater in study area fulfilling water quality standard of WHO however, Turbidity, nitrate, fluoride and Ca^{2+} and Mg^{2+} hardness was exceed the limit of World health organization standard. Maximum WQI occurred at Barija(Nyagatare P.S), Bushoga(Cyonyo II), Ndama and Bwera/ Rutungu cell.

Table 0.4:Water quality index summary

SN	Cell	WQI
1	Kabeza	34.81
2	Kirebe	55.70
3	Bwera/ Rutungu	70.52
4	Bwera	43.51
5	Matimba	55.73
6	Rukorota	59.25
7	Rutare	27.63
8	Nyakigando	44.42
9	Rubira	31.70
10	Gishuro	43.37
11	Gitengure	31.09
12	Rwisirabo	53.58
13	Ndama	74.03
14	Kibirizi	33.74
15	Kijojo	33.50
16	Rutaraka	28.51
17	Bushoga	30.63

18	Bushoga(Cyonyo II)	75.66
19	Barija	34.20
20	Barija(Nyagatare P.S)	97.42
21	Gashenyi(Rukomo HC	64.59

The value of electrical conductivity depends on the concentration, types of soluble ions as well as the temperature of the water. In this study, the conductivity values ranged between 45 and 157 μ S/cm (Table 4.26). The mean conductivity value for all samples analyzed was 91.20 μ S/cm with a standard deviation of 32.38 μ S/cm (table 4.26).

Total dissolved solids (TDS) in drinking water has been associated with natural source, agricultures activities, fertilizers and chemicals. Excessive levels of TDS can give water an unwanted flavor, smell, or color, which could cause negative reactions in the user. The TDS in this study exhibited a wide variation with a minimum value of 20.70 mg/l and a maximum value of 201.55 mg/l (table 4.26). All the TDS values were below the maximum allowable value of 1000 mg/l prescribed by the WHO. The average TDS of underground water in Nyagatare district is 74.52 mg/l.

Table 0.5:Physico-chemical parameters of borehole water samples from selected area

Parameters	Mean	Median	SD	Minimum	Maximum	WHO standard	Percentage compliance (%)
pH	6.16	6.03	0.71	4.99	7.36	8.5	76
Conductivity	91.01	89.11	29.81	45.18	157.25	1400.0	100
Total dissolved solutes	74.52	65.50	54.01	20.70	201.55	1000.0	100
Turbidity	4.62	3.04	4.45	0.98	19.00	5.0	71
Total Hardness	121.76	65.22	113.96	19.74	360.88	500.0	100
Calcium Hardness	49.24	44.40	26.89	7.89	101.11	75.0	76
Magnesium Hardness	15.49	5.37	19.10	0.77	56.15	50.0	85
Nitrate-nitrogen	5.60	5.44	4.19	0.57	13.89	10.0	76
Chloride ions	37.45	28.47	33.03	9.80	138.74	250.0	100
Fluoride	1.82	1.44	1.43	0.08	5.94	1.5	62
Sulphate	99.44	95.26	42.08	21.22	166.14	200.0	100
Total iron	0.13	0.11	0.09	0.02	0.30	0.3	100
Manganese	0.03	0.02	0.03	0.00	0.09	0.1	100
MPN	0.60	0	1.59	0	4.22	0.0	80

Turbidity of the water samples showed wide variations ranging from 0.98 NTU to as high as 19.0 NTU (Table 4.26). The turbidity values of all the samples were within the maximum acceptable limits of the WHO standard except samples from Barija cell (Nyagatare P.S) in Nyagatare sector with 19 NTU, Gashenyi cell (Rukomo HC) in Rukomo sector with 12.3 NTU, Bushoga cell (Cyonyo II) in Nyagatare section with 10.5 NTU, Bwera cell/ Rutungu in Rwimiyaga sector with 7.5 NTU, Nyakigando cell in Katabagemo sector with 5.5 NTU. Total hardness is chemically expressed as the total concentration of Ca²⁺ and Mg²⁺ as milligram per liter equivalent of CaCO₃. Physically, hardness could be referred to as the resistance of water to lather soap. The total hardness values recorded ranged from 19.74 to 274.0 mg/l for all the samples analyzed (Table 4.26). The total hardness measurements for all the samples were below the 500 mg/l recommended by the WHO for drinking water (Table 4.26), suggesting that they were all compliant with the WHO guideline and also safe for drinking. Eastern province is facing the problem of hardness[35].

All borehole samples analyzed contained varying concentrations of Ca²⁺ from 7.89 to 101.11 mg/l with mean and standard deviation of 49.29 mg/l and 26.89 mg/l, all the samples were within the

maximum acceptable limits of the WHO standard except samples from Rukorata and Kirebe cell in Rwimiyaga sector and Ndama, Bushoga(Cyonyo II) and Barija(Nyagatare P.S) cell.

Mg²⁺ concentrations varying from 0.77 to 56.15 mg/l with mean and standard deviation of 15.49 mg/l and 19.10 mg/l, all the samples were within the maximum acceptable limits of the WHO standard except samples from Rukorata and Kirebe cell in Rwimiyaga sector and Ndama cell. Sulphate measurements for all the samples were below the 200 mg/l recommended by the WHO for drinking water (Table 8), suggesting that they were all compliant with the WHO guideline and also safe for drinking[39].

Nitrate and nitrite are the forms of nitrogen most commonly associated with groundwater contamination. Although the presence of nitrate does not pose any health threat to adults, ingestion by infants can cause low oxygen levels in the blood, a potentially fatal condition. For this reason, the WHO has established a drinking-water maximum allowable threshold of 10 mg/l nitrate as nitrogen. All borehole samples analyzed contained varying concentrations of nitrate ranging from 0.57 to 13.89 mg/l with mean and standard deviation of 5.6 mg/l and 4.19 mg/l, respectively. all the samples were within the maximum acceptable limits of the WHO standard except samples from Bwera and Kirebe cell in Rwimiyaga sector and Nyakigando cell in Katabagemo sector whose nitrate were 12.12, 13.21 and 13.89 mg/l respectively.

Chlorides Combination of chlorine (Cl) gas with a metal results in formation of inorganic compounds known as chlorides such as sodium chloride (NaCl). Chlorine is used as a disinfectant and is highly toxic in nature. Surface water is contaminated by chlorides through several sources such as agricultural run-off, wastewater from industries, and effluent waste from water treatment plants and also from rocks containing chlorides. High level of chlorides in freshwater and lakes affects the health of aquatic organisms. Chlorides also affect the taste of food products and corrode metals. All the chlorides values were below the maximum allowable value of 250 mg/l prescribed by the WHO. Where chloride ranging from minimum 9.8 and maximum of 138.74 mg/l with mean and standard deviation of 37.45 and 33.03mg/l, respectively. Weathering of shallow rocks also contributes where groundwater flows through units rich in fluoride-bearing minerals. Alkaline igneous rocks are an important source of such minerals and globally recognized as a dominant groundwater fluoride source. High concentration of fluoride in drinking water leads to severe conditions such as dental and skeletal fluorosis.[40] Consumption of high levels of fluoride in

drinking water also reduces the absorption of iron which further leads to iron deficiency and related problems. All sources had some concentrations of fluoride, however seven samples values (38%) were not under the accepted standard level of 1.5 mg/L. Fluoride values ranged between 0.08 and 5.94 mg/l (Table 4.26). The mean fluoride value for all samples analyzed was 1.82 mg/l with a standard deviation of 1.43 mg/l . It is not only maximum fluoride value occurred at Ndama cell in Karangazi sector exceeded recommended WHO standard but also Bwera, Matimba, Rukorota, Gashuro, Rwisirabo and Barija cells samples tested exceeded the recommended 1.5 mg/l by the WHO.

High concentration of iron and manganese in groundwater may not pose any health hazards but may not be patronized by consumers due to unpleasant odour and taste that is normally associated with underground water with higher iron concentrations. Iron in groundwater may be derived from natural sources as well as steel pumps and casings. The total iron and manganese concentration were between 0.02 to 0.30 mg/l and 0.0 to 0.09 mg/l respectively with mean value of 0.13 and 0.03 mg/l respectively (Table 4.26). The total concentration of iron and manganese were within the range of 0.0–0.3 mg/l and 0.0–0.1mg/l respectively as per the WHO standard. Thus, the water from all the samples is considered satisfactory for human consumption. A wide range of microorganisms can be present in drinking water and it is often impossible to test for all of these microorganisms. In order to monitor microbial quality of drinking water, certain indicator microorganisms can be measured to test for faecal pollution. Here, we used the MPN assay to test for the presence of common bacterial contaminants in the borehole water samples[41]. Overall, 20% of groundwater samples tested exceeded the recommended 0.0 cfu/100 ml for coliforms by the WHO, indicating the presence of bacterial contaminants. The total number of coliforms ranged from 0.0 cfu/100 ml to more than 4.22 cfu/100 ml with a mean of 0.60 cfu/100 ml (table 4.26). The presence of coliforms in these groundwater samples studied can be attributed to the absence of residual chlorine, an indication that the borehole water had not been chlorinated prior to sampling. Presence of coliforms in infected boreholes renders the water unwholesome, unless it is chlorinated. This is because excess coliforms may give an indication of the presence of other pathogens, which could cause waterborne diseases such as typhoid fever, hepatitis, gastroenteritis and dysentery. The WQI datasets resulting from the 21 samples ranged from 27.63 to 97.42 and were categorized accordingly as being excellent water, good water, poor water and very poor water (Table 4.27).

Majority of the water samples 14 (66.67%) were classified as “excellent and 7 (33.33%) Good water.

Table 0.6: Classification of water samples analyzed based on the WQI

SN	WQI range	Interpretation	Number of samples (%)
1	<50	Excellent water	14 (66.67%)
2	50-100	Good water	7 (33.33%)
3	100-200	Poor water	0 (0.0%)
4	200-300	Very poor water	0 (0.0%)
5	>300	Water unsuitable for drinking	0 (0.0%)

water” whereas only 7 (33.33%) was classified as “good water”. None of the water samples had WQI within the categories of “poor water” and “very poor water”. Therefore, all the water samples without the presence of coliforms were considered suitable for human drinking. Since WQI is dependent on physico-chemical parameters, the values of WQI making the water suitable for drinking can be inferred from the acceptable concentration of parameters such as TDS, turbidity, conductivity, nitrates, nitrites, total hardness, calcium ions and magnesium ions.

4.2 STATISTICS OF GEOSTATISTICAL PREDICTION MAPS OF WATER QUALITY ANALYSIS

The geostatistical prediction maps of water quality analysis for boreholes show the spatially distributed concentrations water quality parameters in the Nyagatare district. Referring to Fig.4.1 Turbidity, from 4.23 NTU to 6.73 NTU. total hardness, Ca, Mg values are 70.87-99.97,43.22-60.5,5.4-8.58) mg/l respectively.

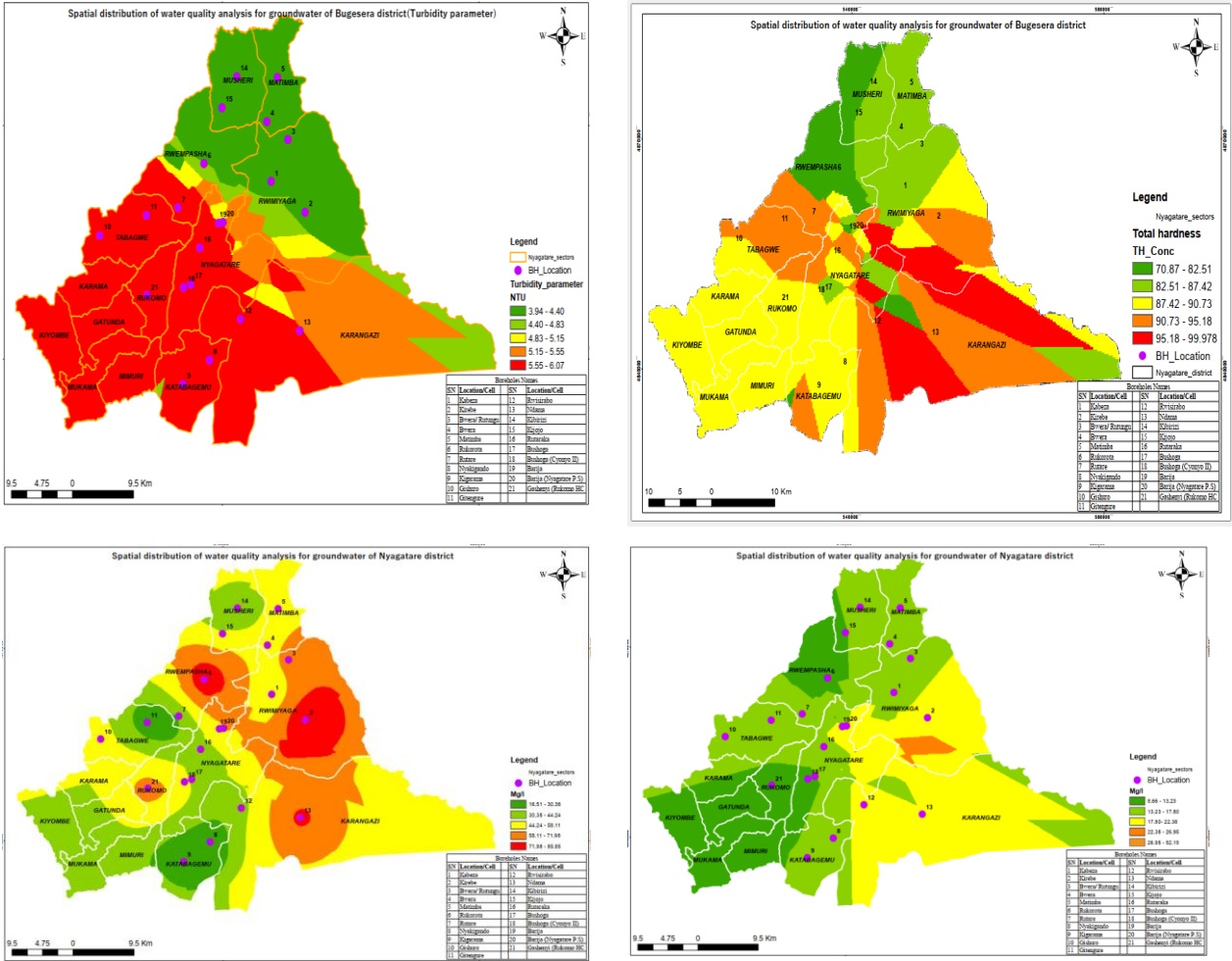


Figure 0.1: Spatial distribution of groundwater quality analysis for (Turbidity, Total hardness, Ca and Mg)

Sulphate values ranged between 82.34 and 120.24 mg/l, nitrate ranging from 0.32 to 13.86 mg/l, chloride ranging from minimum 24.43 and maximum of 48.28 mg/l. Fluoride values ranged between 1.62 and 2.45 mg/l. as shown in figure 4.2 nitrate and fluoride are exceed the range of standard.

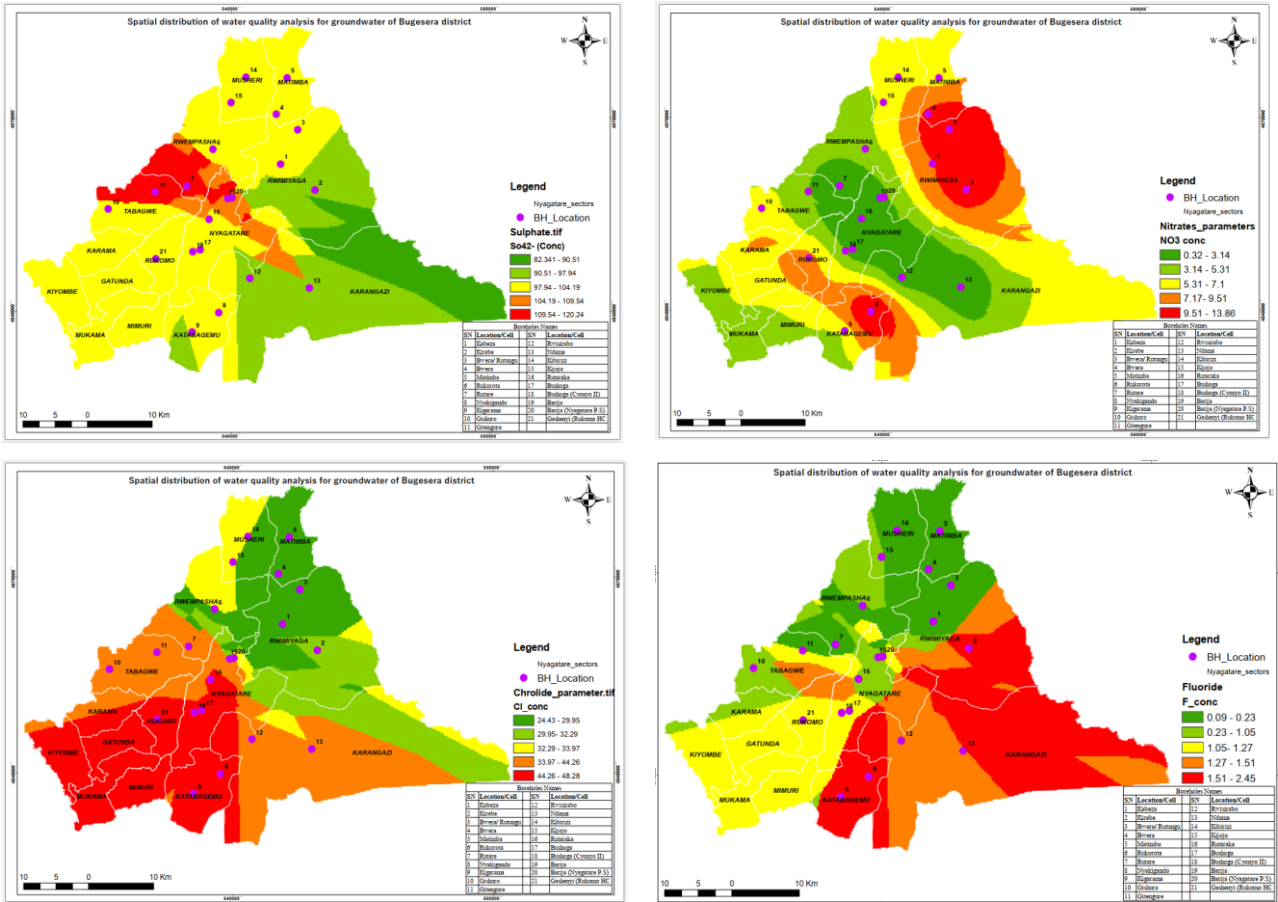


Figure 0.2: Spatial distribution of groundwater quality analysis for (Sulfate, Nitrate, chloride and fluoride)

the total iron and manganese concentration were between 0.0028 to 0.29 mg/l and 0.0 to 0.0005 mg/l respectively the total iron and manganese concentration were between 0.0028 to 0.29 mg/l and 0.0 to 0.0005 mg/l respectively. Recommended 0.0 cfu/100 ml for coliforms by the WHO, indicating the presence of bacterial contaminants. The total number of coliforms ranged from 0.089 cfu/100 ml to more than 0.84 cfu/100 ml.

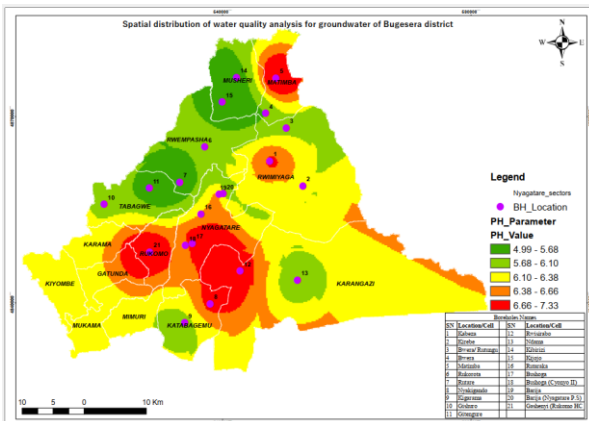
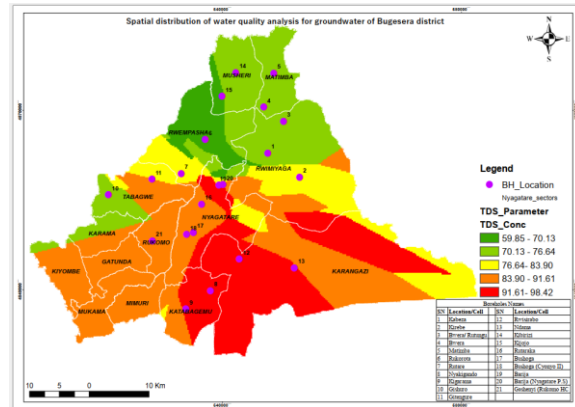
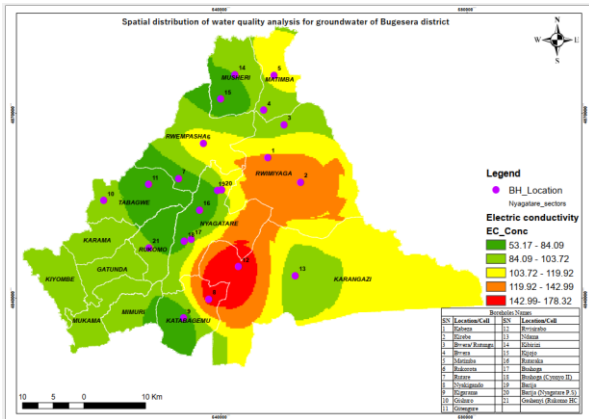
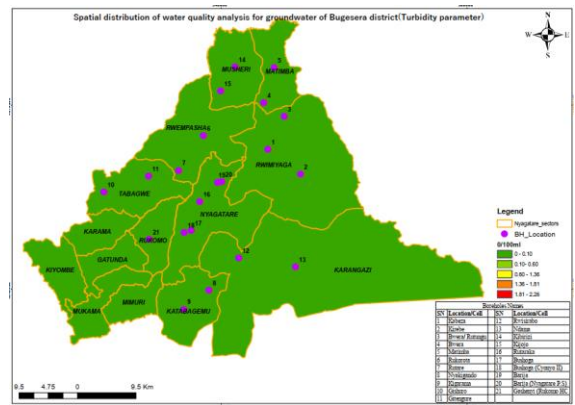
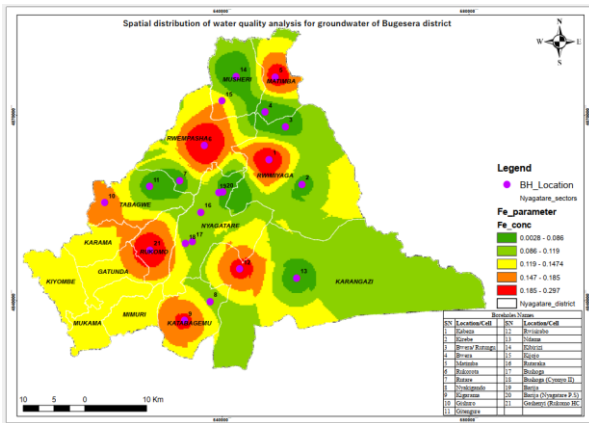


Figure 0.3: Spatial distribution of groundwater quality analysis for (Fe, fecal, EC, TDS and PH)

CHAP V: CONCLUSION AND RECOMMANDATION

5.1 CONCLUSION

From a groundwater quality point of view, most of the data for the physico-chemical parameters indicated tolerable quality. Bacteriological quality of a few of the water samples analyzed in this study did not meet the standard requirements set for drinking water by the WHO. This study was designed to assess groundwater quality in Nyagatare district, turbidity, Nitrate, fluoride and fecal are parameters was the highest determined in all twenty-one sampled using laboratory analysis and Geospatial Analysis using GIS in Nyagatare district due livestock which producing the microbes and agriculture activities produce the nitrate the fertilizers.

The WQI datasets resulting from the 21 samples ranged from 27.63 to 97.42 and were categorized accordingly as being excellent water, good water, poor water and very poor water. Majority of the water samples 14 (66.67%) were classified as “excellent and 7 (33.33%) Good water. water” whereas only 7 (33.33%) was classified as “good water”. None of the water samples had WQI within the categories of “poor water” and “very poor water”. Therefore, all the water samples without the presence of coliforms were considered suitable for human drinking. Since WQI is dependent on physico-chemical parameters, the values of WQI making the water suitable for drinking can be inferred from the acceptable concentration of parameters such as TDS, turbidity, conductivity, nitrates, nitrites, total hardness, calcium ions and magnesium ions.

5.2 RECOMMENDATIONS

- ✚ Establishing permanent groundwater (boreholes) quality analysis, maintenance and monitoring
- ✚ Creating buffer zone of boreholes which should be fenced to protect contamination from livestock and agriculture activities.
- ✚ To establish groundwater aquifer type of Nyagatare district so that they should facilitate effective hardness removal of boreholes in eastern province
- ✚ It is also suggested that policy makers, implementers, donors and any funding agencies with various interests in water and natural resources management should take the advantage of scaling up the water treatment facilities for groundwater in order to realize perfection of calcium and magnesium hardness, and therefore improving the living standards

- ✚ We recommend that Surface contamination should be studied within the entire catchment and not just some rivers, because these nitrate and fluoride affect water quality and can cause ground-water pollution.
- ✚ We recommend to other research to conduct geological investigation for aquifer types which should also contribute in groundwater hardening.

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APPENDIX

Table 0.1: value of water quality index (WQI) boreholes at Rwimiyaga-Kabeza

Parameter	Weight (wi)	Relative weight (Wi)	va(mg/l)	vs(mg/l)	qi value	WQI
pH	3	0.073	6.780	8.5	79.765	5.84
Conductivity	3	0.073	124.000	1400	8.857	0.65
Total dissolved solutes	5	0.122	57.800	1000	5.780	0.70
Turbidity	1	0.024	3.840	5	76.800	1.87
Total Hardness	3	0.073	47.720	500	9.544	0.70
Calcium Hardness	3	0.073	38.210	75	50.947	3.73
Magnesium Hardness	3	0.073	2.031	50	4.063	0.30
Nitrate-nitrogen	5	0.122	9.290	10	92.900	11.33
Chloride ions	5	0.122	17.310	250	6.924	0.84
Fluoride	5	0.122	0.080	1.5	5.333	0.65
Sulphate	3	0.073	121.140	200	60.570	4.43
Total iron	1	0.024	0.250	0.3	83.333	2.03
Manganese	1	0.024	0.071	0.1	71.000	1.73
Total	41	1.0				34.81

Table 0.2: value of water quality index (WQI) boreholes at Rwimiyaga-Kirebe

Parameter	Weight (wi)	Relative weight (Wi)	va(mg/l)	vs(mg/l)	qi value	WQI
pH	3	0.073	6.147	8.5	72.318	5.29
Conductivity	3	0.073	143.900	1400	10.279	0.75
Total dissolved solutes	5	0.122	66.170	1000	6.617	0.81
Turbidity	1	0.024	2.140	5	42.800	1.04
Total Hardness	3	0.073	89.110	500	17.822	1.30
Calcium Hardness	3	0.073	65.140	75	86.853	6.36
Magnesium Hardness	3	0.073	5.120	50	10.240	0.75
Nitrate-nitrogen	5	0.122	12.120	10	121.200	14.78
Chloride ions	5	0.122	10.060	250	4.024	0.49
Fluoride	5	0.122	0.290	1.5	19.333	2.36
Sulphate	3	0.073	124.550	200	62.275	4.56
Total iron	1	0.024	0.060	0.3	20.000	0.49
Manganese	1	0.024	0.085	0.1	85.000	2.07
Total	41	1.0				55.05

Table 0.3: value of water quality index (WQI) boreholes at Rwimiyaga- Bwera/ Rutungu

Parameter	Weight (wi)	Relative weight (Wi)	va(mg/l)	vs(mg/l)	qi value	WQI
pH	3	0.073	6.030	8.5	70.941	5.19
Conductivity	3	0.073	97.200	1400	6.943	0.51
Total dissolved solutes	5	0.122	111.200	1000	11.120	1.36
Turbidity	1	0.024	7.500	5	150.000	3.66
Total Hardness	3	0.073	166.220	500	33.244	2.43
Calcium Hardness	3	0.073	98.000	75	130.667	9.56
Magnesium Hardness	3	0.073	14.572	50	29.144	2.13
Nitrate-nitrogen	5	0.122	13.210	10	132.100	16.11
Chloride ions	5	0.122	28.540	250	11.416	1.39
Fluoride	5	0.122	3.330	1.5	222.000	27.07
Sulphate	3	0.073	21.220	200	10.610	0.78
Total iron	1	0.024	0.040	0.3	13.333	0.33
Manganese	1	0.024	0.000	0.1	0.000	0.00
Total	41	1.000				70.52

Table 0.4: value of water quality index (WQI) boreholes at Matimba-Bwera

Parameter	Weight (wi)	Relative weight (Wi)	va(mg/l)	vs(mg/l)	qi value	WQI
pH	3	0.073	5.690	8.5	66.941	4.90
Conductivity	3	0.073	89.110	1400	6.365	0.47
Total dissolved solutes	5	0.122	65.500	1000	6.550	0.80
Turbidity	1	0.024	1.900	5	38.000	0.93
Total Hardness	3	0.073	74.110	500	14.822	1.08
Calcium Hardness	3	0.073	55.470	75	73.960	5.41
Magnesium Hardness	3	0.073	3.982	50	7.963	0.58
Nitrate- nitrogen	5	0.122	10.200	10	102.000	12.44
Chloride ions	5	0.122	18.920	250	7.568	0.92
Fluoride	5	0.122	1.800	1.5	120.000	14.63
Sulphate	3	0.073	21.470	200	10.735	0.79
Total iron	1	0.024	0.027	0.3	9.000	0.22
Manganese	1	0.024	0.014	0.1	14.000	0.34
Total	41	1.000				43.51

Table 0.5:value of water quality index (WQI) boreholes at Matimba- Matimba

Parameter	Weight (wi)	Relative weight (Wi)	va(mg/l)	vs(mg/l)	qi value	WQI
pH	3	0.073	7.360	8.5	86.588	6.34
Conductivity	3	0.073	111.450	1400	7.961	0.58
Total dissolved solutes	5	0.122	75.140	1000	7.514	0.92
Turbidity	1	0.024	4.400	5	88.000	2.15
Total Hardness	3	0.073	77.990	500	15.598	1.14
Calcium Hardness	3	0.073	44.900	75	59.867	4.38
Magnesium Hardness	3	0.073	7.068	50	14.136	1.03
Nitrate-nitrogen	5	0.122	6.150	10	61.500	7.50
Chloride ions	5	0.122	62.670	250	25.068	3.06
Fluoride	5	0.122	2.620	1.5	174.667	21.30
Sulphate	3	0.073	89.990	200	44.995	3.29
Total iron	1	0.024	0.230	0.3	76.667	1.87
Manganese	1	0.024	0.089	0.1	89.000	2.17
Total	41	1.000				55.73

Table 0.6: value of water quality index (WQI) boreholes at Rwempasha-Rukorota

Parameter	Weight (wi)	Relative weight (Wi)	va(mg/l)	vs(mg/l)	qi value	WQI
pH	3	0.073	5.880	8.5	69.176	5.06
Conductivity	3	0.073	121.110	1400	8.651	0.63
Total dissolved solutes	5	0.122	25.890	1000	2.589	0.32
Turbidity	1	0.024	2.710	5	54.200	1.32
Total Hardness	3	0.073	58.140	500	11.628	0.85
Calcium Hardness	3	0.073	50.170	75	66.893	4.89
Magnesium Hardness	3	0.073	1.702	50	3.405	0.25
Nitrate-nitrogen	5	0.122	4.240	10	42.400	5.17
Chloride ions	5	0.122	10.060	250	4.024	0.49
Fluoride	5	0.122	1.820	1.5	121.333	14.80
Sulphate	3	0.073	110.740	200	55.370	4.05
Total iron	1	0.024	0.300	0.3	100.000	2.44
Manganese	1	0.024	0.089	0.1	89.000	2.17
Total	41	1.000				55.25

Table 0.7: value of water quality index (WQI) boreholes at Rwempasha-Rutare

Parameter	Weight (wi)	Relative weight (Wi)	va(mg/l)	vs(mg/l)	qi value	WQI
pH	3	0.073	5.050	8.5	59.412	4.35
Conductivity	3	0.073	70.900	1400	5.064	0.37
Total dissolved solutes	5	0.122	55.400	1000	5.540	0.68
Turbidity	1	0.024	4.900	5	98.000	2.39
Total Hardness	3	0.073	27.800	500	5.560	0.41
Calcium Hardness	3	0.073	24.200	75	32.267	2.36
Magnesium Hardness	3	0.073	0.769	50	1.538	0.11
Nitrate-nitrogen	5	0.122	2.090	10	20.900	2.55
Chloride ions	5	0.122	17.250	250	6.900	0.84
Fluoride	5	0.122	0.870	1.5	58.000	7.07
Sulphate	3	0.073	160.410	200	80.205	5.87
Total iron	1	0.024	0.045	0.3	15.000	0.37
Manganese	1	0.024	0.011	0.1	11.000	0.27
Total	41	1.000				27.63

Table 0.8: value of water quality index (WQI) boreholes at Katabagemu-Nyakigando

Parameter	Weight (wi)	Relative weight (Wi)	va(mg/l)	vs(mg/l)	qi value	WQI
pH	3	0.073	6.870	8.5	80.82	5.91
Conductivity	3	0.073	157.250	1400	11.23	0.82
Total dissolved solutes	5	0.122	43.580	1000	4.36	0.53
Turbidity	1	0.024	5.500	5	110.00	2.68
Total Hardness	3	0.073	36.140	500	7.23	0.53
Calcium Hardness	3	0.073	18.950	75	25.27	1.85
Magnesium Hardness	3	0.073	3.672	50	7.34	0.54
Nitrate- nitrogen	5	0.122	13.890	10	138.90	16.94
Chloride ions	5	0.122	34.540	250	13.82	1.68
Fluoride	5	0.122	0.980	1.5	65.33	7.97
Sulphate	3	0.073	77.980	200	38.99	2.85
Total iron	1	0.024	0.110	0.3	36.67	0.89
Manganese	1	0.024	0.050	0.1	50.00	1.22
Total	41	1.000				44.42

Table 0.9: value of water quality index (WQI) boreholes at Katabagemu-Rubira

Parameter	Weight (wi)	Relative weight (Wi)	va(mg/l)	vs(mg/l)	qi value	WQI
pH	3	0.073	5.920	8.5	69.647	5.10
Conductivity	3	0.073	66.770	1400	4.769	0.35
Total dissolved solutes	5	0.122	27.950	1000	2.795	0.34
Turbidity	1	0.024	2.470	5	49.400	1.20
Total Hardness	3	0.073	19.850	500	3.970	0.29
Calcium Hardness	3	0.073	7.890	75	10.520	0.77
Magnesium Hardness	3	0.073	2.555	50	5.109	0.37
Nitrate-nitrogen	5	0.122	5.520	10	55.200	6.73
Chloride ions	5	0.122	41.200	250	16.480	2.01
Fluoride	5	0.122	1.050	1.5	70.000	8.54
Sulphate	3	0.073	89.240	200	44.620	3.26
Total iron	1	0.024	0.210	0.3	70.000	1.71
Manganese	1	0.024	0.042	0.1	42.000	1.02
Total	41	1.000				31.70

Table 0.10:value of water quality index (WQI) boreholes at Tabagwe- Gishuro

Parameter	Weight (wi)	Relative weight (Wi)	va(mg/l)	vs(mg/l)	qi value	WQI
pH	3	0.073	6.017	8.5	70.788	5.18
Conductivity	3	0.073	97.410	1400	6.958	0.51
Total dissolved solutes	5	0.122	35.140	1000	3.514	0.43
Turbidity	1	0.024	3.170	5	63.400	1.55
Total Hardness	3	0.073	87.270	500	17.454	1.28
Calcium Hardness	3	0.073	54.440	75	72.587	5.31
Magnesium Hardness	3	0.073	7.012	50	14.025	1.03
Nitrate-nitrogen	5	0.122	6.240	10	62.400	7.61
Chloride ions	5	0.122	12.870	250	5.148	0.63
Fluoride	5	0.122	1.660	1.5	110.667	13.50
Sulphate	3	0.073	122.550	200	61.275	4.48
Total iron	1	0.024	0.170	0.3	56.667	1.38
Manganese	1	0.024	0.020	0.1	20.000	0.49
Total	41	1.0				43.37

Table 0.11: value of water quality index (WQI) boreholes at Tabagwe- Gitengure

Parameter	Weight (wi)	Relative weight (Wi)	va(mg/l)	vs(mg/l)	qi value	WQI
pH	3	0.073	5.260	8.5	61.882	4.53
Conductivity	3	0.073	52.100	1400	3.721	0.27
Total dissolved solutes	5	0.122	28.210	1000	2.821	0.34
Turbidity	1	0.024	1.870	5	37.400	0.91
Total Hardness	3	0.073	19.740	500	3.948	0.29
Calcium Hardness	3	0.073	11.070	75	14.760	1.08
Magnesium Hardness	3	0.073	7.012	50	14.025	1.03
Nitrate- nitrogen	5	0.122	3.140	10	31.400	3.83
Chloride ions	5	0.122	66.120	250	26.448	3.23
Fluoride	5	0.122	1.110	1.5	74.000	9.02
Sulphate	3	0.073	154.870	200	77.435	5.67
Total iron	1	0.024	0.050	0.3	16.667	0.41
Manganese	1	0.024	0.020	0.1	20.000	0.49
Total	41	1.000				31.09

Table 0.12: value of water quality index (WQI) boreholes at Karangazi- Rwisirabo

Parameter	Weight (wi)	Relative weight (Wi)	va(mg/l)	vs(mg/l)	qi value	WQI
pH	3	0.073	6.980	8.5	82.118	6.01
Conductivity	3	0.073	180.000	1400	12.857	0.94
Total dissolved solutes	5	0.122	220.000	1000	22.000	2.68
Turbidity	1	0.024	11.000	5	220.000	5.37
Total Hardness	3	0.073	56.580	500	11.316	0.83
Calcium Hardness	3	0.073	36.080	75	48.107	3.52
Magnesium Hardness	3	0.073	4.379	50	8.758	0.64
Nitrate- nitrogen	5	0.122	1.280	10	12.800	1.56
Chloride ions	5	0.122	54.500	250	21.800	2.66
Fluoride	5	0.122	2.900	1.5	193.333	23.58
Sulphate	3	0.073	98.250	200	49.125	3.59
Total iron	1	0.024	0.220	0.3	73.333	1.79
Manganese	1	0.024	0.017	0.1	17.000	0.41
	41	1.0				53.58

Table 0.13: value of water quality index (WQI) boreholes at Karangazi- Ndama

Parameter	Weight (wi)	Relative weight (Wi)	va(mg/l)	vs(mg/l)	qi value	WQI
pH	3	0.073	5.700	8.5	67.059	4.91
Conductivity	3	0.073	89.580	1400	6.399	0.47
Total dissolved solutes	5	0.122	71.550	1000	7.155	0.87
Turbidity	1	0.024	2.070	5	41.400	1.01
Total Hardness	3	0.073	85.250	500	17.050	1.25
Calcium Hardness	3	0.073	50.880	75	67.840	4.96
Magnesium Hardness	3	0.073	7.341	50	14.683	1.07
Nitrate-nitrogen	5	0.122	0.980	10	9.800	1.20
Chloride ions	5	0.122	28.470	250	11.388	1.39
Fluoride	5	0.122	4.870	1.5	324.667	39.59
Sulphate	3	0.073	95.260	200	47.630	3.49
Total iron	1	0.024	0.040	0.3	13.333	0.33
Manganese	1	0.024	0.020	0.1	20.000	0.49
Total	41	1.000				74.03

Table 0.14: value of water quality index (WQI) boreholes at Musheru-Kibirizi

Parameter	Weight (wi)	Relative weight (Wi)	va(mg/l)	vs(mg/l)	qi value	WQI
pH	3	0.073	5.210	8.5	61.3	4.48
Conductivity	3	0.073	84.580	1400	6.0	0.44
Total dissolved solutes	5	0.122	100.050	1000	10.0	1.22
Turbidity	1	0.024	1.110	5	22.2	0.54
Total Hardness	3	0.073	35.740	500	7.1	0.52
Calcium Hardness	3	0.073	30.170	75	40.2	2.94
Magnesium Hardness	3	0.073	1.190	50	2.4	0.17
Nitrate- nitrogen	5	0.122	6.980	10	69.8	8.51
Chloride ions	5	0.122	33.740	250	13.5	1.65
Fluoride	5	0.122	1.080	1.5	72.0	8.78
Sulphate	3	0.073	112.210	200	56.1	4.11
Total iron	1	0.024	0.015	0.3	5.0	0.12
Manganese	1	0.024	0.010	0.1	10.0	0.24
Total	41	1.000				33.74

Table 0.15: value of water quality index (WQI) boreholes at Musheru- Kijojo

Parameter	Weight (wi)	Relative weight (Wi)	va(mg/l)	vs(mg/l)	qi value	WQI
pH	3	0.073	4.990	8.5	58.706	4.30
Conductivity	3	0.073	64.410	1400	4.601	0.34
Total dissolved solutes	5	0.122	66.410	1000	6.641	0.81
Turbidity	1	0.024	3.750	5	75.000	1.83
Total Hardness	3	0.073	51.890	500	10.378	0.76
Calcium Hardness	3	0.073	42.250	75	56.333	4.12
Magnesium Hardness	3	0.073	2.059	50	4.118	0.30
Nitrate-nitrogen	5	0.122	5.440	10	54.400	6.63
Chloride ions	5	0.122	18.050	250	7.220	0.88
Fluoride	5	0.122	0.770	1.5	51.333	6.26
Sulphate	3	0.073	166.140	200	83.070	6.08
Total iron	1	0.024	0.147	0.3	49.000	1.20
Manganese	1	0.024	0.000	0.1	0.000	0.00
Total	41	1.000				33.50

Table 0.16: value of water quality index (WQI) boreholes at Nyagatare- Rutaraka

Parameter	Weight (wi)	Relative weight (Wi)	va(mg/l)	vs(mg/l)	qi value	WQI
pH	3	0.073	6.390	8.5	75.176	5.50
Conductivity	3	0.073	52.780	1400	3.770	0.28
Total dissolved solutes	5	0.122	20.700	1000	2.070	0.25
Turbidity	1	0.024	1.080	5	21.600	0.53
Total Hardness	3	0.073	65.220	500	13.044	0.95
Calcium Hardness	3	0.073	39.040	75	52.053	3.81
Magnesium Hardness	3	0.073	5.592	50	11.184	0.82
Nitrate- nitrogen	5	0.122	0.570	10	5.700	0.70
Chloride ions	5	0.122	9.800	250	3.920	0.48
Fluoride	5	0.122	1.350	1.5	90.000	10.98
Sulphate	3	0.073	88.870	200	44.435	3.25
Total iron	1	0.024	0.090	0.3	30.000	0.73
Manganese	1	0.024	0.010	0.1	10.000	0.24
Total	41	1.000				28.51

Table 0.17: value of water quality index (WQI) boreholes at Nyagatare- Bushoga

Parameter	Weight (wi)	Relative weight (Wi)	va(mg/l)	vs(mg/l)	qi value	WQI
pH	3	0.073	7.080	8.5	83.294	6.09
Conductivity	3	0.073	102.360	1400	7.311	0.53
Total dissolved solutes	5	0.122	36.890	1000	3.689	0.45
Turbidity	1	0.024	5.070	5	101.400	2.47
Total Hardness	3	0.073	47.410	500	9.482	0.69
Calcium Hardness	3	0.073	22.270	75	29.693	2.17
Magnesium Hardness	3	0.073	5.370	50	10.740	0.79
Nitrate-nitrogen	5	0.122	0.880	10	8.800	1.07
Chloride ions	5	0.122	12.080	250	4.832	0.59
Fluoride	5	0.122	1.440	1.5	96.000	11.71
Sulphate	3	0.073	91.100	200	45.550	3.33
Total iron	1	0.024	0.089	0.3	29.667	0.72
Manganese	1	0.024	0.000	0.1	0.000	0.00
Total	41	1.000				30.63

Table 0.18: value of water quality index (WQI) boreholes at Nyagatare- Bushoga (Cyonyo II)

Parameter	Weight (wi)	Relative weight (Wi)	va(mg/l)	vs(mg/l)	qi value	WQI
pH	3	0.073	6.410	8.5	75.412	5.52
Conductivity	3	0.073	66.440	1400	4.746	0.35
Total dissolved solutes	5	0.122	181.240	1000	18.124	2.21
Turbidity	1	0.024	10.500	5	210.000	5.12
Total Hardness	3	0.073	174.540	500	34.908	2.55
Calcium Hardness	3	0.073	120.080	75	160.107	11.72
Magnesium Hardness	3	0.073	11.633	50	23.265	1.70
Nitrate- nitrogen	5	0.122	3.340	10	33.400	4.07
Chloride ions	5	0.122	54.210	250	21.684	2.64
Fluoride	5	0.122	4.080	1.5	272.000	33.17
Sulphate	3	0.073	155.900	200	77.950	5.70
Total iron	1	0.024	0.110	0.3	36.667	0.89
Manganese	1	0.024	0.000	0.1	0.000	0.00
Total	41	1.000				75.66

Table 0.19: value of water quality index (WQI) boreholes at Nyagatare- Barija

Parameter	Weight (wi)	Relative weight (Wi)	va(mg/l)	vs(mg/l)	qi value	WQI
pH	3	0.073	6.490	8.5	76.353	5.59
Conductivity	3	0.073	77.480	1400	5.534	0.40
Total dissolved solutes	5	0.122	37.480	1000	3.748	0.46
Turbidity	1	0.024	3.040	5	60.800	1.48
Total Hardness	3	0.073	61.440	500	12.288	0.90
Calcium Hardness	3	0.073	44.400	75	59.200	4.33
Magnesium Hardness	3	0.073	3.640	50	7.279	0.53
Nitrate-nitrogen	5	0.122	1.240	10	12.400	1.51
Chloride ions	5	0.122	17.580	250	7.032	0.86
Fluoride	5	0.122	1.520	1.5	101.333	12.36
Sulphate	3	0.073	80.240	200	40.120	2.94
Total iron	1	0.024	0.110	0.3	36.667	0.89
Manganese	1	0.024	0.080	0.1	80.000	1.95
Total	41	1.000				34.20

Table 0.20: value of water quality index (WQI) boreholes at Nyagatare- Barija(Nyagatare P.S)

Parameter	Weight (wi)	Relative weight (Wi)	va(mg/l)	vs(mg/l)	qi value	WQI
pH	3	0.073	5.970	8.5	70.235	5.14
Conductivity	3	0.073	109.770	1400	7.841	0.57
Total dissolved solutes	5	0.122	188.740	1000	18.874	2.30
Turbidity	1	0.024	19.000	5	380.000	9.27
Total Hardness	3	0.073	274.000	500	54.800	4.01
Calcium Hardness	3	0.073	107.000	75	142.667	10.44
Magnesium Hardness	3	0.073	35.671	50	71.342	5.22
Nitrate-nitrogen	5	0.122	2.970	10	29.700	3.62
Chloride ions	5	0.122	99.820	250	39.928	4.87
Fluoride	5	0.122	5.940	1.5	396.000	48.29
Sulphate	3	0.073	78.780	200	39.390	2.88
Total iron	1	0.024	0.000	0.3	0.000	0.00
Manganese	1	0.024	0.033	0.1	33.000	0.80
Total	41	1.000				97.42

Table 0.21: value of water quality index (WQI) boreholes at Nyagatare- Gashenyi(Rukomo HC

Parameter	Weight (wi)	Relative weight (Wi)	va(mg/l)	vs(mg/l)	qi value	WQI
pH	3	0.073	7.220	8.5	84.941	6.22
Conductivity	3	0.073	87.520	1400	6.251	0.46
Total dissolved solutes	5	0.122	201.550	1000	20.155	2.46
Turbidity	1	0.024	12.000	5	240.000	5.85
Total Hardness		0.073	202.220	500	40.444	2.96
Calcium Hardness	3	0.073	150.400	75	200.533	14.67
Magnesium Hardness	3	0.073	11.069	50	22.138	1.62
Nitrate-nitrogen	5	0.122	7.880	10	78.800	9.61
Chloride ions	5	0.122	138.740	250	55.496	6.77
Fluoride	5	0.122	1.290	1.5	86.000	10.49
Sulphate	3	0.073	27.240	200	13.620	1.00
Total iron	1	0.024	0.250	0.3	83.333	2.03
Manganese	1	0.024	0.019	0.1	19.000	0.46
Total	41	1.000				64.59



Location

Nyagatare district (Nyagatare P.S)

Date

26/05/2024

Description

Water sampling from boreholes for groundwater quality assessment



Location

Nyagatare district (Katabagemu)

Date

28/05/2024

Description

Water sampling from boreholes for groundwater quality assessment



Location

Kigali city (CST laboratory)

Date

29/05/2024

Description

Some water samples from boreholes for groundwater quality assessment for analysis



Location	Kigali city (CST laboratory)
Date	06/06/2024
Description	water quality analysis



Location	Kigali city (CST laboratory)
Date	12/06/2024
Description	water quality analysis using UV Screening Method

