COLLEGE OF SCIENCE AND TECHNOLOGY

School of Architecture and Built Environment

MSc in Geo-Information Science for Environment and Sustainable Development

SPATIAL ASSESSMENT OF POTABLE (PIPED) WATER AVAILABILITY & ACCESSIBILITY IN THE GREATER VIRUNGA LANDSCAPE.

Case study: KINIGI SECTOR

Thesis submitted to the University of Rwanda: College of Science and Technology in partial fulfillment of the requirements for the award of the Degree of Master of Science in Geo-Information for Environment and Sustainable Development.

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Kigali, June 2023

DECLARATION

I declare that this thesis entitled **"Spatial assessment of potable (piped) water availability and accessibility in the Greater Virunga Landscape, Case study: Kinigi Sector"** submitted for the award of the Degree of Master of Science in Geo-Information science for Environment and Sustainable Development is my original work that has never submitted to any University or other higher learning institution.

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APPROVAL

It is hereby confirmed that this thesis entitled **"Spatial assessment of potable (piped) water availability and accessibility in the Greater Virunga Landscape, Case study: Kinigi Sector"** submitted by Jean Pierre HABIMANA was assessed in relation to the fulfillment of the requirements for the award of the Degree of Master of Science in Geo-Information for Environment and Sustainable Development, in the school of Architecture and Built Environment.

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ABSTRACT

This research argued that there is deficiency in piped water distribution in Kinigi Sector. The high rate of human growth has increased the rate of water demand which makes potable water to be insufficient and a great population travel long distance and spend much time in searching drinking water to survive. This study aimed at assessing the spatial availability and accessibility of piped water in Kinigi sector. The specific objectives are to ascertain the spatial coverage of the water supply system as well as evaluating the current status of water availability and accessibility and strategically propose the required spatial interventions to improve water accessibility for various users in the Kinigi Sector. To achieve this, primary and secondary data were collected and processed in ArcGIS 10.8 mainly by proximity and overlay analysis while analyzing the existing water distribution with respect to the households. The findings showed that the existing water network is composed of main water pipes connected with 14 reservoirs which distribute water to users with secondary and tertiary pipes through 32 public water taps. The distance travelled to access potable water services is the main factor in assessing the level of accessibility: 27.9% perceived to have a good accessibility and travel less than 300m to reach the nearest water tap, 31.7% have moderate accessibility; travel 300-500m, while 13.6% and 26.8% have a poor accessibility and access water taps within 500-750m and 750m above respectively. Thus, only 61% of the study area are well served by potable water facilities while 39% are not well served and they are served within the distance greater than 750m. Moreover, availability and accessibility of potable water have been proposed to be improved where 32 water taps added to the water network and the piped system also extended. This will improve potable water service in Kinigi sector where the well served inhabitants would increase from 42% to 92.1% and inadequate served area decreased from 58% to 7.9%. Therefore, the potable water supply system was recommended to be upgraded as well as using spatial analysis tools and integrating local community as stakeholder in water distribution management while meeting NST1 targets and WHO standards in terms of potable water availability and accessibility.

Key-words: Potable water availability and accessibility, GIS tool, Proximity analysis, water distribution in rural areas. GVL.

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LIST OF ACRONYMS AND ABBREVIATIONS

AHP	: Analytical Hierarchy Process
DDP	: District Development Plan
DEM	: Digital Elevation Model
DGPS	: Different Global positioning System
EDPRS	: Economic Development and Poverty Reduction Strategy
EICV	: Enquête Intégrale sur les Conditions de Vie des ménages
GIS	: Geographic Information System
GPS	: Global Positioning System
GVL	: Greater Virunga Landscape
GVTC	: Greater Virunga Transboundary Collaboration
Ha	: Hectares
HH	: Households
IWRM&D	: Integrated Water Resources Management and Development
LULC	: Land Use and Land Cover
l/c/d	: Litter per Capita per day
MCDM	: Multi-Criteria Decision Making
MDDS	: Musanze District Development Strategy
MDGs	: Millennium Development Goal
MININFRA	: Ministry of Infrastructure
MoW	: Ministry of Water resource
NLA	: National Land Authority
NST	: National Strategy for Transformation
OLI	: Operational Land Imager
RHA	: Rwanda Housing Authority

SDGs	: Sustainable Development Goals
SRTM	: Shuttle Radar Topography Mission
SSA	: Sub-Saharan Africa (SSA)
UN	: United Nations
UNICEF	: United Nations Children's Fund
USA	: United States of America
USGS	: United State for Geological Survey
VNP	: Volcanoes National Park
WASAC	: Water and Sanitation Corporation
WASH:	: Water, Sanitation and Hygiene
WBG	: World Bank Group
WHO	: World Health Organization
WSS	: Water Supply System

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CHAPTER I: GENERAL INTRODUCTION

1.1 Background of the study

Water is a mutual common resource fundamental to life and in sustaining the environment as well as enhancing the social and economic development of our wellbeing. According to the World Health Organization (WHO), water is an essential natural resource that shapes the landscape and it is significantly vital for ecosystem functioning as well as the social-economic wellbeing of people living in the integrated environment (Postel, 2000).

All living organisms mainly need water for better living. The flora and the fauna that makes up those ecosystems, especially for human beings relying on water not only for drinking but also for several multipurpose services in daily life as well as sustaining the environment for socio-economic development for fundamental strategic input helping at poverty alleviation through enhancing food security, domestic hygienic, hydropower, mining, industrial development, navigation and different activities necessary for environmental resilience for the ecosystem (MoW, 2005).

The billions of people worldwide had indicated a poor availability of drinking water that restricts consumption patterns and affects the quality of life. At present, globally at least one billion people experience an interruption to their water supply throughout a 24 h period and around 3.1 billion individuals depend on unreliable, non-piped water supplies that are located on-premises. Despite international progress towards achieving universal access to drinking water, in sub-Saharan Africa (SSA), only 57% of the population report having an improved water supply that is fully functional, available when needed, easily accessible, and provides good quality and safe water (Mair *et al*., 2020).

Currently, there is insufficient data in Africa to estimate the population using water source that is “available when needed”, suggesting a need for evidence to fill this gap. In addition, systematic evidence about how related measurement criteria is used in studies of water availability is limited, as it is the extent to which reported availability varies by setting or study design (Mair *et al*., 2020).

According to the WHO (2019), more than 785 million people did not have access to at least basic water Services and more than 884 million people did not have safe water to drink. The data shows that 8 in 10 people living in rural areas lacked access to these services and in one in four countries with estimates for different wealth groups, coverage of basic services among the richest was at least twice as high as among the poorest. The report also says that 2.1 billion people have gained access to basic sanitation services since 2000 but in many parts of the world the wastes produced are not safely managed. It also reveals that 2 billion people still lack basic sanitation, among 7 out of 10 live in rural areas and one-third live in the least developed countries (WHO, 2019).

There are 783 million people in Africa who do not have access to safe water. 40% live in sub-Saharan Africa, and more than 320 million people lack access to safe drinking water (Aboniyo & Umulisa, 2017). Poverty is a huge barrier to access to water and sanitation, and most of the world's poorest countries are in sub-Saharan Africa. While Northern Africa has 92% safe water coverage, Sub-Saharan Africa remains at a low 60% of coverage leaving 40% of the 783 million people in that region without access to clean drinking water. Some of these differences in clean water availability can be attributed to Africa's extreme climates (Ballweber, 2015).

For Rwandan population, only 57 percent has access to safe drinking water within 30 minutes of their house; which causes children to spend time collecting water and keeps them out of school. This is an issue, especially for girls, who are often expected to take on the majority of household tasks. Even if water is available near the home, that water is often not safe to drink. When children drink contaminated water, they risk severe illness and even death from water-borne diseases (Mishra, 2015).

By this standard measure, the Greater Virunga Landscape, particularly the Kinigi Sector, appears to be facing an issue of lower clean drinking water coverage due to a lack of available piped water resources for users. According to hydrological report conducted by GVTC in 2015, the Kinigi Sector region remarked as water-stressed during the dry season while a great number of households travel more than 1.5Km, with greater than 30min to reach the nearest water resource and the neighborhoods further use the average per day 20 to 60 liters of water per household leads to 6 to 10 liters of water per person which is unaffordable compared to WHO recommended 20 liters per person (Jared, 2014).

Although, the availability of potable water supply for drinking and other domestic use of good quality reduces time spent for fetching potable water while increasing health standards by reducing the incidences of debilitating water-borne diseases such as diarrhea and cholera, and thus improves the socio-economic wellbeing of users (WHO, 2019). This required improvements to the regions where there is inequitable access to safe and affordable drinking water should be prioritized accordingly. However, progress has not been universal, and problems remain. According to the UN's definition, a rural household is considered to have safe drinking water coverage if there is a safe water source within 1.5 km of the household (Adam *et al*., 2015).

1.2 Problem statement

Rwanda is facing freshwater planning and management challenges. High water demands and lack of effective and sustainable strategies for addressing natural and man-made problems affecting water resources including climate variability led Rwanda to be physically and economically water-stressed. Although Rwanda has a population of 13.46 million, it faces similar problems as 31 percent of its population, or 3.4 million, lack access to clean water, and about 3,000 children die each year from diarrhea caused by a lack of access to safe water and inadequate sanitation. Water infrastructure in Rwanda consisted of 15 urbans and about 796 rural water systems in 2012. Only 32% of Rwandans use piped water, but 3.4 % have access to it within their house or plot (urban: 17%, rural: 0.9%) (World Bank Group, 2019). On average, household women and children spend 29 minutes per day fetching water in rural areas while the time is 9 minutes in urban areas (Bahri *et al.,* 2019).

The high rate of human growth has increased the rate of water demand which makes potable water to be insufficient in some regions like in the GVL especially in Kinigi Sector, compared to the current population. Moreover, people who live near VNP sometimes in dry season fetch water from the park or use inadequate rainwater harvesting facilities. Hence, the relationship between water supply and water demand indicates that the domestic water consumption in GVL is between 4 to 12l/c/d while the standards provide 20l/c/d and the water demand is estimated to 2.7m^3/s while the available supply is 0.68m^3/s (Nahayo, et al., 2015).

The lack of access to safe drinking water is a human problem in Rwanda. Hence, EDPRS II (2009), had the objective to improve water resources management and access to safe drinking water and sanitation. The purpose of the Water and Sanitation Sector was to ensure sustainable and integrated water resources management and development (IWRM&D) for multipurpose use including increased access for all to potable water and sanitation services (EDPRS II, 2016). Furthermore, the government's strategies of 2050 visions through National Strategies for Transformation (NST1:2018/19-2023/24) highlighted among its five pillars through urbanization: universal access to daily amenities including high access to safe and clean water (scaled up to all from 87.4% by 2016/17 to 100% by 2024) which plays a vital role in social and economic development, poverty reduction and public health (NST1, 2018 & MININFRA, 2019).

Nevertheless, the sector has planned activities in six areas to meet its EDPRS targets (84.7% by 2017) as well as measures were taken to increase access to water for economic purposes and the vision 2050 ensuring a seven years governmental programme in order to meet SDG's target through NST1; a series of actions have been planned to improve access to safe drinking water for all to 100% by 2023/2024. Unfortunately, there is a problem of achieving the aforementioned goals in Kinigi Sector as one developing region by different urbanization activities including tourism where potable water is still a scarce (MININFRA, 2019).

On average, 43.9% of households in Musanze District are located within 15 minutes of walking distance of piped water resource while 56.1 % of the households still walk more than 30minutes to reach the nearest water source. Looking at the sector level, more than 60% of inhabitants of Kinigi sector as one rural sector of Musanze District face the challenge of improper availability and accessibility to potable water where they travel more than 1000m or 30minutes to reach the nearest water point (Musanze DDP, 2018).

Consequently, rural water supply schemes in Rwanda have few household connections, other than those of public institutions. This leads to very low consumption, typically of the order of 5 liters per capita per day. This situation is not desirable from a hygiene promotion point of view and keeps the revenue base for scheme operation at a very low level (MININFRA, 2019).

1.3 Objectives of the study

1.3.1 General objective

The general objective of this research is to assess piped water accessibility and propose potential locations for new water infrastructures while improving its availability and accessibility for the local communities in Kinigi Sector.

1.3.2 Specific objectives

At the end of this research, the following specific objectives were achieved:

1. To ascertain the current spatial coverage of the water supply system in the Kinigi sector
2. To evaluate the current status of water availability and accessibility for various users in the Kinigi sector,
3. To strategically propose the required spatial interventions to improve water accessibility by various users in the Kinigi Sector.

1.4. Research questions

1. What is the spatial coverage of the water supply system in the Kinigi sector?
2. How are the water availability and accessibility in the Kinigi sector?
3. What can be spatial interventions required for improving water accessibility for various users in the Kinigi Sector?

1.5. Justification of the study

This study has been chosen for examining the problem of water availability and accessibility in Greater Virunga Landscape mainly in Kinigi Sector. To improve this water accessibility, a geospatial technique was used to map the existing water resources and measure water accessibility within the study area, identifying the most vulnerable area for water provisioning and suitable location for potential water resources to solve the aforementioned situation for sustainable development.

1.5.1. Academic interest

It was one of the academic necessities for the award of a Master's degree in Geo-Information Science for environment and sustainable development. It will enable students and other researchers to have a curiosity about their future research and serve them as academic documents.

1.5.2. Social interest

The study will help the decision-makers to know about assessment availability and accessibility of water for sustainable livelihoods for the people in the Kinigi sector. Furthermore, this research will guide the planners and developers to improve the current situation of water availability while accessibility within the study area and provide a probable solution to improving water resources in the Kinigi sector.

1.6. Scope of the study

The scope of this study was limited in the function of time, space due to financial means. the study focused especially on potable water availability, and accessibility in the Kinigi sector. However, other critical issues regarding other potable water distribution and accessibility are namely as demand, distribution, use, and production. The major limitations of this study include social-economic factors like water availability and long-distance travelled to access the nearest water point; environmental factors like elevation/slope as well as climatic factors like rainfall. Additionally, proximity analysis in the function of the water point service area was conducted with distance to evaluate the availability and accessibility to piped water within the Kinigi community.

1.7. Research matrix

The research matrix describes how the research was operationalized. It shows the type of required data, methods for data collection and analysis in relation with the research questions and objectives through expected results as shown in table 1.

Table 1: Research matrix

No	**Specific objectives**	**Research questions**	**Required data**	**Research methods**	**Expected results**
1	To ascertain the current spatial coverage of the water supply system in the Kinigi sector	-What is the current spatial coverage of the water supply system in the Kinigi sector? - How far water points are from households?	-Existing water supply data -Road network -LULC - Footprint (HH)	Proximity analysis in terms of service area,	Map of Spatial coverage of water infrastructures.
2	To evaluate the current status of water availability and accessibility for various users in Kinigi sector	How are the water availability and accessibility in Kinigi sector?	-Respondent (questionnaire analysis). - Existing water supply data -Footprint(HH)	-Interview /Questionnaire - Proximity analysis in terms of service area	Accessibility and availability of water resources maps.
3	To strategically propose the	What can be the	-DEM was used	-Proximity	Proposed the

	required spatial interventions in order to improve water accessibility by various users in Kinigi Sector.	spatial interventions required for improving water accessibility for various users in Kinigi Sector?	to generate the slope of Kinigi -LULC of Kinigi generated from satellite image	analysis in terms of service area	required spatial interventions to improve water accessibility in the Kinigi Sector

1. 8 Organization of the study

This research project was organized into five chapters. Chapter one unfolded the importance of the selected problem and offers a clear description of the problem. It also gives the objective of the research, how to achieve them, and an outline of the research project. The second chapter review and explain different terminologies used in research. In this chapter, some published information on our subject area with the aim of getting some advice about all the most pertinent and relevant subjects has been discussed. The third chapter gave a brief description of materials and methods which showed the techniques, methodologies applied to meet the objectives. The fourth chapter presents the obtained results, their analysis, and discussion. The fifth chapter draw the conclusion and recommendations formulated with respect to the predefined research objectives

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter consists of review of the literature relating to this research and takes hints from those concepts and theories which support the research content and context. Among of these are definition of key concepts and theories related to water availability and accessibility as well as the selected analysis applied through GIS techniques.

2.2. Definitions of key concepts

2.2.1 Water

Water is a finite resource, which is essential for sustaining life on earth and is indispensable to human survival and to the ecological functions of plants and animals. Water is also necessary for human and socio-economic development as an input in industrial processing, energy generation, transport, agriculture and tourism, among other commercial activities. However, water can also cause harm to humans, plants, and animals as well as to social and economic activities as a result of disasters arising from floods, drought and water-borne diseases (Haberl *et al*., 2011).

Water is fundamental life-support, which cannot be treated as a commercial commodity with supply and demand manipulated to increase its value and with alternatives that can be substituted. Water is a public trust issue and must not be privatized. New developments in international human rights law provide a viable framework to measure and improve government performance. The United Nations Committee on Economic, Social, and Cultural Rights has elaborated specific rights, roles, and responsibilities at different levels and it provides an enforceable framework for recognizing water as a human right. And it states that Governments must assert their primary responsibility for providing and regulating water and sanitation services (Beriha, 2015).

2.2.2 Potable water

2.2.2.1 Definition

Potable water is defined as the water that can be considered safe for drinking and can be used for food preparation. It is filtered and treated properly and is finally free from all the contaminants and harmful bacteria. Purification of water can be done by various processes like using Ultra Violet filtered water purifier, reverse osmosis, etc. (Dinka, 2018).

Potable water, also known as drinking water, comes from surface and ground sources and is treated to levels that meet state and federal standards for consumption. The Joint monitoring program for Water Supply and Sanitation set up by the World Health Organization (WHO) and United Nations Children's Fund (UNICEF) defined safe drinking water as "water with microbial, chemical and physical characteristics that meets WHO guidelines or national standards on drinking water quality. "The guide languageless includes an assessment of the health risks presented by the various microbial, chemical, radiological and physical constituents that may be drinking watering water (Beriha, 2015). Water from natural sources is treated for microorganisms, bacteria, toxic chemicals, viruses, and fecal matter. Drinking raw, untreated water can cause gastrointestinal problems such as diarrhea, vomiting, or fever (Reasoner & Geldreich, 2016).

2.2.2.2 Benefits of Potable Water

Water of satisfactory quality is the fundamental indicator of health and well-being of a society and hence, crucial for the development of a country. Contaminated water not only has the potential to pose immediate threat to human, but also can affect an individual productive rate. According to WHO report, an estimated 1.1 billion people in the world drink unsafe water. Approximately 3,1% of the global annual death (1.7% million) and 3.7% of the annual burden(disability) (54.2 million) are caused by the use of unsafe water and lack of basic sanitation and hygiene. (Dinka, 2018).

In cognizant to the benefits of water, the newly introduced ambitious Sustainable Development Goal(SDG) by UN in 2014, considers water as one of the main development pillars under SDG 6. In fact, water was also one of the main goals of the UN-MDGS. The UN-SDG 6 states that "water sustains life but safe, clean drinking water defines civilization." The UN-SDG 6 recommended a dedicated SDG for water under five target areas such as (i) WASH, (ii) Water Resources, (iii) Water governance, (iv) Water quality and wastewater management and (v)Water-related disasters. This indicates that the benefit-cost ratio of water is very high since it has social, economic, financial, and environmental benefits. The benefits of water extend to other development activities/sectors such as health, education, agriculture and food production, energy, industry, and other economic activities (Ballweber, 2015).

2.2.2.3 Potable Water Availability

Water availability is the quantity of water that can be used for human purposes without significant harm to ecosystems or other users. Consideration is given to demands from human and ecosystem needs, equitable apportionment of water among uses, and indicators of stress to the water resource.

Water availability refers to both sufficient quantities and reliability of service provisions. Reliability refers to continuity of the service provision for the current and future generation, which is covered under the principle of sustainability, system robustness and resilience. Potable water is moving in a constant motion on the Earth between the atmosphere, oceans, rivers, and streams, in snowpack's and ice formation even underground where it forms pockets and reservoirs both as surface water and groundwater, for agriculture, human consumption, industry, and energy generation that is critical. (Galloway, 2022).

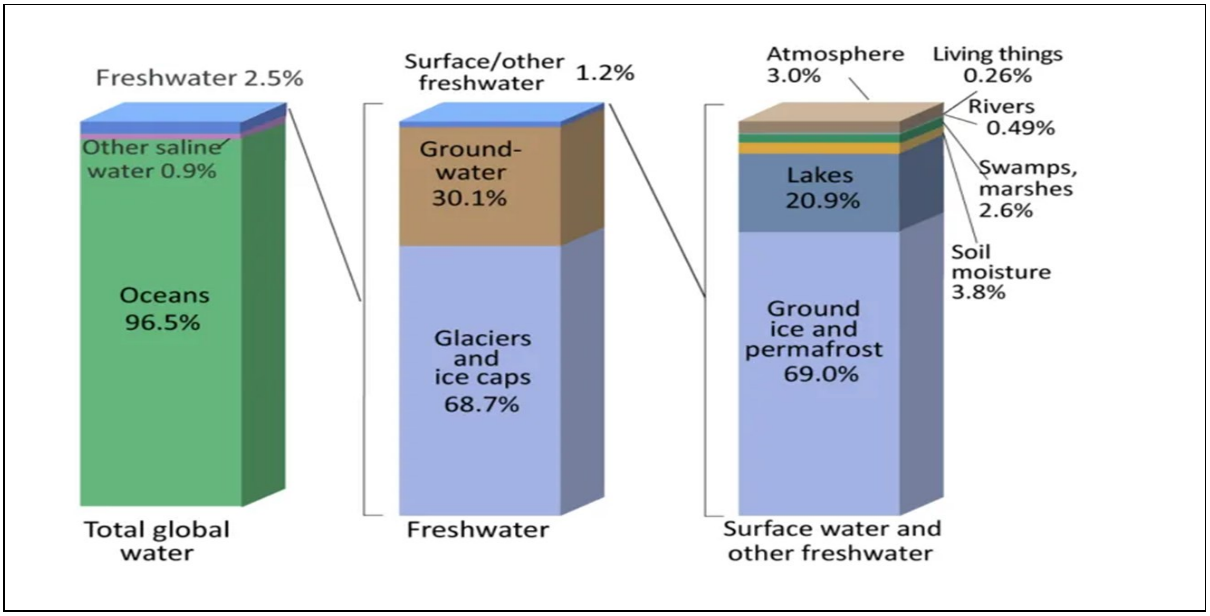

Figure 1: World's water resources

Data source: USGS/Water Science School, 2019

There has been much said over the years about the importance of Potable water. 71% of the world's surface is covered with water**.** Water also exists where you can't see it such as underground and in the air as water vapor**.** The most important fact about water is that it is a finite source.

Only a small percentage is usable by humans 0.03% and some of that water is unattainable. The rest, the other 99.7 percent is in the oceans, soils, icecaps, and floating in the atmosphere. The majority of freshwater that is used by humans is located underground and from surface water from rivers and lakes which is a small portion compared to the total amount of earth's water or sources of water on earth. (Galloway, 2022)

- Ocean water: 97.2 percent
- Glaciers and other ice: 2.15 percent
- Groundwater: 0.61 percent
- Freshwater lakes: 0.009 percent
- Inland seas: 0.008 percent
- Soil Moisture: 0.005 percent
- Atmosphere: 0.001 percent
- Rivers: 0.0001 percent.

2.2.3 Factors affecting water availability

There are several reasons why global water supply is not even. Access to a fresh water supply is affected by the following factors (Jønch, 2004).

2.2.3.1 Climate

Low levels of rainfall and high temperatures lead to water deficits. When rainfall is low, there is less water available. When temperatures are high, water evaporates and so there is less available to use. Water surpluses are common where rainfall is high and temperatures are lower.

2.2.3.2 Geology

Rainfall flows down to the rocks beneath the ground. Some rocks are permeable and allow water to flow through them. Permeable rocks can lead to less surface water. For example, limestone landscapes often have dry rivers - the rivers only exist when rain has just fallen. Permeable rocks form aquifers, which mean they are stores of water. 70 per cent of the water supply in the south east of England comes from the chalk aquifer beneath the surface. Other rocks are impermeable. These rocks do not hold water, but they can trap it in the layers above.

2.2.3.3 Pollution

Some places have plenty of water, but pollution has made it unsafe to use. Untreated sewage and waste water from factories cause problems. Groundwater is usually cleaner, although pollutants can travel down into the ground. Gold mining near Johannesburg, South Africa, has led to uranium, arsenic and sulphric acid polluting streams and rivers.

2.2.3.4 Over-abstraction

When water is taken from aquifers, groundwater levels fall. If the amount of water taken is greater than the amount of water falling as rain, it is called over-abstraction. The Sonoran Desert in Arizona has experienced over-abstraction as water is taken for irrigation and urbanization. The land here is subsiding and water is becoming scarcer.

2.2.3.5 Limited infrastructures

Pipelines are needed to safely move water from place to place. Sealed pipes reduce the potential for leaks and pollution. Some places do not have these pipes in place. They can be expensive to lay as they need to be buried underground. Water pumps also form part of the water infrastructure. Water pumps in villages across Kenya were recently fitted with transmitters that send text messages if the devices break down.

2.2.3.6 Poverty

Nearly 1 billion people in Africa do not have access to clean, safe water. This locks them in a cycle of poverty - they cannot afford water so they become ill and when they become ill then cannot work and earn money.

2.2.3.7 Politics

Communication needs to take place within countries and across borders. There needs to be cooperation between states for the use of water resources that cross international borders. If, for example, water is polluted in one country then this will affect all other countries downstream.

Water politics, sometimes called hydro-politics, is politics affected by the availability of water resources. The River Nile, for example, is the primary water source for both Egypt and Sudan. The Nile is classed as an international river and flows through nine countries before reaching the Mediterranean Sea.

2.2.3.8 Impacts on water insecurity

Water security is when the entire population of a country has sustainable access to adequate quantities of acceptably clean water. There are several impacts of water insecurity. Some of these impacts are linked in a cycle of poverty.

2.2.3.9 Waterborne disease

Drinking or using dirty water puts people at risk of waterborne diseases and illnesses, such as diarrhea, malaria and schistosomiasis. Schistosomiasis is an illness caused by a parasitic worm that enters the body through the skin coming into contact with water that contains untreated sewage. It has been reported in 78 countries and 90 per cent of people receiving treatment for it live in Africa.

2.2.3.10 Food production

Water insecurity can lead to lower levels of food production. Irrigation can increase crop yields by as much as 400 per cent. Places that do not have enough water to irrigate crops have less food to eat.

2.2.3.11 Industrial output

Industry needs water for all stages of production. Water is used as a raw material, a coolant, a method of transport, and in some cases, a source of energy. Areas that experience water insecurity are unable to operate factories and make products. This leaves them relying on imports, which may be expensive.

2.2.4. Water supply

It means the abstraction from a water resource, conveyance, treatment, storage, and distribution of potable water, including all the organizational and sensitization arrangements necessary to ensure sustainable services and benefits. This includes domestic water supply (drinking water and other household uses) as well as the provision of water for economic activities through public piped networks (MININFRA, 2010).

2.2.4.1 Water Supply System

A water supply system is a system for the collection, transmission, treatment, storage and distribution of water from source to consumers, for example, homes, commercial establishments, industry, irrigation facilities and public agencies for water related activities (fire-fighting, street flushing and so forth).

2.2.4.2 Water Distribution System

Distribution system is used to describe collectively the facilities used to supply water from its source to the point of usage. The water distribution system starts where the main supply conduit from the treatment or source ends. The purpose of distribution system is to deliver water to consumer with appropriate quality, quantity and pressure.

2.2.4.3 Water Demand

Water demand is defined as the volume of water requested by users to satisfy their needs. Also, water demand can be defined as the volume of water, which has to be put into a supply and distribution system to satisfy the requirements of consumers plus leakage and other waste, which may be incurred in the process. In a simplified way it is often considered equal to water abstraction, although conceptually the two terms do not have the same meaning. (Agency E. , 1999)

Determination of water demand is indispensable when it comes to the design of a proper water work project. An accurate estimation of water demand helps to determine the quantities of water and moments when the water will be used therefore generating various demand patterns. The demand arises mainly for residential, institutional, industrial and public uses (Ballweber, 2015).

2.2.4.4 Types of Water Demands

Water demands can be classified as follow (Ballweber, 2015):

- Domestic Water Demand
- Industrial Water Demand
- Institutional and Commercial Water Demand
- Public and Civil Use
- Fire Demand
- Waste and Thefts

2.2.4.5 Per capita demand(q)

The Per Capita Demand is defined as the annual average amount of daily water required by one person, and includes the domestic use, industrial and commercial use, public use, wastes, thefts, etc. It may, therefore, be expressed as (Galloway, 2022):

Per Capita Demand(q) in liters per day per head

$$= \frac{\textit{Total Yearly requirement of the city in litres}}{365 \times \textit{Design population}}$$

2.2.4.6 Factors affecting per capita demand

The annual average demand for water (i.e. per capita demand) considerably varies for different towns or cities. This figure generally ranges between 100 to 360 liter/capita/day for Indian conditions. These variations in total water consumption of different cities or towns depend upon various factors, which must be thoroughly studied and analyzed before fixing the per capita demand for design purposes (Goswami et. al., 2017), these factors are discussed below:

- Size of the City
- Climatic Conditions
- Types of Gentry and Habits of People
- Industrial and Commercial Activities
- Quality of Water Supplies
- Pressure in the Distribution System
- Development of Sewerage Facilities
- System of Supply
- Cost of Water
- Policy of Metering and Method of Charging

2.2.5. Water Problem Assessment

Water problem assessment comprises reliable assessment of water quality and quantity, water accessibility, affordability, water demand and water shortage.

2.2.5.1 Water quality

The quality of water has to meet the standards and has to be safe for drinking and cooking. Globally, there are several drinking water standards but they are basically similar, such as World Health Organization (WHO), national standards, local authorities' standards, etc (Roccaro et al., 2005). As there is for the moment neither national water-drinking quality standards nor guidelines in each country there is a need to find universal water quality standards values. The “Guidelines for drinking water quality” proposed by the WHO set a complete list of parameter values which “ensures aesthetically pleasing water and does not result in any significant risk to the health of the consumer”. These values are internationally recognized because health issue oriented; however, it does not take into account the specific context of the country or area (WHO, 2000). In fact, concerning developing countries, these parameters need to be adjusted, considering the cost of treatment involved, cost and availability of water testing in the country, as well as the type of water supply management, which defines the financial affordability of these costs.

2.2.5.2 Water quantity

The quantity of water collected and used by the household has an important influence on the heath. There is a basic human physiological requirement for water to maintain adequate hydration and additional requirement for food preparation. There is a further requirement for water to support hygiene, which is necessary for health. Estimates of the volume of water needed for health purposes vary widely. In deriving World Health Organization (WHO) guidelines values, it assumed that the daily per capita consumption of drinking water approximately 2 liters for adults, although actual consumption varies according to climate, activity level and diet. A party domestic purpose, water can be used for economic development (WHO, 2006).

2.2.5.3 Water accessibility

Distance to water points is a major determinant to water access since it influences the time taken and amounts that can be fetched at any single trip. According to WHO, Reasonable access to water is defined as water supply in the home or within 15 minutes walking distance or the daily provision of 20l/d/p of water, within a distance of 200 m of the user’s dwelling in urban area and 500 in rural area. Actually, a proper definition should be adopted taking the local conditions into account; in urban areas, a distance of not more than 200 meters from a house to a public stand post may be considered reasonable access (WHO, 2019).

Howard *et al.* (2003) describes four levels of access to water, or service levels; based on the distance the consumer travels or the time spent collecting water. Data reviewed by Howard *et al.* (2003) indicate that water quantity is not as important as service level, and volumes of water can be associated with different service levels as described in table 2.

Table 2: **Water service levels description**

Service levels	**Distance to source &Total collection time**	**Approximate quantities collected**
Non access	>1000 m	Very low
	>30 minutes	Less than 5L/c/d
Basic access	100-1000 m	Low
	5-30 minutes	Unlikely to exceed 20L/c/d
Intermediate access	On-plot	Medium
	Single standpipe on compound or in house	Around 50L/c/d
Optimal access	Multiple taps in house	Varies
		Average of 100L/c/d and possibly up to 300L/c/d

Source: Howard *et al.* (2003*)*

2.2.5.4 Water affordability

Affordability of water may be defined as the use of water and selection of water sources. Households with the lowest levels of access to safe water supply frequently pay more for their water than do households connected to a piped water supply.

The high-cost water may force household to use alternate sources of water of poorer quality that represent a greater risk to hearth. Furthermore, high cost of water may reduce the volume of water used by household, which in turn may influence hygiene practices and increase risks of disease transmission (WHO, 2000).

2.2.5.5 Water Demand

This is the volume of water, which has to be put into a supply and distribution system to satisfy the requirements of consumers plus leakage and other waste, which may be incurred in the process. The total demand in each category of uses; domestic, commercial and public or institutional, is made up of several water use activities such as drinking, washing, gardening, etc. (UFC, 2001). A person needs 1 or 2 liters of water a day to live, but water is also required for domestic needs, industry and agriculture. UNDP (1994) estimates that human beings need about 5 liters of water each day for cooking and drinking.

The amount of water used in a country, however, does not depend only on minimum needs and/or how much water is available. It also depends on the levels of economic development and urbanization. The level of water uses in a given country depends on its level of economic development. Furthermore, in non-developing regions, people use far less water per capita for personal use than in developed regions. In 2003, UNESCO reports that industrial use of water increases with national income. It is ranging from 10% for low- and middle-income countries to 59% for high-income countries. According to PAI (1999) two-thirds of the world's populations in developing countries get their water from public standpipes, community wells, rivers and lakes or rainfall collected off roofs. Often rural people, usually women and girls, walk several kilometers and spend several hours to bring water for their households and in Africa; for instance, such activity consumes 40 billion person-hours annually. This depresses the possibility of economic advancement. So, water use significantly increases with development and urbanization and this can be quantified.

Rapid population growth and increasing water consumption for agriculture, industry and municipalities have too heavily stressed the world's freshwater resources. It is not surprising that, in some areas the demand for water already exceeds nature's supply with a growing number of countries expecting to face water shortages in the near future. Generally, there are two classes of solutions for water problems: increasing the supply of water (developing new resources) and/or decreasing the demand for water (managing available resources). According to Loucks (2000) everyone involved in water management and development has an obligation to assure that these systems should provide sufficient quantities and qualities of water at acceptable prices and reliabilities, while protecting the environment and preserving the biodiversity.

2.2.6. Water distribution in Rwanda

Water supply affects broad areas of human life. The provision of adequate WSS services plays a crucial role in preventive health care and is more generally a prerequisite and indicator for socio-economic development. Access to drinking water is also a basic amenity, ranked among the highest priority public services by Rwanda's population. It reduces time spent on fetching water and has a positive impact on school enrolment and attendance, particularly for girls. The lives of women are strongly affected by unsafe, distant water supply, as women are generally responsible for water collection and handling, for household hygiene and for caring of the sick (MININFRA, 2018).

2.2.6.1 Potable water

According to WASAC Magazine (2020), 32% of Rwandans use piped water, but only 3.4 % have access to it within their house or plot (urban: 17%, rural: 0.9%) 7. On average, household's women and children spend 29 minutes per day on fetching water in rural areas (9 minutes in urban areas). Daily per capita consumption is of the order of 6 to 8 liters per day in rural areas, a figure by far lower than the envisaged standard consumption of 20 liters. Where water is accessible from easily and freely available unprotected sources (unprotected springs, open wells, surface water bodies) an (unknown) part of the population tends to use these sources, at least for purposes other than human consumption (drinking and cooking). The sustainable operation and management of rural water supply infrastructure is one of the key challenges of this sub-sector (Kirby *et al*.,2017).
The standards in the clean water sector state that a minimum of 20 liters and 80liters/person/day are provided respectively in rural and urban areas. The Water Points should serve a maximum of 250 people and should be within 500 and 200 meters of the population served respectively in rural and urban areas. In addition, for institutions (schools and health centers a minimum of 3/liters/person/day must be provided and the water points should not exceed the distance of 200meters from water users (MININFRA *et al.,* 2010).

The key challenge in infrastructure development is to preserve the achievements and good practices of the national rural water programs while strengthening decentralized implementation capacities. Sector financing is still fragmented, with a variety of different financial management arrangements. A harmonized sector financing mechanism is desirable in order to streamline the flow of resources, reduce the transaction costs and reporting requirements and facilitate monitoring. Delegated management through private operators is seen as the main strategy to enhance the sustainability of rural water supply infrastructure. However, recent studies on PPP and tariffs10 have shown that the regulatory oversight of PPP arrangements selection criteria, contract management and compliance monitoring, accounting practices, tariffs, etc. is still deficient. This is expected to improve with the increasing involvement of RURA in rural water supply but support and guidance by the sector institutions are also needed (Aboniyo et. al., 2017).

2.2.6.2 Potable Water accessibility

Accessibility to Potable water refers to the accessibility to a reliable supply on a continuous basis close to the point of demand: within everyone's reach: homes, schools, work, public places. It is related to the distances of water source from the point of demand (30minutes walk or 0.2km). That means the water has to be accessible for everyone, including children, elders and disabled ones.

Potable water is an essential element for human survival and wellbeing. Although water is the most widely occurring substance on earth, only 2.5% is fresh water with less than 1% being readily accessible for direct human uses (Postel *et al*., 1996). Nearly 20% of the world's population does not have easy access to drinking water, and 40% lack proper sanitation facilities (Postel, 2002).

One of the major challenges driving water stress in developing nations is rapid urbanization. Approximately half of the world's 7 billion people live in urban areas. Predictions of the world's future urban population classified Asian and African countries as high urban concentration areas (Jiang, Young, & Hardee, 2017). The increasing number of people living in urban areas is associated with increasing water demand and difficulties for many people to access an adequate supply of clean water and sanitation (Postel, 2002), whereas rural people have to use multi-sources due to the lack of a stable water supply system in the villages. Households usually classify them based on their purpose for using water. For instance, tap water for drinking, wells for hygiene, rainwater and thawed water for garden irrigation, etc. (Bahri, 2008).

In many developed and developing countries provision of quality urban and rural infrastructure, systems has become a major concern. Contrary to this, less attention has been given to the quality aspect of water supply. The low quality of infrastructures such as water supply and sanitation may be detrimental to the environment leading to unhealthy living conditions The performance of one infrastructure may affect the other due to their interconnection for instance water supply and sanitation are highly interrelated. Hence, understanding this integration and interrelation provide a better consideration on the importance of providing quality infrastructure (Salendu, 2010).

2.2.6.3 Potable water availability and accessibility in Rwanda

There are many options of technologies mainly used in rural areas. To capture or supply safe water are technological options used to deserve the surrounding populations including the Protected springs, that are Sometimes used as a synonym for 'well'.

The natural springs (holly wells) have been modified by man, i.e., have been deepened to improve the supply. Occasionally, a flowing spring has actually been created by excavation (Protection of springs). A second well-known source is a Water wells, which is a man-made excavation, constructed for the purpose of drawing water from or monitoring the groundwater system. The third type is called Borehole, which is a particular type of well in the form of a narrow hole in the ground constructed by a drilling machine in order to gain access to the groundwater system. Boreholes are usually narrow (typically 150 mm (6 inches) in diameter) and can be constructed quickly (IGI, 2013).

Rainwater harvesting and surface water are other types of sources. Rainwater harvesting include gutter and water tanks that requires prior treatment or direct use according to the use purposes, while surface water is intake from rivers, lakes, etc… Technological options exist to supply clean water directly from captured underground waters, or water surface or rain water prior treatment. The water can be used immediately or supplied in distance to other communities (Nahayo et.al., 2015).

In Rwanda, only 57 percent of the population access safe drinking water that is within 30 minutes of their home. When children spend time collecting water, it often keeps them out of school. This is an issue, especially for girls, who are often expected to take on the majority of household tasks. Even if water is available near the home, that water is often not safe to drink. When children drink contaminated water, they risk severe illness and even death from water-borne diseases. According to the latest Integrated Household Living Conditions Survey, EICV3 report, the proportion of Rwandan households using surface water (rivers or lakes) as drinking water has decreased from 18 to 12 per cent over last five years (Huttinger, Dreibelbis, Kayigamba, & Ngabo, 2017).

"The good news is that rural households can now reach an improved water source more quickly than they could five years ago. However, the report also stressed that even though significant progress has been made, there is a clear trend that fewer households receive their water for free when compared to five years earlier. Although the majority of rural population were still not being using improved drinking water sources in the past, official statistics indicate that the proportion of households having access to potable water without paying in these remote areas decreased falling down from from 81 percent to 69 per cent between 2005 and 2011 (Van Jaarsveld *et al*., 2005).

2.2.7. Geographic Information System (GIS)

Geographic Information System (GIS) are computer-based systems for the storage, analysis and manipulation of spatial data. A GIS is a tool that allows the analysis of all forms of geographically referenced information and identifying the spatial relationships between different geographic features or as phrase it, “simply put, a GIS combines layers of information about a place”. GIS allows us to view, understand, question, interpret, and visualize our world in ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts (Healey, 2018).

2.2.7.1 GIS application in the evaluation of water supply system

GIS refers to an integrated collection of computer software and data used to view and manage information connected with specific locations, analyze spatial relationships, and model. WSS uses a spatial database, GIS technology can act as an important role in collecting, storing, managing, and analyzing spatial data sets that are used in designing WSS (Mohd, 2015).

The use of GIS and remote sensing in water monitoring and management has been long recognized. In fact, the capability of this technology offers great tools of how the water quality monitoring and managing can be operational in this country. Potential application and management are identified in promoting concept of sustainable water resource management. Remote sensing and GIS technologies coupled with computer modelling are useful tools in providing a solution for future water resources planning and management to government especially in formulating policy related to water quality (Mohd, 2015).

WSS is a complex system that integrates several spatial features. Therefore, it is needed to use multi- support information system to have capability of storing; managing and analyzing the large data set. Geographical Information System (GIS) provide some of the most comprehensive tools for storing, manipulation and analyzing. The implementation of GIS can not only reduce the time needed for analyzing information but also can ensure a more efficient use of the resource with high flexibility in time and scale. It enables user to store and display large amount of data graphically to greatly enhance the interpretation and analysis. One important GIS capability is in handling both digital spatial features and the associated databases of attribute information for map features (Healey, 2018).

GIS also provide the tools for spatial queries, spatial calculations and spatial data modeling and generate the attribute maps. Once all the data are stored, both the digital map and the database can be manipulated simultaneously. This is particularly important in many water planning applications, which require data on a wide variety of physical, geological, social and environmental attributes (Jared, 2014)

2.2.7.2 Spatial Analysis Process

The spatial analysis is a set of procedures whose aim is to choose an inferential model that explicitly considers the spatial relationship present in the phenomenon. The initial procedures of analysis include the set of generic methods of exploratory analysis and the visualization of data, in general through maps. These techniques permit the description of the distribution of the variables of the study, the identification of observations that are outliers not only in relation to the type of distribution but also in relation to its neighbors, and to look for the existence of patterns in the spatial distribution. Through these procedures it is possible to propose hypothesis about the observations, in a way of selecting the best inferential model supported by the data (Vernius, 2008).

The aim of Spatial Analysis is to measure properties and relationships, taking into account the spatial localization of the phenomenon under study (e.g.: public water points) in a direct way.

2.2.7.3 Proximity analysis

According to Jared, 2014, Proximity analysis is a GIS tool that can be used to analyze the spatial relationships between different features or objects in a geographical area while determining the relationship between selected geographical elements by identifying the locations of other elements within a specified distance. Creating buffer zone regions is the most common method used in proximity analysis.

Buffer operation refers to a basic GIS function in which a buffer of some specified width is delineated around spatial features. In terms of asking how far one point is from another, we might turn the question around and identify all of the points within a certain distance of a reference point. For example, it might be for interest to outline on a map the area that is within 500 m of the household's location, and subsequent sections will cover several applications of this concept. In GIS the term buffer is used, and we say that the circle created by this operation constitutes the 200 m or 500 m buffer around the households. Buffers can be created for any kind of object like points, lines, or areas and are very widely used in GIS analysis (Kuria et.al, 2014).

In water distribution systems, proximity analysis can be used to identify the spatial relationship between various water sources, distribution networks, and demand locations. For example, proximity analysis can be used to estimate the distance between water treatment plants and the areas they serve, the distance between water storage tanks and the areas they supply, and the distance between water meters and customer locations. GIS-based proximity analysis can be used to optimize the location of water treatment plants, storage tanks, and distribution networks in order to minimize transportation costs, reduce energy consumption, and improve overall system efficiency. It can also be useful in identifying areas that are underserved or have inadequate water supply (Yukio, 2005).

2.2.7.4 Analytical hierarchy process

The analytical hierarchy process (AHP) is a semi-quantitative approach in which decisions are taken using weights through pairwise relative comparisons without inconsistencies in the decision process (Saaty, 1980). In this research, Analytical hierarchical process (AHP) was used to determine the weights of the criteria bases on a common standard as developed by Thomas Saaty. The input criteria have been each assigned a weightage of influence computed through AHP based on its relative importance, then the result successively multiplying the results by each of the constraints.

2.3. Rwanda's current targets in respect to improving water access

The Government of Rwanda has committed itself to reaching very ambitious targets in water supply and sanitation, with the targets to reach 85% by 2016/17 as per the Economic Development and Poverty Reduction Strategy (EDPRS II) and vision to attain 100 per cent service coverage by 2023/24 of potable water access for all as per National Strategies for Transformation (NST1). The importance of adequate water supply and sanitation services as drivers for social and economic development, poverty reduction and public health is also fully acknowledged in Rwanda’s flagship policy documents and national goals. Furthermore, The NST1 will pick up from where the EDPRS 2 left off, and continues in an effort to accelerate the transformation and economic growth with the private sector at the helm. (MININFRA, 2019).

According to (MININFRA, 2018), the Government has adopted the 2030 Agenda for Sustainable Development to end poverty and promote prosperity for all while protecting the environment and addressing climate change. The SDGs has water and sanitation at its core. Reaching the ambitious objectives of the SDGs demands that we address universal and equitable access to drinking water and sanitation along with issues of quality and supply, in tandem with improved water management to protect ecosystems and build resiliency. They include two main goals:

(1) Ensure availability and sustainable management of water and sanitation for all

(2) Strengthen the means of implementation and revitalize the global partnership for sustainable development.

On the other hand, the health impact of improved water supply alone is known to be limited without adequate attention for sanitation and hygiene awareness. Safe management of liquid and solid waste as well as storm water is an issue of both environmental health and the protection of water resources. Closely interlinked with other development sectors, the provision of adequate WSS services is therefore a core element of development strategies and indicators, including Rwanda's Vision 2050 and NST1. It is well known that several SDGs, not just the targets directly related to WSS, are linked to the improvement of water supply and sanitary conditions. Providing access to at least basic water supply and sanitation services is in the public interest and should be affordable for the entire population. While the primary responsibility for WSS services provision rests with local governments and the Utility, central Government has an obligation and interest to make sure that these institutions are able to comply with these responsibilities (WASAC Magasine, 2020).

CHAPTER 3: RESEARCH METHODOLOGY

3.0 Introduction

This research methodology provides a particular discussion of methods and techniques that have been used to carry out the application of remote sensing and GIS in spatial analysis of potable water availability and accessibility in Kinigi Sector. It described the materials and methods that were used to fulfill and to achieve the objectives of this study and to address the research problems. This includes both materials and methods used for data collection and data processing analysis, steps to carry out the study as well.

3.1. Study area description

Kinigi sector is one of the fifteen (15) sectors of Musanze District in Northern Province. The sector has five cells which are Nyabigoma, Nyonorima, Kmpanga, Kaguhu and Bisoke. Geographically with regard to other neighboring sectors, Muhoza is limited by the Musanze sector in the South, Uganda in the North, Shingiro in South West, Nyange sector in South East. From spatial extent point of view, Kinigi sector is situated between 29 º28’34.56” and 29 º36’43.87” East while in South is 1 º23’11” and 1º28’54.83” and then Kinigi sector has an area of 21.3439 km^2 with a population of 27,221 (Rana, 2011).

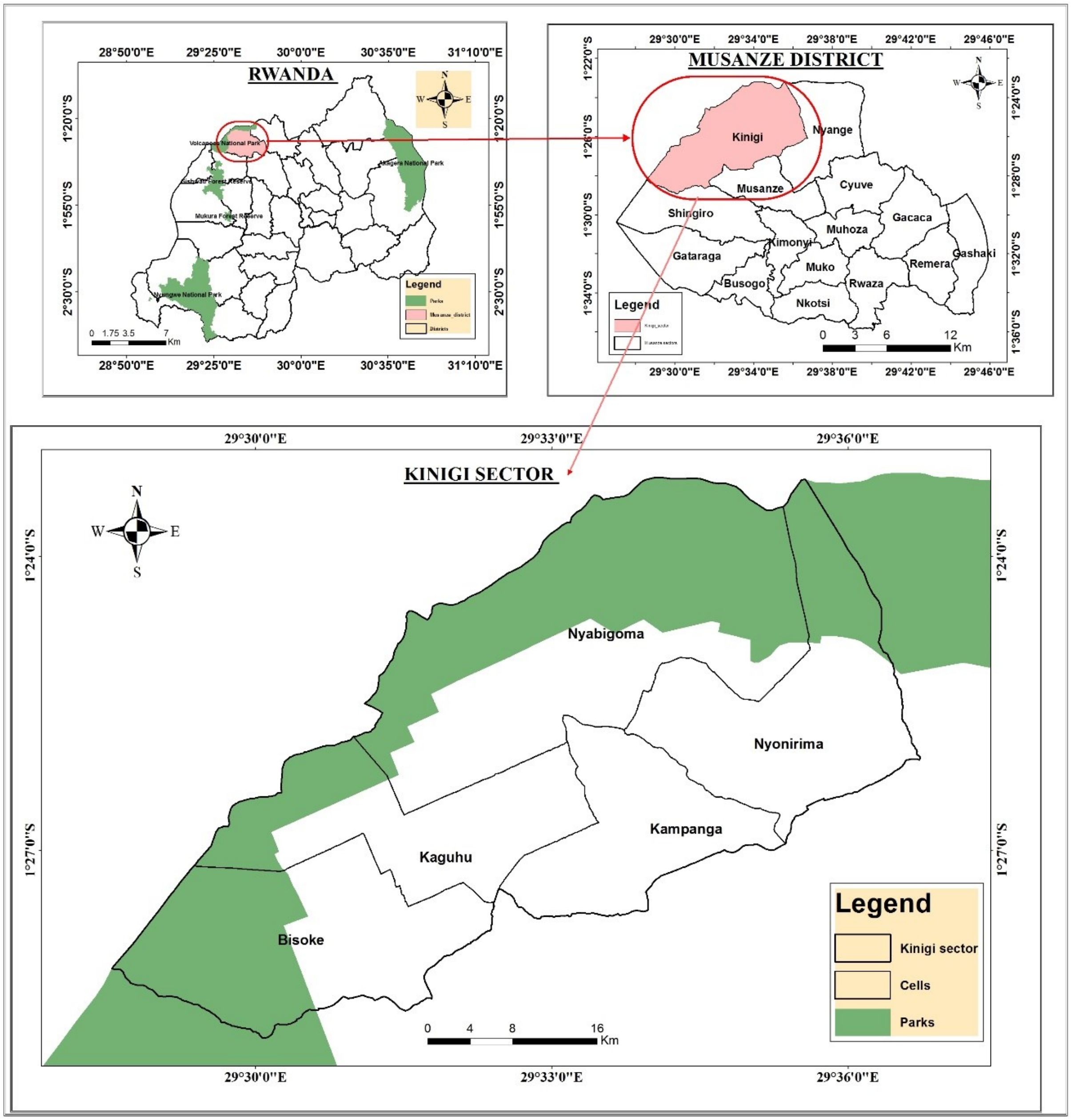

Figure 2: **Location of the study area**

Data source: Administrative boundaries (Rwanda Geoportal, 2012)

Due to the Kinigi sector's high elevation rainfalls are generally abundant, ranging from 1,400 mm to 1,800 mm annually. The climate has four seasons, two of them are rainy seasons as well as two dry seasons: the big dry season, between mid-June and mid-September, as well as the brief dry season, from September to December; the short rainy season, from January to mid-March and the big rainy season, from March till the end of May. Concerning to the climate, Kinigi Sector has a moderate tropical climate with an average temperature oscillating between 11ºC to 25 ºC and it is constant all over the year (Gaidashova *et al.,* 2010). Concerning the soil type, there are various types of soil that undergo diverse environmental pressures. The soil is mainly classified by its texture, proportions and different forms of organic and mineral compositions. Kinigi sector as study area is located in Northern and western province around Volcanoes National Park where it is dominated by volcanic soil and very permeability with narrow depth mountains and deposited soil with high depth in swamps (Nsabimana *et al*., 2008).

Recently the most water sources around the Kinigi sector are rainwater harvesting and water from tap stands of WASAC (Water and Sanitation Corporation). In this regard, the quality and quantity of water resource is low in dry season compared to wet season. Water demand within Kinigi sector is highly estimated (2.7 m^3/s) with respect to water capacity (0.28 m^3/s); that subjected to water scarcity in the study area, unless the available water supply (0.68 m^3/s) might be contribute to solving the water shortage if well managed (Nahayo *et al.*, 2015).

The Virunga national park regions experience an average precipitation of 1500 mm per year, its geological nature is mainly composed of permeable rock means that there is no flowing water that can be easily tapped. The problem of water accessibility is particularly severe in all sectors adjacent to Virunga National Park, especially in the Kinigi sector. This problem was compounded by the consequences of the 1994 war and the insecurity of 1997-1998, in which hydraulic infrastructure was damaged (water pipes, public water points, water tanks) (Ekise *et al*., 2016).

Due to the problem of access to drinking water, Rwanda National Water and Sanitation programs have aimed to make measurable and sustainable improvements in water supply, sanitation, hygiene, and the overall environment in the whole country especially in the Musanze district, Kinigi sector (MDDS, 2018).

3.2. Material and methods

This section emphasizes on identifying different data used in this study while describing their types and sources. In addition, the methods used to process and interpret the obtained data were also described.

3.2.1 Data collection

The data for this study was obtained from both primary and secondary sources. The primary sources include HH location that were collected using handheld GPS. Moreover, other primary data were obtained through the engagement of the respondents in an exercise of questions and answers while seeking to obtain their primary experiences and transformation through the potable water around Virunga national park and Secondary data was gathered using the documented sources and journals.

For secondary data include existing water network distribution (From WASAC), topographic information (SRTM data) that was downloaded from USGS website, administrative boundaries were obtained from National Land Authority. In the study multi parameter analyzer, hardware and software's were applied through using ArcGIS 10.8 software. Then, sampling, contacting and informing respondents about the research intentions were followed. The table 3 listed all datasets that used in this study.

Table 3: **Source of data used**

No	Types of data	Source of data	Spatial resolution	Year of acquisition	format
1	Digital Elevation Model (DEM)	Vertex.daac.asf.alaska.edu	12.5m	2016	Raster
2.	Landsat 8 OLI satellite image	Earthexplorer.usgs.gov	30m	2020	Raster
3	Study area boundary shape file	Rwanda Geoportal	-	2012	Vector

4	Road shape file	Rwanda Geoportal	-	2012	Vector
5	Number of Household	District office	-	2021	excel
6	Water supply system infrastructures	WASAC	-	2021	Vector
7	House/building footprints	RHA (Rwanda Housing Authority)	-	2021	Vector

3.2.1.1 Sample size

The simple random sampling technique were adopted during sample size determination in order to get respondents (Households), and therefore, a face-to-face interview was administered to concerned households in Kinigi sector. The sample size was derived from number of population household heads using Slovene's formula at a confidence interval of 95% and margin of error of 5% as described below (Jiang, Young, & Hardee, 2017):

$$n = \frac{N}{1 + N(e)^2}$$

Where:

n is the minimum sample size of household-heads

N is the population from which the sample was drawn estimated at households

e is the margin of error estimated at 5 %.

The total number of households living in the Kinigi sector is estimated to 27,221 and the sample size of this study is 100 households distributed randomly to five cells of Kinigi Sector.

3.2.1.2 Instruments for Research

The researcher gathered primary data using a survey, face–to–face interviews, and a questionnaire. These questionnaires were personally to the respondents (Household) in order to acquire completed replies in the shortest amount of time. A structured discussion was created between the researcher and the respondents in order to acquire specific information from them and answering questions on paper.

3.2.1.3 Questionnaire for the household

Household's questionnaires have been administrated to local communities in Kinigi sector, the researcher used questionnaire because of its low cost and it is free from bias. Respondents have adequate time to give well thought out answers and large samples can be used and thus the results can be made more dependable and reliable. The questionnaire has been addressed to a hundred farmers who constitute the principal sample.

3.2.1.4 Interview

Semi-structured interviews, in conjunction with focus group discussions focus group discussions

and key informants (local authorities) interviews, were intended to be employed in this study to help acquire the essential information in addition to household surveys. The researcher used the semi structured interview schedule for guidance during the data collection process. The face-to-face interview was designed and administered on executive secretary of Kinigi Sector and households' heads in the sampled cells in order to evaluate the level of perception of water infrastructure services within the study area.

3.2.2. Data analysis

The processing of both primary and secondary data was completed. For further analysis, the interviews and questionnaires were transcribed in Microsoft word. Tables indicating the percentages of responses to a question were created based on information provided by respondents.

The researcher used the questionnaire and asked the questions in Kinyarwanda, then translated the response into English on the spot and recorded it on the questionnaire, or left it blank and translated afterwards. Wherever possible, recording was used, and the translation completed at the conclusion of the day. Because the researcher went throughout the study area and met the respondents at their homes, the interviews took place at their residences or sometimes near the water infrastructures.

In order to address selected specific objectives, all secondary data include DEM, LULC (classified from Landsat 8), household and existing water supply system which was in digital format were processed using GIS software version 10.8 within proximity and overlay analysis.

3.2.2.1 Proximity analysis

In this study, a researcher created buffers (multiple ring buffers) with respect to the existing water distribution system especially water taps and secondary pipelines surrounding houses or footprints and suitable sites for allocating new potable water infrastructures were identified and addressed based on WHO standards as well as meeting NST1 targets.

3.2.2.2 Potable water accessibility

The distance traveled by the people to access water service constitutes an important factor in assessing the level of accessibility. It influences the time taken and quantity that can be fetched at any single trip. The time traveled to access water points in terms of distance and time referring to MININFRA access to safe water is measured by the proportion of population with access to an adequate amount of safe drinking water located with a convenient distance from the user's dwelling. This was addressed by using proximity analysis through multiple ring buffer with respect to the existing water taps and secondary pipelines at respective buffer distances of 300m, 500m, 750m and above; the extent area in which people have access to water was mapped in consideration of operational water points, results from spatial coverage analysis of potable water infrastructures.

3.2.2.3 Overlay analysis

After analyzing the spatial distribution of potable water infrastructures, there was identification of suitable location for new drinking water infrastructures in order to improve water availability at the same time accessibility in Kinigi Sector. This was done by selecting and evaluating the main factors through AHP process in order to identify suitable site for allocating new potable water infrastructures where Land use land cover, status of spatial distribution of water infrastructures and elevation were the weighted parameters.

To capture the land use/cover in the study area from the satellite imagery, data and image processing was performed through supervise classification technique. Elevations of Kinigi sector was also reclassified from DEM. The suitable site for allocating new potable water infrastructures was also considering the existing spatial distribution as well as focusing on the people served by drinking water above 500m.

Although, the appropriate location for new water infrastructures was selected by using the weighted Overlay technique, while weighting all parameters based on their respective influences on water availability and accessibility.

Finally, all the material and methods developed to address the specific objectives at the same time achieving to the results of this study were developed above and summarized in the figure 3 below as flow chart methodology.

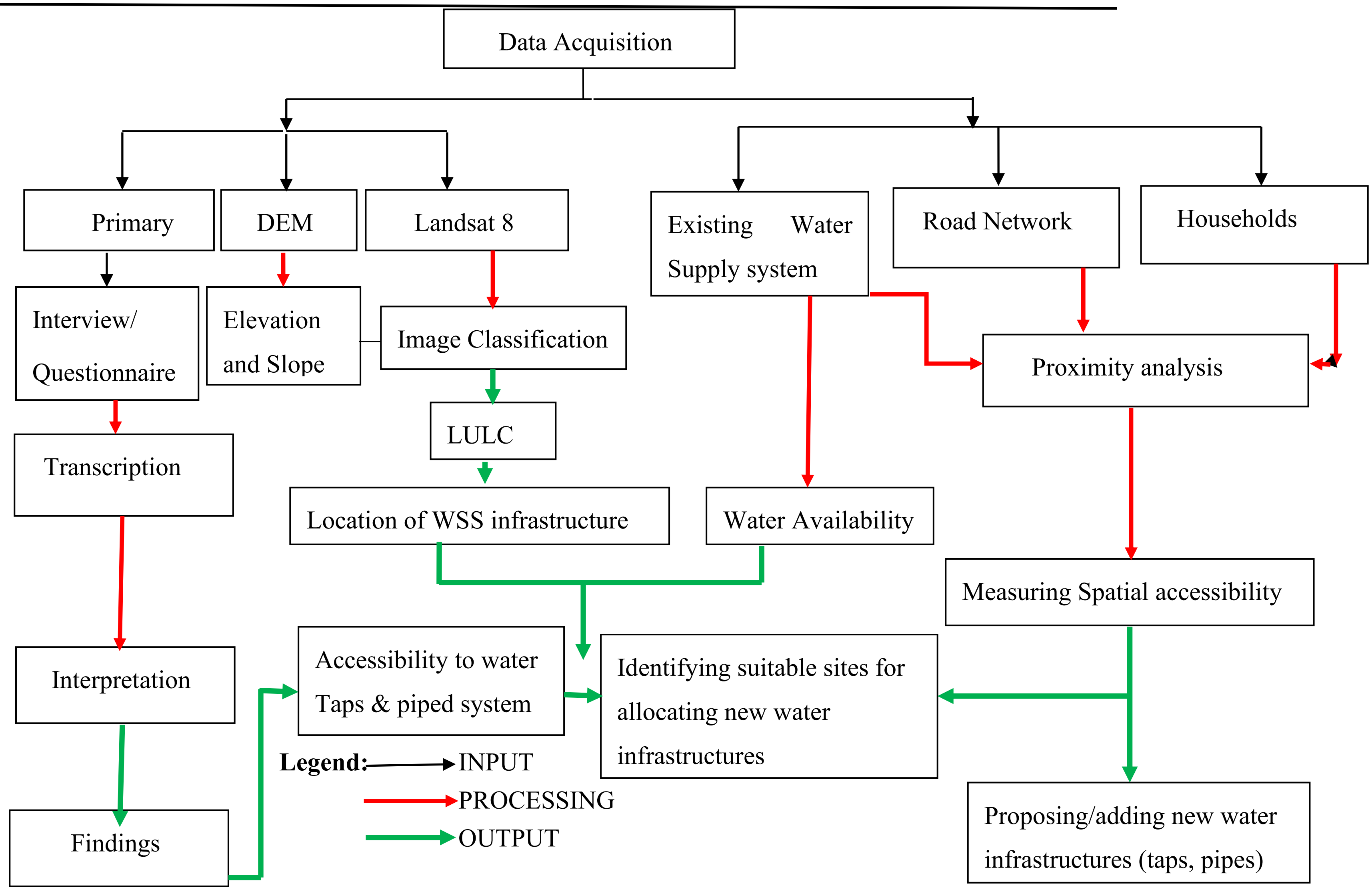
Data Acquisition
Primary
DEM
Landsat 8
Existing Water Supply system
Road Network
Households
Interview/ Questionnaire
Elevation and Slope
Image Classification
Proximity analysis
LULC
Transcription
Location of WSS infrastructure
Water Availability
Measuring Spatial accessibility
Interpretation
Accessibility to water Taps & piped system
Identifying suitable sites for allocating new water infrastructures
Legend:
INPUT
PROCESSING
OUTPUT
Findings
Proposing/adding new water infrastructures (taps, pipes)

Figure 3: Flow chart methodology

CHAPTER IV: RESULTS AND DISCUSSIONS

This chapter includes the results of the current spatial coverage of the water supply system in the Kinigi sector, evaluates the current status of water availability and accessibility for various users in the Kinigi sector, and assesses spatial interventions in order to improve water accessibility by various users in the Kinigi Sector.

4.1. Spatial coverage of potable water infrastructures

The current status of water availability and accessibility for various users in the Kinigi sector is expressed by existing water network as well as reservoirs, pipelines and travelled distances to access the existing water taps as indicated in the figure 4.

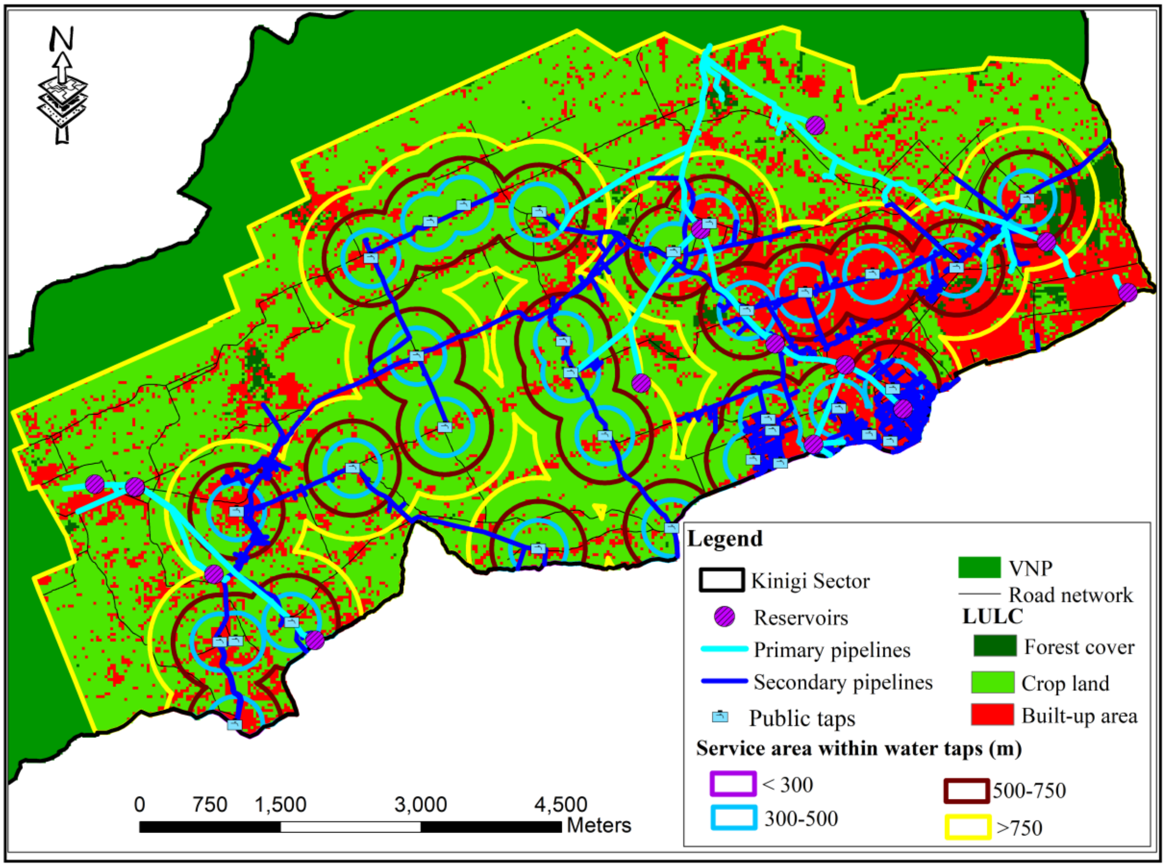

Figure 4: **Spatial coverage of potable water infrastructures in Kinigi Sector**

Data source: - Administrative boundaries (Rwanda Geoportal, 2012)

- **Piped water supply system (WASAC, 2021)**
- **LULC: Earthexplorer.usgs.gov (Landsat 8 OLI, 2020)**

The figure 4 illustrates the current water distribution network and LULC within the study area. In Kinigi Sector the use of land is mainly categorized into 3 classes namely Forest cover, vegetation cover and built-up land. The existing water network is composed of main pipelines connected with 14 reservoirs which distribute water to client users with secondary and tertiary pipelines and the whole water network in Kinigi comprises of 32 public water taps which are in service within 6 hours per day mainly in early morning and evening.

According to the respondents, the availability of water in pipes is good in rain season but moderate in dry season. Therefore, all existing water taps cannot be fully operational and some water taps are out of service.

Regarding to the water accessibility, the distance to water infrastructure is a major determinant to water access since it influences the time taken and amounts that can be fetched at any single trip.

Regarding the service area by public water infrastructures, 13% can be serviced within less than 300m, 29% have access to water tap within 300-500m of walking distance of an improved water source, 19 % have access to water within 500-750m, while 39% access water greater than 750m. Thus, results from spatial coverage analysis of potable water infrastructure and related statistics are provided in the figure 4 and table 4 respectively.

Table 4: Spatial coverage on public water infrastructures

Serviced distance from water tap (m)	Service area (Ha)	%
< 300	496.896	13
300-500	1610.688	29
500-750	789.612	19
>750	2114.802	39
Total	**5011.998**	**100**

4.2. Spatial variability of potable water accessibility and availability by users in Kinigi Sectors

Based on findings, 60% of HHs in the study area have access to piped water, this is slightly low than the NST1 targets: "access to water for all (100%) by 2023/2024 as well as EDPRS II targets (85%) By 2016 where 84.8 percent of households nationwide had access to an improved water source, 23 percent relied on protected springs, 9 percent collected rainfall, and 9 percent had water pumped into their home or yard.

The distance travelled by the people to access potable water services constitutes an important factor in assessing the level of accessibility (Kumamaru, 2019); as **good accessibility**, **moderate accessibility**, **poor accessibility** and **very poor accessibility (inaccessible)** while basing to threshold distances less than 300m, 300-500m, 500-750m and greater than 750m respectively.

According to MININFRA (2018), access to potable water is measured by the proportion of population with access to an adequate amount of safe drinking water located with a convenient distance from the user's dwelling; hence, the Services area created from threshold distances as indicated above with respect to public water infrastructures and neighbourhoods can be described by the map below.

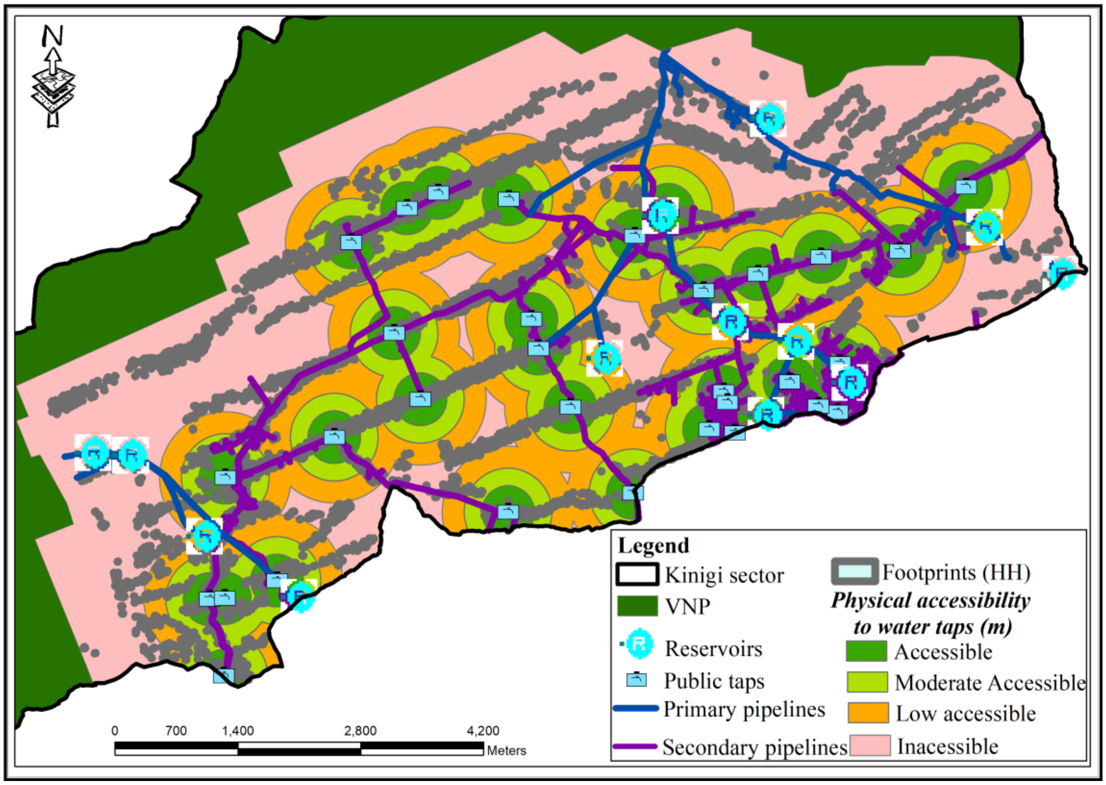

Figure 5: Physical accessibility to water taps

Data source: - Administrative boundaries (Rwanda Geoportal, 2012)

- Piped water supply system (WASAC, 2021)

- Building footprints (Rwanda Housing Authority, 2021)

The figure above indicates the perception on physical accessibility to water taps in function of travelled distance. In this regard, 27.9% of HH access to water taps within the distance less than 300m and have a good accessibility, 31.7% of HH can access water tap within the distance between 300-500m and lead to moderate accessibility, while 13.6% have a poor accessibility and can access water taps within 500-750m then 26.8% can access water point within more than 750m and are considered to be inaccessible to water infrastructures.

Table 5: **Accessibility of potable water supply system in Kinigi**

Physical accessibility (m)	Perception rate	Nber of HH (Footprint)	%
<300	Good accessible	2956	27.9
300-500	Moderate accessible	3684	31.7

500-750	Low accessible	1274	13.6
>750	Inaccessible	2686	26.8
TOTAL		10600	100

The perception on spatial variability of potable water accessibility in function of distance travelled to reach the water taps is presented statically in the table 5 and figure 6 respectively.

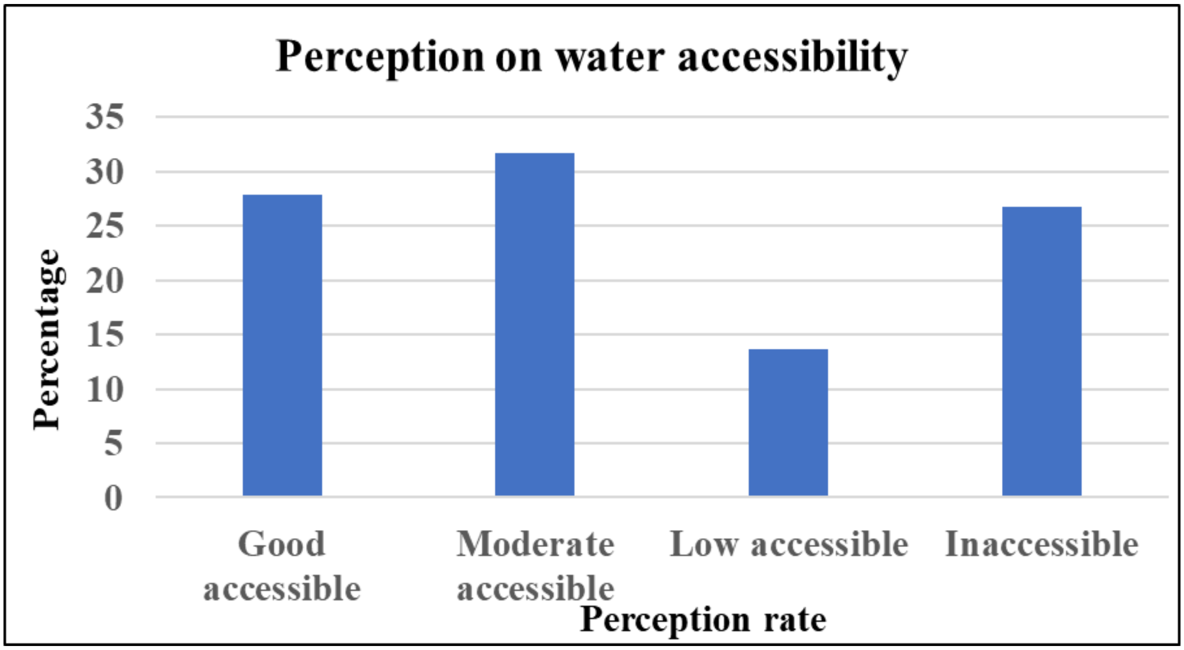

Figure 6: Perception on potable water accessibility

Data source: - Piped water supply system (WASAC, 2021)

- Building footprints (Rwanda Housing Authority, 2021)

For the concept of potable water availability, the conducted research highlighted that the greater part of the study area is in rural area, where 70% perceived that the service of water supply is quite good. This resulted to the amount of water available in function of domestic consumption per day which is low than 20 liters per day per person and not meeting WHO standards. Moreover, in the study area 8 out of 32 water taps found to be not fully operating and water points are not serving frequently, which increase the rate of water demand with respect to consumers.

Another revealed problem is that the availability of water is seasonally and not continuous due to the awareness of water sources that are not well serving during dry season and the scarcity in water is high. Although, the conducted research has indicated that the availability of potable water is on medium rank comparing to the serviced secondary and tertiary water pipes that can serve water to Kingi's local community as illustrated in the figure 7.

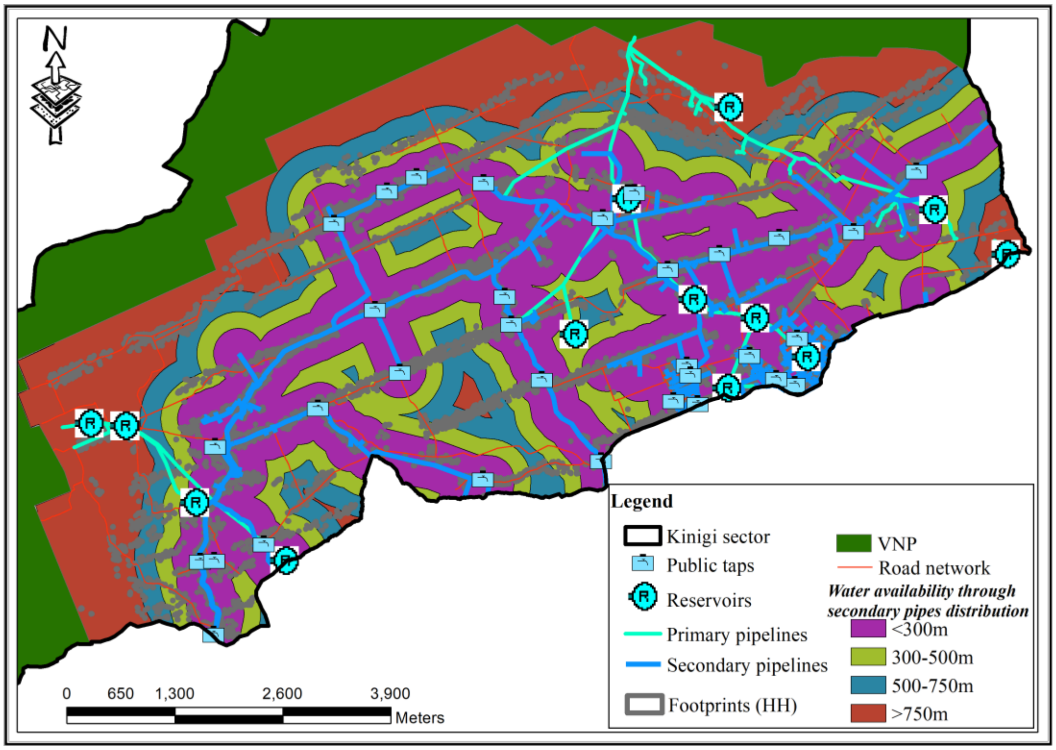

Figure 7: Spatial availability of water in Kinigi Sector

Data source: - Administrative boundaries (Rwanda Geoportal, 2012)

- **Piped water supply system (WASAC, 2021)**
- **Building footprints (Rwanda Housing Authority, 2021)**

Potable water is vital for human consumption. The availability of safe drinking water is mainly expressed by its supply (availability through pipelines) and domestic consumption per person, per year in a region (Kumamaru, 2019).

According to figure 7, the distribution of potable water is described in function of pipeline network. To explain the rate of water availability, the distances serviced within secondary pipelines was established to evaluate the way water are available to the neighborhood.

The obtained results indicate that 2022.04 Ha i.e 51.3% of Kinigi Sector; potable water is available through pipeline within the distance less than 300m, 575.12 Ha (16.5%) can be served by secondary pipeline in 300-500m, 424.1 Ha (9.5%) the water is available within 500-750m while 1990.738 Ha equivalents to 22.7% the neighborhood can be served by secondary pipe line within the distance greater than 750m and the water is said to be not available.

Despite, a great number of surveyed have addressed the issue of water scarcity. The availability of water in pipes is only good in wet season and not good in dry season where some public taps are not in service due to water shortage. In addition, more than 65% of HH indicate the scarcity in potable water where there is a consumption less than 15l/c/d in average which is out of WHO recommendation of 20l/c/d minimum.

4.3. Spatial interventions in order to improve water accessibility by various users in the Kinigi Sector

In fact, the current and future water demand is still being a problem compared to water availability and accessibility in the Kinigi Sector. In order to meet the government target in water availability and accessibility the existing water distribution system should be improved.

4.3.1 Factors considered for locating new water infrastructures

4.3.1.1 Land Use / Land Cover

The Land use land cover of Kinigi Sector as one part of Greater Virunga Landscape was classified into four main categories including Built-up area, cropland, forests cover and bare soil.

Apart from 3058.77 Ha occupying by VNP as a protected ecosystem, there are 2173.88 Ha (43.3 %) occupied by crop land, 1969.94 Ha (39.3%) occupied by built-up, 527.8 Ha is occupied by forest cover (tree plantation) with 10.5% and 346.41 Ha i.e 6.9% that was classified as bare soil.

As identified in figure 4 which express the spatial coverage of water infrastructures, the results show that greater than 45% of Kinigi communities are not accessible to potable water and are far from water taps with more than 750m to the nearest water point.

Furthermore, the rate of built-up area (population density) in LULC is a key element to express the high-water demand compared to the existing water infrastructures and it will contribute to improve water distribution to the area which are not well served by water infrastructures as shown in figure 4.

4.3.1.2 Distribution of water infrastructures

The improvement of water availability and accessibility in Kinigi Sector will be basically based on the way water infrastructures are distributed with respect to the service area.

Based on the findings as described in figure 5 and figure 7; where explaining the concept of availability and accessibility in the study area.

Moreover, the obtained results have showed that the rate of accessibility and availability to local community is less than 65% where the neighbourhoods can access and served by piped water network within more than 500m.

To meet WHO standards (good access < 200m) of well-being with respect to water accessibility (Kumamaru, 2019), and reach the NST1 targets (drinking water access for all by 2023/24) the water distribution should be mainly improved based on the area which are not well served by water distribution as well as decreasing the distance of accessibility to potable water by proposing new water taps and extending the piped system with respect to the area served within the distance more than 500m.

4.3.1.3 Elevation

The existing water network in the area under study is a piped system conducted based on the gravity. In fact, proper slope of gravity drainage is important so that liquids flow smoothly; and it is also commonly thought that pipes that are too steep will allow liquids to flow so quickly. Meanwhile, the spatial intervention of improving water network distribution in Kinigi Sector, will take into consideration the difference in elevation between concerned water infrastructures noting that water flows from steep to gent slope.

Therefore, in improving the spatial intervention of existing potable water distribution network the gradient in elevation should be considered while extending the pipeline network and adding different water taps where necessary. The information about elevation with respect to the water distribution network of the area under study is described in figure 8.

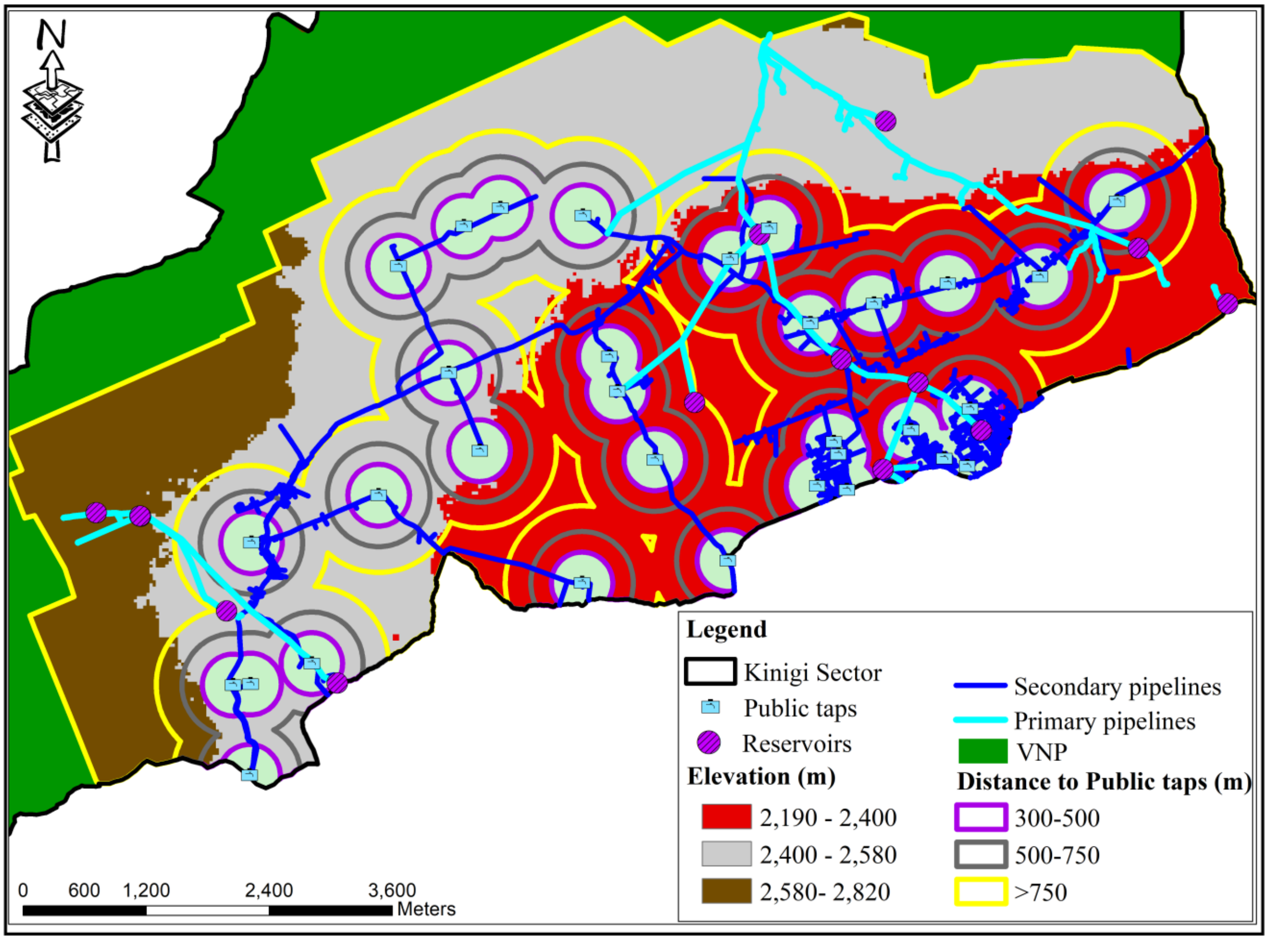

Figure 8: Elevation of Kinigi sector

Data source: - Administrative boundaries (Rwanda Geoportal, 2012)

- **Piped water supply system (WASAC, 2021)**
- **Digital Elevation model: Vertex.daac.asf.alaska.edu (USGS, 2019)**

4.3.2 Finding optimal location for new public water infrastructures

Based on research findings, around 60% of Kinigi communities are far from existing water infrastructures mainly water taps; where they use more than 500m (>30 minutes) to reach the nearest water point. This means that the available water distribution system needs an upgrade and extension in order to NST1 and vision 2050 targets as well as having good access to safe drinking water for all by 2023/24.

In order to upgrade and extend the water distribution system in Kinigi Sector, new potable water infrastructures including water taps and pipelines will be allocated through the network based on the highlighted factors and the suitable map for potential distribution system identified as well as it can help in water management, knowing where to place a new water point while sparing distance travelled and time spent on deciding which route to take, etc…

To identify the suitable location for new public water infrastructures factors as population density (LULC), awareness of water infrastructures (poorly distributed) and elevation were considered. Those variables were weighted through AHP and the poorly served area was the high potential value in producing the suitability map below.

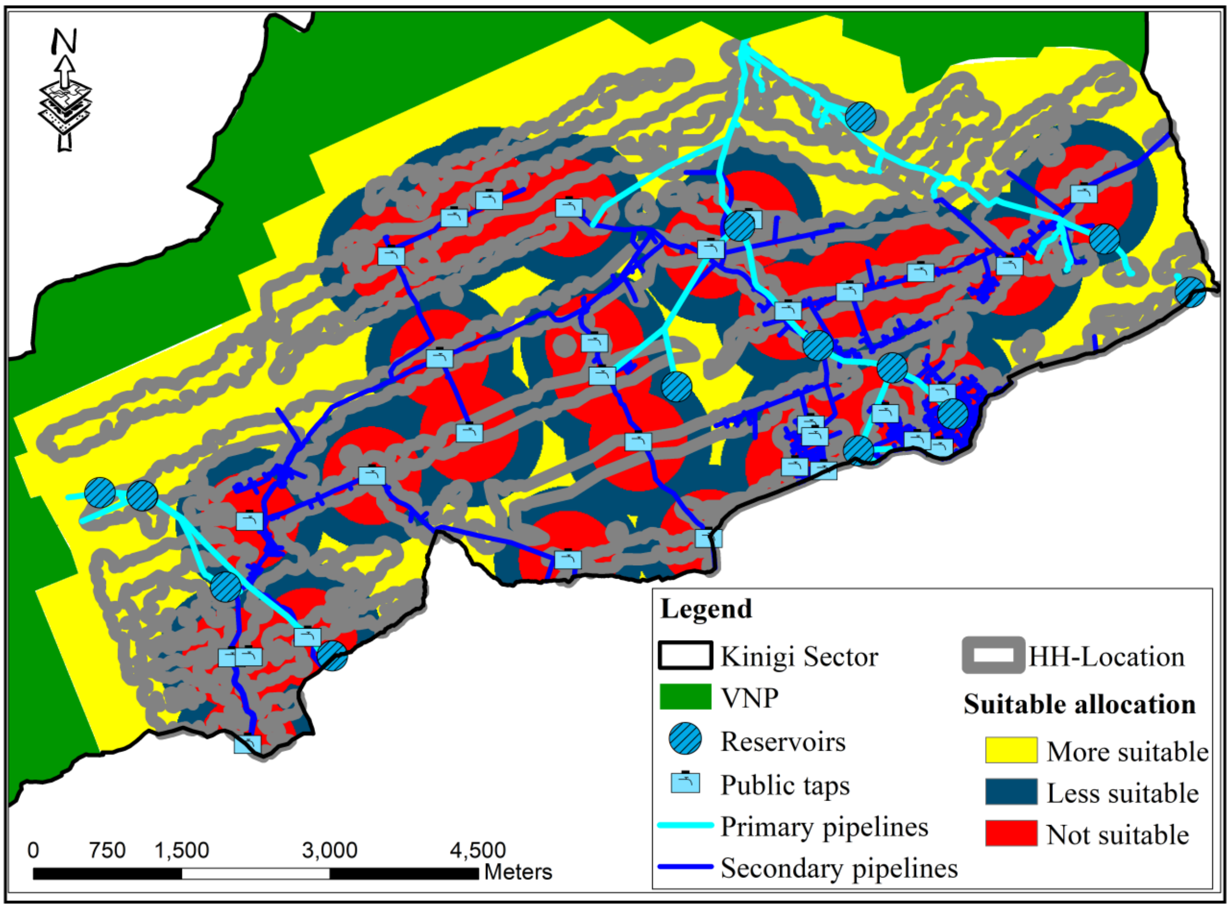

Figure 9: **Optimal location for new public water infrastructures**

Data source: - Administrative boundaries (Rwanda Geoportal, 2012)

- **Piped water supply system (WASAC, 2021)**
- **Building footprints (Rwanda Housing Authority, 2021)**

The figure 9 illustrates the suitable area for locating new public water infrastructures within Kinigi Sector. Accessibility to potable water is equally important as availability. Furthermore, the research findings indicate that several parts of the study area are deprived from potable water mainly in Bisoke cell where there are only 4 water taps in the entire cell.

In order to overcome the aforementioned issue, 32 new public taps were proposed to be added to the poorly served area as well as improving water distribution within the study area while extending the piped system as indicated in the figure 10.

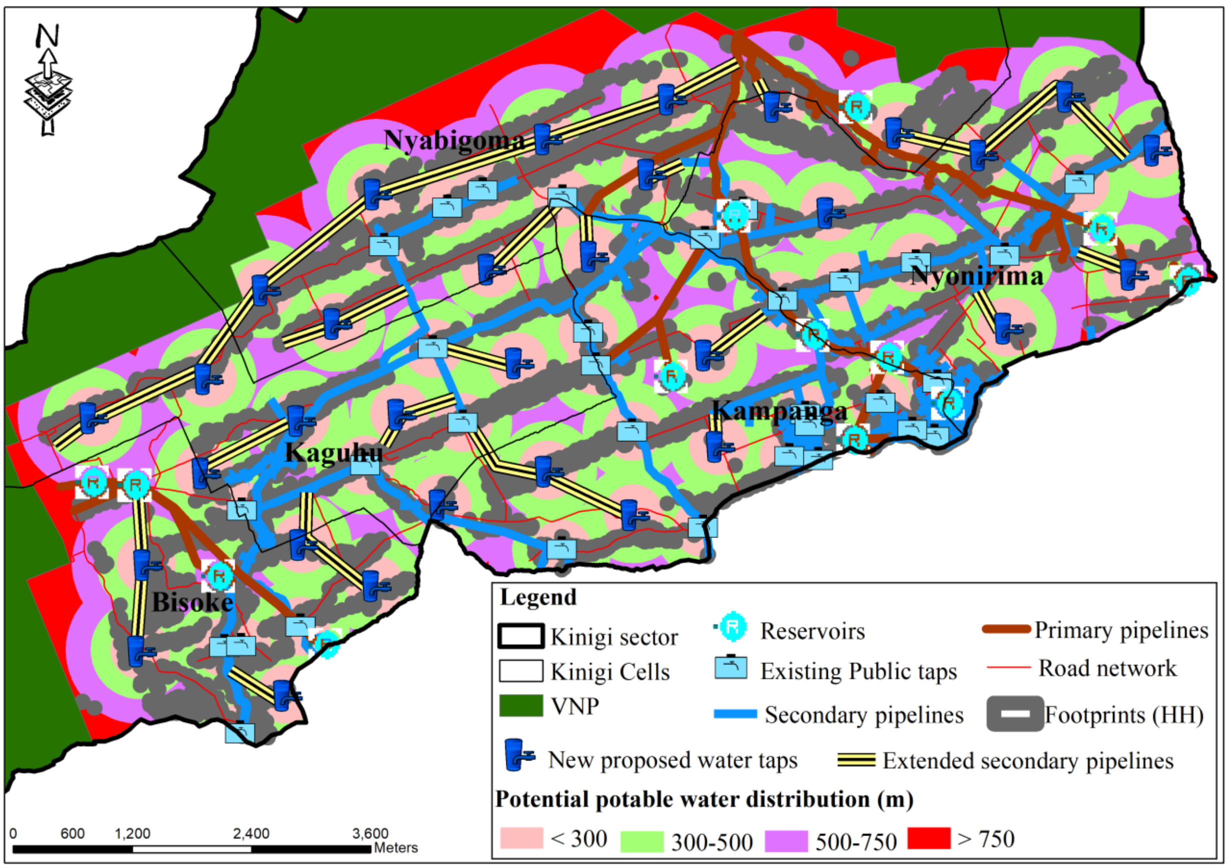

Figure 10: Proposed potential potable water distribution

Data source: - Administrative boundaries (Rwanda Geoportal, 2012)

- **Piped water supply system (WASAC, 2021)**
- **Building footprints (Rwanda Housing Authority, 2021)**

According to figure 10, the potential water distribution will improve water availability and accessibility in Kinigi sector mainly in the indicated poorly serviced area as described by the suitability map in figure 9.

Based on findings, the 71.5% equivalent to 3583.68 Ha will be potentially served by potable water infrastructures within the distance less than 300m and said to have a good accessibility to drinking water while 20.6% or 1032.55 Ha proposed to be served by potable water within the distance between 300-500m which will provide a moderate accessibility as described in the table 6 below.

Table 6: Proposed potential drinking water accessibility in Kinigi sector

Physical accessibility (m)	Potential Service area (Ha)	Percentage	Perception rate
<300	3583.682	71.5	Good accessible
300-500	1032.551	20.6	Moderate accessible
500-750	312.422	6.2	low accessible
>750	83.343	1.7	inaccessible
TOTAL	5011.998	100.0	

As described in the table 6, above 90% of the study area will have a good accessibility to the water facilities where there will supposed to be served by water infrastructures within the distance less than 500m and only 7.9% will remain poorly served by water infrastructures due to informed settlements.

The figure 12 explain the rate of spatial intervention to improve water availability as well as accessibility in the study area.

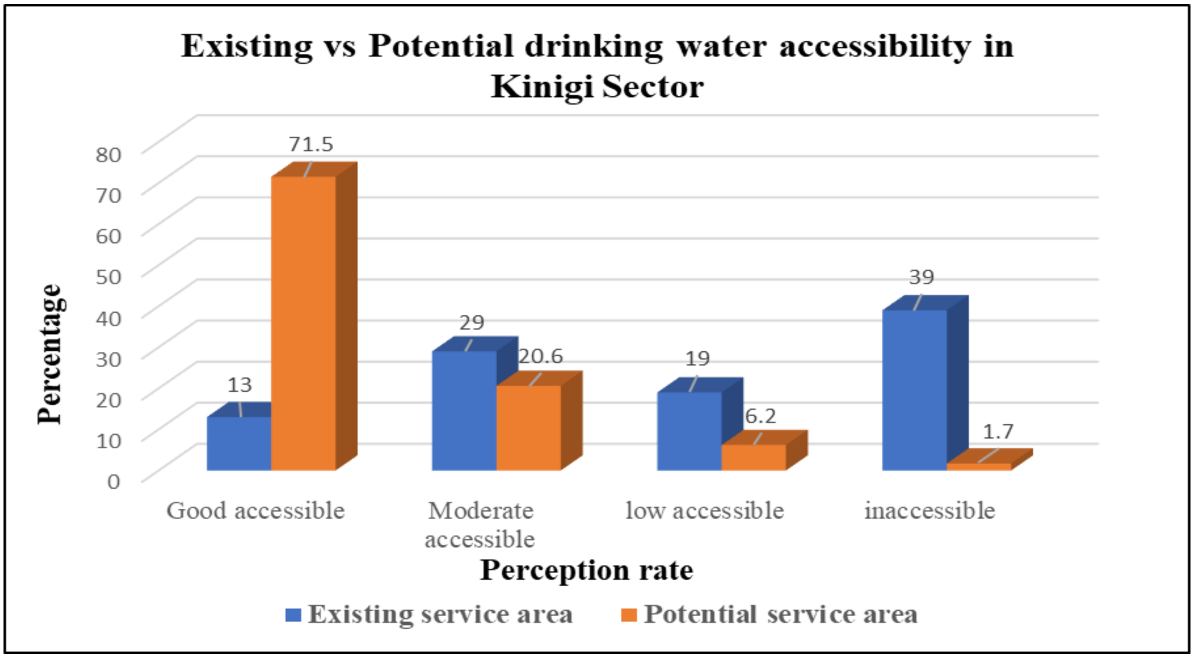

Figure 11: **Spatial intervention of potable water accessibility in Kinigi Sector**

Data source: - Piped water supply system (WASAC, 2021)
- Building footprints (Rwanda Housing Authority, 2021)

According to the statistics in figure 11 above, potable water distribution in Kinigi Sector will be well improved as well as the area with good accessibility i.e served by water infrastructures within the distance less than 300m will increase from 13% to 71.5%, while the area with inadequate access with the travelled distance to the water point between 500m-750m and greater than 750m will decrease with high rate from 19% to 6.2% and 39% to 1.7% respectively. Thus, the potential spatial distribution of potable water in Kinigi Sector will highly improved from 42% up to 92.1% which meets vision 2050 targets.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Access to safe drinking water is crucial, not only for people's health and wellbeing, but also for poverty reduction and economic development. Improving the access, quality, availability and sustainability of water supply services in Rwanda is among the top priorities to reach SDGs targets by 2030 through the different programs such as the NST1 and 7 Years Government Program with the aim of achieving universal access to basic water and sanitation services by 2024.

This research discussed the spatial assessment of potable water availability and accessibility in Kinigi Sector as one among 11 sectors that composed the Greater Virunga Landscape in North-West part of Rwanda especially in Musanze District. Kinigi sector is considered as rural area but recently developing by tourism activities. Rapid urbanization and high rate of human growth has increased the pressure on potable water demand which is 2.7m^3/s and the availability is 0.68 m^3/s. This scarcity in water availability has also decreased the domestic water consumption which is less than 20l/d/p as recommended by WHO. Nevertheless, water accessibility is a major challenge to Kingi's community due to the great number of neighborhoods travelling a long distance greater than 500m to reach the nearest potable water facility.

The main purpose of this study was to assess spatially the current potable water distribution in the study area and produce a road map of water supply infrastructures while proposing probable solutions that can guide decision makers and water supply providers to improve water supply system in the study area. In order to achieve the goal of this research, the specific objectives were formulated as follow: to ascertain the current spatial coverage of the water supply system, to evaluate the current status of water availability and accessibility for various users and to strategically propose the required spatial interventions to improve water accessibility by various users in the Kinigi Sector. As methodology, all needed material and methods were gathered together while primary and secondary data were collected. The primary data were collected through structured interviews on water accessibility and availability while secondary data were mainly the current water supply system shapefiles, DEM, Landsat 8 OLI satellite image and building footprints. In addition, those data were processed and analysed in ArcGIS 10.8 through proximity and overlay analysis in order to improve the potable accessibility and availability in the study area.

The key resulted findings prove that water availability and accessibility to potable water facilities in the study area is inadequate. Based on the special coverage, the water distribution network comprises 14 reservoirs that distribute drinking water to 32 water taps through piped system. The existing water facilities do not serve frequently where the availability is quite good in rain season but wrong in dry season. In fact, most consumers rely on water from springs, rain water and few number on piped water. Currently, the potable water infrastructures such as water taps, and kiosks are generally random and uneven, with a little clustering sampled household that were interviewed at the region of Kinigi sector, and as one moves away from the center, the sparser the water points become. A greater number of interviewed households indicated that accessibility to potable water is still scarce where only 70 % are still walking long distance with more than 500m to reach the nearest water tap which is not meeting NST1 targets, others are using water obtained from different sources such as improper harvested rainwater, springs etc. Based on research findings, physical accessibility to the existing water tap is good on the rate of 59.6% and low at 13.6% where people access the nearest water tap within the distance less than 500m and between 500m-750m respectively and then 26.8% are said to be inaccessible to the water taps as the are in the distance more than 750m to the water point. Even if the accessibility is generally insecure, the obtained results indicate that 51.3% of the study area can be served by water facilities through secondary pipelines within the distance less than 300m, Kinigi Sector; potable water is available through pipeline within the distance less than 300m, 16.5% in the distance between 300-500m, 9.5% within the distance between 500-750m while 22.7% can be served by secondary pipe line within the distance greater than 750m and potable water is said to be not available.

Furthermore, according to the aforementioned issues, potential new water infrastructures have been proposed in the highlighted deprived area based on the produced suitable sites in order to improve water accessibility same as availability in Kinigi Sector. Meanwhile, the current water distribution system was proposed to be improved and 32 new water taps added to the network as well as the piped system extended in order to upgrade the accessibility and availability of potable water in the study area. This was done based on the poorly served area and population density and finally the good served area will be increased from 13% to 71.5% while poorly and inaccessible areas decreased from 19% to 6.2% and 39% to 1.7% respectively.

Although, the spatial assessment of potable water accessibility is an important exercise that can provide valuable insight into the availability of safe drinking water for the population. The use of various mapping tools and methods has helped in identifying areas with inadequate access to potable water, thus informing policy decisions for the efficient and effective provision of clean water in the area under study.

5.2 Recommendation

After gathering all the information concerning water availability and accessibility from surveyed area, to improve on the quality of services rendered by the water supply infrastructures it has been necessary to formulate some recommendations as follow:

- Although potable water facilities are insufficient compared to the population growth and long distance travelled to reach the nearest water tap. Therefore, WASAC and government Leaders should give more effort in improving potable water distribution network in the study area by adding more water taps while extending the WSS in order to balance the potable water demand with respect to the need as well as reducing the travelled distance to reach the water tap up to 500m maximum as recommended by WHO.
- Integration of spatial analysis and planning: There is a need to integrate spatial analysis tools and methods in water planning and management. This would help to identify areas with poor water access and prioritize interventions to address these issues and challenges.
- Promotion of community participation: There is a need to involve communities in the decision-making process for water provision. This would increase their ownership of the process and improve the sustainability of water supply projects.

- Investment in water infrastructure: Kinigi sector is considered as a rural area but it is a zone prior to tourism activities. Therefore, there is a need for continued investment in water infrastructures, particularly in remote and hard-to-access areas. This should be done with due consideration of environmental sustainability and ecological balance as including sanitation for instance avoid using water from unprotected springs, etc…
- In addition, the future researchers are encouraged to conduct more researches related to the impact of land use and climate change on water sources availability and the advanced management use of rainwater harvesting for environmental restoration. This will describe different way of improving the quality of rainwater harvesting for domestic use in the way piped water are in deficit.

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APPENDICES

Appendix 1: Spatial location of potable water infrastructures

I. Existing water taps

#	Easting	Northing	Elevation	Cell
1	448465.3	4841729.96	2505.89	Nyabigoma
2	452711.67	4840024.37	2265.65	Kampanga
3	447012.72	4836783.77	2560.69	Bisoke
4	447619.5	4837870.6	2485.55	Bisoke
5	450264.09	4842220.95	2446.37	Nyabigoma
6	450521.66	4840851.68	2377.72	Kaguhu
7	450966	4839849.92	2326.96	Kampanga
8	447030.45	4839044.3	2521.12	Kaguhu
9	452082.29	4842099.67	2379.49	Nyonirima
10	454723.3	4841629.65	2313.88	Nyonirima
11	450256.81	4838653.21	2326.86	Kampanga
12	454014.39	4839790.55	2205.4	Kampanga
13	455477.62	4842361.52	2367.12	Nyonirima
14	454043.12	4840346.31	2239.32	Kampanga
15	451679.34	4838871.96	2258.67	Kampanga
16	452549.5	4839595.73	2250.63	Kampanga
17	449256.59	4839938.18	2418.31	Kaguhu
18	450601.18	4840516.92	2366.4	Kaguhu
19	448956.71	4840692.81	2444.2	Kaguhu
20	451701.41	4841799.45	2370.38	Nyonirima
21	452841.52	4839557.91	2244.64	Kampanga
22	449458.02	4842293.3	2462.44	Nyabigoma
23	446852.29	4837661.2	2545.04	Bisoke
24	453105.73	4841367.48	2312.72	Nyonirima
25	452756.28	4839904.66	2259.44	Kampanga
26	453825.54	4841562.92	2331.77	Nyonirima
27	452484.32	4841176.46	2322.24	Nyonirima
28	448271.9	4839505.62	2444.18	Kaguhu
29	449102.33	4842118.1	2476.54	Nyabigoma
30	453790.68	4839861.54	2214.19	Kampanga
31	453467.58	4840138.06	2245.63	Kampanga
32	447022.27	4837671.21	2528.77	Bisoke

II. Existing reservoirs

#	Type	Easting	Northing	Elevation	Cell
1	Stones	445950.755	4839300.13	2259.07	Bisoke
2	Stones	451356.413	4840405.936	2334.11	Kampanga
3	Stones	454153.4141	4840132.37	2222.38	Nyonirima
4	Steel	451990.684	4842034.992	2383.24	Nyonirima
5	Bricks	446791.2639	4838378.863	2444	Bisoke
6	Bricks	445945.9208	4839302.919	2259.19	Bisoke
7	Bricks	447871.0655	4837680.289	2440.26	Bisoke
8	Stones	453538.0885	4840598.926	2268	Nyonirima
9	Stones	453197.1563	4839757.808	2243.88	Kampanga
10	Bricks	456558.4346	4841366.126	2256.01	Nyonirima
11	Stones	455688.2478	4841904.357	2331.71	Nyonirima
12	Bricks	452788.5196	4840823.526	2304.9	Kampanga
13	Stones	445518.8623	4839332.771	2259.45	Bisoke
14	Stones	453220.6683	4843138.626	2485.12	Nyabigoma

III. PROPOSED WATER TAPS

#	Easting	Northing	Cell
1	456012.57	4841451.81	Nyonirima
2	454746.80	4840906.72	Nyonirima
3	456250.47	4842716.00	Nyonirima
4	455370.06	4843260.54	Nyonirima
5	454496.06	4842665.23	Nyonirima
6	453644.13	4842892.51	Nyabigoma
7	452414.77	4843158.72	Nyonirima
8	451353.49	4843230.80	Nyabigoma
9	450102.39	4842827.18	Nyabigoma
10	451149.80	4842469.80	Nyabigoma
11	450566.88	4841638.02	Kampanga
12	449536.60	4841507.98	Nyabigoma
13	452954.20	4842080.00	Nyonirima
14	451727.40	4840635.67	Kampanga
15	451837.42	4839705.74	Kampanga
16	450978.73	4839011.67	Kampanga
17	449812.49	4840552.77	Kaguhu
18	448386.53	4842268.80	Nyabigoma
19	447258.18	4841293.91	Nyabigoma

20	447978.61	4840954.04	Nyabigoma
21	450114.34	4839455.36	Kampanga
22	448625.01	4840031.82	Kaguhu
23	449045.63	4839116.88	Kaguhu
24	447638.56	4838711.73	Bisoke
25	447476.56	4837182.73	Bisoke
26	446004.81	4837630.92	Bisoke
27	446065.60	4838508.20	Bisoke
28	446652.12	4839437.06	Kaguhu
29	447615.74	4839970.93	Kaguhu
30	446678.70	4840394.04	Kaguhu
31	445520.54	4839997.95	Kaguhu
32	448371.10	4838292.71	Bisoke

Appendix 2: Spatial location of surveyed households

#	X (m)	Y (m)	Z (m)	Cell
1	447208	4836868	2379	Bisoke
2	446539	4837233	2313	Bisoke
3	446752	4837902	2326	Bisoke
4	447969	4838328	2205	Bisoke
5	447299	4838693	2367	Kaguhu
6	446478	4838724	2239	Bisoke
7	446174	4838298	2326	Bisoke
8	445718	4839149	2521	Bisoke
9	446022	4839180	2379	Bisoke
10	445140	4839910	2313	Kaguhu
11	445596	4840001	2326	Kaguhu
12	446296	4840396	2205	Kaguhu
13	446813	4840731	2367	Kaguhu
14	447482	4839910	2239	Kaguhu
15	447604	4839393	2258	Kaguhu
16	448486	4839636	2250	Kaguhu
17	449733	4839362	2418	Kampanga
18	448455	4839393	2366	Kaguhu
19	448942	4839058	2444	Kaguhu
20	449702	4838906	2370	Kampanga
21	450159	4838632	2244	Kampanga
22	450676	4838632	2462	Kampanga
23	451223	4838754	2545	Kampanga
24	451710	4838967	2312	Kampanga
25	451892	4839210	2259	Kampanga
26	452257	4839301	2331	Kampanga
27	452592	4839666	2322	Kampanga
28	452775	4839879	2444	Kampanga
29	453261	4839849	2476	Kampanga
30	452835	4839606	2214	Kampanga
31	454022	4839940	2245	Kampanga
32	454113	4840275	2528	Kampanga
33	454447	4840336	2505	Nyonilima
34	453991	4840792	2265	Nyonilima
35	452744	4840366	2560	Kampanga
36	451801	4840001	2485	Kampanga
37	450524	4840457	2446	Kaguhu
38	449337	4840001	2377	Kaguhu

#	X (m)	Y (m)	Z (m)	Cell
51	450493	4840944	2462	Kampanga
52	451193	4840731	2545	Kampanga
53	451862	4840609	2312	Kampanga
54	450432	4839697	2377	Kampanga
55	451010	4839849	2379	Kampanga
56	453048	4840731	2313	Nyonilima
57	452714	4840914	2326	Kampanga
58	452318	4841035	2205	Kampanga
59	452927	4841309	2367	Nyonilima
60	453505	4841491	2239	Nyonilima
61	453565	4841005	2258	Nyonilima
62	454508	4841279	2250	Nyonilima
63	455086	4841887	2418	Nyonilima
64	455847	4841157	2366	Nyonilima
65	456394	4841218	2444	Nyonilima
66	456060	4841552	2370	Nyonilima
67	455603	4842495	2244	Nyonilima
68	454843	4842769	2462	Nyonilima
69	453900	4842252	2545	Nyonilima
70	452775	4842009	2312	Nyonilima
71	451801	4841948	2259	Nyonilima
72	451771	4842252	2370	Nyonilima
73	450432	4842100	2244	Nyabigoma
74	449885	4842374	2462	Nyabigoma
75	450067	4843073	2545	Nyabigoma
76	450585	4842830	2312	Nyabigoma
77	451345	4843073	2377	Nyabigoma
78	451649	4842708	2379	Nyabigoma
79	452257	4842891	2313	Nyonilima
80	452927	4842678	2326	Nyonilima
81	452714	4843256	2205	Nyabigoma
82	453839	4843043	2367	Nyabigoma
83	453352	4842039	2250	Nyonilima
84	454539	4842404	2418	Nyonilima
85	455421	4843347	2366	Nyonilima
86	454387	4843195	2444	Nyabigoma
87	447847	4839241	2370	Kaguhu
88	447908	4840184	2244	Kaguhu

39	448303	4840366	2244	Kaguhu
40	447543	4840761	2462	Nyabigoma
41	447421	4841339	2545	Nyabigoma
42	448121	4841491	2312	Nyabigoma
43	448638	4842374	2259	Nyabigoma
44	449459	4842739	2258	Nyabigoma
45	449155	4842009	2250	Nyabigoma
46	449489	4841765	2418	Nyabigoma
47	448790	4841461	2366	Nyabigoma
48	449064	4840701	2444	Kaguhu
49	449763	4841066	2370	Kaguhu
50	450493	4841339	2244	Kampanga

89	448182	4841035	2462	Nyabigoma
90	450007	4840244	2545	Kaguhu
91	451284	4841796	2312	Kampanga
92	451010	4841248	2259	Kampanga
93	452014	4841613	2370	Nyonilima
94	450828	4843438	2244	Nyabigoma
95	456060	4842739	2462	Nyonilima
96	446113	4837629	2545	Bisoke
97	446204	4837051	2370	Bisoke
98	445657	4838419	2244	Bisoke
99	446661	4839819	2462	Kaguhu
100	454235	4841613	2545	Nyonilima

Appendix 3: Photos for interview on water availability and accessibility

(1) Interviewed respondents with good accessibility to potable water

(2) Interviewed respondents with inadequate accessibility to potable water: Cyabirego unprotected spring (Rebero village- Nyabigoma cell)

Appendix 4: Questionnaire for household survey

0. Introduction

Good morning? Good afternoon?

My name is Jean Pierre HABIMANA. I am pursuing a Master's Programme in Geo-Information Science for Environment and Sustainable Development at the University of Rwanda, College of Science and Technology in the School of Architecture and Built Environment and Department of Geography and Urban Planning. Since then, I am conducting MSc research on "SPATIAL ASSESSMENT OF POTABLE WATER AVAILABILITY & ACCESSIBILITY IN THE GREATER VIRUNGA LANDSCAPE, especially in Kinigi Sector.

Due to the research that I am conducting in this area, I would be interested in understanding your points of view about water availability and accessibility. I would gratefully guarantee you if you allow me a few minutes of your time to ask you a few questions, that I will keep confidential all the information you will give which will only be used for this research purpose.

Thank you very much!!!

Section I: Identification of the Interviewee

1) Names: ....

2) Gender (optional): Male: ☐ Female: ☐

3) Age (Please specify): Under 15: ☐ , 15-35: ☐ , 35-45: ☐ , above 45 ☐ years:

4) District: Musanze Sector: Kinigi Cell: ………………………...

5) What is the size of your family? 1person: ☐ 2-3people: ☐ 4-6 people: ☐ >6 people: ☐

6) Level of education:

None: ☐ Primary: ☐ Secondary: ☐ University: ☐

7) Employment status:

Public Service: ☐ Specify.....................................

Private Service ☐ Specify....................................

NGOs' employee ☐ Specify....................................

Unemployed ☐

Section II: Existing situation mode of potable water supply

8) Which kind of water source are you using?

a) Public aquadynamic Piped water (public tap) ☐

b) Private drinking water connection in dwelling ☐

c) Protected spring ☐

d) Unprotected spring ☐

e) River water resource: ☐ Specify which river:.…...............

f) Rainwater tanks ☐

9. From the time you settled here safe potable water availability is

- Increasing ☐
- Decreasing ☐
- Remain the same Section ☐

Section III: Potable Water Availability and Accessibility

10. a) Are you connected to the tap water from WASAC?

(i) Yes: ☐ (ii) No: ☐

b) If not, why don't you have a water connection in your home?

(i) We cannot afford bills from WASAC. ☐

(ii) It is difficult to fulfill the requirements for being a subscriber of WASAC. ☐

(iii) I am satisfied with the water I get from other sourc☐

(iv) Others …………………………, Specify..

11. How do you get potable water?

a. We buy water from the neighborhood ☐

b. We buy water from public standpipes of WASAC ☐

c. We fetch water from protected boreholes ☐

d. We fetch water from unprotected boreholes ☐

e. We fetch water from wetlands, rivers, and ponds ☐

f. Others (specify)..

12. How long-distance traveled to reach the water supply?

a) Below 300m ☐

b) Between 300m and 500m ☐

c) Between 500m and 750m ☐

d) >750m ☐

13. Once you reach a water source, how much time do you take waiting to fill a Jerrycan1?

a) Under 5minutes ☐

b) Between 5 and 20 minutes ☐

c) Between 20 and 30 minutes ☐

d) Above 30 minutes Try to specify...............

14. What is the quantity (number of Jerrycans) is your family's daily water consumption?

a) Below 1 Jerrycan ☐

b) Between 1 and 3 Jerrycans ☐

c) Above 3 Jerrycans ☐

15. Is potable water free of charge in your home?

a) Yes ☐ No ☐

16. If charged, how much does a jerrycan (20 liters) of potable water cost?

a) Under 20Frws ☐

b) Between 20 and 50Frws ☐

c) Between 50Frws and 100Rfws

d) Above 100Frws ☐

17. If you pay a monthly/annual contribution, how much is it? ……………………………

18. What are the parameters influencing water accessibility in the among of the followings**?**

a) Distance ☐

b) Time ☐

c) Land Use /Land Cover ☐

D) Population ☐

E) Slope ☐

E) if any others please specify …………………

19. a) Do you have any contribution to the creation or maintenance of water infrastructure?

(i)Yes ☐ ii. No ☐

b) If yes,

(i) How much do you pay per month? …………………………………………

(ii) According to you, is it easy for you to get such funds?

a. Yes ☐ b. No ☐

iii) Are you ready to increase your contribution to improving the water supply?

a) Yes ☐ b) No ☐

20. (a) Is there any support provided to poor households to pay that domestic water tax?

(i)Yes ☐ (ii) No ☐

(b) If yes, specify...

Section VI: Effect of Safe Potable Water Shortage

21. How do you clean the water to consume?

a. We drink without cleaning ☐

b. We use Sur' Eau (Chemical Products) ☐

c. We boil it others ☐ Specify..............................

22. In which year do you predominantly face potable water scarcity?

a. Short rain season ☐

c. Long dry season ☐

b. Short dry Season ☐

d. Long rainy season ☐

23. What are the consequences of the lack of safe potable water you face in your family or your region?

a. Poor hygiene ☐

b. Frequent illness ☐

c. None ☐

d. Others ☐ Specify..

24. In case of water scarcity, how do you get water to use?

a. Water Pond ☐

b. River water source ☐

c. Wetlands water ☐

d. Others ☐ Specify.........................

25. What are the problems for children and women facing from potable water scarcity around Virunga national park?

....
....

26.What are your suggestions to solve these problems?

....

....

27. Do you have any other comments?

....

....

....

....

Thank you for your time!!!